Working Paper No. 28

May 2024

Barriers to Industrial Heat Decarbonisation

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A working paper commissioned by the Climate Change Advisory Council, Ireland.

BARRIERS TO INDUSTRIAL HEAT DECARBONISATION

Report for Climate Change Advisory Council

Ricardo ref. ED18904

10th May 2024

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Customer reference:
N/A

Report issue:
v1.2

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Date:
10th May 2024

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EXECUTIVE SUMMARY

Ireland's National Climate Objective is to transition to a climate resilient, biodiversity rich, environmentally sustainable and climate neutral economy by 2050. The Irish government's National Climate Action Plan 2023 (NCAP23) provides a roadmap for meeting Ireland's emissions reduction targets across key sectors, including industry, whilst allowing for a transition towards a competitive, low-carbon economy.

Industrial heat demand remains a major source of Ireland's greenhouse gas emissions. The Climate Change Advisory Council commissioned Ricardo to assess progress in decarbonising industrial heat, the barriers facing industry in reducing emissions and provide suggestions for overcoming them. From reviewing publicly available data and progress to date, meeting Ireland's NCAP23 targets for 2025 will be very challenging.

The report examines three main industrial heat decarbonisation strategies: energy efficiency, fuel switching (bioenergy, hydrogen, electrification, district heating), and Carbon Capture and Utilisation, or Storage (CCUS). Common barriers include implementation costs, volatile or uncertain policies or markets, limited complementary resources and infrastructure, inexperience, and poor stakeholder alignment. Energy efficiency faces the fewest barriers, fuel switching has moderate barriers, and CCUS faces the most severe barriers. Each strategy has specific challenges too, requiring careful intervention to address. As examples:

- Industrial heat electrification is partly limited by high electricity costs and grid connections.
- The sustainability of bioresources could limit the benefits from bioenergy.
- Hydrogen and CCUS are less mature, currently high cost, and require policy to grow.
- District heating can best supply plants requiring lower heat grade sites in close proximity with other heat users.

Several policies are in place or emerging in Ireland and at EU level. Additional policy focus could accelerate industrial heat decarbonisation. Actions to consider could include:

- Deepening stakeholders' understanding on industrial energy use in Ireland.
- Improving underlying economic case or provide longer-term visibility for financial support.
- Aligning stakeholders to encourage and optimise the sustainable development of complementary infrastructure and resources (for fuel switching and/or CCUS).
- Bringing forward innovative approaches to decarbonising medium and high temperature processes.

TECHNICAL SUMMARY

Energy-intensive industrial processes provide an important opportunity for reducing Ireland's CO_2 emissions, and many energy-intensive businesses are focussed on reducing their emissions to maintain competitiveness. In 2022, emissions from Ireland's industrial sector accounted for 6.6 $MtCO_{2eq}$ out of 61 $MtCO_{2eq}$ total emissions.[5] [8] NCAP23 outlines targets for decarbonising industry, including the role of different energy sources and tackling processes with different temperatures (heat grades).

In November 2023, The Climate Change Advisory Council commissioned Ricardo to conduct a short desk-based review of Ireland's progress against the NCAP23 targets, understand the technology options available for industrial heat decarbonisation, the barriers to implementing these, and provide suggestions to accelerate progress.

The approach taken for this report combined review of publicly available data and reports with stakeholder workshops.

The report starts with a review of current emissions and energy use in industry. Industrial energy use and emissions vary substantially, linked to size, sector, fuel, and processes.

- In 2022, the largest five CO_2 emitters in Ireland accounted for 60% of industrial CO_2 emissions recorded in the ETS, with a long "tail" of sites with lower emissions.
- Natural gas and oil account for 42% and 15% of industrial fuel consumption, respectively. Only 8% of industrial energy consumption was met by renewables in 2022. [13]
- Industrial heat energy demand is evenly distributed across high (>500ºC), medium (150 – 500ºC), and medium/low (100 – 150ºC) heat grades. Low heat grade demand (<100ºC) is estimated to account for less than 10% of total industrial heat demand.

The table below shows that progress in 2022 towards the NCAP23 targets; there are limitations with publicly available data and assumptions are needed as part of assessing progress. However it appears there is a large gap between industrial heat use in 2022 and the targets set for 2025.

Table 1: Estimated progress against NCAP23 targets

NCAP23 Target for 2025	Estimated progress as of 2022
Reduce fossil fuel use in industry from 64% of final consumption (2018) to 45% by 2025	88% fossil fuel use in industry
Source 50-55% of industrial heating from carbon neutral sources	12% of industrial heating came from carbon neutral sources
35% of low/medium grade heat (up to 150ºC) to be electrified	Likely to be <10% of low/medium grade heat electrified
12% of low/medium grade heat (up to 150ºC) to be converted to sustainable biomass	Likely to be < 5% of low/medium grade heat converted to sustainable biomass
64% of high-grade heat (>500ºC) to be converted to direct/hybrid electrification technology	Likely to be <5% of high-grade heat converted to direct/hybrid electrification technology

The report next considers the decarbonisation opportunities afforded by energy efficiency, fuel switching and carbon capture and storage, with fuel switching options including bioenergy, electrification, hydrogen, and district heating. Chapter 4 outlines that the barriers adopting decarbonisation technologies remain severe in the short term, resulting in the carbon reduction of strategies having a relatively low impact out to 2030. Action is required now to improve the net carbon reduction impact of decarbonisation technologies beyond 2050. The table below provides an estimate of the scale of impacts on overall emissions reductions possible from each measure independently, with full detail provided in Chapter 4.

Table 2: Summary of impact assessment for industrial heat decarbonisation strategies

Year	Energy Efficiency	Electrification	Biomass, Biogas, Bioliquids and Renewable wastes	Heat supply from District heating	Green Hydrogen	CCUS
2025	LOW	LOW	LOW/MEDIUM	LOW	NO IMPACT	NO IMPACT
	Early stages of steady adoption	Electrification of lower temperature (<150ºC) heat uses	Limited potential impacts due to lack of biomass supply chains	Low grade (<100ºC) heat supply available for industrial sites able to connect to District Heat Network (DHN)	Limited to demonstration opportunities, as the availability of hydrogen is limited. Costs of hydrogen is prohibitively high	Limited/no impact due to lack of infrastructure and technology readiness
2030	LOW	LOW	MEDIUM	LOW	LOW	VERY LOW
	Adoption of measures increase, potentially reaching a plateau due to saturation	Assuming grid expansion and decarbonisation takes place to accommodate additional electrical loads	Biomass adoption increases, assuming low-cost sustainable supply chains are established	The potential impact on low-grade heat supply may grow, assuming DHN expansion	A small but growing number of sites adopt hydrogen usage, assuming the cost of hydrogen reduces	Limited impact due to high costs and lack of infrastructure
2050	LOW	HIGH	HIGH	MEDIUM/HIGH	MEDIUM	LOW/MEDIUM
	Potential saturation achieved	Grid expansion and decarbonisation accommodates electrical loads. Technology developments enable variety of electrical technology alternatives to become available	Biomass adoption further increases, assuming a continued low-cost and sustainable supply	Expansion of DHN infrastructure, increasing the number of sites able to connect to the network	An increased number of sites adopt hydrogen, assuming hydrogen infrastructure is developed, and low-cost hydrogen is more attainable	CCUS to have an impact on a small number of sites only, assuming infrastructure is established and there is reduction in costs

The report examines barriers to these decarbonisation strategies. Across all technologies, there are common barriers associated with implementation costs, volatile market prices, policy and planning uncertainties, limited infrastructure and supply chains, and stakeholder alignment. Table 3 shows the relative impacts of these barriers for different technologies.

Table 3: Severity of barriers identified for decarbonising industrial heat in Ireland

Strategies		Up-front Cost	Ongoing Cost	Technology Maturity	Developed Supply Chains	Process compatibility	Stakeholder confidence, support or alignment	Available infrastructure or resources
Energy Efficiency		Low	Very low	Very low	Low	Low	Very low	Very low
Fuel Switching	Electrification	Low	Moderate	Low	Moderate	Low	Low	Low
	Biogas	Moderate	Moderate	Low	Low	Low	Low	Moderate
	Biomass	Low	Low	Low	Low	Low barrier	Low	Moderate
	Waste	Low	Low	Low	Low	Moderate	Low	Severe
	Hydrogen	Moderate	Severe	Severe	Severe	Severe	Severe	Severe
CCUS		Severe	Severe	Severe	Severe	Severe	Severe	Severe
District Heating		Low	Very low	Very low	Moderate	Low	Low	Moderate

The barriers to adopting decarbonisation strategies for industrial heating vary in severity depending on the application, and have unique suggested interventions to overcoming them. Generally, Ireland requires clear long-term policy to facilitate businesses to make investment decisions, with increased data collection and transparency de-risking private investment. There is also some disparity between the social and environmental drive for decarbonisation and the cost to implementing these strategies, with ongoing economic incentives required to drive companies to make investments. A primary example is high electricity prices in Ireland when compared to natural gas, resulting in delayed investment in electrification due to high ongoing costs. Key suggested interventions to overcoming these barriers is outlined in Chapter 5 of the report, with Table 4 providing a summary.

Table 4: Summary of Key Suggested Interventions

Activity	Key Suggested Intervention
Measuring progress against targets	**Ireland's decarbonisation progress should be regularly measured against key NCAP23 targets,** with the following requirements. 1) Standardise calculations for regular progress assessments by defining a precise methodology to calculate high, medium, and low-grade heat demands for each sector. 2) Collect yearly fuel consumption data of cement, lime and refining sites. SEAI granted permission for the use a data set from 2019, which detailed the fuel consumption of cement, lime and refining sites across Ireland. 3) Collect disaggregated electrical demand data, separating electrical demand for heat, cooling and other uses as a minimum.
Strengthening Ireland's evidence base	**A stronger evidence base is required to align stakeholder decision making and de-risk investment.** Facilitate a techno-economic assessment which forecasts future supply chain development of low carbon fuels, projected fuel costs and performance data from relevant international demonstration and commercial projects.
Fossil Fuel Planning	**Clarify policy and regulatory expectations on the future availability for unabated fossil fuel use** for industrial heat, for example continued use of natural gas infrastructure.
Capital support planning	**Establish comprehensive support schemes to address ongoing financial support gaps and prepare for the closure of existing schemes.** The approaching closure of the Support Scheme for Renewable Heat (SSRH) in 2027, the main funding source for industrial heat pump, solid biomass, and biomethane installations, may lead to sites reverting to fossil fuels unless alternative funding is secured.
Ongoing Funding Support	**Ensure decarbonisation support is ongoing, accounting for high operating costs due to 'green' premium.** Electrification, hydrogen, and CCUS are likely to have high additional operating costs, which may not be fully covered by carbon pricing, or available revenue support schemes, in the short term.
Infrastructure planning	**Begin to develop infrastructure that enables the transportation, storage and delivery of low carbon technologies.** This study highlights that biogas, biomass, district heating, hydrogen, electrification, and CCUS approaches demand complementary infrastructure and resources *outside* the physical boundaries of industrial sites, but the availability of this is highly uncertain. For example; 1) Review whether the pace, amounts and locations of investment into electricity networks will be sufficient to support the electrification of industrial heat. 2) District heating stakeholders should consider locations of investment and if industrial adoption is feasible, including the viability of local networks.
Supply chain security and development	**Enhancing supply chain resilience by assessing and publishing forecasted feedstock availability, and sourcing increased supply where required.** For example, 1) Assess options for increasing bioenergy supply, potentially from both domestic and international sources, of sustainable bioenergy fuels for industrial heat decarbonisation 2) Projections of available waste given the increasing circular economy approach will assist industry in projecting the availability and quality of waste into 2030.

Activity	Key Suggested Intervention
Aligning stakeholders within the same supply chains	**Facilitating discussions with waste providers and industrial consumers (i.e. cement) will enable additional clarity as to the supply and quality of waste into the future.**
Streamlining planning processes	**Streamlining planning and grant application processes by resourcing key agencies and providing support to industrial sites with large decarbonisation potential.**
Decarbonisation planning	**Publishing updated plans and statements and periodically reviewing them.** Currently, the hydrogen and biomethane strategies have been released, outlining projections on supply chain availability and future infrastructure development. Other strategies are yet to be released, and should cover; 1) Supply chain availability 2) Infrastructure planning 3) Future funding support 4) Priority uses for fuels
Periodically review CCUS planning	**Evaluate periodically the levels and focus of support for CCS, and where appropriate keeping this option open as a route to industrial heat decarbonisation.** 1) Keeping Ireland's CO_2 storage capacity (offshore and surrounding areas) estimates up to date with latest understanding. 2) Assess the impacts of options for enabling policy and regulation on geological CO_2 storage in Ireland.
Research & Development	**With potentially long lead times for deployment, Ireland should ensure research, development and demonstration of the technologies supports industrial heat decarbonisation in line with the National Climate Action Plan**. 1) Future technology research, development and demonstration for low carbon heating should prioritise processes with temperatures above 150 °C. 2) Future R&D financial support, such as Capital grant funds[,92] (and successors to the Climate Action Fund and Disruptive Technologies Innovation Fund), tax credits[1], and EU initiatives such as Horizon Europe, should recognise that medium and high grade heat users face fewer mature technology solutions than for low heat grades. 3) Support R&D into electrification for medium and high temperature processes, for which few options are commercially mature.

[1] Irish Tax and Customs (2024), R&D Corporation Tax Credit, https://www.revenue.ie/en/companies-and-charities/reliefs-and-exemptions/research-and-development-rd-tax-credit/index.aspx

1. BACKGROUND AND OBJECTIVES

In 2022, the Irish government published the National Climate Action Plan 2023 (NCAP23) which provides a roadmap for meeting Ireland's emissions reduction targets, whilst still allowing for a transition towards a competitive, low-carbon, and climate-resilient economy. More recently the National Climate Action Plan 2024 (NCAP24) was published[2]; however, this study predominately focusses on NCAP23. The overall objective of the NCAP23 is to reach Net Zero emissions by 2050, a legally binding target for all EU Member states. To achieve the required level of emissions reduction, the NCAP24 outlines key performance indicators for 2025 and 2030. By 2025, public bodies will specify low carbon cement materials, amongst other measures, and by 2030 an interim target has been set to achieve a 51% reduction in greenhouse gas (GHG) emissions, relative to 2018 levels.[40] Moreover, three Carbon Budgets were set in Ireland for 2021 – 2025, 2026 – 2030, and 2031 – 2035. A Carbon Budget represents the total amount of emissions, measured in tonnes of CO_2 equivalent ($MtCO_{2eq}$), that is permitted to be emitted by a country during a five-year period.[3]

Ireland's GHG emissions decreased by 1.9% in 2022, reaching 60.76 Mt CO_{2eq}; this represents a reduction of 1.19 Mt CO_{2eq} compared to 2021 emissions. The largest contributors to overall emissions were agriculture (38%), transport (19%), and energy industries (17%), with industrial processes contributing approximately 4%, and manufacturing combustion 7%. [4] Despite the observed reduction, Ireland exceeded its 2022 annual limit under the European Union's Effort Sharing Regulation (EU 2018/824) and has already used up 47% of Ireland's Carbon Budget for 2021 – 2025, highlighting the need for further action.[5]

Based on the disaggregated emission data above, it is evident that industry related emissions are relatively significant, particularly when their energy use is considered. In 2022, Irish industrial emissions were 6.6 $MtCO_{2eq}$; emissions resulting from energy use for industry was 3.7 Mt CO_{2eq}, which is approximately one third of the energy industries' emissions that same year[8]. A reduction in industrial emissions of around 35% may be required by 2030 if NCAP23 targets are to be met[6].

Industry is critical to Ireland's economy and contributed approximately EUR 200 billion contribution to the nation's EUR 500 billion GDP in 2022. Heat demand represents a major source of CO_2 emissions within the industrial sector, primarily driven by the reliance of fossil fuels for heat generation. Industrial heat decarbonisation faces a multifaceted challenge due to the diverse nature of its use within the sector, as heat generation and utilisation spans a wide range of processes as well as temperature requirements. This variety in utilisation directly impacts the potential for employing different decarbonisation strategies, requiring a nuanced approach for each specific heat demand, as confirmed by the Heat Study published by Sustainable Energy Authority Ireland. [7] The study also highlights the need for rapid action on several fronts.

Following competitive tender held in autumn 2023, Ricardo was awarded a project to study barriers to decarbonisation of industrial heat demand in Ireland for the Climate Advisory Council. The Climate Change Advisory Council is an independent advisory body in Ireland established to provide advice and recommendations on climate policy and actions to the Irish government. The Council's primary function is to assess and monitor Ireland's progress in achieving its climate targets, as well as to offer expert guidance on climate change mitigation and adaptation measures.

Our project methodology is built around the three Tasks specified in the Invitation To Tender:

Task 1: A review of existing heat demand within the industrial sector in Ireland, comparing this to the NCAP23 targets.

Task 2: A review of technical options for industrial heat decarbonisation.

Task 3: Identification of barriers to implementing industrial heat decarbonisation in Ireland.

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[2] Irish Government (2024), Climate Action Plan 2024, gov - Climate Action Plan 2024 (www.gov.ie)

[3] GOV.ie (2022), Carbon Budgets, https://www.gov.ie/en/publication/9af1b-carbon-budgets/

[4] EPA (2023), Latest Emissions Data, https://www.epa.ie/our-services/monitoring--assessment/climate-change/ghg/latest-emissions-data/

[5] EPA (2023), Ireland's 2022 Greenhouse Gas Emissions show a welcome decrease, but much work remains to be done, https://www.epa.ie/news-releases/news-releases-2023/irelands-2022-greenhouse-gas-emissions-show-a-welcome-decrease-but-much-work-remains-to-be-done.php

[6] KPMG (2023), Ireland's Climate Action Plan 2023, https://assets.kpmg.com/content/dam/kpmg/ie/pdf/2023/02/ie-irelands-climate-action-plan-2023-2.pdf

[7] SEAI, summary report available at National-Heat-Study-Summary-Report.pdf (seai.ie)

We complemented desktop review activities with two online stakeholder workshops to gain insight directly from various industry in Ireland as to what barriers they experience. At project outset it was confirmed that the project would focus on direct emissions reductions associated with existing industrial heat demand. This means that so-called process CO_2 emissions (arising from chemical reactions integral to industrial processes), energy associated with cooling, and indirect emissions from remote generation, new industrial heat demand, or changing industrial processes to make alternative products, were out of scope of this project.

The remainder of this report is divided into four Chapters:

- Chapter 2 reviews the amount and make up of industrial heat demand in Ireland, current fuel used to meet this demand, and how this compares to the NCAP23 targets.
- Chapter 3 reviews the main decarbonisation strategies available for existing heat-intensive businesses in Ireland, and their potential.
- Chapter 4 reviews the barriers to implementing these industrial heat decarbonisation strategies in Ireland.
- Chapter 5 reviews potential ways forward for stakeholders in Ireland to overcome these barriers, along with a prioritisation of actions over the next five years.

The report is accompanied by a supporting technical appendix.

2. OVERVIEW OF INDUSTRIAL HEAT IN IRELAND

This chapter provides an summary of industrial heat in Ireland, quantifying emissions and heat demands by sector. This provides an opportunity to quantify the decarbonisation potential of various decarbonisation strategies and to measure Ireland's progress against key NCAP23 targets.

This chapter provides an overview of industrial heat in Ireland, beginning with a breakdown of industrial emissions, followed by a summary on fuel use within industry. Section 2.3 focuses on industrial heating demand per sector, heat grade and technology type. The chapter finishes with commentary on progress against decarbonisation targets.

The public data sources most used in this Chapter to understand industrial CO_2 emissions and energy use by sector are listed below. Additional data sources and calculations performed are detailed in the Appendix.

1) The European Union Emissions Trading Scheme Data (EU ETS), which quantifies the CO_2 emissions of the largest industrial consumers,
2) The SEAI National Energy Balance, which quantifies the fuel and electricity consumption by industrial sub-sector, and
3) The SEAI National Heat Study, which splits industrial heat demand by heat grade and sub sector.

At the commencement of this study in November 2023, heat demand calculations were performed using several publicly available data sets for the year 2022, including SEAI's National Energy Balance for Ireland and EU ETS data. After the completion of this draft report, 2023 data for the EU ETS was released, with a summary of findings outlined in Appendix D.

2.1 INDUSTRIAL CO_2 EMISIONS

According to SEAI and the Environmental Protection Agency (EPA), Ireland's industrial sector emitted 6.6 $MtCO_{2eq}$ in 2022, marking a notable 7% reduction compared to 2021.[8] [4] In 2022, emissions in the stationary Emissions Trading Scheme (ETS) sector decreased by 4.3% in Ireland.[4] The EU ETS, which applies to all EU Member States leverages market mechanisms to address GHG emissions by enabling bodies to buy and sell emission allowances amongst themselves with the aim to achieve substantial cuts in emissions by establishing a carbon price.[9]

Figure 1 illustrates the reported EU ETS emissions for Ireland in 2022, where the largest five CO_2 emitters account for 60% of industrial CO_2 emissions. The ten largest emitters under the EU ETS are presented in Figure 2, including the corresponding industrial sector. Five sectors dominate the top ten; these include metals, cement, refining, food and beverages, and lime. The largest emitter is Rusal Aughinish alumina refinery, which a part of the metals sector, producing 1.10 $MtCO_{2eq}$ of emissions. Cement production follows, accounting for the next four largest emitter sites which totals 2.86 $MtCO_{2eq}$. The cement sites include Irish Cement (Platin & Limerick) plants, as well as the Scotchtown and Breedon cement plants. Irving Oil's Whitegate oil refinery is the sixth largest emitter, accounting for 0.31 $MtCO_{2eq}$.[10] The next two sites belong to the food and beverage sector, contributing 0.16 $MtCO_{2eq}$ of emissions. Typically, the food and beverages sector have more sites with diverse sizes, including 30 sites within the EU ETS and approximately 700 sites that are not in the EU ETS. [11]

[8] SEAI (2023), Key Insights from SEAI's 2022 National Energy Balance, https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/Key-Insights-from-2022-National-Energy-Balance.pdf

[9] Eurostat, Glossary: Emissions trading system (ETS), https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Emissions_trading_system_(ETS)#:~:text=The%20European%20Union%20Emission%20trading,change%20from%20reaching%20dangerous%20levels.

[10] European Union Emissions Trading Scheme Database Phase IV 'Verified Emissions for 2022',: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/union-registry_en, last accessed 10th Jan 24

[11] SEAI's Heating and Cooling in Ireland Today: https://www.seai.ie/data-and-insights/national-heat-study/heating-and-cooling-in-ir/, last accessed 10th Jan 24

Figure 1: ETS Site Emissions[10]

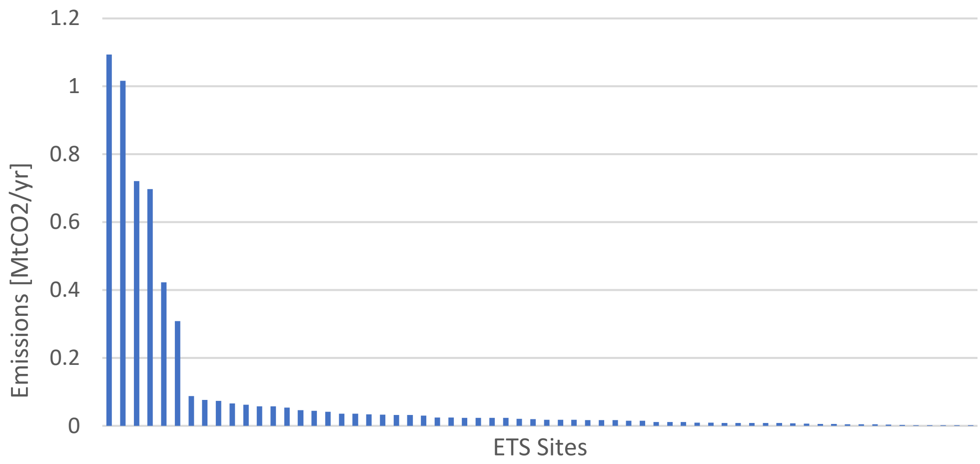
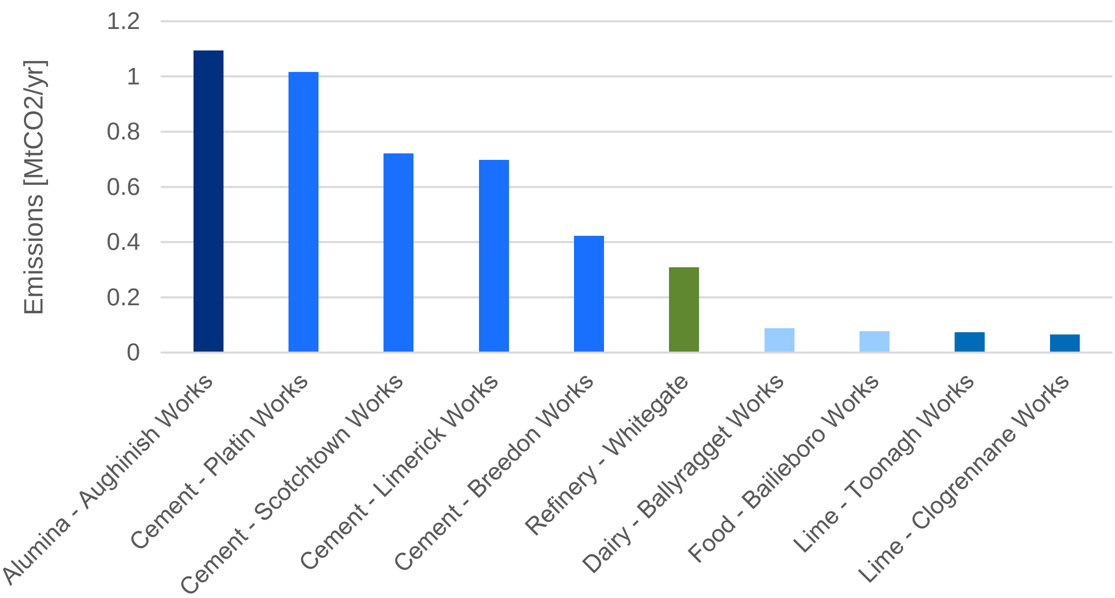


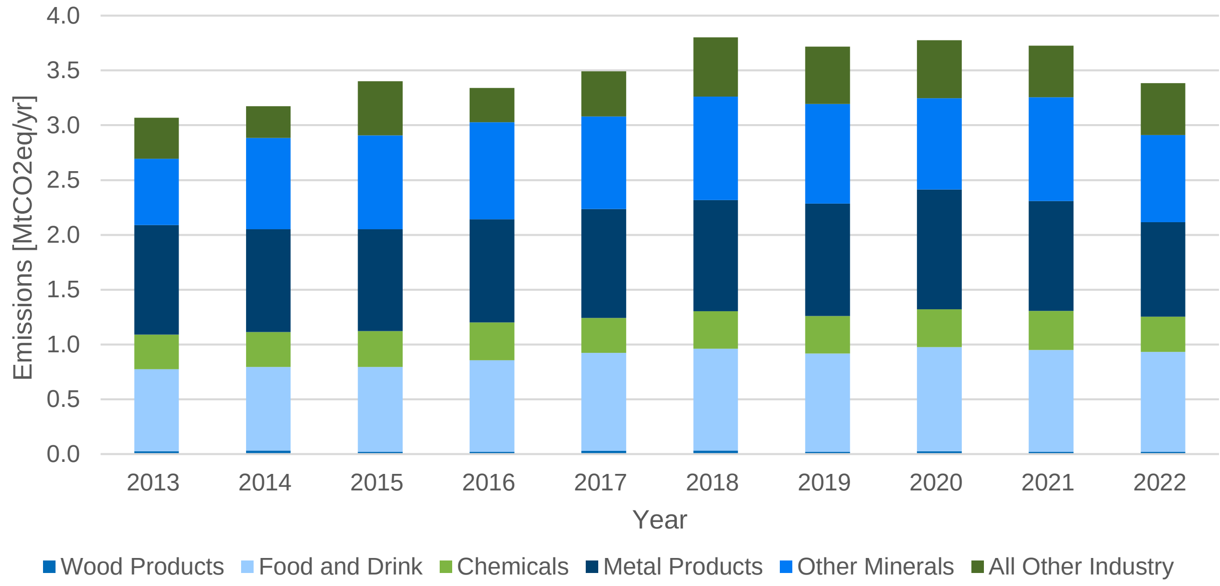
Figure 2: Top 10 Industrial Sites by Emissions 2022[10]



Significant variation exists across the ten largest EU ETS emitting sectors regarding their energy requirements, as well as within the industrial sector itself, which will be further discussed in Section 2.3. Annual energy-related emissions from industry in Ireland between 2013 and 2022 is depicted in Figure 3, with values calculated from the *EU ETS* and *SEAI's National Energy Balance*. There has been slight variation in energy-related CO_2 emissions across industry from 2013 to 2022, with a modest decrease from 3.9 $MtCO_{2eq}$ in 2021 to 3.7 $MtCO_{2eq}$ in 2022.[12]

[12] SEAI, CO2 Emissions, CO2 Emissions | Energy Statistics In Ireland | SEAI

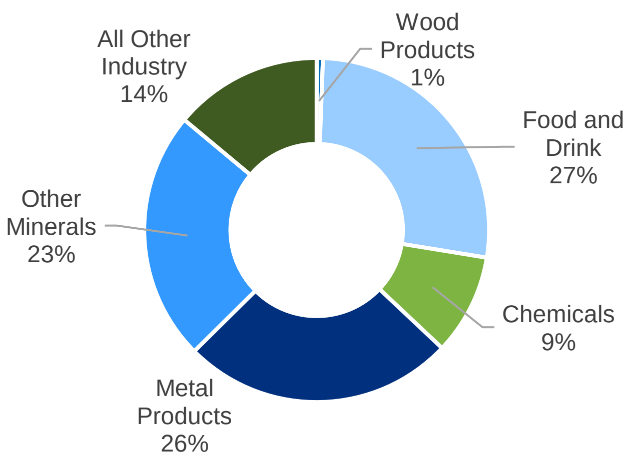
Figure 3: Energy Related Industrial Emissions 2013 – 2022 [13]



Cement emerges as the dominant industrial emitter, responsible for 40% of energy-related emissions in 2022, followed by the metals sector at 15%, predominantly driven by alumina production. The food and drink sectors collectively contribute 12%, exhibiting a diverse makeup that covers pasteurising dairy products, meat processing, and distilleries.[14] The wood products sector, which includes paper and pulp manufacturing, presents a significantly lower emissions profile compared to other industrial sectors; this can be attributed to the extensive utilisation of biomass as a fuel source, accounting for 78% of its total energy consumption.

Figure 4 illustrates the share of CO_2 emissions by industrial sector in 2022, with data collected from the *EU ETS data base* and *SEAI's National Energy Balance*. This excludes CO_2 associated with combustion of renewable biomass, as emissions from renewable sources are not reported in the EU ETS.

Figure 4: Industrial Emissions by Sector in 2022 [15]



Ireland has demonstrated encouraging progress in addressing overall industrial emissions, with several sectors successfully reducing emissions whilst concurrently increasing manufacturing volumes, typically through increased renewable energy use. However, a significant acceleration of emissions reductions would

[13] SEAI's National Energy Balance 2022 available: https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/

[14] The metals sector comprises a large Alumina site which is within the EU ETS, with ~800 non EU ETS sites.

[15] Graphic developed from SEAI's National Energy Balance 2022 Database, available at https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/, last accessed 10th Jan 24

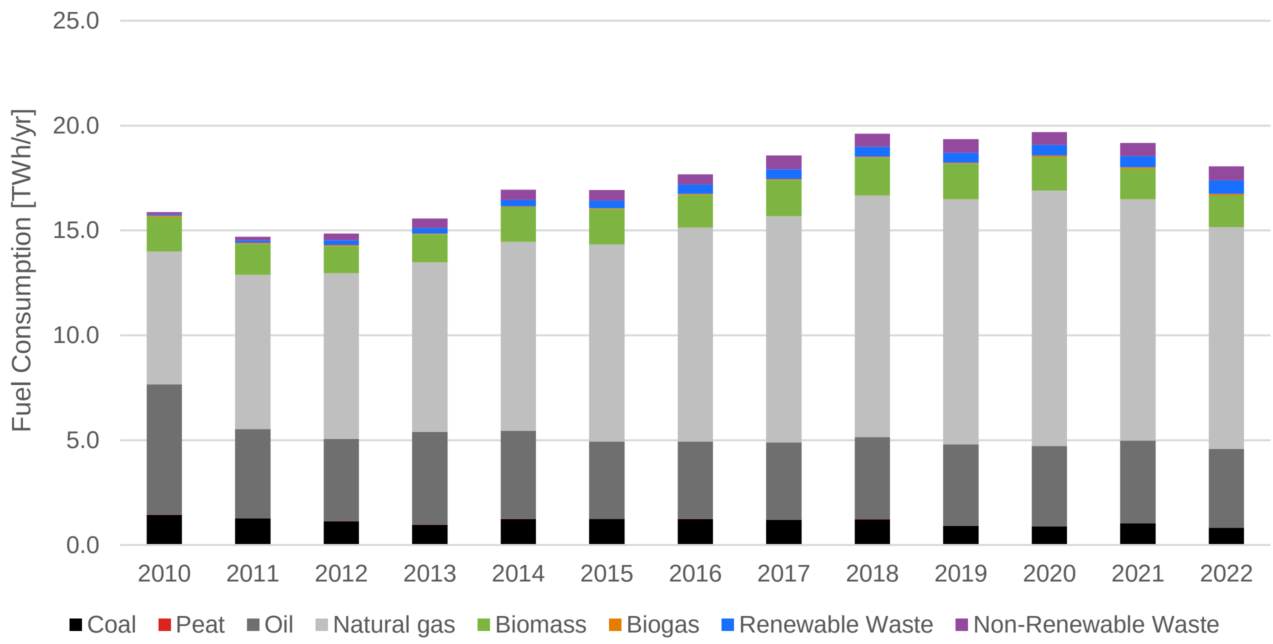
be needed for industrial decarbonisation to support the emissions reductions needed to meet Ireland's first carbon budget period of 2021-2025, as well as the 2030 SEC target.

2.2 INDUSTRIAL ENERGY USE

NCAP23 also includes dedicated targets for industrial heat, which states that the share of carbon-neutral heating in industry is to reach 50 – 55% by 2025, with the share increasing to 70 – 75% by 2030, further emphasising the need to electrify heat as well as reduce fossil fuel use.[40] In this section we collate publicly available data to illustrate the fuel consumption in industry and demand over time.

Ireland has shown progress towards reducing fossil fuel consumption in the past 5 years, as illustrated by Figure 5 which shows the distribution of fuel demand within industry over time.

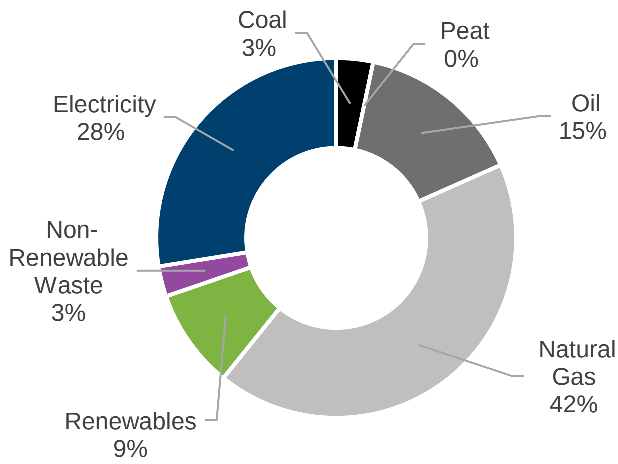
Figure 5: Industrial Fuel Consumption for heat by year [13]



High carbon intensive fuels such as natural gas and oil dominate energy consumption within industry in 2022, accounting for 42% and 15% of industrial energy consumption, respectively. The remaining emissions stemmed from renewables (8%) and a range of non-renewable sources including coal (3%), non-renewable waste (3%) and peat (<1%), as illustrated in Figure 6. Finally, electrical demand accounts for 28% of industrial energy consumption, which can be attributed to industrial process, electrical and heating demands. The final consumption of energy across the industrial sector in 2022 was approximately 24.5 TWh, with total fuel consumption (excluding electricity demand) totalling roughly 18 TWh[16].

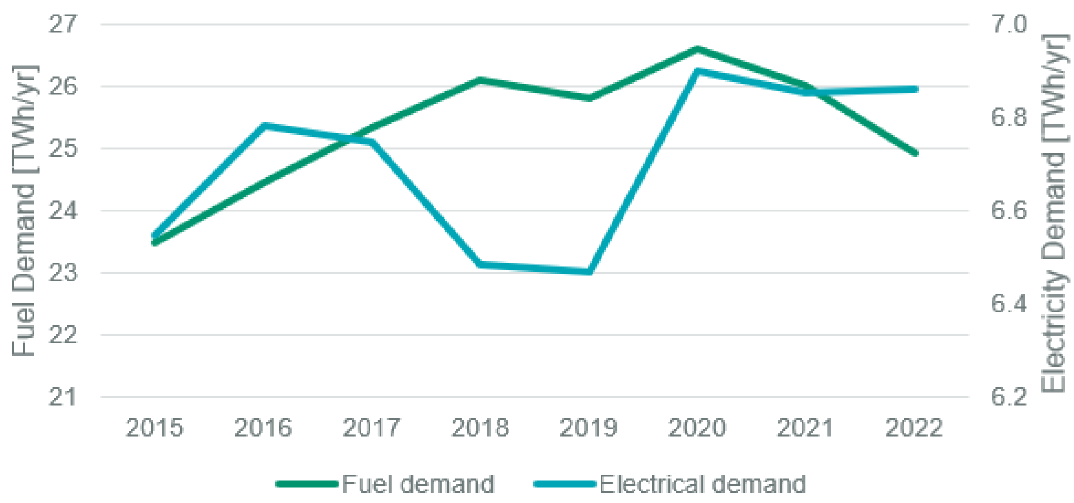
[16] SEAI's National Energy Balance 2022 Database, available at https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/, last accessed 10th Jan 24

Figure 6: Industrial Energy Consumption in 2022 [% of TWh][13]



SEAI's National Energy Balance provides industrial fuel and electricity consumption in 2022, as depicted in Figure 7. The total electrical consumption includes demands such as process and cooling, as well as electrically driven industrial process heating (heat pumps, electric boilers). According to *SEAI's Heating and Cooling in Ireland Today* report, electrical demand for cooling is generally concentrated in the Food and Drink sector, with a significant proportion also in the chemicals sector. However, at the time of this study there was no readily available information which allowed for the allocation of electrical consumption within industrial sectors, and therefore the calculation of electrical consumption for heat-intensive industrial processes was not possible. Therefore, electrical demands have not been included in total heating demand calculations in subsequent sections of this report.

Figure 7: Fuel and Electricity Consumption in Industry (SEAI's National Energy Balance)



The associated heat requirements across industrial technologies are varied, with individual processes requiring specific heat grades and heat types to operate. Therefore, the suitability of heat decarbonisation strategies is dependant on the heating process, heat grade and technology type. This section disaggregates heat demand across various sectors, heat grades and technology types, providing valuable insights into the decarbonisation potential of Irish industry. In 2022, the industry's total heat demand across ETS and non-ETS sites was approximately 16 TWh, excluding any heat generated from electricity.

2.2.1 The Use of Heat in Industry

Heating technologies used in industry can differ significantly across sectors as they vary with process requirements. Industrial heat can be supplied either *directly*, whereby the heating medium (such as gas) comes into direct contact with the desired material, or *indirectly*, which involves using an external heat source to heat water or air, which subsequently transfers this heat to the desired product via an interface, such as a heat exchanger. The SEAI study divides the heat use into four grades: high, medium, medium/low, and low. Section 2.3.3 goes into further detail about heat grades.

Understanding which technologies are suitable for industrial processes is central to understanding how heat is used in industry and assessing the potential for decarbonisation strategies. Examples of heat-intensive processes in different sectors are shown in Table 5.

Table 5: Examples of Main Heat Intensive Processes by Sector

Sector	Main Heat Intensive Processes	Heating Type	Process Temperature (°C)
Metals	Steam generation	Indirect	100 - 150
	Bayer process	Indirect	150 – 500
	Calcination	Direct	>500
	Rolling	Direct	150 – 500/ >500
	Melting	Direct	150 – 500/ >500
	Sintering	Direct	150 – 500/ >500
	Melting and other high temperature processes	Direct	150 – 500/ >500
Cement	Clinker preparation	Direct	150 - 500
	Kiln firing	Direct	>500
Refining	Crude oil distillation/ Primary distillation	Indirect	150 – 500
	Catalytic cracking (conversion process)	Indirect	150 – 500/ >500
	Delayed coking process	Direct	150 – 500
	Thermal cracking (conversion process)	Direct	150 – 500/ >500
	Low temperature process	Indirect	150 – 500/ >500
	Drying/ separation	Indirect	150 – 500
	Space heating	Indirect	100 - 150
Wood Products	Refining (mechanical pulping)	Indirect	<100
	Pressing	Indirect	150 – 500
	Paper drying	Indirect	>500
	Ancillary	Direct	100 - 150
	Low Temperature process	Indirect	100 - 150
Other Minerals (Including Glass/Ceramics)	Batch/ cullet preparation	Direct	150 – 500
		Indirect	100 - 150
	Melting	Direct	>500
	Kiln firing/ product annealing	Direct	>500
	Drying	Direct	150 – 500
	Low temperature process	Indirect	100 - 150
Food and Drink (Including dairy/ meat)	UHT treatment/ sterilisation	Direct	100 - 150
		Indirect	100 - 150
	Pasteurisation/ blanching	Indirect	<100
	Cooking (ovens) / blanching/ boiling	Direct	<100
	Evaporation (concentration)	Direct	100 - 150
	Low temperature process	Indirect	100 - 150
	Drying	Indirect	100 - 150
Lime	Calcination	Direct	>500
Chemicals	Cracking	Indirect	150 – 500/ >500
	Steam reforming	Indirect	150 – 500/ >500
	High temperature	Indirect	150 – 500
	Turbine	Indirect	150 – 500

Given the diverse range of heat-intensive processes and temperature requirements across industry, an evaluation of heat demand by sectors is crucial for gaining a deeper understanding of industrial heat use in Ireland. Section 2.3.2 covers the heat demand by sector in Ireland, however, to illustrate the range of heating requirements and corresponding technologies employed across various industrial sectors, an outline of the main heat intensive processes in the cement and dairy sectors is outlined below.

Cement production sites generate a larger volume of CO_2 emissions compared to individual dairy production facilities; this is due to emissions associated with both underlying chemical processes and emissions from heating. Cement manufacturing relies on high-temperature processes like calcination and clinkering, typically exceeding 1400°C. These processes involve direct, high temperature heating technologies like furnaces and kilns. This direct heating demand, combined with CO_2 released during calcination, makes the industry a major emitter, contributing 40% of Ireland's industrial emissions.

Unlike cement, dairy production utilises lower temperatures (up to 150°C) for various stages like pasteurisation, curd formation, and milk concentration. The industry often employs indirect heating via steam generated in boilers, with efficiency and precision crucial for product quality and safety. While heating requirements vary based on the product, they generally involve lower temperatures and indirect methods compared to cement production.

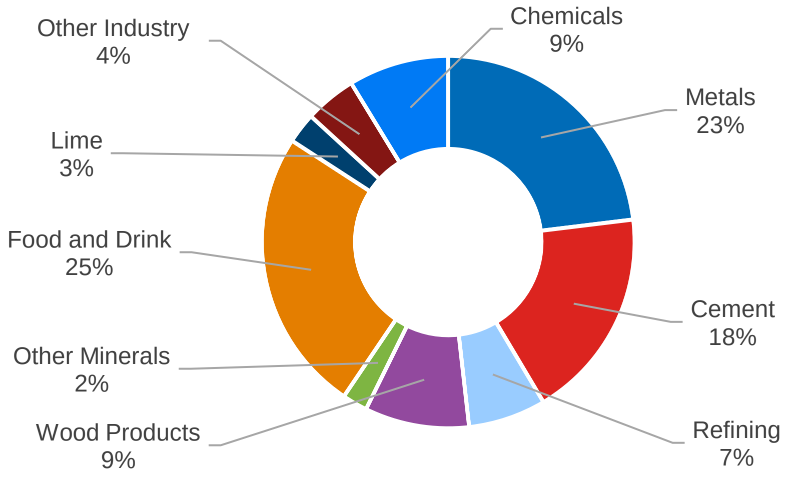
2.2.2 Heat Demand by Sector

Despite the energy-related emissions reduction targets for industry set in the NCAP23, such as the increased share of carbon-neutral heating, heat use data across industry in Ireland is not collated. As this metric is not collated, several adaptions, assumptions, and considerations have been made to quantify the heat demand in each sector from the available data sets.

An adaption made to EU ETS Data as it relates to fuel use in Combined Heat and Power (CHP) units, as the industrial sector in Ireland accounted for 17% of CHP units in 2019. [17] It can't be assumed that all reported emissions in industry is utilised entirely for heating, particularly when considering CHP, where both power and heat is generated from the fuel input. Similarly, to determine the heat demand across industry, the electricity used for non-heating applications was subtracted from the 2022 SEAI National Energy Balance given the electrification of heat is not readily available data.

The share of industrial heat demand across industry in Ireland is illustrated in Figure 8, where it can be seen that the food and drinks sector are the largest consumer at 25%. This is closely followed by the metals and cement sectors, with a share of 23% and 18%, respectively. Wood products and chemicals each contribute to 9% of industrial heat demand. The sectors with the largest heat demand corelate to the sectors responsible for the largest energy-related emissions (Figure 3), particularly the food and drink, metals, and cement sectors.

Figure 8: Share of Industrial Heat Demand by Sector in Ireland



[17] SEAI's Combined Heat and Power in Ireland 2020 Update Report, available at https://www.seai.ie/publications/CHP-Update-2020.pdf, last accessed 10th Jan 24

The food and drinks industry, a significant contributor to Ireland's industrial heat demand, also stands out for its prominent electricity use. This is particularly relevant considering the *SEAI's National Energy Balance 2022* encompasses all imported electricity consumption to industrial sites, including general lighting, process consumption, refrigeration, and heating. Stakeholder engagement indicates that moves to electrify industrial heat have been limited to date but are now starting to grow, for example, through the adoption of heat pumps. Stakeholder workshops reinforced our expectations that so far electric heating systems today still play a minimal role in meeting industrial heat demand.

2.2.3 Heat Demand by Heat Grade

Heat grade can be divided into four tiers; Table 6 illustrates the heat demand associated with each tier. The heating grades used in this analysis are in line with those from SEAI's 2019 National Heat Study. Low or medium grade can be directly or indirectly supplied through hot water and/or steam from boilers, dryers, or CHP. High grade heat, for example direct firing in kilns and furnaces, is common in cement, lime, and alumina (metals) production.

Table 6: Industry Heat Demand by Heat Grade in Ireland

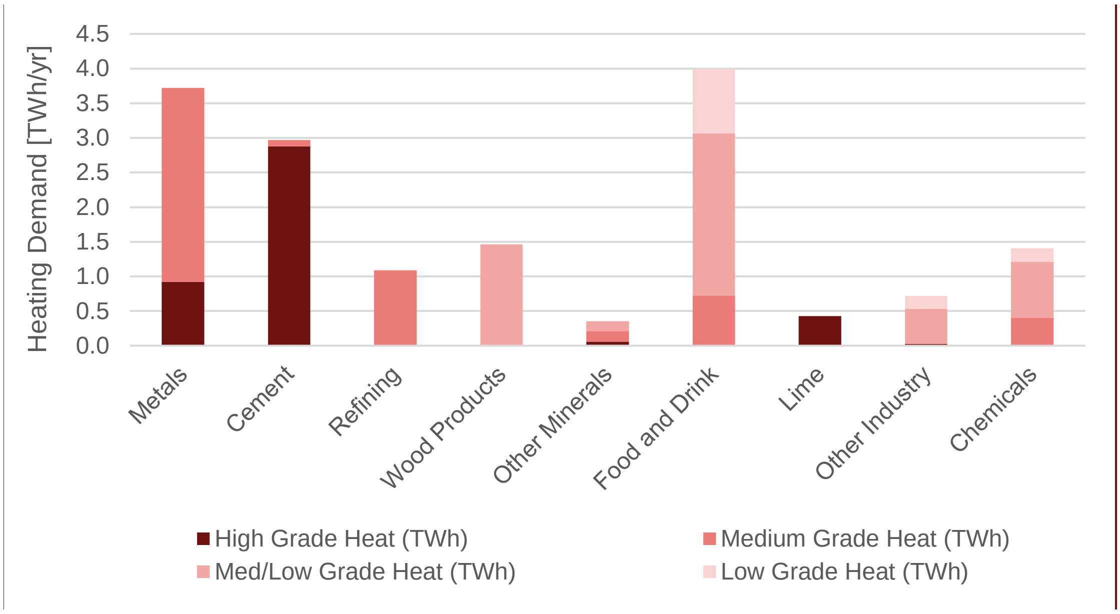
Heat Grade	Temperature (ºC)	Estimated industrial heat demand by heat grade (TWh/yr)[18]	Approx. % of industrial heat demand
High	>500	4.3	26.7%
Medium	150 – 500	5.3	32.6%
Medium/Low	100 – 150	5.3	32.7%
Low	<100	1.3	8.1%

Table 6 also illustrates the total heating demand in different industrial sectors by grade of heating. Approximately 66% of industrial heat demand in Ireland is of medium and medium/low grade, with ~27% for high and <10% for low heat grades. The quantity of heat being generated by particular heating technologies can inform the suitability of different low-carbon heating strategies, explored in subsequent chapters.

The breakdown of industrial heat demand based on heat grade is depicted in Figure 9, where *SEAI's National Energy Balance* and *SEAI's National Heat Study* have been used to segregate fuel consumption from each sector into heat grades. High grade heat demand is concentrated in the metals, cement, lime, and other minerals sectors, with medium/low and low heat grades prominent in all sectors. There is limited low grade heat use, with only food and drink, other industry, and chemicals being the main users.

[18] We have combined 2019 data from SEAI heat study on heat grades with 2022 energy and CO_2 data.

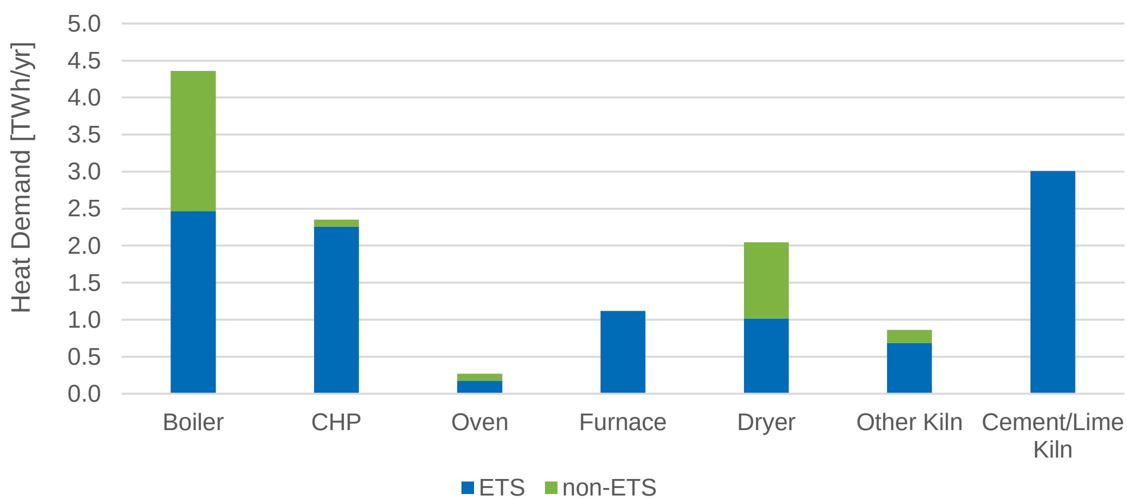
Figure 9: Heating Demand by Heat Grade and Sector [10 11 13]



2.2.4 Heat Demand by Technology Type

Separating heat demand into technology types provides further insight into the scale of decarbonisation opportunities for various technologies, identifying where the greatest impact lies. Figure 10 illustrates the heating demand of different technologies, separating ETS and non-ETS demands.

Figure 10: Heating Demand by Technology Type [10 11 13]



ETS heat demand encompasses the majority of heat demand for the various technologies, and in the cases of kilns and furnaces, covers all heat demand; cement/Lime kilns are responsible for 3TWh/yr and ~1.1TWh/yr, respectively. Direct-fired heating equipment, such as furnaces and kilns, also play a prominent role in ETS heat demand.

Indirect heating dominates the non-ETS heat demands, with boilers being the largest component of this. The three largest industrial consumers of heat through boiler use in Ireland are metals, food and drink, and chemicals, with 1.4TWh/yr, 2.2 TWh/yr and 1.0 TWh/yr, respectively. Through fuel switching of boilers for large emitting sites in the EU ETS, there is potential to decarbonise 2.5TWh/yr of industrial heat in Ireland.

2.3 PROGRESS AGAINST DECARBONISATION TARGETS

2.3.1 NCAP23 Targets

The Irish Government has set ambitious emission targets for the industrial sector, including carbon budgets and the NCAP2023. NCAP2023 outlines targets for fossil fuel reduction and carbon neutral industrial heating, with large roles for electrification and sustainable biomass, as shown in Table 7.

Table 7: Ireland's Industrial Decarbonisation Targets from the NCAP23

2025	2030
Reduce fossil fuel use in industry from 64% of final consumption (2018) to 45% by 2025	Reduce fossil fuel use in industry from 64% of final consumption (2018) to 30% by 2030
Source 50-55% of industrial heating from carbon neutral sources	Source 70-75% of industrial heating from carbon neutral sources
35% of low/medium grade heat to be electrified	55% of low/medium grade heat to be electrified
12% of low/medium grade heat to be converted to sustainable biomass	20% of low/medium grade heat converted to sustainable biomass
64% of high-grade heat to be converted to direct/hybrid electrification technology	88% of high-grade heat converted to direct/hybrid electrification technology

2.3.2 Progress against Targets

There is no standard reporting of progress against NCAP, with comprehensive data sources and agreed methodology. Therefore, accurate measurement of progress against the NCAP targets is challenging.

Table 8: Estimated progress against NCAP23 targets

KPI	2022
% fossil fuel use in industry	88%
% of industrial heating from carbon neutral sources	12%
% of low/medium grade heat electrified	Likely to be low (<10%)
% of low/medium grade heat to be converted to sustainable biomass	5%
% of high-grade heat converted to direct/hybrid electrification technology	Likely to be low (<5%)

**Ricardo judgement has been used based off stakeholder engagement and available datasets.*

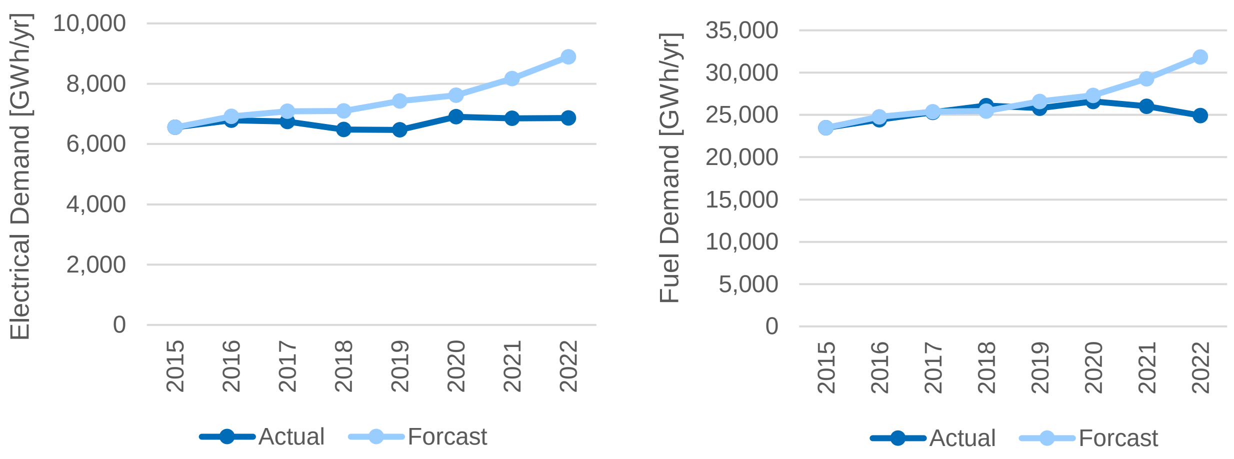
Industry energy demand in 2022 was mainly satisfied by natural gas (42%), electricity (28%) and oil (15%). The remaining 15% was attributed to bioenergy, renewable and non-renewable waste. *SEAI's National Energy Balance 2022* illustrates that approximately 12% of fuel consumption for heating is attributed to carbon neutral sources in 2022, therefore it is unlikely that Ireland will achieve 50-55% of industrial heating from carbon neutral sources by 2025.

2.3.3 Targets for Electrification of Heat

Data on the electrification of heat in industry in Ireland is limited. *SEAI's National Energy Balance 2022* provides a good starting point, but additional information to split out different electricity consuming processes to disentangle heating from other processes is lacking.

To assess if industrial heat is contributing to increasing electrical demand, the actual electricity demand in Ireland has been compared to the production indexed electrical demand. The *Central Statistics Office* Production Volume Index was used to project electrical and fuel demand from the base indexed year of 2015. Figure 11 depicts the projected demand given production volume indexing when compared to the actual demand from *SEAI's National Energy Balance*.

Figure 11: Industrial Electrical and Fuel Demand (Actual vs Production Indexed)



Across industry, electricity demand has generally remained constant, with fuel demand decreasing. This may indicate that energy efficiency measures may be widely adopted, causing electricity demand to remain constant and fuel consumption to decrease given increasing production. However, from these results it is difficult to determine the driving factors behind electricity and fuel consumption trends.

There are several factors which could impact the reduced electrical demand when compared to production indexed demand, these include:

- Energy efficiency measures reducing overall electrical consumption.
- Electrification of heat increasing electrical demand, however given electricity demand has remained constant, Figure 11 indicates that electrification in industry could be minimal. This is supported by stakeholder feedback that electrification of heat is has not yet been widely adopted in industry.
- Diminishing marginal returns with increasing production, whereby increasing production results in marginal increases in electricity and consumption.
- Demands at the aggregate level might be skewed by the results in one of the larger sectors.

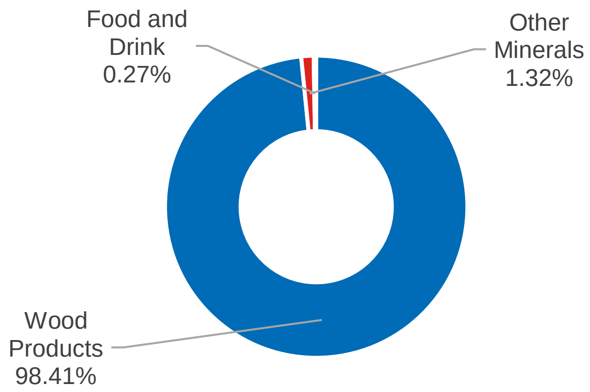
It is difficult to determine if Ireland's electrification of heat targets are being met given the availability of public data. However, stakeholder engagement indicates that the electrification of heat in industry is only starting.

2.3.4 Sustainable Biomass for Heat Targets

Approximately 5% of low and medium grade heat in industry in 2022 was sourced from biomass. Therefore, based on 2022 data, we consider it unlikely that Ireland will meet the NCAP2023 target to source 12% of low/medium grade heat to be converted to sustainable biomass by 2025.

SEAI's National Energy Balance shows that 1.5 TWh of biomass is consumed within the wood products such as pulp and paper manufacturing, food and drink and other minerals, as illustrated in Figure 12. Within these sectors, low and medium grade heat dominates overall heat demand, with 68% of demand attributed to low to medium heat grades. It is assumed that all biomass consumed within these sectors is used for low and medium heat grades given that high grade heat within the sectors would presumably arise from direct fired kilns.

Figure 12: Share of Biomass Consumption Across Sectors



The datasets identified in this study do not record the sustainability of the biomass.

2.3.5 Future data collection priorities

The methodology for calculating progress against NCAP targets is detailed in Appendix A, which outlines the assumptions made to enable alignment of data sets from different sources, including 2019 data that may now be out of date.

Additional future reporting on energy use in industry is required to accurately understand progress against NCAP targets.

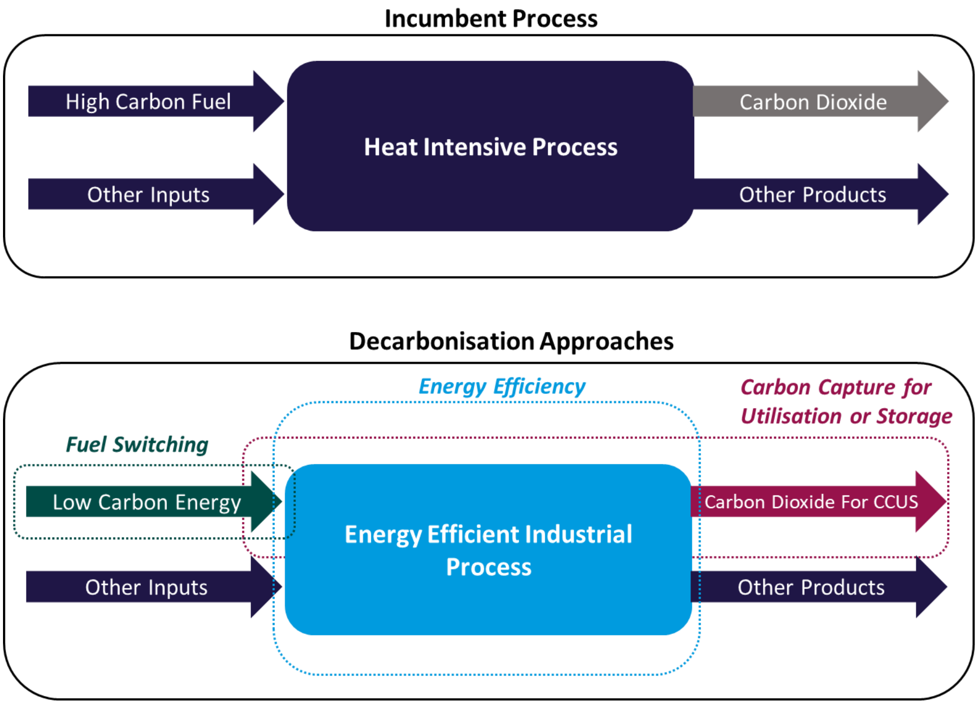
1) ***Standardise calculations for regular progress assessments by defining a precise methodology to calculate high, medium, and low-grade heat demands for each sector***. The calculations required several assumptions and data adaptions to calculate industrial heating demand by technology type and heating grade. Generally, calculations and assumptions should remain consistent for targets to be measured consistently, and progress accurately ascertained.
2) ***Fuel consumption of cement, lime and refining sites***. SEAI granted permission for the use a data set from 2019, which detailed the fuel consumption of cement, lime and refining sites across Ireland. As this data is now 5 years old and it is assumed that these sites (particularly cement and lime) are now consuming more alternative fuels, therefore the calculations for heating demand in these sectors may be inaccurate. The weighted emissions factors calculated for these sectors will not be representative of actual operation.
3) ***Quantity of electricity consumed for heat in industry***. There is no clear way to determine what proportion of electricity consumed in SEAI's National Energy Balance is used for heating for industrial processes, and other processes. Therefore, it is not possible to accurately determine industrial progress against the electrification of heat targets outlined in the NCAP23 report. As a minimum, disaggregation could include industrial process heat (heat pumps, electric boilers) and all other uses.

Additional data is essential to address these gaps in our understanding of the energy landscape and support the effective implementation of carbon-neutral strategies.

3. STRATEGIES FOR DECARBONISING INDUSTRIAL HEAT

This chapter explores the relevance of three conceptually different approaches that hold significant potential for decarbonising industrial heat demand in the period to 2050. These conceptual approaches are Energy Efficiency, Fuel Switching, and Carbon Dioxide Capture, Utilisation and Storage (CCUS), their relationship of which is depicted in Figure 13.

Figure 13: Overview of conceptual approaches to industrial heat decarbonisation



The decarbonisation approaches differ in their site energy and carbon impacts. Energy efficiency measures applied reduce site heat energy demands and thereby site CO_2 emissions. Conversely, fuel switching technologies all reduce site direct CO_2 emissions; this is based on the assumptions that indirect emissions (e.g., upstream emissions) are excluded, as well as CO_2 emissions from bioenergy and wastes.

The leading fuel switching options considered in this study are electrification, hydrogen, bioenergy (including biomass, biogas, bioliquids), renewable wastes, and district heating. Site energy use when fuel switching from solid, liquid or gaseous fossil fuels to solid, liquid or gaseous biofuels would likely remain similar. Electrically-driven heat pumps are particularly energy-efficient, and reduce energy use and site CO_2 emissions. Upstream energy requirements associated with production of electricity or hydrogen are out of scope of this study.

CCUS involves chemical process that divert CO_2 emissions from the atmosphere towards utilisation or permanent storage. Although CCUS reduces site emissions to the atmosphere, the energy needed to run some capture processes and conditioning the captured CO_2 for onward transportation or utilisation can lead to *increases* in site energy use.

Within each conceptual approach, several technologies are emerging worldwide. These technologies differ in their compatibility with incumbent processes, their maturity, economics (particularly capital and operating costs), performance, risks, and barriers, for example the need for supporting infrastructure. The impact on site energy use and CO_2 emissions of the different conceptual approaches are shown in Table 9.

Table 9: Common site energy and carbon impacts from different conceptual decarbonisation approaches

Conceptual approach	Predicted typical impact on site energy use	Predicted typical impact on site CO_2 emissions
Energy efficiency	Modest reduction	Modest reduction
Fuel switching (e.g., electrification, hydrogen, bioenergy, waste, or district heating)	Limited, except heat pumps which can reduce site energy demand substantially	Substantial reduction
CCUS	Modest increase	Substantial reduction

The remainder of this chapter is structured to illustrate the suitability of energy efficiency, fuel switching and CCUS technologies for a number of heat-intensive processes (Section 3.1). The prominence of these heat-intensive processes across the different industry sectors is also investigated to infer a high overall technical potential for industrial heat decarbonisation (Section 3.2). Resource and infrastructure availability in Ireland for industrial heat decarbonisation and an evaluation of the scale of heat decarbonisation opportunity is investigated in Sections 3.3 and 3.4 respectively.

3.1 SUITABILITY OF DECARBONISATION STRATEGIES

Across the different heat grades and industrial sectors, a range of decarbonisation technologies are available. This section reviews these decarbonisation technologies as a function of the temperature or heat grade for heat-intensive processes. As previously shown in Table 6, industrial heat demand in Ireland is distributed relatively evenly across high, medium, and medium/low heat grades, with low heat grade comprising the least demand (<10%).

3.1.1 Energy Efficiency

Energy efficiency measures are suitable across all industrial sectors, although, individual measures vary considerably particularly in relation to cost and carbon reduction opportunity as illustrated in Table 10. Energy efficiency has been a strategic priority for the Energy Union, with an 'energy efficiency first' principle widely promoted throughout industry, adoption is understood to be growing.[19]

Table 10: Energy Efficiency Measures[20]

Measure	Description	Relative Cost	Relative CO_2 Reduction Opportunity
Heat Recovery	Onsite waste heat recovery and reuse	Low / medium	Medium
	Supplying waste heat recovered from industrial processes to others via district heating network	High (if no infrastructure)	Low/Medium
Upgrade/change of equipment	Replacing equipment with higher efficiency units	High	Medium/High
Upgrade/change of process	Changing or upgrading the process to utilise less energy.	Medium/High	Medium/High
Improved control	Improved understanding and control of energy usage through metering and implementation of e.g., Building or Energy Management Systems.	Low	Low

[19] European Parliament (2015), Understanding Energy Efficiency, Understanding energy efficiency (europa.eu)
[20] MAKE UK (2023), Driving Industrial Energy Efficiencies: A Best Practice Guide

Measure	Description	Relative Cost	Relative CO_2 Reduction Opportunity
Best practise greenfield design	Insulating warmer and cooler processes from other parts of the process. Undertaking regular maintenance	Low	Medium

3.1.2 Fuel Switching

Fuel switching encompasses a diverse range of alternative energy sources, including electrification, hydrogen, bioenergy, waste, and district heating. Each option possesses unique characteristics, influencing its suitability for various heat grades, heat types (indirect or direct), and industrial sectors. Table 11 summarises the applicability of electrification, biofuels, and hydrogen to direct and indirect heating technologies across the different heat grades. The reported heat demand across Irish industry covers a wide range of temperature requirements, including low to high heat grades, as well as both direct and indirect heating technologies. This comprehensive scope necessitated the inclusion of all these criteria in Table 11.

Table 11: Potential Fuel Switching Technologies[21]

Heat Type	Heat Grade	Traditional gas, oil, or coal-fired heat-intensive processes	Electrification	Biomass/ biogas/ bioliquid	Hydrogen
Direct Heating	High	Kilns or Furnaces	Electric kilns, furnaces, calciners and Electric plasma gas heaters*,	Biomass/waste combustion** Biomass/biogas/bioliquid kilns	Hydrogen heaters, furnaces, kilns and calciners
	Medium & Medium/ Low	Dryer	Infrared dryers, air dryers	Biogas dryers (Recuperative/ regenerative burners)	Hydrogen dryers
		Oven	Electric ovens	Biogas ovens Recuperative/ regenerative burners	Hydrogen ovens
	Low	Dryer	Electric heaters, microwave assisted heaters.	Biogas dryer (Recuperative/ regenerative burners)	Hydrogen heaters, Recuperative/ regenerative burners
Indirect Heating	High	Heaters	Electric heaters	Biomass/biogas/ bioliquid heaters	Hydrogen heaters
	Medium	Boiler, CHP	Electric boilers	Biomass boilers Bioliquid boilers	Hydrogen boilers
	Medium & Low	Boiler	Electric boilers, Heat Pumps, CHP	Biomass/bioliquid /biogas boilers, CHP, biogas heat pumps	Hydrogen boilers, CHP
	Low	Dryer	Heat pumps, Microwave dryers,	/	/

**Up to 25% substitution*

[21] Element Energy (2018), Industrial Fuel Switching Market Engagement Study, [Industrial fuel switching market engagement study (publishing.service.gov.uk)]

***Up to 80% substitution when producing cement.*

Fuel switching from natural gas, oil, and coal for *indirect* heating for low, temperature processes (e.g. via steam or hot water) is growing globally where there is good access to low-cost electricity or bioenergy. Fuel switching can be more restricted for processes where there is *direct* contact with the process inputs. For example, gases released from the combustion of fuel in glass kilns have direct contact with the inputs and products, therefore, alternative fuels must be further studied to assess their effects on product quality. There may also be impacts on operability or flexibility associated with alternative fuels.

Electric technologies are widely applied across lower temperature heat grades, where there are multiple mature technologies currently available. Switching to grid electricity from carbon-intensive fuels reduces site emissions, due to the lower carbon emissions associated with grid electricity. However, it is important to note that overall emissions reduction will depend on the mix of energy sources used by the grid. Ongoing decarbonisation of Ireland's electrical grid will reduce associated indirect emissions (the carbon intensity of electricity in 2022 was 332 gCO_2/kWh, which is higher than natural gas (NCV 204 gCO_2/kWh).[22] Direct medium/low and low-temperature heating technologies, such as electric boilers and ovens, are a proven technology with an established market and have comparable costs to their gas-powered alternatives.[23] In contrast, industrial high-temperature heat pumps and electromagnetic heaters are more expensive than gas boilers due to high initial costs, complex installation, immaturity, and limited production and installation that reduces economies of scope and scale. [24]

Biofuels are commonly used across industry, with biomass, bioliquids and biogas used as fuel sources for production of electricity, as well as heating and cooling purposes, such as in boilers and CHP systems. Beyond the end use application, biomass, biogas, and bioliquids generally have different markets, costs, and supply chains, and therefore these fuels are considered separately in this assessment.

Biomass can be solid, in forms such as waste wood and municipal solid waste (MSW), or liquid such as bioethanol, Hydrogenated Vegetable Oils (HVO), or biodiesel.[25] The wood products sector has the highest consumption of biomass in industry, as the waste wood by-product is used for low to medium temperature applications onsite. Alternative fuels are becoming more widely adopted in the cement industry, with fuels such as solid recovered fuels (SRF), secondary liquid fuels (SLF) and meat and bone meal being used as alternative fuels in kilns[26].

Biogas has a very different application within industry, with fuels consisting of syngas and biomethane. Syngas usage is generally focused within the production of transportation fuels.[27] In contrast, biogas produced from biomass through anaerobic digestion is typically comprised of approximately 60% methane and 40% CO_2 with trace amounts of other gases. Biogas can be upgraded to biomethane, where CO_2 and impurities are removed leaving a gas with a methane concentration of >97%. Most commonly, biogas is utilised in CHP systems, whilst biomethane has wider applications[28]. Most notably, biomethane (with additives such as propane) can be made fully compatible with the Irish natural gas network and existing equipment and therefore injected into the mains gas network to supply distributed users. Once inside the network, natural gas and biomethane are effectively indistinguishable. However, emissions benefits can be traded through certification and guarantee schemes. The biomethane market is already established and available on the European market and satisfies the Renewable Energy Directive II's (RED II) life cycle analysis.[29]

Bioliquids are a type of biofuel typically derived from biomass sources; Examples are virgin or used vegetable and seed oils, such as palm and soy. These fuels exist in various forms, including raw liquids directly extracted from biomass (e.g., vegetable oils), and refined biocrudes similar to conventional crude oil. Due to this diversity, bioliquids exhibit a range of fuel properties. Consequently, for optimal utilisation in specific technologies, adaptations may be necessary to accommodate these variations in properties. Hydrotreated vegetable oil (HVO) is the most common type of liquid biofuel that can be used in modified oil boilers, and in some cases

[22] SEAI, Conversion Factors, Conversion Factors | SEAI Statistics | SEAI

[23] Ambienta (2023), Electrifying Industrial Heat: A Trillion Euro Opportunity Hiding in Plain Sight, 2023_I-Ambienta-Lens_Electrifying-Industrial-Heat.pdf (ambientasgr.com)

[24] Heat Pump Chooser (2023), Useful Guides, Why are Heat Pumps so expensive? (heatpumpchooser.com)

[25] World Bioenergy Association, Liquid Biofuels A Sustainable Solution for Transport Sector, 200707_Liquid_Biofuels_Factsheet.pdf (worldbioenergy.org)

[26] CEMEX (2024), Alternative Fuels, CEMEX leads the industry in utilising alternative fuels | CEMEX UK

[27] iScience (2020), Biogas Reforming to Syngas, A Review, Biogas Reforming to Syngas: A Review (cell.com)

[28] European Biogas Associated (2024), About Biogas and Biomethane, About biogas and biomethane | European Biogas Association

[29] Gas Networks Ireland (2023), Biomethane Energy Report, biomethane-energy-report.pdf (gasnetworks.ie)

as a drop-in fuel. Blending bioliquids with conventional fuel is a viable option, not only to improve viscosity, but enables use without significant or in some cases any adaptions. [30]

Hydrogen fuel switching (either as 100% hydrogen, or 'blending' in combination with other fuels) could be feasible across a range of sectors and industrial processes. Hydrogen combustion can support a wide range of temperatures, including the high grade temperature applications. There areother factors which should be considered when converting to hydrogen, such as the re-engineering design of systems, such as in relation to safe design and procedures,or the management of NOx emissions.

District heating networks (DHNs) can be considered a form of fuel switching. DHNs provide space and water heating (or cooling) through a network of insulated pipes. Most commonly these would supply low grade heat via hot water, but medium-low steam networks are also possible, for example for industrialised estates. Centrally generated heat, captured waste heat from industry, data centres or sewers, can be supplied to a defined network area. DHNs can contribute to decarbonisation efforts if they incorporate low carbon energy sources such as biomass or recovered heat. Industrial sites can either be suppliers of the heat network, as well as users.

3.1.3 Carbon Capture, Utilisation & Storage

Carbon Capture, Utilisation and Storage (CCUS) plays an important role in decarbonising hard to abate sectors, such as the cement and lime industries, because of the unavoidable process emissions associated with these sectors. In this report, carbon capture and storage (CCS) is considered for large-scale implementation projects, while the potential to utilise carbon (categorised under the term CCUS) is deemed applicable only for smaller-scale sites. There are many carbon capture options including post-combustion carbon capture, pre-combustion carbon capture, oxy-fuel combustion, chemical looping, carbonate looping and supercritical CO_2 (the Allam cycle). Different capture approaches will integrate with more ease or difficulty to different industrial processes; CCUS is particularly applicable for sectors where emissions are concentrated in a small number of stacks and with high concentrations of CO_2. Table 12 illustrates the sectors in Ireland with the highest CCUS potential.

Table 12: Potential for CCUS [31] [32] [33]

Sector	Suitable CCUS Technology	Technical potential to reduce CO_2 emissions from heat demand in sector
Cement and lime	Post-combustion (solvent-based), Oxyfuel combustion, Chemical Looping	50-90% CO_2 reduction
Other minerals (glass and ceramics), refineries, chemicals, metals, wood products	Post-combustion, Oxyfuel, Some pre-combustion processes	Medium/High

3.2 APPLICATION OF DECARBONISATION STRATEGIES IN IRELAND

This section explores the diverse range of industrial heat decarbonisation technologies applicable in the Irish context, considering the options available for the various heat intensive processes present in industrial sectors. The relative importance of deploying decarbonisation technologies for different heat-intensive processes is

[30] T.Seljak et al (2020), Bioliquids and their use in power generation – A technology review, Bioliquids and their use in power generation – A technology review - ScienceDirect

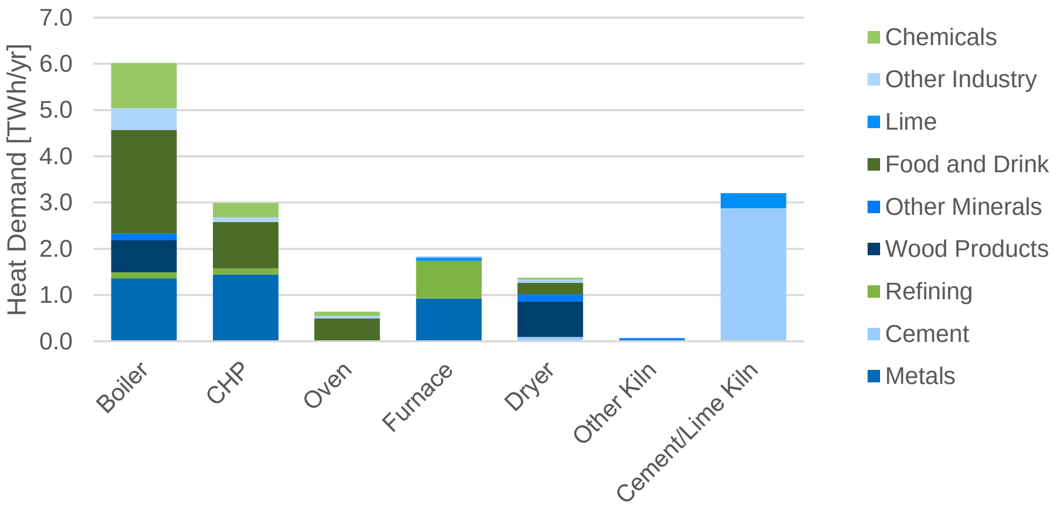
[31] A. Gailani et al (2023), Assessing the potential of decarbonisation options for industrial sectors, https://www.sciencedirect.com/science/article/pii/S2542435124000266

[32] G. Faria et al (2022), Integrating oxy-fuel combustion and power-to-gas in the cement industry: A process modelling and simulation study, Integrating oxy-fuel combustion and power-to-gas in the cement industry: A process modeling and simulation study - ScienceDirect

[33] B. Caudle (2023), Integrating carbon capture and utilization into the glass industry: Economic analysis of emissions reduction through CO2 mineralization, Integrating carbon capture and utilization into the glass industry: Economic analysis of emissions reduction through CO2 mineralization - ScienceDirect

shown in Figure 14, which illustrates the associated heat demand of key incumbent industrial technologies deployed in Ireland.

Figure 14: Incumbent Technology Types and Heat Demand Across Sectors in Ireland 2022



As illustrated in Figure 14, the heat demand profile across key incumbent technologies, particularly boilers, CHP units, and cement/lime kilns suggests the potential for two complementary strategies to maximise emissions reductions.

The first strategy involves decarbonisation of low-temperature indirect heating technologies such as boiler and CHP units. Due to the large number of installations, this strategy would address 56% of Ireland's total industrial heating demand. In 2022, boilers alone provided the largest single heating demand, with approximately 6TWh, demonstrating the significant decarbonisation potential. The second strategy involves decarbonisation of high-temperature direct heating processes such as cement/lime kilns and furnaces within the metals and oil refining sectors. Despite the smaller number of installations, furnaces and kilns account for approximately 1.7 $MtCO_2$/yr of industrial emissions, as well as 5 TWh/yr of heating, which is 32% of Ireland's total heating demand,

Fuel switching approaches involve the partial or complete replacement or modification of traditional coal, oil, or gas-fired boilers to utilise alternative fuel sources such as electricity, biomass, biogas, renewable wastes, hydrogen, or district heating. Blending various energy inputs can potentially enhance performance, economic viability, or risk profile, though the feasibility of specific combinations necessitates equipment-specific analysis and consideration of association energy infrastructure.

Table 13 provides a comprehensive overview of Ireland's key industrial sectors, highlighting the primary heat-intensive processes within each sector and outlining potential decarbonisation strategies. A full description of each sector's heat intensive processes and decarbonisation technologies is supplied in the appendix.

Table 13: Heat decarbonisation technologies available for different industrial sectors in Ireland [53] [54] [55] [56] [57]

Sector	Illustrative heat intensive processes	Energy Efficiency	Electrification	Bioenergy	Hydrogen	CCUS	Alternatives
Alumina production	Bayer Process Calcination	Mechanical vapour recompression Heat recovery	Electric boilers Electric calcination	-	Hydrogen calcination	Applicable	-
Refineries	Distillation, Catalytic Cracking, Thermal Cracking	Heat recovery	Electric boiler	-	Hydrogen furnace	Applicable	Process integration
Cement	Raw meal preparation (dryer) Pyro processing - calcination and clinker formation - (kiln)	Heat recovery Clinker substitution Upgraded kiln with low pressure drop cyclone / preheater and precalciner	Plasma torches	Alternative fuels (kiln)	Hydrogen/Plasma calciner Hydrogen kiln	Applicable	Alternative clinker systems
Food & Drink	Cookers, fryers, Systems generating steam/hot water, ovens/dryers, distillation, heat-driven cooling & freezing, packaging	Steam and hot water generation and distribution efficiencies. Heat recovery. MVR.	Electric steam and hot water boilers Heat pumps Induction cooker, Electric ovens, Microwave, Air Fryer	Biomass/biogas boilers	Hydrogen boiler	-	Membranes for separation instead of heat.
Chemicals	Depends upon sub-sector (i.e., ammonia, fertilisers, polymers, speciality chemicals, pharmaceuticals). Steam for reaction & separation, direct heat in reaction furnaces.	Steam and hot water generation and distribution efficiencies. Heat recovery. MVR.	Electric steam and hot water boilers Heat pumps	Biomass/biogas boilers	Hydrogen boiler	Applicable	Membranes for separation instead of distillation.
Pulp & Paper	Pulp production Vacuum systems (for dewatering) General paper machine Drying	Steam and hot water generation and distribution efficiencies. Better pre-dryer dewatering Heat recovery, especially MVR.	Electric boilers Heat pumps	Biomass/biogas boilers	Hydrogen boiler	-	Process integration. Efficient vacuum systems for dewatering. New drying technologies (non-thermal water removal).
Ceramics	Raw material preparation, component forming, green product drying, green product firing.	Efficient burners Heat recovery from firing for drying. Other heat recovery Better kiln insulation materials Low thermal mass kiln furniture	Electric kilns Microwave assisted drying and firing.	Biogas burners	Hydrogen burners	Applicable	Integration of drying and firing kilns. Low thermal mass kiln furniture and continuous kilns.

Sector	Illustrative heat intensive processes	Energy Efficiency	Electrification	Bioenergy	Hydrogen	CCUS	Alternatives
Glass	Batch preparation, melting, product annealing (lehrs) – container, flat and glass fibre	Regenerative furnace Oxy-fuel fired furnace Recuperative burners Heat recovery Use of more glass cullet	Electric furnace	Biogas burners	Hydrogen burners	-	-

3.3 RESOURCE AND INFRASTRUCTURE AVAILABILITY

The achievement of Ireland's NCAP23 targets, particularly those pertaining to and relying on fuel switching, is directly contingent upon the nation's resource and infrastructure availability. Energy efficiency measures are generally easier to implement and are well may have few and well-defined interactions with external stakeholders, whilst fuel switching and CCUS strategies are generally site specific and require careful planning to optimise the interactions between different systems and stakeholders.

Electrification

All heat-intensive businesses in Ireland will already have an electricity grid connection; several of which will already have on-site power generation from renewables or gas-fired CHP. Industrial heat decarbonisation through electrification would place significant additional demands on power generation and electricity networks which are already almost at capacity, consequently compromising security. The 2022–2031 Generation Capacity Statement (GCS) highlights Ireland's electricity supply challenges, including reduced power generation capacity, managing intermittent renewables, diversification and supporting electrification of heat and transport. [34] In a few cases, the new low carbon power generation could be delivered by integrating more on-site or local low carbon generation and smart energy storage.

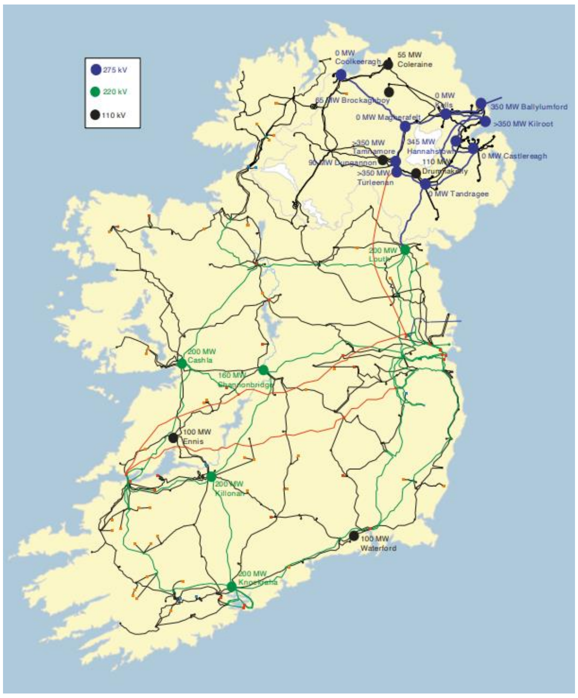
The EirGrid All-Island Ten-Year Transmission Forecast Statement 2022 included an analysis on the demand opportunity for 2027, the results of which are depicted in Figure 15. Transmission stations across Ireland and Northern Ireland were analysed for demand opportunities, which consisted of 110kV, 220kV and 275kV stations. These stations identify locations that are potentially suitable for major industrial load centres with large power requirements[35]. It can be seen from Figure 15 that the locations identified correspond to Ireland's major cities.

Achieving a significant contribution from electrification towards meeting the 10 TWh/yr demand for medium/low-grade heat necessitates substantial investments in both clean power generation capacity and associated grid infrastructure. This strategic approach would mitigate potential risks to the security and reliability of electricity supplies. Additional grid capacity and security is required to meet the additional demand from industrial heating, which is subject to efficiency improvements and improved coefficient of performances for heat pumps.

[34] EirGrid (2022), Ireland Capacity Outlook 2022 – 2031, All-Island Generation Capacity Statement 2022-2031 | Eirgrid

[35] EirGrid and SONI (2023), All-Island Ten-Year Transmission Forecast Statement 2022, All Island Ten-Year Transmission Forecast Statement 2022 (eirgrid.ie)

Figure 15: EirGrid Map of capability for additional demand at 275kV, 220kV, and 110kV stations in 2027 [35]



Biomass

Estimates from SEAI indicate that there is enough biomass resource availability to supply approximately 30% of Ireland's overall current energy use, the majority of which will be met using energy crops. [36]

Scenarios predicting favourable market conditions and mitigation of supply-side barriers for bioenergy resources in Ireland indicate a promising outlook by 2035. Under these assumptions, the total production of solid, liquid, and gaseous bioenergy could reach 38.26TWh (138 PJ) annually. This projected output represents a significant contribution to Ireland's energy needs, potentially meeting 10% of the total demand when utilised for electricity generation or nearly 30% if directed towards heat production[37].

Bioliquids

The SEAI forecasts that resources traditionally used for liquid biofuel production are only economically viable at high market prices, and even under these most optimistic market scenarios, these resources contribute a maximum of 4% to the total potential bioenergy resource. Conversely, if current low market prices persist coupled with unresolved supply-chain challenges, the potential in 2035 is projected to be significantly lower, at just 11.63TWh (41 PJ), representing a decline of over two-thirds. SEAI's projections suggest a very limited potential for bioliquids under a business-as-usual approach extending to 2035.[37]

Biogas/Biomethane

Biogas production, often achieved through anaerobic digestion of organic matter, offers a potential renewable heating solution for industry. Unless upgraded to biomethane, its utilisation and value depend heavily on its composition and proximity to demand. While typically rich in methane, some cases yield syngas, which is a mixture of hydrogen, methane, and carbon monoxide. Locally produced biogas used directly for heating and CHP systems benefits from low upfront processing costs but faces limitations in capacity, distance, and equipment compatibility.

Upgrading bigas to biomethane involves removing impurities and CO2. While processing can be expensive, the resulting biomethane boasts greater versatility and value. Biomethane can replace natural gas with minimal modifications to equipment and infrastructure, and can be transported more easily to other users or injected into the gas grid. Renewable certification schemes facilitate the accounting of carbon benefits associated with the injected methane molecules, which are fungible within the grid. Furthermore, opportunities exist for

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[36] SEAI, Sustainable Biomass Fuels in Ireland, Sustainable Biomass Fuels in Ireland | Bioenergy | SEAI

[37] SEAI (2016), Bioenergy Supply in Ireland 2015 -2035 Report Summary and Key Findings, Bioenergy-Supply-in-Ireland-2015-2035-Summary-Report.pdf (seai.ie)

industrial heat decarbonisation using biogas imported to site. This study focuses on the barriers associated with industrial heating via on-site biogas production and utilisation, alongside the use of locally or imported biogas for off-grid facilities.

In Ireland there are 16 biogas plants, 15 of which utilise anaerobic digestion technology, and 54 biomethane facilities operating. There are a further 8 biomethane facilities under construction and over 65 in the pipeline.[38] [39] Ireland produced 41 GWh of biomethane in 2022, and an estimated 62 GWh in 2023.

The Irish government has outlined ambitious targets to meet biogas demand and carbon reduction KPI's. The 2023 NCAP outlines a significant push for biomethane deployment as a key driver of emissions reduction. [40]The plan sets ambitious targets:

- **Production:** 1 terawatt hour (TWh) of biomethane by 2025, scaling up to 5.7 TWh by 2030.
- **Infrastructure:** Construction of 20 anaerobic digestion (AD) plants by 2025, expanding to 200 plants by 2030, laying the groundwork for a robust production network.

The Biomethane report published by Gas Networks Ireland in 2023 details the need for the gas network to transition to renewables gases (such as biomethane). Natural gas can be directly substituted by renewable gases such as biomethane, and therefore will be important to decarbonising the gas network. It states that Ireland has the potential for a 14.8 TWh/yr biomethane industry, which represents a 26% replacement of current gas demand. By substituting natural gas with renewable gases such as biomethane, existing gas infrastructure can be leveraged, reducing costs, and causing minimal disruption. [29] While clearly growing rapidly, the 2023 level for biomethane still falls short of the CAP's target of 1TWh by 2025.[29]

Hydrogen

Proponents of the use of hydrogen argue hydrogen is highly versatile and can replace many fuels, due to its high energy density. Hydrogen combustion can produce the high temperatures needed for the glass, cement, and steel sectors, and trials are underway in many countries.[41] Due to Ireland having competitive wind resources, there is potential for the country to develop "Green Hydrogen" value chains. Ireland's National Hydrogen Strategy targets installing 2GW of offshore wind capacity dedicated to green hydrogen production by 2030. [26] [42] [43] Additionally, Ireland is already in the process of establishing a pilot hydrogen hub in the Galway region, acting as proof of concept to illustrate the ability to produce and utilise hydrogen locally.[44] Prior to 2030, hydrogen is to be produced using grid connected electrolysis from surplus renewables.[26]

While Ireland possesses existing capabilities in hydrogen handling, primarily through the Whitegate refinery in County Cork, which currently serves as the nation's largest industrial hydrogen processor, the release of the Hydrogen Strategy has spurred a surge in proposed projects, indicating a growing focus on this clean energy source.

Growing opportunities for hydrogen demonstration in industry

Opportunities for demonstrating hydrogen's role in industrial heat decarbonisation in Ireland include: [26]

- **Firlough Project**, a wind-hydrogen electrolysis plant, operated by Mercury Renewables at An Bord Pleanála
- **Galway Hydrogen Hub:** Set to launch in 2024, this hub focuses on pilot initiatives. [45]
- **Mount Lucas Green Hydrogen Production Project:** Expected to be operational in 2025, this project will produce 2MW of green hydrogen to decarbonise the transportation and industrial heating sectors.[46]

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[38] Anaerobic Digestion Community (2022), How Irish Biogas Plants Can Help Ireland Achieve Renewable Energy Targets, Irish Biogas Plants to Multiply in New Move - Avoid Grass Madness: Landia (anaerobic-digestion.com)

[39] Gas Networks Ireland (2022), Investors ready for Irish biomethane facilities as demand for green energy soars, Investors ready for Irish biomethane facilities as demand for green energy soars (gasnetworks.ie)

[40] Government of Ireland (2023), Climate Action Plan 2023, 94a5673c-163c-476a-921f-7399cdf3c8f5.pdf (www.gov.ie)

[41] K. Martins, J.G Carton (2023), Prospective roles for green hydrogen as part of Ireland's decarbonisation strategy, https://www.sciencedirect.com/science/article/pii/S2590123023001573

[42] DIAGEO (2022), Encirc and Diageo announce hydrogen powered furnace to change the face of UK glass manufacturing industry, Encirc and Diageo announce hydrogen powered furnace to change the face of UK glass manufacturing industry

[43] GLASS International (2023), Four glass industry facilities to start full-scale hydrogen trials, Four glass industry facilities to start full-scale hydrogen trials (glass-international.com)

[44] Agriland (2021), €120m green hydrogen plant planned for Cork, €120m green hydrogen plant planned for Cork (agriland.ie)

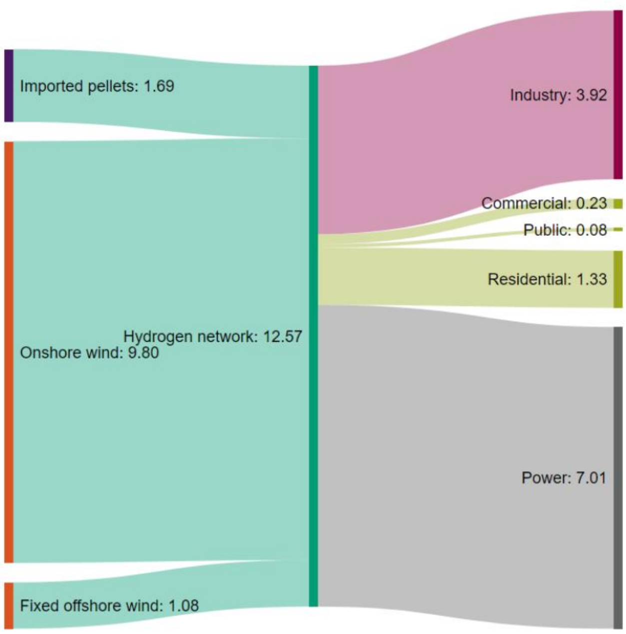
[45] SSE Renewables (2022), Details of Galway Hydrogen Hub (GH2) announced, Details of Galway Hydrogen Hub (GH2) announced | SSE Renewables

- **The Green Atlantic at Moneypoint project:** Anticipated to be operational by the end of this decade, this project aims to harness surplus renewable electricity from a floating wind farm to produce green hydrogen. This hydrogen will serve power generation, heavy goods vehicles, and various industries such as pharmaceuticals, electronics, and cement. [46]

The combustion temperature for hydrogen is high, which presents a potential solution for decarbonising high-heat industrial processes. However, its utilisation as an energy vector remains limited and in its early stages of development. The distinct physical and chemical properties of hydrogen compared to natural gas necessitate adaptations when converting existing gas-fired processes. Furthermore, careful consideration of techno-economic factors is crucial for hydrogen value chains. This includes optimising the sizing and storage of hydrogen, as well as minimizing costs through strategic placement of production, distribution infrastructure, and demand centres.

Hydrogen is expected to see widespread use across various sectors covering existing and future uses, leading to increased competition. According to the Balanced Scenario in the Net Zero by 2050 paper, the power sector will consume over half of the produced hydrogen in 2050, while industry will be the second-largest user, accounting for 3.9 TWh (see Figure 16).[79] Therefore hydrogen could satisfy a large fraction of high-temperature heat demands in Ireland (4.3 TWh in 2022, see Table 6).

Figure 16: Sankey diagram for hydrogen production and use in 2050 [47]



CCUS

CCUS presents opportunities for decarbonising heavy industries that are difficult to tackle through other means. The technology can be retrofitted to existing sites, capturing up to 90% of the originally emitted carbon. Actual abatement levels may be around 75% in this scenario due to the energy consumed for capture, and will vary depending on the technology and installation parameters. There is interest in CCS from the cement and oil refining industries, since CCS provides a unique opportunity to reduce both fossil fuel usage and process-specific emissions[48]. The combination of CCUS with biomass opens the opportunity for net zero (i.e. negative emissions).[48]

NCAP23 outlines that feasibility assessments on CCUS technologies should be conducted in 2023, and action to advance policy position on CCS in 2024[40]. Current CCUS infrastructure across the value in Ireland needs

[46] ESB, Green Atlantic at Moneypoint, Green Atlantic at Moneypoint (esb.ie)

[47] IEA (2021), Net Zero by 2005: A Roadmap for the Global Energy Sector, https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

[48] SEAI (2022), National Heat Study Carbon Capture Utilisation and Storage (CCUS), Carbon Capture Utilisation and Storage | National Heat Study | SEAI

significant development if it is to be deployed at large scale, particularly centred around transport and storage. Transport infrastructure comprises of offshore and onshore pipelines to transport the compressed CO_2; however, other means can also be utilised such as ships, rail, or road tankers. It is important to note that at present CO_2 storage in geological formations is limited in Ireland through the S.I No. 575/2011 – European Communities (Geological Storage of Carbon Dioxide) Regulations. Ireland has yet to ratify an amendment to the London Protocol which would allow the international transport of CO_2. [49] [50]

If the legal status of CO_2 storage and transport in Ireland changes, there are deep geological formations beneath Ireland's offshore sedimentary basins that are potential candidates for CO_2 storage, such as the Kinsale Head and Corrib gas fields. As of 2020, Kinsale Head gas field entered decommissioning, whilst the Corrib gas field is expected to remain active. Preliminary estimates the CO_2 storage capacities of Kinsale Head and Corrib gas fields to be 321 Mt and 44 Mt, respectively. Research suggests that the depleted Kinsale Head field could hold the equivalent of up to 40 years of CO_2 emissions from Ireland's top ten point-source emitters (as of 2020). [51]

While CO_2 storage remains a key component of CCUS, utilisation presents an alternative pathway. However, established and commercially viable applications currently predominantly consist of uses that do not result in long-term CO_2 storage, such as abattoirs, breweries, and enhanced oil recovery. Other utilisation opportunities exist, particularly within the food and beverage sector, including use in greenhouses, food product packaging, and beverage carbonation. Notably, these applications often necessitate high CO_2 purity, requiring additional processing following capture.

Industrial sites which are close or accessible to potential carbon storage sites, and which have high process emissions, are likely to be more attractive for CCUS. Moreover, the economies of scale in capture, transport and storage make CCUS a good fit for large point sources of CO_2, for example cement and lime plants.

Despite the potential, there are significant challenges associated with the deployment of CCUS, namely due to its high costs. This high-cost barrier hinders widespread adoption of CCUS, particularly for industries facing tight profit margins. Additionally, the lack of established infrastructure for CO_2 transportation, utilisation, and storage further adds to the economic burden, creating a significant hurdle for large-scale deployment of this technology.

3.4 SCALE OF DECARBONISATION OPPORTUNITY

The scale and pace at which Ireland can adopt these decarbonisation strategies depends on several factors such as availability of sustainable inputs, as highlighted previously, as well as technology costs and the maturity of the technologies. Table 14 provides a summary of the applicability of fuel-switching options across various cross-sectoral process, including Technology Readiness Level (TRL), emissions savings and efficiency. Moreover, mapping the incumbent technologies with decarbonisation strategies allows for carbon reduction opportunity to be identified.

Mature technologies are becoming more widely adopted in industry, with some technologies still requiring time to reach full deployment. A key indicator of a technology's maturity, and hence likelihood of deployment is known as its TRL. A TRL of 1-9 is available, with 1 being the lowest (basic) and 9 being the highest (extensive implementation). TRLs can be grouped as follows:

- TRL 1 – 3: Research (concept to proof of concept)
- TRL 4 – 6: Development (to pilot scale)
- TRL 7 – 9: Demonstration (to normal commercial operation)

By assessing the TRL, emissions saving potential and efficiency of various decarbonisation technologies, the carbon reduction potential of various decarbonisation strategies in Ireland can be determined. Note that Ahmed Gailani et al.'s publication *Assessing the potential of decarbonization options for industrial sectors* [31] shows the TRL, emissions savings potentials and efficiencies of various decarbonisation technologies. At the time of this study, updated TRL's and emissions savings potentials were not found for some technologies.

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[49] Carbon Gap, Ireland, https://tracker.carbongap.org/region/ireland/

[50] Irish Statute Book (2011), S.I. No. 575/2011 - European Communities (Geological Storage of Carbon Dioxide) Regulations 2011, https://www.irishstatutebook.ie/eli/2011/si/575/made/en/print

[51] J. English, K. English (2022), Carbon Capture and Storage Potential in Ireland – Returning Carbon Whence It Came, Carbon Capture and Storage Potential in Ireland — Returning Carbon Whence It Came | Earthdoc

Table 14: Scale of Decarbonisation Opportunity [31]

Incumbent Technology	Carbon Emissions (ktCO2/yr)	Decarbonisation Technology	TRL	Emissions Savings Potential (%)
Kilns[1, 2] (Cement & Lime)	1,230	Electric (plasma torch) kilns	3 – 8	40
		Hydrogen kilns	6 – 8	16 - 40
		Biogas kilns	-	-
		Biomass kilns	6 – 8	16 - 40
Boilers	1,050	Electric boiler	9	100
		Biomass boiler	9	100
		Hydrogen boiler	9	100
		Heat pumps	9	100
		High Temperature heat pumps	3	-
Furnace	430	Electric furnace	7 - 9	80
		Hydrogen furnace	6	80
		Biogas furnace	8	80
Dryers	320	Infrared/ microwave dryer	6	-
		Electric dryer	9	20
		Hydrogen dryers	5	-
		Biogas fuelled dryer	5	-
Ovens	95	Electric oven	9	100
		Hydrogen ovens	9	100
		Biogas fuelled oven	9	-
		Recuperative/ regenerative burners (biomass & hydrogen)	-	-
Heaters	Not calculated	Electric heaters[3]	9	100
		Hydrogen heaters	-	-

[1] Efficiency upgrades for cement kilns can include; upgraded kiln with low pressure drop cyclone (TRL 9, emissions savings potential 7%), upgraded kiln with cyclone preheater and pre-calcinator (TRL 9, emissions saving potential 7%)

[2] Emissions savings potential for cement and lime kilns is inclusive of process and heating emissions.

[3] Results for electric hot water heaters only

It can be seen from Table 14 that the decarbonisation technologies available for boilers possess high TRLs (9), illustrating that electric, biomass, and hydrogen boilers, as well as heat pumps are already proven technologies ready for full commercial deployment. Moreover, these decarbonisation technologies have efficiencies over 90% and have the potential for 100% emissions savings. High temperature heat pumps are the exception within this category, with a TRL of 3. The potential of industrial high temperature heat pumps is widely recognised, although, there are several technical and economic barriers preventing their large-scale deployment. Whilst industrial heat pumps are currently able to provide temperatures of up to 120-160ºC, prototypes are operating at approximately 180ºC. As illustrated in Figure 10, the industrial heating demand of boilers in Ireland is approximately 4.5TWh/yr, the largest of all technology types, therefore, decarbonising boilers has the potential to make a great impact on reducing heat-related industrial emissions (1,050 ktCO_2/yr). To caveat, despite the mature nature and high TRL associated with heat pumps and hydrogen, electric, and biomass boilers, they are yet to be widely adopted in Ireland, in part due to high electrical costs and technical feasibility.

The decarbonisation technologies for cement/lime kilns and furnaces are a lot more diverse in terms of TRL and emissions savings potential, ranging from TRL 3 – 9 and emissions savings of 14 – 80%; oftentimes this range is found within individual technologies as well. Decarbonisation technologies include electric, biomass, biogas, and hydrogen fuelled kilns and furnaces. Despite the large carbon emissions associated with kilns and furnaces in Ireland, which are 1,230 ktCO_2/yr and 450 ktCO_2/yr, respectively, it may be some time before full scale commercial demonstration of the decarbonisation technologies, as many of these technologies are still within the research or development stages.

Dryers are responsible for 320 ktCO_2/yr, one of the smaller contributors to industrial heat emissions in Ireland. The TRLs of the decarbonisation technologies sit within the development stage (TRLs 5 and 6), apart from electric dryers that have a TRL 9. Electric dryers are a well-established, commercially operating technology; however, they only offer a 20% emissions savings potential.

Contributing 95 ktCO2/yr, ovens are responsible for the lowest industrial heating related carbon emissions in Ireland; this correlates to the low heating demand of ovens observed in Figure 10. The decarbonisation technologies include electric, hydrogen and biogas fuelled ovens, all of which possess TRLs of 9, demonstrating their commercial operation. Moreover, hydrogen and electric ovens have an emissions reduction potential of 100%, representing a significant decarbonisation opportunity, even though the overall impact may be smaller due to the low emissions associated with current industrial ovens compared to other incumbent technologies.

The decarbonisation potential of various incumbent technologies is multifaceted, contingent upon factors such as their TRL. The impact of these decarbonisation technologies is directly linked to their emissions savings potential and their scale of deployment across industry. It is crucial to recognise that TRL's, emissions savings potential and efficiencies of technologies will improve over time as they mature through to commercialisation.

There are several carbon capture technologies available for retrofit across a limited number of industrial sectors. The suitability of carbon capture deployment depends on a multitude of factors, such as the industrial process, concentration of CO_2, and space requirements on site. Although a variety of technologies are available, the most common have been represented in Table 15.

Table 15: Scale of Carbon Capture Utilisation and Storage Decarbonisation Opportunity [52]

Technology	Applicable Industry	TRL	Capture rate
Amine post combustion capture	Cement, Lime, Wood products, Refining	7	>90%
Oxyfuel combustion	Cement	4 - 6	>90%

Post combustion amine systems are often deployed to capture CO_2 from flue gas streams and have been successfully demonstrated in operational environments (TRL 7), achieving capture rates of >90%. This technology holds significant potential for reducing CO_2 emissions across several key sectors, including cement, lime, refining and wood products. These industries, excluding wood products, are major emitters with hard-to-abate CO_2 emissions. The technology's ability to capture 90% of CO_2 emissions makes it a particularly impactful solution for these industries' decarbonisation efforts. Oxy-fuel combustion technology on the other hand shows potential for use only within the cement sector; however, the technology is still in the development stages (TRL 4 – 6), therefore it may take time before it is suitable for commercial operation.

The strategic deployment of carbon capture technologies has the potential to make a significant contribution to industrial heat decarbonisation, particularly for sectors with processes that lack alternative low-carbon

[52] T. Hills (2016), Carbon Capture in the Cement Industry: Technologies, Progress, and Retrofitting.

solutions. Due to the status of CCUS technologies, further research and development efforts are still required to enhance their commercial feasibility and widescale adoption.

Associated costs of the technologies have not been included in Table 14, therefore it is recommended that a detailed economic assessment of potential is undertaken.

The potential impact of implementing the various heat decarbonisation strategies, including energy efficiency, fuel switching, and CCUS, in Ireland from 2025, 2030, and 2050 are shown in Table 16. To summarise:

- **Energy Efficiency:** In 2025, the potential impact of energy efficiency measures results in modest energy and CO_2 emissions reductions, reaching a plateau from 2030 due to potential saturation on heat demand and limitations of technology.
- **Electrification:** Electrification has limited potential for low and medium/low grade heat in 2025 and 2030. Assuming grid expansion and decarbonisation, by 2050 electrification has the potential to make significant reductions in CO_2 emissions for all heat grades.
- **Bioenergy:** The potential impact of bioenergy is relatively low in 2025, having impact in a limited number of industrial sectors only. In 2030 the potential impact increases, and by 2050, there is high potential for sustainable, low-cost, bioenergy deployment across all industries and heat grades.
- **District heating:** There is limited potential for low-grade heat supplied by district heating to connected industrial sites in 2025 and 2030. The potential grows in 2050, making a reasonable impact for sites with low grade heat demand close to the networks.
- **Green hydrogen:** In 2025 the use of green hydrogen has low impact as it may be limited to demonstration opportunities due to the limited availability and high costs of hydrogen. The potential of green hydrogen remains low in 2030, expanding slightly to a small number of sites. By 2050 the potential for use increases, assuming infrastructure developments and reduction of costs.
- **CCUS:** There is limited impact on CO_2 emissions from CCUS in 2025, potentially only making a low impact by 2030, although, this is restricted by high costs and lack of infrastructure. Assuming the affordability and infrastructure improves, CCUS has the potential to make a great impact on reducing CO_2 emissions from a small number of sites in 2050.

Table 16: Summary of potential impact for industrial heat decarbonisation strategies

Year	Energy Efficiency	Electrification	Biomass, Biogas and Renewable wastes	Heat supply from District heating	Green Hydrogen	CCUS
2025	**LOW**	**LOW**	**LOW/MEDIUM**	**LOW**	**NO IMPACT**	**NO IMPACT**
	Steady adoption drives modest energy reduction and CO_2 savings.	Limited potential impact only affecting low and medium/low grade heat uses. As grid decarbonises, results in reduction of energy demand and hence site CO_2 emissions.	Limited potential impacts for the industrial sector as a whole, instead, the impacts are concentrated in selected industries.	Limited potential impacts only affecting low-grade heat supply for industrial sites able to connect to DHN.	Potential impact limited to demonstration opportunities. Further limited by availability of hydrogen and high costs.	Limited/no impact due to lack of infrastructure and technology readiness.
2030	**LOW**	**LOW**	**MEDIUM**	**LOW**	**LOW**	**VERY LOW**
	Potential saturation on heat demand and hence limited CO_2 impacts could result if technology innovation stagnates.	Assuming grid expansion and decarbonisation, there is limited potential impact to be made on CO_2 emissions for both low and medium grade heat.	Assuming low-cost sustainable supply, there is potential impacts on CO_2 emissions to be seen as an increase in adoption across multiple industries occurs.	Assuming DHN expansion, the potential impact on low-grade heat supply grows to include more industrial processes.	Assuming the cost of hydrogen reduces, the potential impact increases slowly as a small but growing number of sites adopt hydrogen usage.	Limited impact due to high costs and lack of infrastructure.
2050	**LOW**	**HIGH**	**HIGH**	**MEDIUM/HIGH**	**MEDIUM**	**LOW/MEDIUM**
	Potential saturation on heat demand and hence limited CO_2 impacts could result if technology innovation stagnates.	As the grid expanded and decarbonised, providing low cost and low carbon electricity, there is high potential impact to be made across all heat grades. This is also based on the assumption of technology developments for high grade heating technologies.	Assuming a continued low-cost and sustainable supply, there is high potential impacts on CO_2 emissions for all industries and heat grades.	The potential impact for sites with low grade heat demand further increases, particularly for those close to DHNs.	Assuming hydrogen infrastructure is developed and low-cost hydrogen is more attainable, a more widescale adoption of hydrogen leads to greater CO_2 savings.	Assuming established infrastructure and reduction in costs, there is potential for high CO_2 emissions reductions, however only for a small number of sites.

(Low = Less than 25% of Ireland's total industrial heat demand decarbonised, Medium =25-50% of Ireland's industrial heat decarbonised, High = > 50% of Ireland's industrial heat demand decarbonised)

4. BARRIERS TO DECARBONISING INDUSTRIAL HEAT IN IRELAND

Every individual industrial site will have characteristics that influence the scale, economics, ease, risks, speed, and barriers for heat decarbonisation. These site-to-site variations could include size, location, equipment, numbers of processes and their integration with other systems, input and output specifications, space available, permits to support different types of activities, flexibility (e.g., interruptible operation), access to networks, costs, profitability, available capital, competition, or supporting capabilities on site, and experience with technology innovation.

This Chapter provides an overview of the high-level barriers to industrial heat decarbonisation in Ireland, informed by literature review and stakeholder discussions. We group these into over-arching barriers, described in Section 4.1 and technology-specific barriers, described in Section 4.2 onwards. The chapter concludes in section 4.10 with an assessment of the relative severity of these barriers. Barriers are tabulated in each section , followed in some cases by further exploration of the barriers.

4.1 OVERARCHING BARRIERS

The literature search and stakeholder engagement revealed consistent overarching barriers across various technologies illustrates some overarching barriers to decarbonisation in Ireland. We have clustered around economics and financing, technical and technological, policy and regulatory, and stakeholder challenges.

Table 17 illustrates some overarching barriers to decarbonisation in Ireland. We have clustered around economics and financing, technical and technological, policy and regulatory, and stakeholder challenges.

Table 17: Overarching Barriers to Decarbonisation [53] [54] [55] [56] [57] [58]

Barriers	Examples
Economics and Financing High operating costs Long lifecycle of existing equipment High up-front costs Highly competitive markets for core industrial products Lack of capital to finance new assets Opportunity cost/ Payback/hurdle rates High cost uncertainties Competition from high carbon fossil fuel alternatives First of a kind costs	• High energy prices in Ireland. • The long lifecycles of existing natural gas heating systems can result in delays in installing low carbon alternatives. • Manufacturing industry businesses cannot afford high up-front costs for novel technologies or infrastructure. • Implementation of lower carbon heat strategies with high operating costs may result in more expensive (i.e., less competitive) product. • Deep decarbonisation measures not competitive in meeting business KPIs (e.g., payback periods), so that only quick wins from proven and incremental technologies are favoured. • Fewer investors fully understand and have the capabilities to finance innovative and complex industrial heat decarbonisation projects and supporting infrastructure. • Higher costs and risk premium for first-of-a-kind or deep decarbonisation projects • Markets for industrial heat decarbonisation are immature and inefficient (i.e., supply and demand are constrained and uncertain)

[53] WSP (2015), Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Iron and Steel, Iron_and_Steel_Report.pdf (publishing.service.gov.uk)

[54] WSP (2015), Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Chemicals, Chemicals_Report.pdf (publishing.service.gov.uk)

[55] WSP (2015), Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Oil Refining, Oil_Refining_Report.pdf (publishing.service.gov.uk)

[56] WSP (2015), Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Pulp and Paper, Pulp_and_Paper_Report.pdf (publishing.service.gov.uk)

[57] WSP (2015), Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cement, Cement_Report.pdf (publishing.service.gov.uk)

[58] SEAI, Prices, Prices | Energy Statistics In Ireland | SEAI

Barriers	Examples
Ineffective carbon price or carbon tax Risks of businesses reducing industrial output in Ireland, causing carbon leakage Limited financial reserves Network economies of scale and scope (encourage late adoption) Market externalities Missing markets	• Insufficient forward carbon pricing and/or volatility of carbon markets, makes it difficult to justify initial investment. • Missing markets - limited customer benefit and willingness to pay (extra) for lower carbon products. • Uncertain utilisation, lifetime, or technology obsolescence risk for innovative technologies and infrastructure • High asset specificity – there can be option value from taking a wait-and-see approach rather than locking into a potentially high-cost option. • Some cross-border arrangements (e.g., tariffs or their absence) may favour import of products from high carbon production countries (or relocation of entire value chains away from Ireland), ultimately driving carbon leakage. • High spillover effects where innovators and early adopters exposed to costs and risks, without opportunity to share these costs with others who may benefit later. • Higher interest rates reduce capital available for business investment. • Economics of decarbonising remote rural industrial sites can be very different to industrial clusters.
<u>Policy & regulation</u> Uncompetitive policy or regulatory support for decarbonisation Poor alignment of public policies with industry decision making and investment cycles	• Limitations of strategies, targets, leadership, and wider policy or regulatory support to accelerate industrial heat decarbonisation. • Slow policy evolution results in industry delaying investment. • Policy and regulatory design and costs, need to ensure appropriate balancing of costs, risks and benefits with industry to maximise compliance, and minimise arbitrage risks from companies moving to areas with poorer environmental outcomes. • Weak stakeholder engagement processes can lead to policies (e.g., targets) that poorly align with other policy objectives, industry activities, or are unpredictable. • Conflicting priorities – there are difficulties in finding and implementing policies and regulations that satisfy all stakeholders, across multiple challenges, technologies, locations, and markets. • Optimal participation of Ireland stakeholders through EU mechanisms support. • Competing subsidies in other countries draw finite industry decarbonisation investment away from Ireland and into other countries.
<u>Technical & Technology</u> Specialist knowledge Technology risks Technology costs Technology requirements Resource requirements Information gaps/asymmetry Process integration Limited supply chains Lack of complementary infrastructure	• Specialist skills required to design, approve, finance, install and maintain novel technologies and complementary infrastructure may be in low supply. • Many industrial heat decarbonisation technologies and their supply chains are immature and require tailored support for effective commercialisation. • As both existing industrial processes and decarbonisation technologies can be quite complex, optimally integrating existing industrial processes with decarbonisation technologies can be a major undertaking – not all technology solutions are mutually compatible. • Standards, codes and guidelines for decarbonisation technologies can be missing or may change. • Some heat-intensive process equipment is long lifetime (decades), and many high temperature processes are particularly difficult to

Barriers	Examples
Lack of complementary resources	interrupt. Therefore, there are few windows of opportunity to integrate with alternative technologies without incurring costs from additional downtime. • There can be a steep learning curve for users and supply chains for new technologies, with first movers usually exposed to higher costs and risks. • Stakeholders have different information sources, understanding, and needs about individual technologies. • Sites often have constraints on allowable technical activities, for example for health, safety or environmental reasons. • Supply chains for new markets such as industrial heat decarbonisation technologies are invariably more fragile. • Difficult to ensure complementary infrastructure is available at the right time, capacity, location, specification or cost to support industrial heat decarbonisation. • Some technologies require additional safety measures to be adopted. • Many technologies depend on complementary resources which are limited in supply.
<u>Stakeholder & Information</u> Lack of stakeholder familiarity Lack of confidence Lack of support Lack of stakeholder alignment Biases	• Decarbonisation involves multiple stakeholders • Stakeholders for industrial heat decarbonisation do not necessarily work together efficiently or effectively. • Not all stakeholders are aware or supportive of decarbonisation technologies, broader energy and carbon drivers or the implications for sites and complementary infrastructure – all will have biases and competing priorities. • Confidence in changing systems and novel technologies typically builds faster after solutions have been proven locally • Few standardised training and development options tailored for stakeholders in industrial heat decarbonisation in Ireland. • Patchy data flows hamper effective decision making • Increased political and market volatility encourage decision makers to focus on quick wins

Economics and Financing: Ireland's high energy prices increases costs for energy intensive businesses, reducing international competitiveness, and impacting capital available to invest in decarbonisation technologies.

Ireland has experienced a notable surge in energy prices in the past year, with the 2023 energy crisis resulting in a 35% increase in electricity prices compared to the rest of Europe. Figure 17 illustrates the price of fuels in Ireland since 2013, showing significant price increases since 2021. The escalation in energy prices has compounded the longstanding issues of competition from lower-cost producers, particularly in Asia, and shareholder demands for returns on their investments. The result is limited interest in expensive decarbonisation technologies, such as CCUS, hydrogen and electrification.

Economics and Financing: Organisations may be unwilling to replace existing natural gas heating systems that are in good condition and have not reached their end of life with low carbon alternatives.

Around a decade ago, organisations frequently utilised government support programs to upgrade outdated fossil fuel boiler heating systems, like oil boilers, to more energy-efficient and environmentally friendly alternatives such as natural gas boilers. These newly installed gas heating systems boast a lengthy lifespan, often lasting up to 25 years with proper maintenance[59], potentially bringing them to the end of their life cycle around 2040.

Typically, sites aiming to decarbonise their industrial heating systems opt to wait until their equipment nears the end of its life before considering replacement. They tend to resist transitioning from a well-functioning gas

[59] NTT Training (2019), How Long do Boilers Last and How Can They Last Longer?, [How Long do Boilers Last and How Can They Last Longer? (nttinc.com)]

boiler to a low-carbon alternative unless adequately compensated. The reluctance stems from the disruption and additional costs associated with such a switch. This delay could compromise Ireland's progress in decarbonising heavy industry.

Policy & Regulation: Lack of clarity by the government on several decarbonisation strategies, and slow policy evolution, has caused hesitation when implementing decarbonisation technologies.

The lack of clarity on government strategies regarding several key decarbonisation pathways has caused some hesitation in industry. Stakeholder responses indicate that the delay in releasing strategies has resulted in some sectors waiting to understand e.g. the priority uses for bioenergy and the projected timelines on infrastructure.

The delay in forming decarbonisation strategies has created uncertainty in Irish industries about the priority use of zero carbon fuels in various sectors. For example, the upcoming biomass strategy is critical to understanding biomass supply and stock types, particularly given Ireland's limited supplies of domestic biomass with the majority of land share being dedicated to meadows and pastures. Therefore, to meet growing bioenergy demands, Ireland may need to prioritise waste and residues from industry and agriculture, which are ideal for producing biogas through anaerobic digestion, but not for direct burning.[60]

Additionally, supportive policies and regulations for individual technologies in Ireland are crucial for industries to invest. The possibility that these may one day emerge, and the risks of locking in sub-optimal systems, results in delays from a "wait-and-see" approach.

Technical and technology: Skills shortage

The draft Build Up Skills Ireland 2030 (BUSI2030) Roadmap highlights that Ireland is experiencing skills and labour shortages for energy efficiency, renewable energy, decarbonisation, digital and digitalisation processes, life cycle analysis and circular economy processes.[61] These skill gaps result in missed opportunities to identify and implement further measures due to a lack of awareness.[54 55 57] These skill deficiencies also increase the risk of improper installation of measures, potentially impacting equipment operability[56]; the resulting negative feedback from sub-optimal performance of new systems risks further delaying uptake.

4.2 BARRIERS TO ENERGY EFFICIENCY

We understand from stakeholder discussions that energy efficiency measures are being steadily implemented within Ireland, driven by high energy costs, and with private funding available for investigating and implementing industrial energy efficiency.

The specific barriers to energy efficiency are listed in Table 18.

Table 18: Barriers to Energy Efficiency

Theme	Key barriers
Technological	• Several technologies are now mature to improve the energy efficiency of industrial processes, including heat recovery, and data-driven optimising costs through flexible operation.
Inflexibility and incompatibility	• Some heat recovery systems couple different processes, reducing operational flexibility. More generally some modifications risk locking in existing processes, in turn locking in inputs and outputs in ways that limit future decarbonisation options.
Economic and financing	• Some energy efficiency measures have high upfront costs, but ongoing energy savings and carbon savings enable these to be economic. • Economics can be challenged where there are uncertain utilisation factors and lifetimes of assets in volatile markets. • Financing energy efficiency measures can be difficult for some businesses, and has become harder with higher interest rates.

[60] IEA Bioenergy (2021), Implementation of bioenergy in Ireland – 2021 update, CountryReport2021_Ireland_final.pdf (ieabioenergy.com)

[61] Irish Green Building Council, (2024), National Upskilling Roadmap 2024-2030 Draft for Public Consultation, Microsoft Word - BUSI2030_Upskilling Roadmap_Draft for Public Consultation_240119 (igbc.ie)

Theme	Key barriers
Policy and Regulatory	• There are few policy barriers to energy efficiency
Lack of stakeholder familiarity or alignment	• Awareness of energy efficiency options is growing. • There is widespread social and political support for energy efficiency.
Limited complementary infrastructure or resources	• No significant complementary infrastructure or resources expected.

4.3 BARRIERS TO FUEL SWITCHING

4.3.1 Electrification

Electrification offers a route to heat at a range of temperatures. Solutions for low temperature heat applications are mature, and solutions are increasingly available for higher temperatures. The Irish Government is prioritising the electrification of heat, with many heat pumps and electrode boilers being installed, and a focus on higher temperature heat pumps producing steam. This shift is particularly relevant in sectors such as pulp and paper, food and drink, iron and steel, and chemical industries. Despite this, there are some key barriers associated with a lack infrastructure.

Barriers to electrification of industrial heat are summarised in the Table 19 below.

Table 19: Barriers to electrification of industrial heat demand

Theme	Key barriers
Technological	• High temperature direct electric heating systems have limited availability and readiness. • Medium-low temperature heat pumps for indirect heating have limited availability and readiness
Inflexibility and incompatibility	• If needed, energy storage (either for electricity or heat) can create additional costs or site demands
Economic	• Electrification of heat requires confidence in future lower electricity price, high avoided carbon prices, and/or compensatory ongoing incentives. • CoPs for high temperature heat pumps cannot compensate when electricity prices are several multiples of gas prices (except with high carbon prices). • Grid connection upgrades have high capital cost and investments require confidence in future high utilisation at specific sites over long timescales.
Policy and Regulatory	• The Support Scheme for Renewable Heat (SSRH) will be coming to an end in 2027. • Lack of annual financial support to cover high electricity costs. • Public Service Obligation (PSO) levy impacts sites that are electrifying heat demands.
Lack of stakeholder familiarity or alignment	• The timelines and approvals processes for electricity network upgrades unlikely to align with investment cycles for heat-intensive businesses
Limited complementary	• Supporting low carbon power generation capacity is required to meet growing electricity demands.[62] [63] • Lack of electricity grid capacity to install new grid connections – can take time

[62] EirGrid (2024), Ten-Year Generation Capacity Statement 2023-2032, EirGrid SONI GCS 2023-2032

[63] IDRIC, Briefing Note: Grid constraints and industrial decarbonisation, BRIEFING NOTE: Grid constraints and industrial decarbonisation | IDRIC

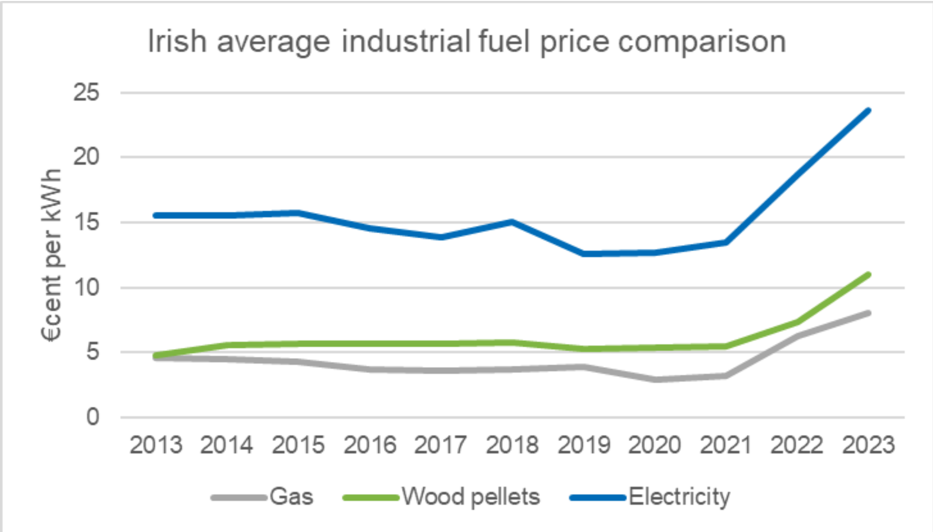
Theme	Key barriers
infrastructure or resources	• Need to mitigate electricity supply risks, e.g. use energy storage to manage extreme weather events. [64] • Electricity network expansion can be disruptive, time consuming, resource intensive, and not necessarily welcomed in all locations

Stakeholder workshops highlighted energy prices, grid connections, low growth in investment in renewable power generation, and limited application for high temperature systems, as limitations for electrification to highlight to policymakers.

Economic: High electricity prices and lack of compensatory ongoing support limiting financial suitability of electrification alternatives.

Figure 17 illustrates the average prices of natural gas, electricity and wood pellets in Ireland since 2013, showing that natural gas is cheaper than electricity (or wood pellets).

Figure 17: Average industrial fuel prices to Irish businesses[65]



In common with many countries, Ireland has experienced a surge in energy prices associated with the Russian invasion of Ukraine. Electricity prices have risen particularly, and are now considerably higher than the EU average[66]. The economics of electrification-based strategies are correspondingly vulnerable.

High energy prices can drive energy efficiency investments - as long as businesses have the resources to invest. Lower temperature heat pumps can have high coefficients of performance (CoP) of up to 3, and the overall economic return of switching from gas to electrically driven heat pump depends on the ratio of their Coefficient of Performance (CoP) to the ratio of electricity and gas price (spark spread), and any avoided ETS payments. The Irish Government has supported the electrification of heat for example through capital grants for heat pumps for low-grade heat from the Support Scheme for Renewable Heat (SSRH) programme[67]. However, the future of the scheme beyond 2027 is unclear. No significant cost support is available to meet additional on-going costs associated with high electricity prices.

Limited infrastructure: Lack of low carbon power generation capacity available to meet growing electricity demands.

To ensure effective emission reductions of future electrification projects, the Irish electrical grid must continue to decarbonise.[53 54 56] Figure 18 illustrates renewable power generation in Ireland, with 38.6% renewable

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[64] MET éireann, Major Weather Events, Major Weather Events - Met Éireann - The Irish Meteorological Service

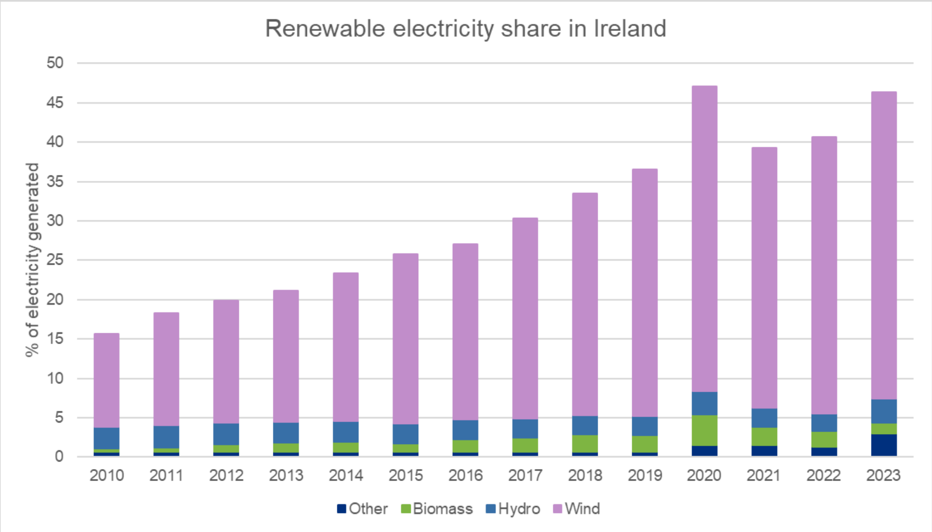
[65] SEAI (2023), Prices, available at Prices | Energy Statistics In Ireland | SEAI

[66] SEAI (2023) Electricity & Gas Prices in Ireland, available at https://www.seai.ie/publications/Electricity-Gas-Prices-2023-H1.pdf https://www.seai.ie/publications/Electricity-Gas-Prices-2023-H1.pdf

[67] SEAI Commercial heat pumps - Renewable Heating for Business (2023), available at https://www.seai.ie/business-and-public-sector/renewable-heating/systems/commercial-heat-pumps/

penetration in 2022, 85% of which is from wind (see below). Continued investment in renewable energy projects is required to ensure the electrification of heat in industry results in declining carbon emissions.

Figure 18: Renewable electricity share in Ireland from 2005 to 2023 [68,69]



Data stretching back from 2010 to 2019 was extracted from the SEAI[68] and from 2020 onwards from the Central Statistics Office[69]

Limited infrastructure: Lack of electricity grid capacity may impact ability to install new grid connections.

There are growing concerns around the stability of Ireland's electricity supply. In particular, the latest annual Generation Capacity Statement from EirGrid predicts electricity capacity to continue to drop until 2032. This is due to a deteriorating availability of existing power plants, with 29% of the thermal capacity being over 30 years old, coupled with 455 MW of previously awarded capacity being withdrawn. This is in contrast to the growing demand on the grid as the economy continues to electrify.[62] These increasing pressures can lead to considerable delays for electrification projects, and around the world grid constraints can result in companies waiting years for new grid connections.[63] There is additional risk that if industry decarbonises industrial heat, then this will add considerable loads to the electrical grid, necessitating further investment from EirGrid to deliver grid upgrades.

4.3.2 Biogas

Biogas can be produced locally and used directly for heating, and some CHP systems, with low up-front processing costs, though there will be limits to the capacity, location, and the compatibility of equipment. The biogas can be also upgraded to biomethane by removing impurities and CO_2, which can be costly, but the output of biomethane is more versatile and valuable: biomethane can replace natural gas with minimal modifications to equipment and infrastructure and can be injected into the gas grid. So far biomethane adoption has been low in Ireland, with two operational biomethane facilities injecting biomethane into the gas grid. This equates to circa 75 GWh per annum, or 0.001% of Ireland's current gas demand[70].

For this study, the barriers listed focus on industrial heating via the production of biogas onsite and using locally or importing biogas for off-grid facilities. See the barriers summarised in the Table 20 below.

[68] SEAI, Renewables, Renewables | Energy Statistics In Ireland | SEAI

[69] Central Statistics Office, Metered Electricity Generation December 2023, Table 3, Metered Electricity Generation December 2023 - Central Statistics Office

[70] Government of Ireland (2024), Ireland's Draft National Biomethane Strategy, 282319_b82783de-f66b-49e1-9bd2-ed2d6442b199 (1).pdf

Table 20: Barriers to biogas adoption in industry[70]

Theme	Key Barriers
Technical and Technological	• Use of biogas at industrial sites constrained by matching of supply of biogas with heat demand. • Gases require special handling to minimise safety risks. • Variation in biogas production, composition, temperature, and pressure, and associated biogas transportation and storage infrastructure, leads to large variations in energy available, equipment modifications needed, costs, and carbon mitigation potential between projects. • Source of biogas (and competing uses for the feedstock and biogas) impact its sustainability (including kg CO_2/kWh heat) and relevance. • Carbon capture can further reduce emissions but adds costs, complexity and its value depend on utilisation or storage of the CO_2 captured.
Economics and financing	• Other sectors compete for limited biogas, for example biomethane is often used as a fuel for road transport or for power generation. • Wide range in feedstock prices (from negative to large positive). • Biomethane can be more expensive than natural gas[71]. • Investment costs for biogas production and handling can be significant.
Policy & Regulatory	• Agencies responsible for permitting AD plants require additional resourcing to handle the anticipated influx of applications. • Limited upfront capital support • Support from the SSRH will close to new applicants in 2027. • Limited policy mechanisms to optimise biogas sustainability and use in hard to decarbonise industrial sectors or locations. • The Department of Agriculture, Food and the Marine may need to streamline approval of plants involved in anaerobic digestion of animal by-products.
Lead times and supply chain	• Connection for biomethane injection into the gas grid or electricity distribution network for biogas CHP can be slow and costly. • Permitting of biogas systems can be challenging. • Difficulties in securing long-term bio-feedstock and offtake agreements. • Small sites lack awareness and skills in construction and operation that would maximise the potential for biogas from sites' own waste.
Lack of stakeholder familiarity or alignment	• Patchy understanding, for example in planning authorities or other agencies involved in approvals, can lead to mixed pace and outcomes. • Local public perceptions around odours, health and safety, or traffic, related to AD plant operations. • The draft Biomethane Strategy indicates that Ireland will need to develop skills and training programmes to bolster the biomethane economy, including awareness of monitoring, verification, and reporting requirements.
Limited complementary infrastructure or resources	• If Ireland upscales the production of biogas to meet bioenergy demands using domestic supplies, then there are potential biodiversity risks associated with this if the fuels are not sourced appropriately. • Poor matching of biogas capacity with industrial heat demand.

Policy and regulatory: Agencies responsible for permitting AD plants require additional resourcing to handle the anticipated influx of applications.

Ireland's Draft National Biomethane Strategy highlights that collaborative efforts between agencies like these are essential in developing standardised codes of practice to guide local authorities in assessing AD and

[71] Ricardo for SEAI (2017) Assessment of Costs and Benefits of Biogas and Biomethane available at https://www.seai.ie/publications/Assessment-of-Cost-and-Benefits-of-Biogas-and-Biomethane-in-Ireland.pdf

biorefining planning applications. Ensuring adequate resourcing for these key agencies is thus imperative to facilitate Ireland's transition towards producing biogas from organic wastes and promoting sustainable practices in the industrial sector. This is particularly true given the fact that these agencies are expected to handle an influx of applications which is projected to reach up to 140-200 plants by 2030.

Policy and regulatory: Limited availability of capital funding for biogas infrastructure projects and the SSRH will close to new applicants soon.

Limited availability of capital funding for biogas infrastructure projects poses a challenge for sites looking to decarbonise industrial heat using waste organic feedstocks for biogas. The SSRH, which runs for new applicants until 2027, offers annual financial support to non-domestic businesses utilising biogas, with a replacement policy essential to incentivising biogas production, particularly given the high capital costs associated with constructing anaerobic digestors. Indirect funding for AD includes the Disruptive Technologies Innovation Fund and Enterprise Emissions Reduction Investment Fund.

Supply chain: Connection for biomethane injection into the gas grid or electricity distribution network for biogas CHP can be slow and costly.

Industrial sectors such as waste processing, dairy, and pulp and paper generate organic waste which can be processed using anaerobic digestion to form biogas. While biogas generated on these sites is generally used for heating and power locally, there may be some opportunity for sites to export biomethane to the gas network which could make the investment more worthwhile.

The National Biomethane Strategy's engagement with stakeholders revealed that a key objective for anaerobic digestion developers is to get direct access to the natural gas network. Under the Connections Policy for biomethane, the biomethane producers are required to contribute 70% of the connection assets, with the customer contributing the remaining 30%. Ireland differs from other countries, with regulators reporting in 17 other countries that network operators are obliged to provide a connection for biomethane injection. This additional cost for industrial sites to produce excess biomethane results in AD plants which are connected to the grid being 2-3 times more expensive than other neighbouring countries. While not necessarily a barrier to decarbonising industrial heat, the expense of grid connections could limit the capacity of AD plants being installed on industrial sites and as a result, the decarbonisation of Ireland's natural gas network.

Economics and financing: Competing uses for biogas preventing the decarbonisation of industrial heat.

Without policy interventions, the sector offering the highest premium for biomethane is likely to secure the resource. Consequently, the competition for biomethane between the transport, electricity, residential and industrial sectors pose a barrier to the decarbonisation of industrial heat, hindering progress towards achieving climate targets. Currently, most biomethane produced in Ireland is utilised in the transport sector under the Renewable Transport Fuel Obligation.

Utilising biomethane for medium and high-temperature industrial processes offers a direct and cost-effective means of decarbonisation in Ireland for sectors requiring temperatures exceeding 200°C, biomethane stands out as a practical solution. The SEAI's National Heat Study identifies biomethane as particularly suited for operations with high heat demands, where alternatives like electrification face challenges. The NCAP24 targets 2.1 TWh of zero-carbon gas consumption in industrial heating by 2030, a goal likely to be met primarily through biomethane. This underscores the significant role biomethane is poised to play in Ireland's heat sector decarbonisation, notably through initiatives like the RHO scheme.

Lack of stakeholder familiarity: Patchy understanding, for example in planning authorities or other agencies involved in approvals, can lead to mixed pace and outcomes

Ensuring the successful development of a biomethane industry in Ireland hinges significantly on non-financial policy enablers that can streamline processes, facilitate timely sector development, and embed best practices from the outset. Similarly, planning permission, another critical aspect, often faces lengthy timelines due to the novelty of AD technology in Ireland, highlighting the need for standardised procedures and enhanced understanding among local authorities. This could be driven by collaboration between the Department of Agriculture, Food and the Marine and the Department of Housing, Local Government and Heritage.

Limited complementary infrastructure or resources: Upscaling the production of bioenergy in Ireland must take into account biodiversity and carbon leakage risks.

If Ireland upscales the production of biogas, as well as biomass, to meet bioenergy demands using domestic supplies, then there are potential biodiversity risks associated with this if the fuels are not sourced appropriately. To ensure that this risk is minimised, the sustainability criteria set out in the RED III must be respected. This includes prohibiting bioenergy production on biodiverse or high carbon stock lands, such as primary forests, diverse wooded areas, grasslands, wetlands, heathlands, and peatlands. Moreover, it mandates that bioenergy production must exceed a minimum threshold of greenhouse gas savings when compared to fossil fuels. Caps are also placed on the production of high-risk biofuels, with crop biofuels and the production of biofuels and biogas from used cooking oil and animal fats being restricted[72].

Considering this, care must be taken when estimating the accessible bioenergy resources in Ireland, ensuring that only resources that are produced in a sustainable way are included. This must account for considerations of upstream greenhouse gas emissions, such as those associated with cultivation, and exclude cultivation on environmentally sensitive land with high biodiversity value or soils rich in organic carbon[73].

4.3.3 Biomass

Solid biomass is considered a viable option for fuel switching. Currently, its application in Ireland is primarily limited to power plants (e.g., the 120 MW Edenderry station and 44 MW Bord na Móna biomass plant), wood products (pulp and paper manufacturing), and cement production.[74] [75] Biomass can play a structural role in direct fired systems such as cement kilns and iron and steel furnaces. Furthermore, it presents an opportunity to substitute petrochemical feedstocks in the chemicals industry, replacing fossil fuels in the production of bulk chemicals such as acetic acid, ethylene, and methanol.[75]

The reluctance to embrace solid biomass technologies so far has been due to supply chain issues, technological issues, uncertainties regarding lifecycle emissions, and a lack of clear incentivises. This has been extracted from the table and paragraphs below, based on stakeholder feedback and the literature.

Table 21: Barriers to solid biomass adoption in industry

Theme	Key Barriers
Technical and Technological	• System optimisation required to manage variability of biomass sources. • Low energy density so attention to distribution strategy and space required to store biomass on site.
Economic and Financing	• Biomass is often more expensive than natural gas and does not offer any additional efficiencies. • Uncertainty of future competition and costs of domestic and imported biomass supply.
Lead times and supply chain	• Limited domestic supply chains for biomass best suited to combustion for industrial heat (e.g., wood pellets). • Multi-year local biomass supply contracts and heat offtake agreements, or high market liquidity, to de-risk investment are hard to secure.
Policy and Regulatory	• Support from the SSRH will close in 2027. • Limited government clarity on priorities and future support for biomass for heating in industry results in businesses holding off investment until policies are clarified.
Incompatibility or inflexibility	• Existing domestic biomass production dominated by wastes and residues from industry and agriculture, which are better suited to anaerobic digestion or co-firing in cement kilns, rather than for direct combustion for heat. [56] [57] 60 • Best suited to stable rather than variable operation

[72] European Commission (2023), Renewable Energy Directive (RED III), Directive - EU - 2023/2413 - EN - Renewable Energy Directive - EUR-Lex (europa.eu)

[73] SEAI (2022), Sustainable Bioenergy for Heat, Sustainable Bioenergy for Heat | National Heat Study | SEAI

[74] Bioenergy Task 39 (2023), Biomass Plants in Ireland, (Biomass Plants in Ireland - Bioenergy Task 39)

[75] I. Malico et al (2019), Current status and future perspectives for energy production from solid biomass in the European industry, Current status and future perspectives for energy production from solid biomass in the European industry - ScienceDirect

Theme	Key Barriers
Lack of stakeholder familiarity or alignment	• Biomass combustion for industrial heat (or industrial combined heat and power) competes with other strategies for land use, use of biomass in AD systems60, or for biochemicals production. • Local stakeholders may object to regular truck deliveries of biomass (cf. using existing natural gas pipelines). • Stakeholders have mixed perceptions on sustainability of biomass, particularly for imported biomass. [54 55 56]
Limited complementary infrastructure or resources	• If Ireland upscales the production of biomass to meet bioenergy demands using domestic supplies, then there are potential biodiversity risks associated with this if the fuels are not sourced appropriately. • Uncertainty over extent (and future costs) of domestic supply of sustainable biomass available for industry in Ireland. • Each biomass supply requires lifecycle emissions accounting.

Economic and financing: High biomass prices relative to fossil fuel alternatives

In 2023, wood pellet prices in Ireland were 37% higher than natural gas, driven by the recent energy crisis[65]. Therefore, switching to woody biomass is uneconomical, especially given that it is less energy dense and does not offer higher process efficiencies (such as heat pumps). These costs constraints are particularly applicable to industries that operate on very low profit margins, such as the dairy industry.

Supply chain and incompatibility: Limited domestic supply chains for biomass which are best suited to combustion for industrial heat, with domestic biomass dominated by wastes and residues.

Ireland has limited supplies of domestic biomass, with the majority of feedstocks available being dedicated to waste and residues from industry and agriculture. These feedstocks are best suited to anaerobic digestion and cement, rather than for direct combustion or thermo-chemical conversion processes.[60] This issue will become exaggerated if there is increasing competition within industrial sectors for the same resource, particularly if the chemicals industry shifts towards utilising biomass as a feedstock or even potentially creating biorefineries, or the iron and steel manufacturers begin incorporating biomass into blast furnace. [56 60]

Policy and regulatory: Support from the SSRH will close in 2027.

The number of government policies dedicated to incentivising the use of solid biomass as fuel is low. The key policy that is in place is the SSRH, which provides annual financial support to non-domestic users of solid biomass for heat. This policy is to close in 2027 without a replacement in place. This form of financial support is essential given the high fuel costs associated with woody biomass (as outlined above).

Policy and regulatory: Limited government clarity on priorities and future support for biomass for heating in industry.

Securing heat contracts is viewed as being very important for the viability of utilising biomass in industry; however, there must be a guaranteed biomass supply in order for these contracts to be put in place. Stakeholder's expressed concern with adopting biomass technologies without the security of heating contracts, particularly given the large ramifications on production if some heating technologies did not have an adequate fuel source. An up-to-date biomass strategy, including the priority uses for biomass, is required for contracts to be put into place.

4.3.4 Bioliquid

The adoption of bioliquids, particularly HVO (Hydrotreated Vegetable Oil) and FAME (Fatty Acid Methyl Esters), present a promising avenue for decarbonising industrial heat. Some bioliquids are commercially available, and can be directly substituted for traditional fossil fuels in industrial applications, while lower quality alternatives often necessitate additional treatment or blending with fossil fuels. The barriers to adopting suitable bioliquids for industrial heating has primarily been due the lack of availability of high-quality fuels, particularly considering the competing use cases with other hard to abate sectors such as transport and aviation. This has been extracted from the table and paragraphs below, based on stakeholder feedback and the literature.

Table 22: Key Barriers to Bioliquids In industry

Theme	Key Barriers
Technical and technology	• High quality bioliquids are required for direct substitution with traditional fossil fuel-based alternatives. Therefore, deployment in industry has thus far been limited
Economic and financial	• Issues relating to price variability due to feedstock competition with other uses, such as energy crops being diverted for food production, transport and used in other bioenergy forms, like biogas and biofuels production.
Lead times and supply chain	• Supply chain development for bioliquids is still in its early stages. • Risk of indirect land-use change (ILUC), such as incentivising the cultivation of feedstocks for bioliquid production on biodiverse or high carbon land. This results in 'carbon debt,' indicating significant carbon loss from land conversion to bioliquids.
Policy and regulatory	• Lack of clarity regarding priority uses of bioliquids and biofuels within industry. • There is a lack of long-term policy certainty supporting the production and use of biomass feedstocks to produce bioliquids, particularly for energy crops.
Incompatibility or inflexibility	• Lower quality bioliquids, such as fuels with higher viscosity, low volumetric energy density, and high oxygen content, often require further processing which limits the amount of blending with some fossil derived fuels.
Lack of stakeholder familiarity or alignment	• There is a lack of expertise and extensive retraining available to the workforce with regards to bioliquids production and use in industry.
Limited complementary infrastructure or resources	• Limited local collection and distribution infrastructure for sourcing energy crops, vegetable and seed oils, and waste and residues for bioliquid production, as well as subsequent distribution to industrial facilities.

Lead times and supply chain: Lack of availability of high quality bioliquids for industrial heating

The supply chain of higher quality bioliquids is still developing, with relatively limited availability when compared to more developed markets. The impact of this is twofold; firstly, the availability of high quality bioliquids such as HVO (which can be directly substituted in some industrial heating applications) is limited. Secondly, while high quality bioliquids have gained some traction in the market over the past few years, its applicability extends beyond industrial heat to encompass diesel generators, heating and transport. Therefore, the adoption of higher quality bioliquids is hindered by limited availability, particularly given the competition with other hard to decarbonise sectors like transport and aviation. This scarcity underscores the need for strategic allocation and prioritisation of bioliquids to ensure calculated access across various industries striving for decarbonisation.

4.3.5 Waste

SEAI's National Energy Balance illustrates that both renewable and non-renewable waste are predominately used as a fuel source in the cement sector. The use of wastes as a combustion fuel for other heavy industrial sectors is limited. Wastes share some barriers with biomass and biogas, as shown in Table 23 below.

Table 23: Key Barriers to Waste In industry

Theme	Key Barriers
Technical and technology	• Heterogeneity of waste causes variability in energy density and heat-intensive processes.
Economic and financial	• High variation in quantities, costs and quality for waste feedstock and waste handling implies bespoke economics for each application.
Policy and regulatory	• Competing strategies for waste management and use with limited incentives to use waste as a source of heat in industry.

Theme	Key Barriers
Incompatibility or inflexibility	• Ensuring compatibility of materials and systems. • For direct firing systems, need to manage risks of variations in product quality.
Fragile supply chains and lead times	• Limited number of small independent suppliers for waste supplies, and equipment for using waste for industrial heating. • Variations in amounts and types of waste feedstock available in different geographies or over time add uncertainty and complexity.
Lack of stakeholder familiarity or alignment	• Experience concentrated in cement sector. • Limited engagement between waste suppliers and industrial heat users – more collaborative models would be required to grow this application.
Limited complementary infrastructure or resources	• Waste feedstock security would be needed to grow use of waste for industrial heat, but there is large uncertainty over future domestic supply of waste with future re-use and recycling rates.

Technical and technology: Heterogeneity of waste causes variability in energy density and heat-intensive processes

Following the stakeholder engagement it was clear the heterogeneity of waste is a particular concern for the cement sector, which requires relatively high-quality waste with high calorific values and low moisture contents. Due to the high-grade heating processes required in kilns, the quality of waste has a significant impact on the kilns ability to reach required temperatures. Communication between suppliers and industry is essential to ensure waste is meeting the minimum requirements of heating demand.

Policy and regulatory: Competing strategies for waste management.

Given Ireland's progress towards improved recycle rates and waste handling, there is some uncertainty on the availability of waste fuels into the future[76]. Stakeholders indicated that having waste feedstock security is essential to pursuing alternate fuels, and future projections of waste supply would assist in operational decision-making. Collaboration, similar to the cooperative model, between manufacturers, waste facilities, and policymakers is key to harnessing the environmental and economic benefits of waste for the non-metallic minerals sector.

4.3.6 Hydrogen

The use of hydrogen within industry is viewed to have significant potential, due to its high energy density, ability to produce high temperatures (suitable for the glass, cement, and steel sectors), and fuel switching capability with existing fossil fuel equipment.[41] Ireland has built on this within their National Hydrogen Strategy, which targets installing 2GW of offshore wind capacity dedicated to green hydrogen production by 2030. The strategy also aims to establish a hydrogen innovation fund to support demonstration projects by 2027, continue demonstrating the technical capabilities of the gas network to transport hydrogen by 2028, and begin to implement measures for a more integrated and long-term planning approach among hydrogen network operators[26]. However, significant barriers remain with regarding to uncertainties with costs, deployment, fuel supply and policy. The barriers to hydrogen for industrial heat are summarised in Table 24 below.

Table 24: Key Barriers to Hydrogen Deployment [54 41 77]

Theme	Key Barriers
Technical or technology	• Hydrogen technologies related to industrial heating are currently immature. • Hydrogen has different physical and chemical properties to other fuels – these need to be carefully managed.

[76] gov - Introduction of new environment levies will incentivise recycling and help Ireland meet our EU waste targets (www.gov.ie)

[77] M. Wanner (2021), Transformation of electrical energy into hydrogen and its storage, Transformation of electrical energy into hydrogen and its storage | The European Physical Journal Plus (springer.com)

Theme	Key Barriers
	• Some combustion scenarios may create additional NOx, that creates additional processes or costs to manage. • It is typically less energy efficient to use electricity to generate hydrogen for low grade heat, rather than using the electricity to produce low grade heat from heat pumps directly. • Using electricity to generate hydrogen for low-grade heat is less energy efficient than using directly in heat pumps for the same purpose.
Economics or Financing	• Green hydrogen is currently more expensive than natural gas[41 79]. • Technologies to convert hydrogen to heat (or heat and power) are currently more expensive than equivalent natural gas systems. • The pace and extent of hydrogen cost reduction expected in Ireland are unclear. • Industrial heating applications, which can be quite low margin businesses, will need to compete for limited amounts of low carbon hydrogen with other users.
Policy or Regulatory	• Beyond EU support, Ireland has limited financial incentives to cover up-front costs or ongoing costs for businesses that switch to hydrogen for heating. • Governments globally have published hydrogen strategies and vie for investment, but uncertainty persists on whether hydrogen will dominate industrial heating investments. • Multinational businesses may favour countries with favourable hydrogen policies.
Supply chains or lead times	• There is currently a shortage of low carbon hydrogen available at the scale and locations needed for industrial heat decarbonisation in Ireland. • It will take time for stakeholders to build trust in hydrogen sustainability certification schemes and interpret emerging regulations, standards, and codes across new value chains.
Inflexibility or incompatibility	• Hydrogen assets are much less fungible than natural gas systems. • Switching to hydrogen for industrial heating may necessitate new equipment or modifications due to its impact on material properties and potential reactivity with other inputs or products. • Different ways of making or transporting hydrogen impact purity, pressure, and temperature, and these can impact costs, risks, and process performance.
Lack of stakeholder familiarity or alignment	• There are no demonstration projects yet operating with hydrogen for industrial heat in Ireland, limiting stakeholder awareness of the technology. • Training is required for stakeholders to make good decisions, and to adjust fully to handle hydrogen. • Seeing considerable market dynamics, individual industry businesses may each wish to wait for lower costs and proven systems, delaying decarbonisation. • Some stakeholders doubt hydrogen's decarbonisation role due to safety concerns, inefficiencies, costs, slow progress, sustainability, and compelling alternatives. • It is important that Enterprise Agencies and other public bodies act quickly on Ireland's hydrogen strategy. • It is not clear that Ireland's stakeholders are maximising the support available from EU hydrogen schemes.
Limited complementary infrastructure or resources	• Currently, there's a shortage of low-carbon hydrogen for industrial heat decarbonisation in Ireland, despite expectations for increased production by the late 2020. • Ireland and EU hydrogen strategies focus on green hydrogen over blue hydrogen, which may limit the ability to scale up production for industry.

Theme	Key Barriers
	• If green hydrogen supply is limited, it may receive higher value when replacing existing grey hydrogen use, for example in the oil refining and chemicals sectors[41], for power grid balancing or transport sectors. • There is currently a shortage of hydrogen transport infrastructure available at the scale and locations needed for industrial heat decarbonisation in Ireland. [26]

Technical: Hydrogen technologies related to industrial heating are currently immature

Hydrogen's use as a decarbonisation fuel in Ireland remains limited. Three hydrogen projects are in development - these include the Galway Hydrogen Hub[45], the Mount Lucas Green Hydrogen Production Project[42], and the Green Atlantic at Moneypoint project.[78] However to our knowledge none of the projects in development are focussed on industrial heat supply.[26] There are long lead times for hydrogen projects.Therefore, at current rates, it is more likely that industrial hydrogen demonstration will happen in other countries during the 2020s, and commercial scale deployment of hydrogen for industrial heat in Ireland would emerge around 2030.[79]

Economics or financing: Green hydrogen is currently more expensive than natural gas

Hydrogen costs are larger than natural gas, dissuading industries from adopting hydrogen until financial incentives are implemented. Such cost constraints are especially burdensome for industries with narrow profit margins. The National Heat Study suggests costs exceed €0.12/kWh, which are expected to drop rapidly during the 2020s. [79]

Economics or financing: Future hydrogen prices for Ireland are unclear.

Forecasting future hydrogen costs is highly uncertain due to the dependency on various factors, including electricity prices, assumptions regarding reductions in upfront capital costs, and what government policies are in place. The National Hydrogen Strategy suggests that by 2050, green hydrogen production costs could decrease to €2.50-4.50/kWh, comparable to natural gas prices before 2022. [26] Conversely, the National Heat Study predicts costs exceeding €10.20/kWh for the same period.[79] This significant discrepancy underscores the uncertainty surrounding future hydrogen prices and the associated risk for industries to adopt the fuel. Thus, financial support mechanisms are essential to facilitate industry investment.

Policy or Regulatory: Ireland has had limited financial incentives to cover additional up-front costs or ongoing costs for businesses that switch to hydrogen for heating.

Industry stakeholders interviewed for this project were broadly supportive of the recent National Hydrogen Strategy, particularly with regards to the timelines suggested and the strategy's consideration of the hydrogen value chain. However, there is a lack of dedicated policy for financing the high capital costs of hydrogen projects, and hydrogen projects currently compete with other low-carbon technologies for funding through programs like the Disruptive Technologies Innovation Fund, ISGB, and Enterprise Emissions Reduction Investment Fund. Businesses in Ireland compete for hydrogen demonstration funding capital with countries where dedicated hydrogen support is in place or rapidly emerging. Therefore, if Ireland wished to be an early mover in the use of hydrogen for heat in industry, it would be important now to design and implement appropriate policies. A key challenge is understanding how to distribute the additional costs and risks of hydrogen investments sustainably, between current and future industrial users, wider electricity consumers, gas consumers, taxpayers, or end consumers.

Supply chains and infrastructure: There is currently a shortage of low carbon hydrogen production and transport infrastructure available at the scale and locations needed for industrial heat decarbonisation in Ireland.

With low stakeholder awareness, weak economic drivers, and few off-the-shelf options, hydrogen projects have taken many years and numerous false starts to develop. However, now with a rise in global investment in hydrogen, there are bottlenecks in supply chains. There's large uncertainty on which sectors will grow, with

[78] ESB, Green Atlantic at Moneypoint, Green Atlantic at Moneypoint (esb.ie)

[79] SEAI (2023), Net Zero by 2050 Exploring Decarbonisation Pathways for Heating and Cooling in Ireland, Net-Zero-by-2050.pdf (seai.ie)

the Balanced Scenario in the Net Zero by 2050 paper suggests industry will be the second-largest user, accounting for 3.9TWh in 2050 (see Figure 16).[79]

Currently, there are no plans for dedicated new hydrogen pipeline networks to supply industrial sites with low carbon hydrogen from various locations on the island or through imports. Developing such infrastructure might take years, so early evidence and planning would be beneficial. [26]

4.4 BARRIERS TO CARBON CAPTURE UTILISATION & STORAGE (CCUS)

CCUS presents significant opportunities for decarbonising heavy industries. The technology can be retrofitted to existing sites, potentially capturing around 90% of the originally emitted carbon, and is applicable across various industrial sectors. In particular, there is interest from the cement and oil refining industries, since CCUS provides a unique opportunity to reduce both fossil fuel usage and process-specific emissions, which fuel switching does not address. Moreover, since three of Ireland's four cement sites already use biomass, then implementing CCUS offers the added advantage of providing negative emissions[80]. However, there remain a multitude of challenges which as are described in Table 25.

Table 25: Barriers to CCUS adoption to support industrial heat decarbonisation

Theme	Key Barriers
Technical and technology	• Ireland has no industrial CO2 capture demonstration projects in operation. • Few capture technologies are technically proven for retrofit to existing industrial sites - many are in a demonstration phase. • Most CO2 capture technologies require dedicated space, heat, and power on site, which may not always be readily available at low cost. • Safe management of capture solvents or CO2 needs to be considered carefully, especially if large volumes need to be stored on industrial sites, or CO2 transported at high pressure or at low temperatures. • CO2 capture is most efficient from sources with high and steady CO2 concentration (which can be a challenge for intermittent gas-fired boilers).
Economics and financing	• CCUS is expensive in terms of equipment cost, financing, operating cost, long-term monitoring and provision for long term monitoring and mitigation of containment risks. • Capturing CO2 from heat-intensive processes in CCS projects carries the highest lifetime cost, exceeding typical capital budgets for industrial sites in Ireland. Operating and energy costs depend on confident projections of high avoided ETS prices or carbon taxes. • Innovative approaches are being developed for CO2 utilisation and cheaper approaches to CO2 storage, however these are currently immature and small scale. • Relocating businesses from their current locations to be nearer future CO2 transport and storage, or shoreline hubs, may be prohibitively expensive.
Policy and regulation	• Ireland has not prioritised CCUS, and no targeted financial support is available from the Irish Government to cover capital or operating costs of CCS for the purpose industrial heat decarbonisation, beyond support through existing EU schemes. • The capture and storage of carbon is currently banned in Ireland under the S.I. No. 575/2011, also known as the European Communities (Geological Storage of

[80] SEAI (2022), National Heat Study Carbon Capture Utilisation and Storage, Carbon Capture Utilisation and Storage | National Heat Study | SEAI

Theme	Key Barriers
	Carbon Dioxide) Regulations 2011. Note that this framework does not outright ban the capture and utilisation of CO2, but focusses on storage81.
Lead times and fragile supply chains	• CO2 capture requires extensive engineering, involving a lengthy process from feasibility, front-end engineering, detailed design, engineering procurement and construction, and commissioning, with various stakeholders, often unfamiliar with CCS, needing to grant approvals at each stage. • The limited presence of CCS project developers, technology developers, suppliers, and financiers in Ireland might lead other countries to take the lead in CCS demonstration activities. • CCS equipment is specialised with long lead times, since suppliers are hesitant to scale up manufacturing before demand due to uncertain CCS markets.
Inflexibility and incompatibility	• Not all capture technologies are compatible with process CO2 emissions that have impurities.
Lack of stakeholder familiarity or alignment	• We understand from the stakeholder workshops, that heat-intensive industry believes there is insufficient social or political support to progress CCUS at present in Ireland. • CCS involves diverse stakeholders from various sectors like energy-intensive industry, energy, infrastructure, and public bodies, often requiring alignment of organisational strategies and resources, leading to delays in some countries.82 • Awareness training may be needed on the benefits, risks and requirements for CO2 capture, transport and storage infrastructure for wider stakeholders who may be affected, as well as participating businesses and approval bodies.
Limited complementary infrastructure or resources	• CO_2 pipeline transport and geological storage are highly capital intensive and have long and complex critical paths to develop[83]. • No CO_2 transport networks exist to connect industrial sites with storage resources, and there have been no investments in repurposing oil and gas infrastructure for CCS transport or storage.[48] • Neither pipeline or shipping infrastructure or regulations are in place that would facilitate cross-border transport and storage of CO_2 from Ireland to neighbouring countries.[83] • There are no mechanisms in place to prioritise CO_2 storage capacity for future industrial users. • Alternative CCUS methods beyond geological CO_2 storage are developing but lack the maturity and scale. CO_2 utilisation near capture sites can alter economic and operational needs compared to CCS, yet markets for such utilisation are limited, with few offering permanent CO_2 sequestration.[83]

Technical and technology: Lack of demonstration of CCUS technologies.

To provide stakeholders with certainty about the future potential of CCUS and whether to invest in the technology, demonstration projects are needed to improve its TRL and demonstrate its viability in an Irish context. This is particularly true given the high upfront capital and planning required to retrofit existing sites with carbon capture. Currently, no such projects exist, with the greatest progress made so far being the completion of a pre-FEED study by Ervia to investigate the key infrastructure required to develop a transport

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[81] electronic Irish Statute Book (2011), S.I. No. 575/2011 – European Communities (Geological Storage of Carbon Dioxide) Regulations 2011, S.I. No. 575/2011 - European Communities (Geological Storage of Carbon Dioxide) Regulations 2011. (irishstatutebook.ie)

[82] Koukouzas et al (2022), Current CO_2 Capture and Storage Trends in Europe in a View of Social Knowledge and Acceptance. A Short Review, Current CO2 Capture and Storage Trends in Europe in a View of Social Knowledge and Acceptance. A Short Review | Semantic Scholar

[83] European Commission (2024), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Towards an ambitious Industrial Carbon Management for the EU, EUR-Lex - 52024DC0062 - EN - EUR-Lex (europa.eu)

and storage network around emitter clusters in Cork and Dublin[84]. Additionally, for industries to store captured carbon, necessary infrastructure, ideally in the form of pipelines, must be in place to facilitate efficient carbon movement from industrial sites to storage. However, no CCUS infrastructure currently exists[48].

Economics and financing: CCUS is expensive in terms of equipment cost, financing, operating cost, long-term monitoring and provision for long term monitoring and mitigation of containment risks.

In the absence of front-end engineering (FEED) studies, the actual technologies and costs of retrofitting industrial plants in Ireland is highly uncertain. In particular, installing CCUS in the cement sectors has a predicted average lifetime cost in the range €54-107/tCO_2 respectively[85,86].The uncertainties on costs are large today, but costs should become clearer as projects are deployed around the world during the 2020s. Please note that passing these costs to customers in certain industries may be highly restricted. CO_2 capture, transport and storage technologies benefit from economies of scale and scope, and long duration. This could favour coordinated and carefully phased procurement integrating clusters where a few large CO_2 emitters (> 100,000 tCO_2/yr) are connected by short pipelines to a nearby CO_2 store.

Lack of stakeholder familiarity: Poor public acceptance of CO_2 transportation and storage is increasing risks associated with CCUS installations.

The introduction of CCUS in Western Europe has resulted in great resistance among stakeholders and the public, particularly with regards to CO_2 transport and storage. This has led to several projects being cancelled. A similar pattern is observed in the UK, with the public having limited awareness on CCUS[82].

Limited infrastructure: CO_2 pipeline transport and geological storage is expensive and takes time to develop, with Ireland lacking the necessary infrastructure and regulations to implement CCUS effectively.

CO2 pipeline transport and geological storage demand significant capital investment and entail long, complex development paths[83]. Each storage site has its unique cost and risk profile, necessitating thorough site studies to assure stakeholders of costs, infrastructure, and long-term containment for making investment decisions. There are no CO_2 transport networks yet planned to connect existing industrial sites with CO_2 storage resources.[48] So far Ireland lacks planned CO2 transport networks and investments for repurposing oil and gas infrastructure to enable this transport and storage.[48] Additionally, neither pipeline or shipping infrastructure or regulations are in place that would facilitate cross-border transport and storage of CO_2 outside of Ireland[83]. Managing impurities, pressure, and temperature in CO2 streams adds to the expenses. Moreover, there's currently no mechanism in place to prioritise CO2 storage for future industrial users.

CCS projects often span a decade from concept to implementation, navigating a complex and delicate path. To drive significant CCS activity in the 2030s, extensive policy development is imperative now. This would involve aligning stakeholders, addressing challenges such as weak economics and technology immaturity, and ensuring the availability of enabling and cost-effective infrastructure.

4.5 BARRIERS TO DISTRICT HEATING

District heating networks offer a low-carbon method of providing heat to a wide range of customers when heat is sourced from renewable heat pumps, CHP, or recovered waste heat. Heat-intensive businesses can be both suppliers and offtakes for district heat networks. Typically, the temperature of the heat in these networks is low-grade (hot water at 60-80°C)[87], although both higher and lower temperatures are possible. Costs (and energy losses) increase substantially with distance. Therefore, heat networks are more competitive in towns and cities, and the use by isolated industrial sites in rural locations (common for food and drink and pulp and paper manufacturing) may be too expensive.

The technology is still in its early stages, with only one large scale network currently operational in Ireland (the Tallaght network). However, there is significant potential for expansion due to its maturity. The National Heat Study suggests that up to 50% of building heat demand could be met by district heating[7], aligning with the NCAP's goal of achieving 2.7 TWh/yr of district heating by 2030[88]. Developers can easily pinpoint suitable

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[84] Ervia (2021), Assessment of the Feasibility of CCS for Deployment in Ireland, Carbon Capture and Storage (ervia.ie)

[85] IEA (2021), Is carbon capture too expensive?, Is carbon capture too expensive? – Analysis - IEA

[86] These costs are based of 2019 data and converted from USD to EUR using the average exchange rate for 2019: USD to EUR Exchange Rate History for 2019 (exchange-rates.org)

[87] SEAI (2016), A Guide to District Heating in Ireland, RDD-000079.pdf (seai.ie)

[88] Irish Government (2024), Climate Action Plan 2024, gov - Climate Action Plan 2024 (www.gov.ie)

locations for district heating networks using the SEAI's Candidate Areas map, which identifies regions with high heat densities capable of meeting the target of 2.7 TWh/yr[89].

The barriers are described in Table 26.

Table 26: Barriers to district heating adoption to support industrial heat decarbonisation

Theme	Key Barriers
Technical and technology	• Existing heat networks are mature, although there is ongoing innovation to reduce costs and wider challenges.
Economics and financing	• Although heat networks are capital intensive and have high running costs, the economics are well understood. • Project specific analysis would be required to understand to what extent district heat is the most sustainable solution (i.e., the most cost effective and lowest environmental impact). • Economics would likely be most attractive for industrial users in areas with large heat supply and demand, but prohibitively expensive for sites that are remote from other heat network users.
Policy and regulation	• Limited national and local policy support or alignment for district heating risks missed opportunities for local optimisation. [87,90]
Lead times and fragile supply chains	• Planning and building new heat networks can take many years, and growing networks is subject to local approvals.
Inflexibility and incompatibility	• Heat networks can only supply modest amounts of low-grade heat.
Lack of stakeholder familiarity or alignment	• Limited awareness on the opportunities and needs associated with district heating, or the skills to implement these[87].
Limited complementary infrastructure or resources	• Critical to the use of district heat is the availability of a heat network with the right capacity and location. The temporal load profile of industrial usage also needs to manage the supply of heat. • Some industrial sites may benefit more from exporting waste heat to district heating networks, creating an additional revenue source without disrupting their processes significantly.

Policy and regulation: Risks of limited national and local authority policy or planning support or alignment for district heating.

Currently, the absence of clear guidelines, regulations, policies, frameworks, or standards concerning district heating poses risks and uncertainty for industrial sites[87,88], and hence discourages them from investigating further and investing (similar points were raised by stakeholders). Furthermore, national-level planning tends to neglect local energy synergies, despite the recognition that local authorities are ideally positioned to oversee the development of these heating networks[87].

Lack of stakeholder alignment: limited specialist skills and knowledge sharing.

The availability of skilled local workers for designing, installing, and operating district heating networks in Ireland is limited. Additionally, there's a general lack of knowledge and awareness about district heating networks, despite their maturity as a technology[87]. These factors hinder the implementation of the technology.

[89] SEAI (2024), District Heating Candidate Areas, District Heating Candidate Areas (seai.ie)
[90] Interreg, IRELAND – national policy framework, https://vb.nweurope.eu/media/12186/ireland-heatnet-nwe_lt-wp11_updated2020.pdf

Limited complementary infrastructure: Lack of availability of heat networks with the right capacity and location.

To be economical, it is best to situate district heating networks near urban areas as this leads to a denser heat demand and hence shorter pipelines[87]. This is feasible given the location of some industrial sites near Dublin, Cork and Waterford.

4.6 SEVERITY OF BARRIERS

In Table 27 we have sought to summarise the barriers facing different decarbonisation technologies up to 2025, illustrating the need for targeted interventions to facilitate sustainable industrial transitions.

Table 27: Current assessment of barrier for decarbonising industrial heat in Ireland

	Up-front Cost	Ongoing Costs	Technology Maturity	Long lead times or fragile supply chains	Incompatibility or inflexibility of processes or sites	Lack of Stakeholder familiarity, confidence priority, support, or alignment	Limited complementary infrastructure or resources	Policy and regulation
Energy Efficiency	Low barrier	Not a barrier	Not a barrier	Low barrier	Low barrier	Not a barrier	Not a barrier	Not a barrier
Electrification	Low barrier	Moderate barrier	Low barrier	Moderate barrier	Low barrier	Low barrier	Low barrier	Low barrier
Biogas	Moderate barrier	Moderate barrier	Low barrier	Low barrier	Low barrier	Low barrier	Moderate barrier	Low barrier
Biomass	Low barrier	Low barrier	Low barrier	Low barrier	Low barrier	Low barrier	Moderate barrier	Moderate barrier
Waste	Low barrier	Low barrier	Low barrier	Low barrier	Moderate barrier	Low barrier	Severe barrier	Moderate barrier
Hydrogen	Moderate barrier	Severe barrier	Severe barrier	Severe barrier	Severe barrier	Severe barrier	Severe barrier	Severe barrier
CCUS	Severe barrier	Severe barrier	Severe barrier	Severe barrier	Severe barrier	Severe barrier	Severe barrier	Severe barrier
District Heating	Low barrier	Not a barrier	Not a barrier	Moderate barrier	Low barrier	Low barrier	Moderate barrier	Moderate barrier

The table highlights that energy efficiency measures face the lowest barriers of the different decarbonisation strategies, whereas hydrogen and CCUS currently face the most barriers. The severity of barriers will decrease over time as costs reduce, technologies and supply chains mature, supporting infrastructure develops, new policies, frameworks and funds are introduced, and stakeholders become more familiar with the technologies. We would expect all the barriers, and particularly bioenergy, CCUS and hydrogen barriers to be reduced by 2030 for example due to implementation around the world.

As outlined in previous sections of this report, each decarbonisation strategy is suitable for varying industrial heating process, heat grade and technology type. There is some overlap between technologies, such as in the food and beverage industry where a gas boiler may be decarbonised via energy efficiency, electrification, bioenergy and hydrogen. Comparatively, for direct high temperature applications such as kilns, the replacement alternatives are far more restricted (as demonstrated in Figure 14 in section 3.2). Therefore, the moderate to severe barriers for hydrogen, waste and CCUS will play a significant role in preventing these higher emitting sectors to decarbonise.

The initiatives that Ireland could enforce to support the adoption of these technologies is outlined in the following chapter.

5. AREAS FOR CONSIDERATION AND FURTHER EVALUATION

This chapter identifies initiatives to support industrial heat decarbonisation in Ireland, recognising strengths and gaps of existing Irish Government and EU initiatives to support the technologies identified in Chapter 3, and overcoming the barriers identified in Chapter 4. We highlight further action that could accelerate technology adoption.

5.1 EXISTING INITIATIVES SUPPORTING INDUSTRIAL HEAT DECARBONISATION

Ireland and the EU already offer, or plan to offer, support for industrial decarbonisation technologies with a mix of technology-neutral, sector-neutral or more targeted thematic support. In the course of this project, several Irish Government and EU initiatives that could potentially support industrial heat decarbonisation were identified. A list of these initiatives are provided in the appendix. A policy evaluation was not possible within the scope of this project, but we have sought to provide a qualitative overview of the relevance of support for the different decarbonisation measures against the barriers identified in Chapter 4. Table 28 shows that there are potential support opportunities, from either Irish Government directly or via EU schemes, for the majority of decarbonisation technologies and the majority of barriers. However, our screening assessment of these suggests that the support that is likely to be available is, or risks being, insufficient to maximise the potential of the technology for industrial decarbonisation.

Table 28: Qualitative overview of relevance of potential Irish and EU policy initiatives

	Up-front Cost	Ongoing Costs	Technology Maturity	Long lead times or fragile supply chains	Incompatibility or inflexibility of processes or sites	Lack of Stakeholder familiarity, confidence priority, support, or alignment	Limited of complementary infrastructure or resources	Demand support (or competition from high carbon approaches)
Overarching support (tech neutral)	+	+	+	+	+	+	+	+
Energy Efficiency	++	+	+	+	+	+	+	+
Electrification	+			+		+	+	+
Biogas	+	++	+	+	+	+	+	+
Biomass	+	++	+	+		+	+	+
Waste								+
Hydrogen	+		+	+		+	+	+
District Heating	+	+	+		+	+	+	+
CCUS	+		+					+

Key - Very limited Irish or EU policy support identified, unlikely to overcome barriers, + = Limited Irish or EU support identified, possibility that barriers may be overcome in some applications, ++ Significant Irish or EU support identified, likely to overcome the barrier in several applications.

5.2 OPPORTUNITIES FOR ADDITIONAL POLICY SUPPORT

Visibility of future capital support

New technologies have upfront costs. The Climate Action Fund[91], Enterprise Emissions Reduction Investment Fund, Disruptive Technologies Innovation Fund[92], and SSRH[87], will cease to accept new applications from 2027. It is not clear whether upfront grant or financing support will be available in Ireland, beyond EU initiatives.

Industry capital stock often has long lifetimes, and there may be limited windows of opportunity to modify equipment. This is particularly true for those high temperature processes which often benefit from long periods of continuous operation, rather than stop-start. Uptake of lower carbon technologies will be more likely if policy support aligns with industry investment cycles, and longer-term certainty allows industries to build familiarity and capability, avoiding inefficient boom and bust cycles in supply chains.

Therefore, Government and industry should explore early the nature and extent of future capital support well before 2027.

Availability and Optimisation of Complementary Resources and Infrastructure

This study highlights that biogas, biomass, district heating, hydrogen, electrification, and CCUS can all contribute to industrial heat decarbonisation in Ireland. These approaches demand complementary infrastructure and resources *outside* the physical boundaries of industrial sites, but the availability of this is highly uncertain:

- There are risks that stakeholders are poorly aligned to develop decarbonisation infrastructure, manage their interdependences, and value wider or longer-term system benefits beyond first projects.
- Some decarbonisation strategies can either complement or compete with each other, sometimes even at the same site. Differing ownership, regulatory, or financing models, or asset investment timescales, may drive narrow or short-term decision making, rather than maximise the potential to reduce emissions or reduce Ireland's total system costs. It is unclear how and to what extent, optimised solutions that maximise the potential to decarbonise or minimise overall cost would be brought forward, nor by whom or when.
- Electrification, hydrogen, and CCUS are likely to have high additional operating costs, which may not be fully covered by carbon pricing, or available revenue support schemes, in the short term.

To ensure cost-effective infrastructure is available, this report suggests strengthening the evidence base and aligning stakeholder decision making to de-risk investments in infrastructure to support heat decarbonisation in industry. This could involve:

1. Facilitating data flows around future energy supply and demand and infrastructure opportunities to enable stakeholders to assess and select the most relevant infrastructure investment options for industrial heat decarbonisation.
2. Support heat-intensive businesses and infrastructure developers to understand and plan for options available through feasibility, techno-economic and engineering studies. This should recognise the potential for sizing or multi-vector approaches where this can reduce costs.
3. Building on the SEAI Heating and Cooling study, further analyse the costs and impacts for Ireland for industrial heat decarbonisation pathways which rely heavily on electrification, hydrogen, district heating, biomass, biogas, waste, CCUS or alternatives, and identify combinations of these which minimise overall costs and risks.
4. Ensuring heat-intensive businesses and infrastructure stakeholders in Ireland access latest information on industrial heat decarbonisation technologies with international projects.
5. Supporting (including funding) demonstrations in Ireland for diverse industrial heat decarbonisation projects, to understand implementation, costs and performance in an Ireland context for the solutions with the highest carbon and cost savings.
6. Review how decision makers could better align to reduce the timescales, costs and risks, or maximise the future benefits, for infrastructure for industrial heat decarbonisation, including joint industry-government road mapping activities.

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[91] Department of the Environment, Climate and Communications (2020), Climate Action Fund, https://www.gov.ie/en/publication/de5d3-climate-action-fund/

[92] Department of Enterprise, Trade and Employment (Unknown), Disruptive Technologies Innovation Fund, https://enterprise.gov.ie/en/what-we-do/innovation-research-development/disruptive-technologies-innovation-fund/

7. Clarify policy and regulatory expectations on the future availability for unabated fossil fuel use for industrial heat, for example continued use of natural gas infrastructure.
8. Identify training opportunities to ensure stakeholders improve decision making to identify and implement enable larger numbers and higher quality industrial heat decarbonisation projects.

Innovation Considerations

With potentially long lead times for deployment, Ireland should support research, development and demonstration of low carbon technologies that enable industrial heat decarbonisation, which are in line with the NCAP24. District heating, alternatively fired boilers or CHP systems, and electrically heat pumps are comparatively mature technologies and familiar approaches for industry for decarbonisation of around heating for processes up to 100-150 °C. Future technology research, development and demonstration for low carbon heating should prioritise processes with temperatures above 150 °C. These are described as medium and high grade in this report, and fewer decarbonisation options are commercially available, even though this range accounts for at least 60% of Ireland's industrial heat demand. Businesses in Ireland can either host research, development or demonstration projects themselves directly, or look to partner with and adopt innovations demonstrated elsewhere, if suitable knowledge sharing processes and supportive actors and institutions are in place. The key sectors that would benefit from medium and high temperature process R&D are lime, cement, metals, oil refining, and some parts of the food and drink industry.

1. Future R&D financial support, such as Capital grant funds[92] (and successors to the Climate Action Fund and Disruptive Technologies Innovation Fund), tax credits[93], and EU initiatives such as Horizon Europe, should recognise that medium and high grade heat users face fewer mature technology solutions than for low heat grades.

There are limited demand side measures to support the adoption of low carbon products and services, relative to higher carbon processes.

2. Therefore, Ireland should explore measures to drive demand of adopting low carbon technologies, building on EU measures. These can include setting increasingly stringent regulations and emission standards for various sectors, and prioritising the purchasing of low carbon technologies in procurement processes.

Electrification Considerations

Electrification features prominently in the NCAP23. There are opportunities to reduce risks associated with limited grid connectivity, high electricity prices, reliable low carbon electricity supply, and technology risks.

1. Ireland's electricity market stakeholders should review whether the pace, amounts and locations of investment into electricity networks will be sufficient to support industrial heat decarbonisation.
2. Continue to invest in low cost, low carbon power generation, and energy storage, so that industrial users benefit from reliable supply and low grid carbon intensity.
3. The National Planning Framework (NPF) lacks specific National Policy Objectives for industrial heat electrification[94]. The NCAP24 acknowledges this and highlights that the NPF will be further revised to support renewable energy integration and tackle grid capacity issues. Therefore, we suggest this updated national planning statement is published to enables the scale up of industrial heat electrification.
4. Understand and potentially implement opportunities to reduce electricity costs for industrial users, or consider whether ongoing price support provides value for money.
5. Continue to provide cost support for electrification at rates consistent with the associated carbon savings, capital costs and technology maturity.
6. Understand and potentially implement opportunities to reduce electricity grid connection costs, timescales and challenges for switching from unabated fossil fuel use for heating to electricity.
7. Consider supporting R&D into electrification for medium and high temperature processes, for which few options are commercially mature.

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[93] Irish Tax and Customs (2024), R&D Corporation Tax Credit, https://www.revenue.ie/en/companies-and-charities/reliefs-and-exemptions/research-and-development-rd-tax-credit/index.aspx

[94] National Planning Framework (2023), A Road Map for the First Revision of the National Planning Framework, https://www.revenue.ie/en/companies-and-charities/reliefs-and-exemptions/research-and-development-rd-tax-credit/index.aspx

Bioenergy Considerations

Bioenergy, which are increasingly understood, have widespread applicability, but can cost more than fossil fuels and have limits to domestic supply. The closure of the SSRH in 2027[87] would limit the primary annual financial support for Irish sites using biogas and solid biomass heating to being largely avoided carbon tax or ETS payments only. This revenue loss could impact the economic viability of new biomass/biogas heating projects, as well as district heating networks that utilise bioenergy.

1. Explore the possible approaches, and their value for money, for continuing ongoing revenue support beyond 2027 when SSRH ends, to ensure competitiveness (once carbon costs are taken into account).
2. Consider how implementation of EU Directives on renewable energy and related policies will impact future supply of biomass, biogas, liquid biofuels or renewable wastes in Ireland for industrial heat decarbonisation, and assess whether additional national efforts are required to ensure bioenergy is used in industry where it is most valuable.
3. The recent Irish Bioeconomy Action Plan aims to enhance solid biomass supply by reviewing the regulatory system[95]. Without further support for growing sustainable biomass supply chains there is a potential limit in the ability of domestic supply to meet growth in demand. It is important for government and industry to balance bioenergy production for industrial heat with competing pressures on land use, biodiversity, and greenhouse gas removal.[88,96] Assess options for increasing the supply, potentially from both domestic and international sources, of sustainable bioenergy fuels for industrial heat decarbonisation.

Waste Considerations

Ireland is increasingly embracing a Circular Economy approach, emphasising reuse and recycling over using solid waste as a fuel for heat and power generation. This shift is evidenced in the recent signing of the Waste Management Regulations 2023 and Circular Economy Regulations. The latter introduces a €10 per tonne levy on recovery operations at landfills, waste-to-energy, and co-incineration plants[97]. Further restrictions are enforced by the EU, with the RED II mandating that member states shall not support the incineration of waste if the separate collection obligations laid down in the Waste Framework Directive have not been complied with[96]. It is therefore unlikely that waste will be a material feedstock for industrial heat decarbonisation. However, there are risks that alternative decarbonisation strategies fail to materialise, and therefore interested stakeholders could:

1. Periodically review the necessity and sustainability of using waste streams for industrial heat decarbonisation.
2. If use of wastes is deemed necessary and sustainable, then consider assessing the costs, benefits and risks of enabling policy or regulation.
3. Develop projections of available wastes, given the increasing circular economy approach, will assist industry in projecting the availability and quality of waste into 2030.
4. Facilitate discussions between waste providers and industrial consumers in order to provide clarity as to the supply and quality of waste available for use into the future.

Hydrogen Considerations

Hydrogen could be an effective solution for a range of heat users. Ireland's hydrogen strategy envisages demonstrations in the late 2020s paving way to adoption in the 2030s. Progress has been made with the

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[95] Department of Agriculture, Food and the Marine (2023), Bioeconomy Policy, https://www.gov.ie/en/publication/a1bb6-bioeconomy-policy/

[96] Institute for European Environmental Policy (2021), Biomass in the EU Green Deal, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://ieep.eu/wp-content/uploads/2022/12/Biomass-in-the-EU-Green-Deal.pdf

[97] Department of the Environment, Climate and Communications (2024), Introduction of new environment levies will incentivise recycling and help Ireland meet our EU waste targets, https://www.gov.ie/en/press-release/75262-introduction-of-new-environment-levies-will-incentivise-recycling-and-help-ireland-meet-our-eu-waste-targets/

National Hydrogen Strategy setting an objective to identify and support strategic hydrogen clusters between 2024-2026[26].

1. Consider starting to identify the most competitive hydrogen use cases through feasibility studies, detailed engineering and demonstration activities.
2. Begin structuring capital and revenue support to encourage demonstration of the use of low carbon hydrogen for industrial processes.
    - One potential approach is to provide support to sites meeting the sustainability criteria outlined in the proposed RHO, with certified sites being deemed eligible for annual financial assistance.
    - Approaches should look to leverage opportunities to leverage EU support for green hydrogen production, distribution, storage and use, which includes R&D, cross-border projects, and supporting supply chains.
3. Promises made under the National Hydrogen Strategy to review current approaches to energy systems planning and support a more integrated approach for hydrogen networks should be progressed. This could be achieved by revising the existing National Planning Framework or establishing a separate framework. [35]
4. Should ensure timely development of supporting hydrogen production, transportation and storage infrastructure, and associated supply chains for these, anticipating the future needs of industrial heat users.

District heating Considerations

For district heating, which can particularly support low grade heat users in towns and cities, there is ambiguity on the connection of industrial sites to heating networks within the planning framework. Use of waste heat *from* industry is already encouraged. [98] Local area heating and cooling planning is likely to drive further work in this area[99].

1. Heat networks are relatively mature technologies and Ireland should adopt best practices to support industry to connect to from heat networks, including knowledge sharing, regulation and planning, capital support, supply chain development, and ensuring the energy supply for district heat is of low carbon intensity.
2. The NCAP24 promises to create a National District Heating Centre of Excellence to offer advice, support, and training. This is still pending but could be a valuable enabler.

CCUS Considerations

CCS can be effective for sites with larger CO_2 emissions, particularly where CO_2 emissions are an unavoidable output from chemical production processes, as well as heating processes. However, at present CCS is not possible in Ireland due to the SI 575 of 2011 (Geological Storage of Carbon Dioxide) Regulations 2011, clearly stating in Section 4 that storage of CO2 is not permitted[50].

Despite the regulations, the Irish Government has conducted feasibility research on CCUS as part of the National Heat Study directed by the SEAI in 2022[48], and a single pre-FEED study led by Ervia as instructed by the CCS Policy and Project Feasibility Steering Group in 2019[87]. Ireland's NCAP24, which aims to develop a CCUS framework dedicated to the construction materials industry by 2031-2035[90].

With long lead times, high up-front and ongoing costs, complex critical paths, few policy or regulatory enablers in place, emissions reductions from industrial CCS will not be available to Ireland in the 2020s. Earlier action could enable stakeholders to assess and prepare for CCUS in Ireland.

1. To ensure that industrial decarbonisation plays its full role in meeting Ireland's Net Zero targets at lowest cost from the 2030s, it would be useful for the public bodies in Ireland to evaluate periodically, the levels and focus of support for CCS, and where appropriate keeping this option open as a route to industrial heat decarbonisation.

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[98] Department of the Environment, Climate and Communications (2023), District Heating Steering Group, https://www.gov.ie/en/publication/3f132-district-heating-steering-group/

[99] European Commission (2021), Directive of the European Parliament and of the Council on Energy Efficiency, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0558

  - These would include keeping Ireland's CO_2 storage capacity (offshore and surrounding areas) estimates up to date with latest understanding, and ensuring stakeholders have aligned expectations, for example around available capacity, technology readiness, safety, permanence, storage development and longer term monitoring requirements, and cost-effectiveness.
  - Assess the impacts of options for enabling policy and regulation on geological CO_2 storage in Ireland. This could be achieved by reviewing the ban on CCS in Ireland, as stated in the SI 575 of 2011 Regulations, and using the mechanisms outlined under Articles 27 and 38 of the EU's Geological Storage of Carbon Dioxide Directive (2009/31/EC) to remove the ban.
  - Periodically updating CCUS techno-economic and regulatory gap assessments, and engineering designs for industrial CCUS in Ireland, and supporting infrastructure, so that stakeholders have access to best available information, to inform decision making. This should include latest costs and performance data from relevant international CCUS demonstration and commercial projects. They should also quantify to what extent combinations of bioenergy and CCUS could help some businesses contribute to Net Zero targets through "negative" emissions.
  - Enable stakeholders to plan and make co-ordinated CCS investments across multiple locations, minimising overall costs and risks. This could include joint R&D, or cross-border CCS projects, where CO_2 captured in Ireland is stored in nearby countries.
    - Ireland's CCS stakeholders could consider EU CCS support including such as the EU's Industrial Carbon Management Strategy, which aims to establish an EU-wide framework for CCUS investment coordination at both EU and national level[100], and Horizon Europe, EU Innovation Fund, InvestEU Fund, or TEN-E.
    - There may also be future opportunities to share CO_2 storage resources with emerging CCS projects in the UK.
2. There may be small and/or niche CO_2 utilisation opportunities – these can be particularly helpful in building familiarity among local stakeholders in integrating CO_2 capture technologies at industrial sites.

Areas of consideration for future research

There are some key considerations for further research that can be taken away from this work:

1. We have not quantitatively assessed how effective each Irish and EU policy has been in promoting the adoption of low carbon technologies for industrial heat decarbonisation. Instead, we have reviewed these policies based on their guidelines, applicability to various technologies, and duration. To enhance future research, consider either measuring the carbon savings achieved by each policy, measure the total number of projects funded by each policy, or measure the total amount of funding raised by each policy that has been directed towards industrial heat decarbonisation. This analysis would provide valuable insights into the success or failure of each policy, which can then be investigated further to identify whether certain support mechanisms or more favourable over others.
2. We did not explore initiatives outside the EU. This comparative analysis could offer valuable lessons for the Irish Government, aiding in understanding which support mechanisms are most effective in driving low carbon heating technology adoption. Some examples of key initiatives include the UK's CCUS and hydrogen production business models, and the USA's Inflation Reduction Act.
3. The designs, costs and performance of international demonstration and commercial industrial decarbonisation projects with novel clean technologies or alternative processes, are not readily available, limiting techno-economic assessments. To address this, consider building a stronger evidence base to facilitate such assessments in the future.

[100] European Commission (2024), Carbon Capture, Storage and Utilisation, https://energy.ec.europa.eu/topics/oil-gas-and-coal/carbon-capture-storage-and-utilisation_en

APPENDICES

Appendix A: Overview of Industrial Heat in Ireland

We have built on SEAI's Heating and Cooling in Ireland Today's publication released in 2021, updating heating demand and emissions for each industrial sub-sector using 2022 energy and emissions data.

This section describes the methodology for profiling heating demand in industry and highlights the main results, following the methodology shown below.

1) Definition of Ireland's key industrial sub-sectors
2) Calculation of energy demand for each industrial sub-sector (including breakdown of sites into ETS and non-ETS)
3) Fuel consumption split by process and equipment type for each process
4) Heating demand separated by grades of heat

The key data sets and publications used as a part of this study are listed and referenced below. For the remainder of this section, the data sets will be referred to by the publication names detailed below.

- The SEAI's Heating and Cooling in Ireland Today report and data set included within the appendix[101], and
- The European Union Emissions Trading Scheme Data (EU ETS)[102], which quantifies the CO_2 emissions of the largest industrial consumers, and
- The SEAI's National Energy Balance for Ireland[103], which quantifies the fuel and electricity consumption by industrial sub-sector, and
- The SEAI's National Energy Balance energy conversion and emissions factors[104] for each fuel type, which defines the energy conversions and emissions of each respective fuel source, and
- The SEAI's data set detailing fuel consumption of cement, lime and refining sites in Ireland for 2019 (private data set not available for publishing)

Definition of Ireland's key industrial sub-sectors

Publications have used different sectoral or sub-sectoral classifications (or definitions). For the present report, we adopt SEAI's Heating and Cooling in Ireland Today sub-sectors. This allowed us to disaggregate heating demand into equipment type and heat grade. Due to this, sub-sectors are (slightly different) from those used in SEAI's National Energy Balance. As outlined in the SEAI Heating and Cooling in Ireland Today publication, this representation balances the scale of a sub-sector's heating demand and emissions in Ireland with how homogenous the processes or heating equipment in a sub-sector is.

A depiction of the different sub-sector definitions is detailed in the table below.

[101] Sustainable Energy Authority of Ireland [SEAI] (2022), National Heat Study – Heating and Cooling in Ireland Today, https://www.seai.ie/data-and-insights/national-heat-study/heating-and-cooling-in-ir/

[102] European Commission (2024), Union Registry Documents (Verified Emissions for 2022), https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/union-registry_en

[103] Sustainable Energy Authority of Ireland [SEAI] (2022), 2022 National Energy Balance, https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/

[104] Sustainable Energy Authority of Ireland [SEAI] (2022), Energy conversion and emissions factors 2022, https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/

Table 29: Industrial Sectors and Corresponding Key Heat Intensive Processes

Industrial Sectors	Key Heat Intensive Processes
Metals	Steam generation, Bayer process, Calcination, Rolling, Melting, Sintering, Melting and other high temperature processes
Cement	Clinker preparation, Kiln firing
Refining	Crude oil distillation/ Primary distillation, Catalytic cracking (conversion process), Delayed coking process, Thermal cracking (conversion process), Low temperature process, Drying/ separation
Wood products	Refining (mechanical pulping), Pressing, Paper drying, Ancillary, Low Temperature process
Chemicals	Cracking, Steam reforming, Turbine, Other high temperature process
Food and drink	UHT treatment/sterilisation, Pasteurisation / blanching, Cooking (ovens) / blanching / boiling, Evaporation, Drying, Other low temperature process
Lime	Calcination
Other minerals	Batch/ cullet preparation, Melting, Kiln firing/product annealing, Drying, Low temperature process
Other industry	Varies depending on application

Calculation of heat energy demand for each industrial sub-sector

The EU ETS data set of sites and verified emissions for 2022 was used to determine the emissions and heating demands at ETS sites. Large energy users with thermal inputs of more than 20 MW operate in the EU's emissions trading scheme. These sites publish data on greenhouse gas emissions each year from scope 1 activities. As an accurate source of data on emissions for the largest industrial sites within Ireland, this ETS data was used to estimate the fuel used on these sites. As sites operating in the refining, cement and lime sub-sectors are typically large energy users, it was assumed that all sites in these sectors are included in the ETS.

Each industrial site listed in the data set was allocated a sector according to Table 29 to determine the tCO_{2e} emissions for each site in the year 2022. Several adjustments needed to be made to this data set given the emissions reported in the ETS are for Scope 1 emissions only, and therefore it is reasonable to assume that all emissions are from the combustion of fuels or other 'process' emissions.

- As described in the main body of the report, cement site emissions comprise of the combustion of fuel in kilns as well as process emissions from the chemical formation of cement in the kilns. Therefore, calculations using BREF documents[105] were made to determine and remove process emissions from the EU ETS verified emissions values. From this adjustment, it was possible to determine the overall emissions due to the combustion of fuels, and therefore emissions from heating.
- The combustion of fuel on industrial sites can be used directly for the generation of heat, or to cogenerate electricity and heat on site. To understand the full energy demand of the industrial sector, the industry end-use data are combined with proportions of the energy use detailed in the CHP plants sector in the energy balance. We estimated the proportion of CHP fuel use within each industrial sector.

Once all adjustments were made, sites with a common sector were aggregated to calculate the total ETS emissions for that respective sector.

The National Energy Balance for Ireland was then used to estimate the overall energy demand for the entire industrial sector (ETS and non-ETS), with the energy balance accounting for fuel consumption used for energy end use. The sectors included in the National Energy Balance for Ireland were reallocated to match the sectors

[105] European Commission (2013), Production of Cement, Lime and Magnesium Oxide, https://eippcb.jrc.ec.europa.eu/reference/production-cement-lime-and-magnesium-oxide

defined in Table 29, ensuring that all sectors were appropriately accounted for. SEAI's conversion factors were used to convert to common units [TWh] and SEAI's emissions factors for each fuel type were used to estimate the emissions for each sector. The difference between the total fuel use and the estimated fuel use on ETS sites was used to estimate the total fuel use in each sector on non-ETS sites.

Fuel consumption split by process and equipment type for each process

Fuel consumption in each of the sectors was then estimated between different processes and equipment types building on SEAI's Heating and Cooling of Ireland Today's report and appendices.'[106]. The proportion of heat allocated to each equipment type and process was then applied to the updated National Energy Balance and EU ETS data to update the total heat demand in industry.

Heating demand separated by grades of heat

The NCAP 2023 targets relate to heat of different temperature grades is required to compare Ireland's progress against NCAP23 targets. The contribution for each heating grade was taken from SEAI's Heating and Cooling of Ireland Today's report and then updated National Energy Balance and EU ETS data were used to update and estimate the total heat demand in industry in 2022.

Conclusions

The methodology outlined in this report required assumptions to enable alignment of data sets from different sources, including 2019 data that may now be out of date.

Opportunities to improve data include:

1) ***Collecting data on fuel consumption of cement, lime and refining sites***. SEAI granted permission for the use a data set from 2019, which detailed the fuel consumption of cement, lime and refining sites across Ireland. As this data is now 5 years old and it is assumed that these sites (particularly cement and lime) are now consuming more alternative fuels, the calculations for heating demand in these sectors may be inaccurate. The weighted emissions factors calculated for these sectors will not be representative of actual operation.
2) ***Collecting data on quantity of electricity consumed for heat in industry***. There is no clear way to determine what proportion of electricity consumed in SEAI's National Energy Balance is used for heating for industrial processes, and other processes. Therefore, it is not possible to accurately determine industrial progress against the electrification of heat targets outlined in the NCAP23 report.

[106] Sustainable Energy Authority of Ireland [SEAI] (2022), National Heat Study – Heating and Cooling in Ireland Today, https://www.seai.ie/data-and-insights/national-heat-study/heating-and-cooling-in-ir/

Appendix B: Strategies for Decarbonising Industrial Heat in Ireland

The following table contains the main heat intensive processes associated with various industrial sectors, including their heating types, grades, and processes temperatures.

Table 30 Industrial Sectors and their Heat Intensive Processes

Sector	Process	Heating Type	Heat Grade	Process Temperature (°C)
Metals	Steam generation	Indirect	Medium/Low	100 - 150
	Rolling	Direct	Medium/High	150 – 500/ >500
	Melting	Direct	Medium/High	150 – 500/ >500
	Sintering	Direct	Medium/High	150 – 500/ >500
	Melting and other high temperature processes	Direct	Medium/High	150 – 500/ >500
Cement	Raw meal preparation	Direct	Medium	150 - 500
	Kiln firing – Calcination	Direct	High	>500
	Kiln firing – Clinker formation	Direct	High	>500
Refining	Crude oil distillation/ Primary distillation	Indirect	Medium	150 – 500
	Catalytic cracking (conversion process)	Indirect	Medium/High	150 – 500/ >500
	Delayed coking process	Direct	Medium	150 – 500
	Thermal cracking (conversion process)	Direct	Medium/High	150 – 500/ >500
	Low temperature process	Indirect	Medium/High	150 – 500/ >500
	Drying/ separation	Indirect	Medium	150 – 500
	Space heating	Indirect	Medium/Low	100 - 150
Wood Products	Refining (mechanical pulping)	Indirect	Low	<100
	Pressing	Indirect	Medium	150 – 500
	Paper drying	Indirect	High	150 – 500
	Ancillary	Direct	Medium/Low	100 - 150
	Low Temperature process	Indirect	Medium/Low	100 - 150
Other Minerals (Glass) (Ceramics)	Batch/ cullet preparation	Direct	Medium	150 – 500
		Indirect	Medium/Low	100 - 150
	Melting	Direct	High	>500
	Kiln firing/ product annealing	Direct	High	>500
	Drying	Direct	Medium	150 – 500
	Low temperature process	Indirect	Medium/Low	100 - 150
Food and Drink (dairy/ meat)	UHT treatment/ sterilisation	Direct	Medium/Low	100 - 150
		Indirect	Medium/Low	100 - 150
	Pasteurisation/ blanching	Indirect	Low	<100

	Cooking (ovens) / blanching/ boiling	Direct	Low	100 - 150
	Evaporation (concentration)	Direct	Medium/Low	100 - 150
	Low temperature process	Indirect	Medium/Low	100 - 150
	Drying	Indirect	Low, Medium/Low	<100
Lime	Calcination	Direct	High	>500
Chemicals	Cracking	Indirect	Medium/High	150 – 500/ >500
	Steam reforming	Indirect	Medium/High	150 – 500/ >500
	High temperature	Indirect	Medium	150 – 500
	Turbine	Indirect	Medium	150 – 500

Sector Specific Heat Decarbonisation Options

This section identifies the heat intensive process and potential decarbonisation options for the largest emitting sectors: metals (alumina), cement and lime, refining, wood production (pulp and paper), food and drink (meat and dairy), chemicals, and other non-metallic minerals.

Table 31 Alumina Sector Decarbonisation Options

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
Bayer Process	Kiln	Direct	High	Hydrogen fired kiln
				Electric fired kiln
				CCS
				Heat recovery
	Boiler	Indirect	Medium	Electric boilers
				CHP
				Heat recovery
				Mechanical vapour recompression
	CHP	Indirect	Medium	Heat recovery
				Mechanical vapour recompression
Calcination	Kiln	Direct	High	Hydrogen calcination
				Electric calcination
				CCS
				Heat recovery

Table 32 Cement and Lime Sectors Decarbonisation Options

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
Raw meal preparation/ Gate pre-heater	Dryer (cyclone pre-heater)	Direct	Medium	Fuel switching
Pyro processing to produce clinker	Cement Kiln	Direct	High	Maximising use of solid biomass and waste fuels*
				Hydrogen fired kiln
				Hydrogen/Plasma calciner
				Clinker substitution
				Alternative clinker systems

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
				CCS
				Plasma torches (electricity)
				Upgraded kiln with low pressure drop cyclone
				Upgraded kiln with cyclone preheater and pre-calciner

Table 33 Refining Sector Decarbonisation Options

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
Crude Oil Distillation/ primary distillation	Boiler	Indirect	Medium	Process integration Recovery of heat (process optimisation) Electrification
Catalytic Cracking (Conversion process)	Reactor	Indirect	High Medium	Process integration Recovery of heat (process optimisation) CCS Electrification
Delayed Coking Process	Furnace	Direct	Medium	Fuel switching: Hydrogen Process optimisation CCS
Thermal Cracking (Conversion process)	Furnace	Direct	High	Fuel switching: Hydrogen Process optimisation CCS

Table 34 Wood Products Sector Decarbonisation Options

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
Pulping, paper making, paper drying	Boiler	Indirect	Medium/Low High	Electric boilers Process integration Efficient vacuum systems for dewatering High temperature heat pumps Heat recovery from drying hoods Microwave drying
Ancillary	Dryers	Direct	Medium/Low	Fuel switching: Biomass Process change: new drying technologies (non-thermal water removal)

Table 35 Food and Drink Sector Decarbonisation Options

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
Drying	Dryer	Direct	Low	Fuel switching
Drying	Dryer	Indirect	Medium Medium/ Low	Fluidised bed dryers Fuel switching: Hydrogen Fuel switching: Electrification
Heating	Oven	Direct	Medium	Fuel switching: Hydrogen / biogas Fuel switching: Electrification

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
	Oven	Indirect	Medium	Electric water heater
Cleaning In Place (CIP)	Boiler	Indirect	Low	Ultrasonic CIP
UHT treatment /Sterilisation	Boiler	Direct	Medium/ Low	Electric/biogas/hydrogen boilers
	Heat exchanger	Indirect		

Table 36 Chemicals Sector Decarbonisation Options

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
Natural gas-based ammonia synthesis	Boiler	Indirect	Medium/High	Blue or green H2 production and ammonia synthesis
				Biomass gasification and ammonia synthesis
				Methane pyrolysis and ammonia synthesis
				Fuel switching for steam generation for Steam Methane Reforming
				CCS
Steam cracker	Furnace	Indirect	Medium/ High	CCS
				Electric steam cracker
				H2 fuel switching for steam cracker
				Methanol to olefins and to aromatics
Steam reforming – hydrogen and methanol	Boiler	Indirect	Medium/ High	AEL/PEM or solid oxide electrolyser
				Biomass/waste gasification
				CCS
Reaction furnace	Oven	Direct	Medium/Low	Recuperative/ regenerative burners
				Fuel switching: Hydrogen
				Fuel switching: Electrification
	Dryer	Direct	Medium/Low	Recuperative/ regenerative burners
				Fuel switching: Hydrogen
				Fuel switching: Electrification

Table 37 Other Non-Metallic Minerals Sector Decarbonisation Options

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
Raw material preparation, Green product drying	Dryer	Direct	Medium	Fuel switching to hydrogen/ biogas
				Recovery of heat
				Microwave assisted drying and firing
				Improved dryer design: automatic controls of dryer circuits, humidity, and temperature.
Green product firing	Kiln	Direct	High	Fuel switching to hydrogen/ biogas
				Integration of drying and firing kilns
				Recovery of heat
				Electric kilns, microwave assisted drying; low thermal mass kiln furniture.
				Oxyfuel furnace
				Increased cullet use

Heat Intensive Processes	Heating Technologies	Heat Type	Heat Grade	Decarbonisation Options
				Regenerative furnace

Appendix C: Policies that Address Barriers to Decarbonising Industrial Heat in Ireland

The following Irish policies, regulations, initiatives, strategies, and papers identified during the literature search are shown in Table 38 below.

Table 38: A list of Irish policies, regulations, initiatives, strategies and papers identified during the literature search that address industrial heat decarbonisation barriers.

Policy, regulation, initiative, strategy, or paper	Purpose
The Disruptive Technologies Innovation Fund	Provides capital funding dedicated to investing in disruptive technologies, including low carbon technologies, which will end in 2027.
Enterprise Emissions Reduction Investment Fund	Assists companies involved in manufacturing combustion processes with investing in carbon-reducing equipment and technologies. The fund offers up to €1M per business and will close in 2027.
Irish Carbon Tax	This tax was introduced in 2009 and is updated on a yearly basis. The current rate of carbon tax for industrial sites burning fossil fuels is €48.50 per tonne of carbon dioxide emitted.
Ireland's Research and Development Tax Credit	Eligible companies can claim a tax credit of 25% on all qualifying R&D expenditure, on top of the standard 12.5% deduction. This is not particular to decarbonisation technologies, but applies to all R&D.
The National Planning Framework (NPF)	The NPF will be used to help achieve National Policy Objectives associated with supporting the circular and bioeconomy, integrating climate action into the planning system, promoting renewable energy use and generation, and improve the sustainable management of wastes.
Decarbonisation Roadmap for Industrial Heat	Anticipated to be published in 2024, this paper will provide clarity to industry on Ireland's roadmap towards decarbonising heat.
The Infrastructure, Climate and Nature Fund (ICNF)	The ICNF aims to prevent pro-cyclicality in capital spending by providing support for capital expenditure during future economic downturns. Such expenditure includes funding future decarbonisation projects.
Business in the Community Ireland (BITCI)	The BITCI has helped gather Irish businesses to make collective statements and commitments around carbon reductions, and is acting as the lead advisor to these businesses on their decarbonisation journey.
Climate Planning Fund for Business	Offers three types of support to businesses: 1.) a Climate Action Voucher valued at €1,800 for engaging consultants to develop plans focusing on resource efficiency and renewable energy; 2.) grant funding covering up to 50% of costs for developing a multi-annual climate change plan aligned with international standards and frameworks; and 3.) covers the expense of hiring an environmental consultant to implement best practice sustainable systems and structures within the business.
The SEAI's National Heat Study.	Provides a comprehensive analysis of the options for reaching net zero emissions for the Irish heating sector by 2050. The includes scenario modelling and the development of decarbonisation pathways.
Enterprise Agencies	By 2024-2025, it is anticipated that Enterprise Agencies will provide support to industry in the use of hydrogen.
Climate Action Plan 2024 (NCAP24)	The Plan provides a roadmap for taking decisive action to halve Ireland's emissions by 2030 and reach net zero by no later than 2050, as committed to in the Climate Action and Low Carbon Development (Amendment) Act 2021.

Policy, regulation, initiative, strategy, or paper	Purpose
The Irish National Energy and Climate Action Plan 2021-2030 (NECP)	A comprehensive plan that outlines Ireland's energy and climate policies in detail for the period from 2021 to 20301. It brings together energy and climate planning into a single process for the first time.
40by30	A roadmap that provides alternative deployment scenarios of achieving the goal of 40% renewable heat by 2030 in Ireland.
The Ireland's National Recovery and Resilience Plan (NRRP)	A comprehensive plan that outlines how Ireland intends to utilise an initial allocation of €915M in grants from the EU's Recovery and Resilience Facility to contribute to a sustainable, equitable, green, and digital recovery effort.
Climate Action Fund	Provide at least €500M in funding by 2027 to decarbonisation projects, initiatives, and research. One such example is supporting the first large-scale renewable gas (biomethane) central grid injection facility in Ireland.
Skillnet Ireland's Climate Ready Academy	A national upskilling initiative that aims to support Irish businesses in developing the skills and talent required to mitigate the effects of climate change. There is specialised training in the areas of Climate Action, Sustainability, and Corporate Social Responsibility.
The Build Up Skills Ireland (BUSI2030) Roadmap	Aims to fill skills vacancies by training skilled industry construction workers and building professionals, and upskilling students in relevant STEM degrees, with the intent of developing a skilled workforce to tackle the issues of decarbonisation and climate change adaptation.
Energy Efficiency Obligation Scheme (EEOS)	Mandates that the largest energy suppliers and distributors in Ireland meet annual energy efficiency targets. This can be achieved by financially supporting businesses who wish to carry out efficiency upgrades.
The Irish Accelerated Capital Allowance (ACA)	A tax incentive scheme that promotes investment in energy-efficient products and equipment.
Excellence in Energy Efficiency Design (EXEED) programme	Provides financial support to companies undertaking energy efficient design projects. As of last year, the level of support for high impact energy efficiency projects has increased to a maximum of €3M.
The SEAI's Large Industry Energy Network (LIEN)	Provides members with a range of support to help implement energy savings measures, such as adopting energy management systems, developing emissions management systems, improving energy performance metrics, and adopting best practices.
The SEAI's Energy Academy	An online learning platform that offers high-quality, on-demand energy training to help individuals and businesses understand their energy use and discover the skills needed to start their energy efficiency journey.
The Support Scheme for Renewable Heat (SSRH)	Provides grants for heat pump installations and annual operational support for solid biomass and biogas heating systems that cover non-domestic heat users. The scheme closes to new applicants in 2027.
The Electricity Infrastructure Report for Ireland	The report provides a comprehensive framework for understanding the costs and scenarios associated with the electrification of heat in Ireland.
Electricity Association of Ireland (EAI)	The representative body for the electricity industry and gas retail sector operating within the Single Electricity Market (SEM) in Ireland. The EAI advocates for the progressive electrification of transport and heating.
Sustainability Criteria Options and Impacts for Irish Bioenergy Resources report	A report that offers a framework tool to assess the sustainability of biomass supply in Ireland.

Policy, regulation, initiative, strategy, or paper	**Purpose**
Bioeconomy Action Plan 2023-2025	Provides a plan to further develop Ireland's bioeconomy in delivering the vision of the 2018 National Policy Statement on the Bioeconomy. This includes a strong focus on bringing sustainable scientific practices, technologies, and biobased innovation into use.
Implementation of bioenergy in Ireland – 2021 update	This report provides an overview of Ireland's existing energy consumption in different industries, the source of bioenergy in Ireland at present, and where bioenergy is used in industry.
National Policy Statement on the Bioeconomy	The statement sets out a vision, common principles, strategic objectives, and a framework for implementation of the bioeconomy.
High-Level Bioeconomy Implementation and Development Group (BIDG)	This group will manage policy and ensure a more coherent approach and greater integration of bioeconomy in the development and implementation of policy.
The Irish Renewable Heat Obligation (RHO)	The obligation will mirror that of the Biofuels Obligation Scheme which operates in the transport sector, incentivising the use of solid biomass, biogas and green hydrogen for renewable heat.
The Gas Innovation Fund	The aim of the fund is to support R&D projects and strategic projects in Ireland dedicated to low carbon gaseous fuels. Thus far 11 projects dedicated to biomethane have been investigated
Green Gas Certification Scheme	Gas Networks Ireland has been appointed as the Issuing Body for Guarantees of Origin for Gas produced from renewable sources. In addition to this, the Commission for Regulation of Utilities (CRU) is set to establish a supervisory framework, against which guarantees of origin can be issued.
National Biomethane Strategy	A comprehensive plan that outlines how Ireland intends to utilise biomethane for energy. The strategy was drafted in agreement with the National Heat Study.
National Energy Security Framework	A framework developed in response to Ireland's energy security needs in the context of the war in Ukraine. The framework has an action to appraise the introduction of supports for biomethane as a replacement for natural gas.
The AD and Biomethane Working Group	Aimed to be formed in 2024, this group will help examine the types of support and incentives necessary to kick start the biogas industry in Ireland, and ensure policy alignment across planning, regulation and markets.
A Guide to District Heating in Ireland	Provides a thorough review of the state of district heating in Ireland as of 2016.
The Irish Heat Atlas	A free and publicly available interactive heat map of Ireland that enables easy analysis of heat densities in Ireland and hence the optimal locations to install district heating networks.
District Heating Steering Group	The group has issued recommendations to enhance district heating in Ireland and at present is examining the optimal funding options to cover the upfront costs of district heating.
Centre of Excellence for district heating	This centre will be fully established within the SEAI to support all providers in the development of district heating.
Engineers Ireland	Offers a one-day course dedicated to the fundamentals of district heating.
Gas Networks Ireland - Network Innovation Centre	The Innovation Centre is being used to understand the full potential of hydrogen in Ireland and ensure that the gas network is capable of safely

Policy, regulation, initiative, strategy, or paper	Purpose
	transporting and storing both blended and up to 100% hydrogen into the future.
National Hydrogen Strategy	The strategy sets out a strategic vision on the role hydrogen will play in decarbonising Ireland's energy system. By 2024, Ireland will develop a work programme for implementing this strategy.
Hydrogen certification scheme	By 2025, Ireland plans to develop a national certification scheme to provide clarity to end users as to the origin and sustainability of their hydrogen.
Ervia pre-feed CCS study	A technical feasibility study on the potential for large-scale CCS in Ireland was completed by Ervia in 2020.

The following EU policies, regulations, initiatives, strategies, and papers identified during the literature search are shown in Table 39 below.

Table 39: A list of EU policies, regulations, initiatives, strategies and papers identified during the literature search that address industrial heat decarbonisation barriers

Policy, regulation, initiative, strategy, or paper	Purpose
EU Innovation Fund	The fund is used to demonstrate innovative low carbon technologies by awarding capital grants. The support lasts from 2021-2030 and covers electrification, hydrogen, CCUS, bioenergy, and food waste treatment (i.e., waste to biogas).
Connecting Europe Facility (CEF)	Provides financial support to projects through innovative financial instruments such as guarantees and project bonds. The fundings end in 2027 and has a particular focus on energy infrastructure projects that contribute to decarbonisation (e.g., CO_2 networks, gas storage, and the electricity sector).
InvestEU Fund	The fund provides financial support primarily through a mechanism known as an EU guarantee (expected to mobilise more than €372B of public and private investment). This programme is focussed on developing sustainable infrastructure.
EU Emissions Trading Scheme (EU ETS)	The scheme operates on a 'cap and trade' basis, setting a limit on total greenhouse gas emissions from covered installations. This cap decreases annually in line with EU climate targets. Emissions are measured in allowances, with one allowance equating to one tonne of CO_2eq. Companies must surrender enough allowances each year to cover their emissions or face fines. Companies primarily buy allowances on the EU carbon market, but also receive some for free. They can trade allowances and, if they reduce emissions, keep spare allowances for future use or sell them.
Carbon border adjustment mechanism (CBAM)	A tax on importing certain carbon-intensive products from outside the EU into the EU (e.g., cement, iron and steel, aluminium, fertiliser, electricity and hydrogen).
LIFE Clean Energy Transition sub-programme	With a budget of nearly €1B over the period of 2021-2027, the programme aims at facilitating the transition towards an energy-efficient, renewable energy-based, climate-neutral and -resilient economy by funding coordination and support actions across Europe. This includes building policy frameworks, accelerating technology roll-out, attracting private finance, and supporting the development of local and regional investment projects.
Horizon Europe	The EU's key funding programme for research and innovation into new low carbon technologies, with a budget of €95.5B. The programme runs from 2021 to 2027.
The Just Transition Fund (JTF)	The JTF supports territories most affected by the transition towards climate neutrality, providing them with tailored financial support and assistance with economic diversification.
The Net Zero Industry Act	The act aims to scale up the manufacturing of clean technologies in the EU by attracting investments and simplifying the regulatory framework. The following technologies are covered: solar photovoltaic and solar thermal, electrolysers and fuel cells, onshore wind and offshore renewables, sustainable biogas/biomethane, batteries and storage, carbon capture and storage, heat pumps and geothermal energy, and grid technologies.

Policy, regulation, initiative, strategy, or paper	**Purpose**
The Corporate Sustainability Reporting Directive (CSRD)	A regulation that sets out environmental reporting requirements for companies. It requires businesses to disclose their environmental and social impacts, and how their environmental, social, and governance actions affect their business.
Long-Term Strategy to 2050	A strategic plan that aims to make the EU climate-neutral by 2050 by investing into technological solutions and encouraging Member States to develop national long-term strategies.
Green Deal Industrial Plan	Aiming to enhance the competitiveness of Europe's net-zero industry by building on four key pillars: a predictable and simplified regulatory environment, accelerated access to finance, improved skills, and open trade for resilient supply chains.
The European Research Area (ERA) Industrial Technology Roadmaps	A roadmap that provides insights on what skills will be needed by industries to prepare for the climate transition. There is a focus on research and innovation, collaboration between members states, and guidance on existing and future low carbon technologies.
The Sustainable and Efficient Energy Use in Industry Working Group	The group aims to help energy-intensive industries become less energy-, resource-, and emissions-intensive and more competitive.
Industrial Forum	This forum provides an inclusive and open mechanism for co-designing solutions with stakeholders when considering the green transition.
EU Energy System Integration Strategy	The strategy calls for application of the "energy efficiency first" principle, acceleration of the electrification of energy demand, and promotion of renewable and low carbon fuels (such as biomethane) for sectors where electrification will not be feasible or cost effective.
The Recovery and Resilience Facility (RRF)	The European Commission raises funds by borrowing on the capital markets to implement ambitious reforms and investments that make their economies and societies more sustainable, resilient, and prepared for the green and digital transitions. Those plans shall include a minimum of 37% of allocated funds related to the green transition.
Renewable Energy Directive (RED)	The RED is the legal framework for the development of clean energy across all sectors of the EU economy. The RED III directive aims for a significant boost in renewable energy use, targeting 42.5% of overall consumption by 2030 with a possibility of reaching 45%. It also sets specific goals for different sectors within member states, including industry, transportation, and buildings. RED III sets a target of 5.5% for advanced biofuels and Renewable Fuels of Non-Biological Origin (RFNBOs) in the share of renewable energy supplied to the transport sector. RFNBOs include synthetic fuels produced using renewable energy and CO_2; this is where CCUS technology can play a significant role. The RED will also facilitate the access of biomethane to the natural gas grid, extend guarantees of origin from renewable electricity to renewable gas, and make the cross-border trade of biomethane easier.
REPowerEU Fund	In light of global energy market disruptions caused by Russia's invasion of Ukraine, the fund aims to assist the EU in saving energy, generating clean energy, and diversifying its energy sources. It does so by financing projects and infrastructure related

Policy, regulation, initiative, strategy, or paper	Purpose
	to energy efficiency, electrification, hydrogen, and biogas/biomethane.
LIFE Climate Change Mitigation and Adaptation sub-programme	The programme supports projects in renewable energies and energy efficiency, providing support for pilot, demonstration, and best practice projects.
Industrial Emissions Directive (IED)	The IED is a key instrument that regulates pollutant emissions from industrial installations across the European Union. The directive incentivises the adoption of Best Available Technologies (BAT) and hence drives energy efficiency adoption within industry.
Special Report: Energy Efficiency in EU Businesses	This report offers fresh analytical insights from EU co-funded energy efficiency projects. It serves as a "lessons learned" exercise for the industry, facilitating better knowledge sharing among sites implementing energy efficiency measures.
Assessment and Communication of Relevant EU-funded Projects Supporting the Market Uptake of Energy Efficiency Measures in Industry and Services	A report that identified a number of lessons learned from the investigation of the achievements and impacts of 41 energy efficiency projects in industry and services.
Circular Biobased Europe Joint Undertaking (CBU JU)	A €2B partnership between the EU and the Bio-based Industries Consortium (BIC) which aims to accelerate the innovation process and development of bio-based innovative solutions; accelerate market deployment of the existing mature and innovative bio-based solutions; ensure a high level of environmental performance of bio-based industrial systems.
The EU Bioenergy Sustainability Report	A report that outlines the progress being made across the EU with regards to bioenergy, providing details on solid biomass supply.
European Committee for Standardisation, Technical Committee 335 (CEN/TC335)	The technical committee responsible for developing the European Norms to describe all forms of solid biofuels within Europe. It outlines standards to ensure classification and wood fuel quality assurance, along with the guarantee of low emissions.
Solid Biomass Supply for Heat and Power: Technology Brief	The International Renewable Energy Agency (IRENA) published a comprehensive report providing a detailed overview of the current state of solid biomass supply in the EU and its potential for future growth.
EU BioBec	Aims to build bridges between the bio-based industry and the education system by interlinking universities, innovation labs, and R&D centres with industrial actors and regions.
Common Agricultural Policy (CAP)	Funding under the CAP will be used to double the planned production of biomethane by 2030 in order to reduce the reliance on gas from Russia.
Waste Framework Directive (2008/98/EC)	The directive mandates EU countries to separate organic waste, providing an opportunity to expand sustainable biomethane production. It also introduces a waste hierarchy that includes energy recovery.
The Biomethane Industrial Partnership	The partnership’s objective is to support the achievement of the EU’s 2030 target of 35 bcm annual production and use of sustainable biomethane and to create the conditions for a further ramp-up of its potential by 2050.

Policy, regulation, initiative, strategy, or paper	Purpose
European Biogas Association (EBA)	An organisation committed to the expansion of sustainable biogas and biomethane production and use across Europe. The EBA focusses on promoting biogas use, advocates for biogas support via policy, and is supporting the transition to a bio-based economy.
Renewable Gas Registry (ERGAR)	A cooperation between European registries of biomethane certificates to enable cross-border trade of biomethane certificates among the member registries. The registry is recognised for administering and mass balancing volumes of renewable gases virtually distributed along the European natural gas network.
International Sustainability and Carbon Certification (ISCC)	The EU has approved voluntary schemes to verify biomethane as a renewable fuel. These schemes conduct lifecycle assessments covering production, transportation of waste feedstocks, and gas delivery. Producers meeting requirements receive proofs of sustainability, certifying their biomethane production as renewable under the ISCC.
District Heating Toolkit	The toolkit provides an overview of the technology options available to support district heating networks.
District heating and cooling in the European Union	The study provides valuable insights into the current state of district heating and cooling markets across the EU, the regulatory frameworks in place, and the potential for growth and development in this sector. The study can be used as a guide for member states in developing and implementing policies and measures to support district heating networks.
European Hydrogen Bank	With a €800M budget, the bank will facilitate private investments in hydrogen value chains. Funding will be awarded through auctions as a fixed premium per kg of verified renewable fuel of non-biological origin (RFNBO) hydrogen produced, with support lasting up to 10 years. Additionally, the bank aims to facilitate imports of green hydrogen into Europe.
The Clean Hydrogen Joint Undertaking or Clean Hydrogen Partnership	A public-private partnership supporting research and innovation activities in hydrogen technologies in Europe.
Important Projects of Common European Interest (IPCEIs)	IPCEIs are cross-border, cutting-edge innovation and infrastructure projects that aim to bring together the public and private sectors. They are designed to overcome major or systemic market failures in strategic value chains. There is particular focus on developing important technological breakthroughs for hydrogen generation technologies and construction of hydrogen-related transport and storage infrastructure.
The EU Hydrogen and Gas Market Decarbonisation Package	The package proposes policy measures to support the development of dedicated hydrogen infrastructure and efficient markets. This includes repurposing natural gas pipelines, establishing a European Network of Network Operators for Hydrogen to facilitate cross-border trade, creating legislation for an EU hydrogen market, and strengthening hydrogen supply resilience and security.
European Clean Hydrogen Alliance	An investment agenda which brings together industry, national and local authorities, civil society, and others to achieve an ambitious deployment of hydrogen technologies.

Policy, regulation, initiative, strategy, or paper	Purpose
The EU Hydrogen Strategy	Sets out an investment agenda for the EU, has designed a framework for hydrogen infrastructure and market rules, and is promoting research and innovation in hydrogen technologies.
Hydrogen Public Funding Compass	An online guide for stakeholders to identify public funding sources for hydrogen projects.
Trans-European Networks for Energy (TEN-E)	TEN-E links EU energy infrastructure by backing Projects of Common Interest (PCIs). This includes developing hydrogen interconnections in Western Europe (HI West) and cross-border CO_2 networks. The CO_2 networks involve transport and storage infrastructure between EU states and neighbouring countries. Eligible infrastructure includes pipelines, storage facilities, and fixed liquefaction and buffer storage facilities.
The European Strategic Energy Technology (SET) Plan	The plan aims to accelerate Europe's transition to a climate-neutral energy system by rapidly developing low-carbon technologies. It fosters collaboration between EU countries, companies, and research institutions, coordinating national research efforts to develop affordable low-carbon energy technologies. This is achieved by aligning national research programs with the SET Plan's agenda and promoting joint efforts across EU and associated countries. The SET Plan consists of 10 actions for research and innovation, including "renewable fuels and bioenergy" and "CCS".
The Industrial Carbon Management Strategy	The strategy seeks to develop a range of carbon management technologies, as well as the associated regulatory and investment framework. Industrial carbon management involves the use of a range of technologies to capture, transport, use and store CO_2 emissions from industrial facilities across the EU. The three main critical pathways being CCS, CCU, and removal of CO_2 from the atmosphere.
CCS Directive 2009/31/EC on the geological storage of CO_2	Establishes a legal framework for environmentally safe geological CO_2 storage in the EU, covering the entire lifetime of storage sites. It includes provisions for capture and transport.
Proposal for EU-wide voluntary framework to certify carbon removals (COM/2022/672)	The first EU-wide voluntary framework certifying high-quality carbon removals to boost innovative technologies and sustainable carbon farming, aiding EU climate goals. The proposed regulation enhances the EU's ability to quantify, monitor, and verify carbon removals. It establishes rules for independent verification and recognises certification schemes ensuring transparency and credibility.
CCUS Forum and Working Groups	Established in 2021, the groups meet annually, bringing together representatives from EU institutions, EU and third countries, NGOs, business leaders and academia to facilitate the deployment of CCUS technologies.

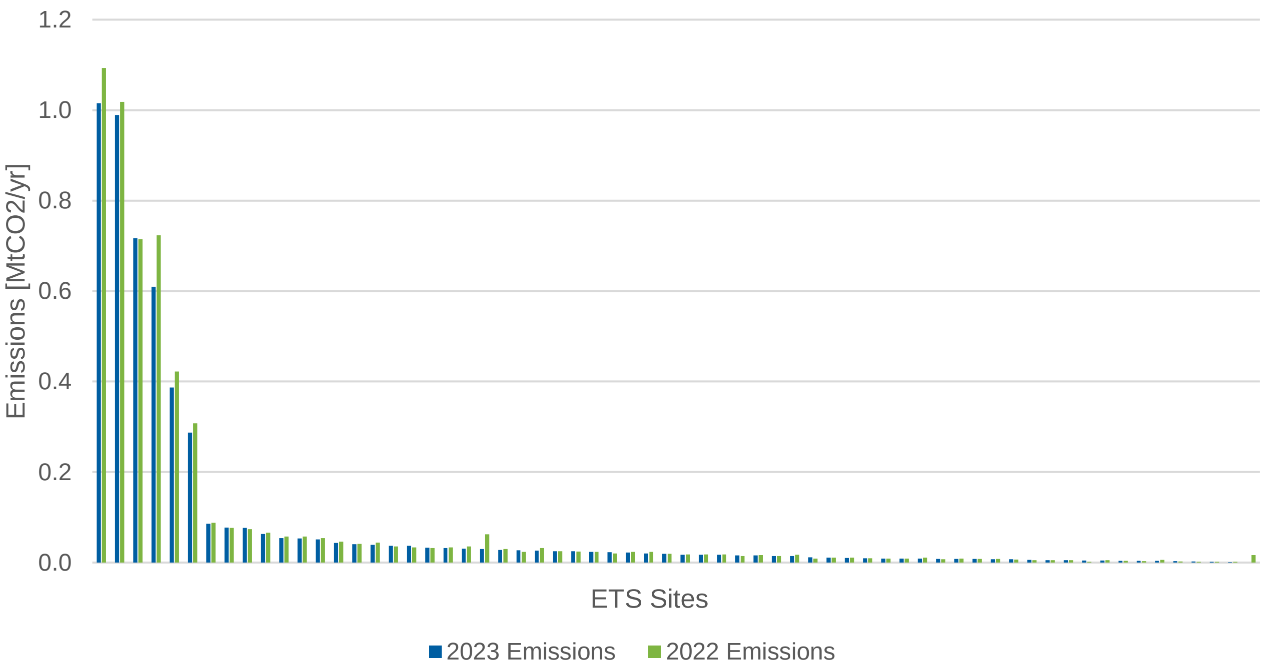
Appendix D: Updated graphics for EU ETS 2023 data

In November 2023, The Climate Change Advisory Council commissioned Ricardo to conduct a short desk-based review of industrial heating in Ireland, including Ireland's progress against the NCAP23 targets. At the time of this study, heat demand calculations were performed using several publicly available data sets for the year 2022, including SEAI's National Energy Balance for Ireland and EU ETS data. A full list of data sets with respective years is listed below.

- The 2020 data set from SEAI Heating and Cooling in Ireland Today report included within the appendix[107], and
- The 2022 European Union Emissions Trading Scheme Data [108], and
- The 2022 SEAI National Energy Balance for Ireland[109], and
- The 2022 SEAI National Energy Balance energy conversion and emissions factors[110] for each fuel type, and
- The SEAI's data set detailing fuel consumption of cement, lime and refining sites in Ireland for 2019 (private data set not available for publishing)

After the completion of this draft report, 2023 data for the EU ETS was released, with a summary of findings outlined in this Appendix. Figure 19 and Figure 20 illustrate the reported EU ETS emissions for Ireland in 2022 and 2023 respectively.

Figure 19: ETS Site Emissions for 2022 and 2023[10]



[107] Sustainable Energy Authority of Ireland [SEAI] (2022), National Heat Study – Heating and Cooling in Ireland Today, https://www.seai.ie/data-and-insights/national-heat-study/heating-and-cooling-in-ir/

[108] European Commission (2024), Union Registry Documents (Verified Emissions for 2022), https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/union-registry_en

[109] Sustainable Energy Authority of Ireland [SEAI] (2022), 2022 National Energy Balance, https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/

[110] Sustainable Energy Authority of Ireland [SEAI] (2022), Energy conversion and emissions factors 2022, https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/

Figure 20: Top 10 Industrial Sites by Emissions for 2022 and 2023[10]

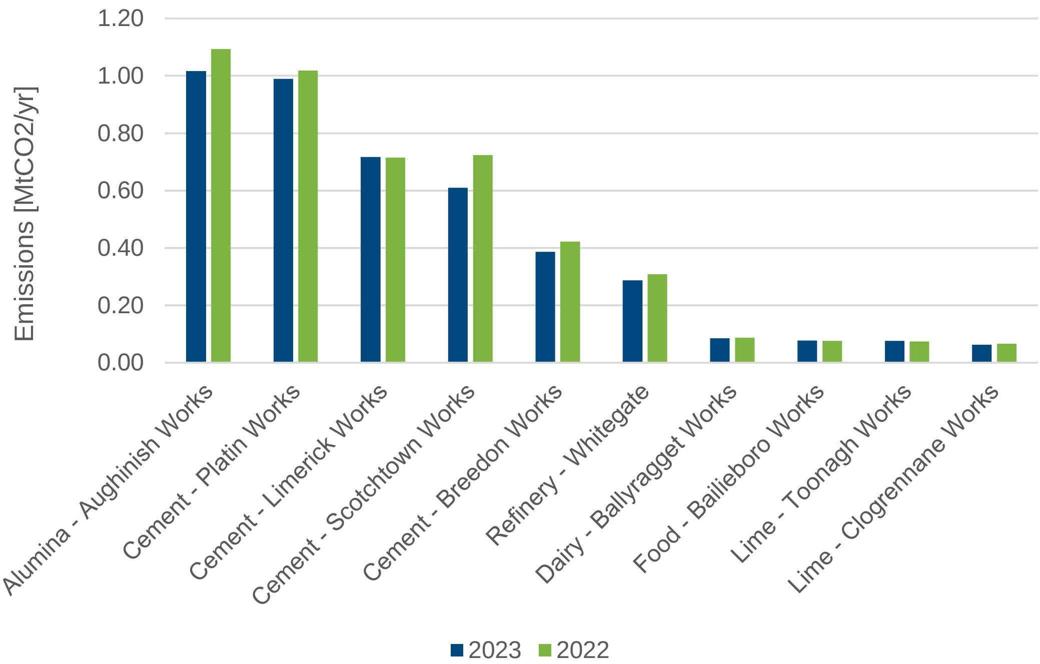


Figure 19 illustrates the reported EU ETS emissions, with total emissions reducing by 6% from 2022 to 2023. The ten largest emitters under the EU ETS remained constant between 2022 and 2023, as presented in Figure 20. The largest emitter is Rusal Aughinish alumina refinery, producing 1.02 $MtCO_{2eq}$ of emissions, a 7% reduction from 2022. Cement production follows, accounting for the next four largest emitting sites which totals 2.70 $MtCO_{2eq}$, down 6% from 2022 The cement sites include Irish Cement (Platin & Limerick) plants, as well as the Scotchtown and Breedon cement plants. Irving Oil's Whitegate oil refinery remains to be the sixth largest emitter, accounting for 0.29 $MtCO_{2eq}$, a 7% reduction in emissions.[111] The next two sites belong to the food and beverage sector, with emissions remaining relatively constant at 0.16 $MtCO_{2eq}$ of emissions. Notably, the largest

[111] European Union Emissions Trading Scheme Database Phase IV 'Verified Emissions for 2022',: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/union-registry_en, last accessed 10th Jan 24

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