Waste Heat Recovery: An introductory guide

This guide has been produced by Ove Arup & Partners Limited, commissioned by Scottish Enterprise in partnership with the Scottish Government.

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Scottish Enterprise

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Riaghaltas na h-Alba

Waste Heat Recovery

An introductory guide

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Ove Arup & Partners Limited

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ARUP

Contents

Appendices

Glossary

Ambient heat recovery	The process of collecting heat from the surrounding environment – typically held in the air, water bodies and the ground, and reusing it in other applications.
Borehole	A deep hole drilled into the ground (typically tens of metres, or kilometres for specialist uses), used to extract heat from underground (directly from the ground or ground water) and used typically by ground source heat pumps to provide heating, cooling, and hot water.
Carbon intensity	Refers to how many grams of carbon dioxide (CO_2) are released to produce a kilowatt hour (kWh) of electricity.
Combined heat and power (CHP)	The process of capturing and using heat that is a by-product of generating electricity, often in specialist combined heat and power engines that are typically powered via natural gas.
CO_2	Carbon dioxide is an important heat-trapping gas, also known as a greenhouse gas. It is produced during the extraction and burning of fossil fuels (such as coal, oil, and natural gas).
Consumer	The party which purchases the heat for their own use.
Curing	A process used for hardening polymers. The curing process can involve the use of heat, ultraviolet radiation, and chemical additives.
Distillation	A process of separating, concentrating, or purifying a liquid by condensing the boiling vapour.
District heat network (DHN) operator	The organisation that manages the operation of a DHN (see also 'Heat Network').
Economiser	A type of heat exchanger used to recover heat from the exhaust gases of boilers or other heat sources. The recovered heat can be used to pre-heat streams of air or water.
Edge computing	An approach that brings computers closer to the servers storing the data the computers are using. The intention is to make computational processes faster.
Efficiency	A measure of a technology's ability to convert one type of energy into another. For example, a gas boiler's ability to convert energy stored in natural gas to useful heat.
Effluent	Liquid waste discharged typically from a sewage system or an industrial process.

Electrolysis	The process of using electricity to split water into hydrogen and oxygen.
Energy centre	Typically, a building that houses heat generation and sometimes power generation equipment, with the heat and power fed into a heat network or the local power grid respectively.
Energy from waste	The process of generating electricity or heat from the treatment or processing of waste.
Feedstock	Raw material that is fed into an industrial process.
Flue	A duct that leads from a furnace, oven, or fireplace through which exhaust gases flow.
Fuel cell	A device that converts a fuel and oxidant, such as hydrogen and oxygen, into electricity directly (i.e. without combustion).
Geothermal energy	Energy stored in the ground in the form of heat. Temperature, quantity and accessibility of heat vary as a function of factors such as depth and geology.
Green hydrogen	Hydrogen produced by splitting water into hydrogen and oxygen using an electrolyser and renewable electricity.
Heat exchanger	A device which transfers heat between two fluids (liquids or gases) at different temperatures as part of heating and cooling processes.
Heat network	In this document 'heat network' is used to refer to a: District heat network – a network by which thermal energy is distributed from one or more sources of production to more than one building Communal heating system – a system by which thermal energy is distributed from one or more sources of production to one building comprising more than one building unit.
Heat pump	A device that extracts heat from an ambient heat source, raises its temperature using mechanical energy, and transfers the heat typically into a heating system. Ground source heat pumps (GSHP) extract heat from the ground, air source (ASHP) generally from ambient air, and water source (WSHP) from water bodies such as rivers, estuaries, and the sea. Heat pumps range in scale from small domestic units providing heating for individual homes to much larger units serving heat networks. Heat pumps can also be used to provide cooling, not just heating.
LHEES	Local Heat and Energy Efficiency Strategy (LHEES) set out the long-term plan for decarbonising heat in buildings

	and improving their energy efficiency across an entire local authority area in Scotland.
Linear heat density	A means of relating annual heat demand to a distance and is expressed as annual heat demand per meter of pipe
Medium	A substance that carries or through which heat (and other types of energy, such as sound) can pass. For example, water is often the medium used to convey heat through a heat network.
Offtaker	The party which purchases the heat from the waste heat producer. This can be the consumer of the heat or an intermediary party who may purchase heat for resale, typically within a heat network.
Refrigerant	A liquid used in heat pumps and heat exchangers that facilitates heat transfer.
Refrigeration	The process of cooling or freezing substances such as foods or process liquids and maintaining them at a temperature below ambient temperature.
Retrofit	Typically used in this context to describe the addition of new technology or features to existing systems and buildings – for example, this may mean upgrading insulation, lighting, windows, and heating systems to improve energy efficiency and reduce carbon emissions.
Sewage	Waste liquids and solids which are carried away for treatment via drains and sewers.
Wastewater	Any water which has been used, either domestically or industrially, and now requires water treatment before reuse or discharge.
Waste heat producer	Used in this document to refer to an organisation with processes producing heat that would otherwise be wasted without the implementation of waste heat recovery methods.
Waste heat recovery	The process of collecting heat, typically from industrial processes and from sources such as exhaust gases, effluent and hot air, and reusing it in other applications.

Units

kW	Kilowatt – unit of power, equivalent to 1000 Watts.
kWh	Kilowatt hour(s) - a standard measure of electrical energy equal to the power consumption of 1 kW for one hour.
MW	Megawatt - unit of power, equivalent to 10^6 Watts.
MWh	Megawatt hour(s) - a measure of electrical energy equal to the power consumption of 1 MW (1,000 kW) for one hour.
GW	Gigawatt – unit of power, equivalent to 10^9 Watts.
GWh	Gigawatt hour(s) - a measure of electrical energy equal to the power consumption of 1 GW (1,000,000 kW) for one hour.
TW	Terawatt – unit of power, equivalent to 10^{12} Watts.
TWh	Terawatt hour(s) - a measure of electrical energy equal to the power consumption of 1 TW (1,000,000,000 kW) for one hour.

1. Introduction

1.1 Aims of this guide

The UK and Scotland is transitioning to a low carbon energy system. This will require making better use of the energy we have.

The aim of this guide is to provide information about heat that is being wasted or not used to its full potential and how to capture it and use it. This includes facilitating better communication and understanding between relevant parties interested in providing and using waste heat. Ultimately, this is to encourage reuse, thus reducing energy consumption and carbon emissions whilst also possibly delivering commercial benefits.

The guidance is directed at non-technical specialists. The goal is to develop knowledge that will enable them to engage with third parties, such as waste heat producers and heat network operators, on the topic of waste heat. This engagement should ascertain if organisations have any initial, high level interest in offering their waste heat and identify potential options for its use.

1.2 Context

1.2.1 What is waste heat recovery?

Waste heat recovery is a process of capturing and utilising heat from industrial and commercial processes, or similar activities, which may otherwise be lost. The recovered heat can be used in a range of applications, including heat networks.

1.2.2 Drivers for providing guidance now

There are several drivers for making better use of waste heat in Scotland:

- Scotland's local authorities are in the process of completing their Local Heat and Energy Efficiency Strategies (LHEES), which are fifteen-to-twenty-year strategies for decarbonising heat across each authority's area[1].
- The 2021 Heat Networks Act (Scotland) gives powers to local authorities to designate heat network zones and sets statutory targets for heat to be supplied by heat networks – 2.6 TWh by 2027, 6 TWh by 2030 and 7TWh by 2035[2].
- The Scottish Government is supporting a growing pipeline of heat network projects with £300 million of capital funding available through Scotland's Heat Network Fund to accelerate deployment[3].
- Previous research by ClimateXChange for the Scottish Government identified over 900 sites in Scotland producing waste heat, totalling 1.7 TWh that could potentially be reused[4].

The combination of national heat network targets and investment, the number of sources and scale of waste heat potentially available, and the work being done by local authorities to identify indicative Heat Network Zones (HNZ), collectively make a strong case for investigating opportunities for linking waste heat with heat networks more systematically.

Historically, heat networks have been largely unregulated compared to gas and electricity, but things are changing. The Heat Networks (Scotland) Act 2021 was the first legislation implemented in the UK in support of the heat networks sector[5]. The Act is anticipated to create the stability needed to unlock the potential of heat networks in Scotland, enabling the sector to grow at pace and make a valuable contribution to the energy transition and Net Zero. The Scottish Government is working with the UK Government and Ofgem to ensure that regulations, such as those regarding consumer protection and technical standards, are interoperable.

At regional scale, the creation of LHEES is enabling local authorities to identify opportunities for potential heat network zones. Although formally designating heat networks zones falls beyond the scope of LHEES, the powers for heat network zoning came into force in May 2023 and further proposals for Scottish legislation are being phased in to ensure a seamless experience for heat network operators and offtakers [6,7].

At local and building scale, heat networks are a critical component of Scotland's Heat in Buildings Strategy[8]. This requires, for example, non-domestic, publicly owned buildings with a heat demand equal to or greater than 73 MWh/year to produce a Building Assessment Report (BAR). A BAR contains information on the heat supply and demand of the building and assesses its suitability to connect to a heat network. This is important because it provides key information about the feasibility of a heat network in a potential heat network zone.

1.2.3 Origins of the guidance

The need for this guidance document was identified by the 'Waste Heat from Industry' Steering Group, which was established by Scottish Enterprise and comprises:

- The Scottish Government (SG)
- Scottish Environment Protection Agency (SEPA)
- Zero Waste Scotland (ZWS)
- Scottish Futures Trust (SFT)
- Glasgow City Council (GCC)
- Fife Council (FC)

2. Scope of the guidance

This non-technical guidance document provides an introduction to waste heat for those seeking to investigate opportunities for waste heat recovery, but who may not be technical or commercial experts. Although the focus of the guidance is on waste heat, it also briefly touches on heat from ambient sources (particularly mine water) where the defining line between waste and ambient heat can be blurred.

This main body of the guide is in three main sections and is supported with more detail in the appendices:

- **Technical characteristics:** an introduction to the technical aspects of waste and ambient heat recovery. This covers classifying grades of heat, different use scenarios, common opportunities and challenges, industrial sector summaries and various heat recovery technologies available.
- **Commercial considerations:** an overview of heat recovery arrangements, what financial assistance is available, and common heat procurement and heat tariff development methods.
- **Next steps:** a brief guide describing the typical project lifecycle and what data is required to enable these projects. Signposts and resources are included to guide potential waste heat producers towards further sources of support.
- **Appendices:**
    - **A -** a comparison of waste heat recovery technologies.
    - **B -** an overview of the potential of waste heat in various industrial sectors.
    - **C -** a section of frequently asked questions with short responses.

3. Technical Characteristics

This section describes the main technical aspects of waste heat recovery and touches briefly on ambient heat. Topics covered are:

- Temperature ratings and grades of waste heat
- Ambient heat – sources and recovery
- Waste heat sources in various sectors
- Mine water geothermal
- Opportunities and challenges
- Options for reusing waste heat
- Heat recovery technologies

3.1 Temperature ratings and grades of waste heat

The most appropriate method of recovering waste heat from an industrial or commercial process will depend largely on the medium (gas or fluid) of the heat and its temperature. Heat emitted from industrial processes and other sources can be categorised or graded broadly as:

- **High-grade heat:** refers to heat **above 400°C.** This is heat typically lost from processes where a fuel is burnt and there is a reliance on high temperatures to catalyse chemical reactions, such as the production of cement. In most of these industries, generally as much heat as possible is recovered for re-use in the process.
- **Medium-grade heat:** heat **between 100 and 400°C**. For example, heat in flue gases emitted from an industrial gas boiler.
- **Low-grade heat:** refers to heat **less than 100°C**. Usually the temperatures are too low for heat to be used directly in industrial processes. It may still be useful, however, for space and water heating in domestic and commercial buildings or to increase the efficiency of some industrial processes. Low-grade heat can also be used as a source for heat pumps, which raise the temperature of the heat to a more suitable temperature, depending on the need. Low-grade industrial heat can also be captured from water used in cooling industrial processes.

3.1.1 Ambient heat – sources and recovery

Ambient heat is held within the air, ground, or water bodies such as rivers and the sea, and it generally originates from solar energy. Ambient heat presents sources of low-grade renewable heat that can be used, typically by heat pumps, to create higher temperature heat.

It is important to recognise the importance of ambient heat, as some applications, such as future heat networks, may rely on multiple sources of heat, including waste and ambient heat. An example is the Queens Quay development in

Dumbarton which is served by a flagship district heat network that uses water source heat pumps to boost the temperature of ambient heat from the Clyde.

Another source of heat that is gaining interest across the UK is mine water. For more information on this, please refer to section 3.3.

3.2 Waste heat from sectors and services

Heat is created and often lost or wasted from a range of sectors and services. This waste heat varies in temperature (or grade – see above) and the medium in which it is conveyed. Sectors and sources and corresponding mediums and grades of heat are summarised in Table 1 below, and further detail is provided in Appendix B.

Table 1: Waste heat categorised by sector or source, medium and grade

Sector or source	Typical medium	Heat source grade
Manufacturing		
Cement production	Flue gas	Medium / high
Paper & pulp manufacturing	Water	Medium
Food & drink manufacturing	Water	Low / medium
Distilleries	Flue gas	Low / medium
Chemical manufacturing	Water	Low
Services		
Energy from waste	Flue gas	High
Industrial laundries	Flue gas	Low / medium
Electrical substations	Oil	Low
Wastewater treatment	Water / sewage	Low
Other		
Hydrogen electrolysers	Air / liquid	Low
Hydrogen fuel cells	Air / liquid	Low
Supermarkets	Water	Low
Data centres & edge computing	Water	Low
Mine water	Water	Low

3.3 Mine water geothermal

Unused, flooded, mine shafts can be used as a heat source. Over time, abandoned mines have filled with water which is constantly warmed by surrounding rocks. Temperatures range from 10 to 20°C and can reach 40°C at depths of around 1 km[9].

Scotland's Midland Valley is thought to have 600 km^3 of abandoned mines. Recorded mine water temperatures for boreholes in the Midland Valley generally range from 12 to 21°C, averaging at 17°C[10]. This may not accurately reflect higher temperatures that could occur in some of the deepest mine workings.

Currently, the two main methods to access mine water are:

1. Drilling boreholes, for which a permit is required from the Coal Authority, together with planning and SEPA permission. This is known as a 'stand-alone' scheme[11].

2. Via a Coal Authority mine water treatment scheme, at which water is brought to the surface and treated to remove impurities to protect drinking water and the environment. Where there is sufficient heat, the Coal Authority can provide access to this water for supply to a heat network. Permits are required from the Coal Authority and SEPA. This is known as a 'bolt-on' scheme.

There are two types of systems for using mine water heat:

1. **Closed loop groundwater geothermal systems** – which work by circulating a fluid around a closed pipe system, with a significant part of the pipe circuit located in a series of boreholes underground to absorb heat from the ground and groundwater and connected to a heat pump in an energy centre or in the building(s) to be heated or cooled.
2. **Open loop geothermal systems** - involve abstracting groundwater, which is used in a heat pump, and then the abstracted water is injected back into the ground.

The British Geological Survey's Glasgow Observatory is a research facility designed for investigating shallow, low-temperature, mine water heat energy and potential heat storage resources. The observatory enables research into the questions that remain about this heat source, from size and sustainability to environmental impacts[12].

Heat from mine water contained in mine workings 150 m beneath the surface is being used to supply a heat network in Gateshead in the northeast of England. A water source heat pump recovers heat and distributes it through a 5 km long heat network. Currently this network supplies heat to 350 homes and various local buildings. This project is estimated to save 72,000 tonnes of CO_2 over 40 years[13].

3.4 Waste heat recovery - opportunities and challenges

Every sector brings unique opportunities and challenges regarding waste heat recovery from the perspectives of recovering and reusing it.

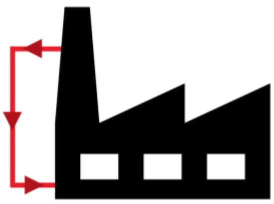
There are common factors, however, which broadly apply across all sectors, some of which are set out in Table 2, below.

Table 2: Cross-sector opportunities and challenges for waste heat

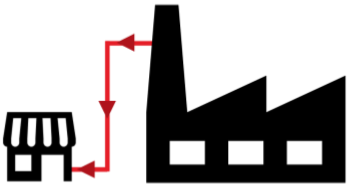
Opportunities	Challenges
• Can improve energy efficiency of the process or plant. • Can reduce future heating costs. • Can avoid costs to dispose of waste heat, e.g. cooling towers. • Has potential to displace carbon intensive energy generation. • Could mitigate the impact of future energy price increases and facilitate stable energy prices. • Can generate an additional revenue stream.	• Payback periods can vary greatly. • Potential disruption caused by installation of equipment. • The ongoing operation and maintenance of equipment. • Can be difficult to guarantee security of supply. • There needs to be sufficient demand for heat to warrant the recovery. • Ensuring heat recovery does not fundamentally alter core operations.

3.5 Options for reusing waste heat

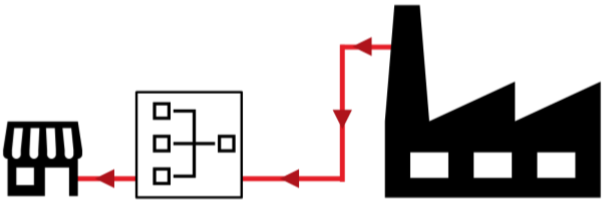
Once a source of waste heat has been identified, it is important to identify an appropriate use or local demand for the heat. There may be multiple alternatives for its use, and each one should be assessed against key criteria before selecting the most appropriate option. This could include one or a combination of the options summarised below.



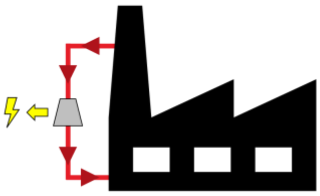
Reuse waste heat in-house: often the most viable option as it is usually the least complex and the loss of heat in distributing it can be minimised. This process is already seen in many energy intensive industries - for example, whisky distilleries recovering heat from hot water to pre-heat other stages of the distilling process. Typically, low-grade heat in industrial processes can only be used in some pre-heating processes or as input to other plant, such as industrial heat pumps[14].



Distribute waste heat to nearby consumers: selling waste heat directly to nearby heat consumers (e.g. swimming pools, residential developments etc.), without the need for a heat network. This can provide an additional source of income. Depending on the source, this can support decarbonisation plans and build a positive relationship with local communities.



Distribute waste heat to a nearby district heat network (DHN): heat is sold to a DHN operator, providing an additional income to the waste heat producer. The DHN operator then distributes this heat to consumers via a pipe network. This option has the advantage of being able to reach consumers further away from the source of waste heat, and may reduce costs for the DHN operator, potentially enabling it to provide heat at lower cost to consumers.



Waste heat used to generate electricity: if the temperature of the heat is sufficiently high, electricity generation may be possible by installing a steam turbine (or similar) to drive a generator. This electricity could be used inhouse or exported. Technologies which enable this are described in Section 3.7.

3.6 Technologies to recover waste heat for reuse

Heat recovery devices can be split into three main categories:

1. Heat recovery for reuse as heat – either in-house to pre-heat processes for example, or for exporting into a heat network
2. Heat recovery for electricity generation - for use on-site or for export to another site or to the grid.
3. Heat recovery and upgrade the temperature for use in a wider range of applications.

3.6.1 Heat exchangers

Heat exchangers are devices that enable the transfer of heat between two fluid mediums (i.e. liquids, air, or gases). Each fluid will be at a different temperature and in a different flow path to avoid mixing, resulting in a transfer of heat from the higher temperature fluid to the lower temperature fluid across a separating wall. The flow paths can be parallel, counterflow or crossflow[15]. Figure 1 shows a typical parallel flow arrangement.

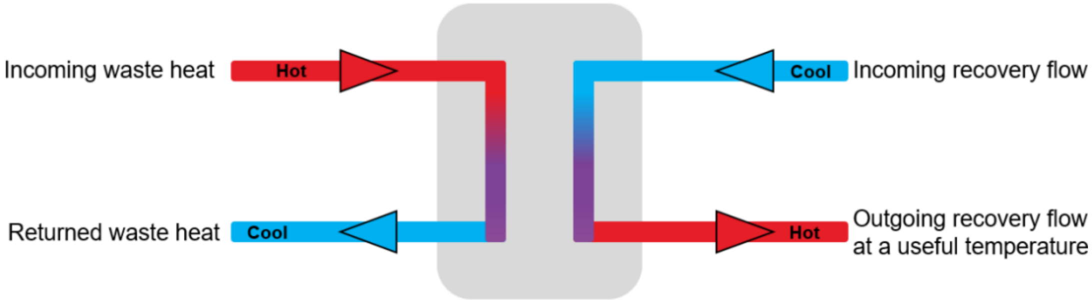


Figure 1: Typical heat exchanger - parallel flow

There are different types of heat exchangers, which vary primarily depending on their physical arrangement. Common types are described in Table 3 below.

Table 3: Common types of heat exchangers

Heat exchanger type	Description	Usual application and/or features
Plate	A series of thin plates with narrow spaces between them. The two fluids flow through alternate spaces, creating a transfer of heat between them via conduction through the plates.	• Compact design • Modular design and easy to scale[16]
Shell and tube	An array of tubes carrying a fluid are housed in an outer shell, creating a volume around the tubes which is filled with another fluid. The transfer of heat occurs between the fluids in the tubes and shell volume respectively.	• Most common heat exchanger type • Suitable for dirty fluids • Suitable for high pressures and temperatures[16]
Double pipe	Two concentric pipes, with a fluid in each, are used to transfer heat from one fluid to another. These are usually in a U-bend type design[16].	• Suitable for high pressures and temperatures[16]

Heat exchangers are commonly used to capture and reuse low or medium grades of heat, and depending on the medium and grade of heat, they can be used in either primary or secondary systems:

- **Primary systems** – where a heat exchanger is used to transfer heat from the waste heat medium directly into the main medium for onward transmission and use.
- **Secondary systems** – where heat is recovered from the waste heat medium into a transfer fluid (such as water or oil) which then flows into a secondary heat exchanger to heat the main medium for use.

Some other commonly used devices which perform the duties of a heat exchanger are described briefly below.

3.6.2 Waste heat recovery boilers

A waste heat recovery boiler works much like a gas boiler. The key difference is that waste process heat rather than gas is used to heat a useful medium, typically water, which is moved and then usually evaporated for use in a different industrial process or for providing space heating or hot water generation.

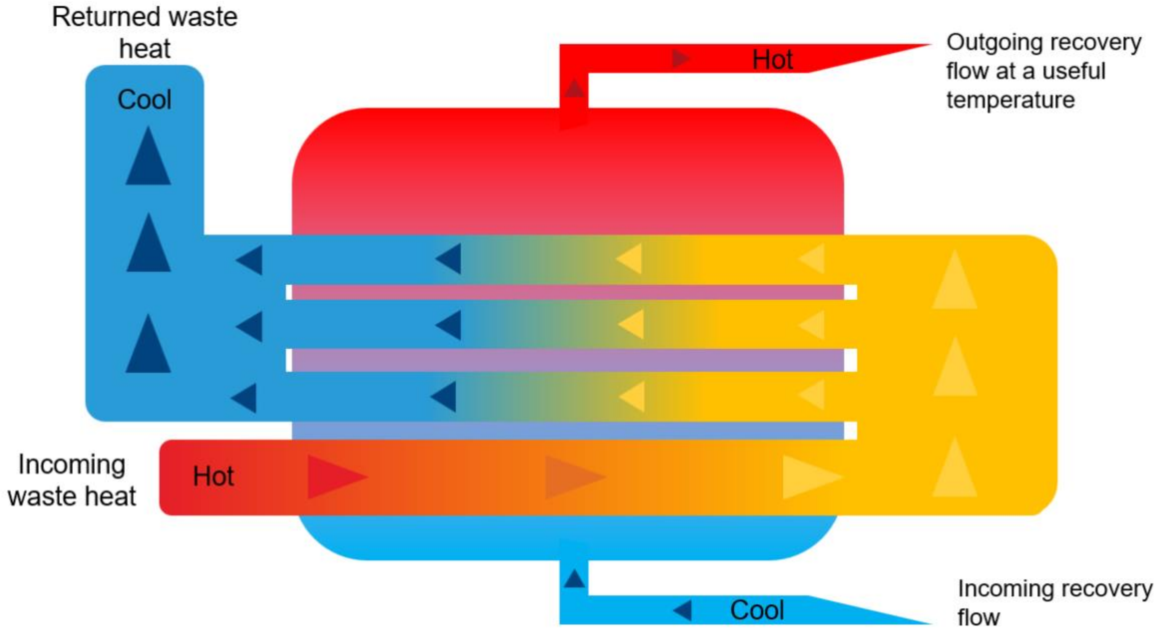


Figure 2: Typical waste heat recovery boiler

3.6.3 Economisers

Economisers are like waste heat recovery boilers, although they serve different purposes. They are used to enhance the efficiency of various processes by preheating plant feedwater, which is used to generate a more useful product (typically steam).

The heat used in economisers is typically low-grade, although this is still sufficient to boost the efficiency of other plant. Using an economiser, for example, could result in feedwater entering a boiler at 50°C rather than 15°C.

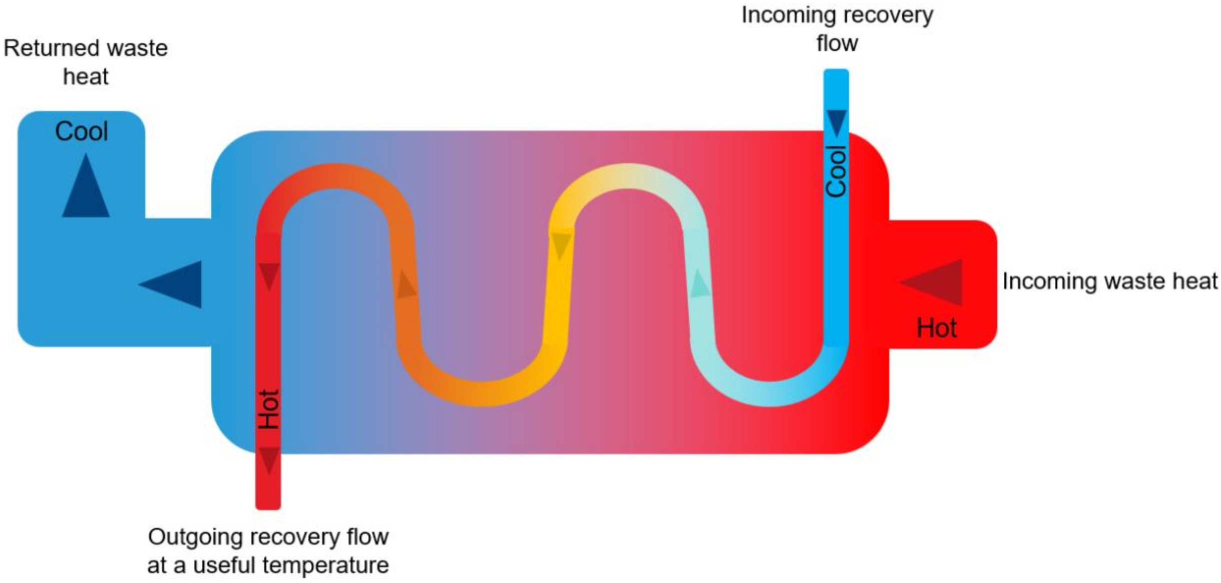


Figure 3: Typical economiser

3.6.4 Absorption chillers

Absorption chillers use waste heat to produce cooling services (typically in the form of chilled water), rather than heat. They are well suited to industries that generate substantial volumes of waste heat but also require cooling.

Waste heat is used to evaporate and separate a water-lithium bromide mix. The water then condenses through a cooling tower and is fed into a different evaporator. A lithium bromide spray system then creates an attraction between the lithium bromide and water. This creates a vacuum which lowers pressure and causes the water to evaporate. This cools the water, which can then be used for cooling purposes.

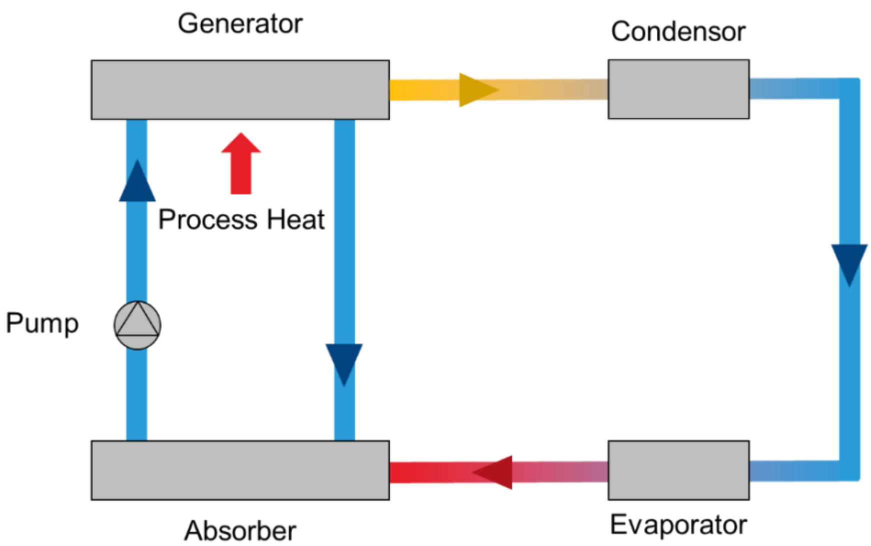


Figure 4: Typical working cycle for an absorption chiller

Lithium-bromide is the most used mixing agent for the working fluid. Ammonia-water mixes are also suitable but are less common due to lower performance and safety concerns.

3.7 Technologies that recover heat for electricity generation

3.7.1 Direct steam to electricity systems - Steam Rankine Cycle (SRC)

This is the most common method of generating electricity from waste heat. A medium grade waste heat source is required (typically high temperature flue gases from a combustion process) and is passed through a heat exchanger to evaporate water into steam.

This steam is then passed through a turbine which rotates a shaft connected to an electricity generator. This process generates electricity which can be used locally or exported to other sites or the grid.

3.7.2 Direct steam to electricity systems - Organic Rankine Cycle

An Organic Rankine Cycle (ORC) system is like the SRC, but it uses an organic working fluid (e.g. methanol) rather than water. These organic fluids have a boiling point lower than that of water, creating an advantage in that the ORC can use lower grade sources of heat, with a minimum operating temperature around 80°C.

Although the ORC is not as efficient as the SRC, it can still be viable if a large volume of lower grade heat is consistently available. The simple schematic in Figure 5 is applicable to both the SRC and ORC.

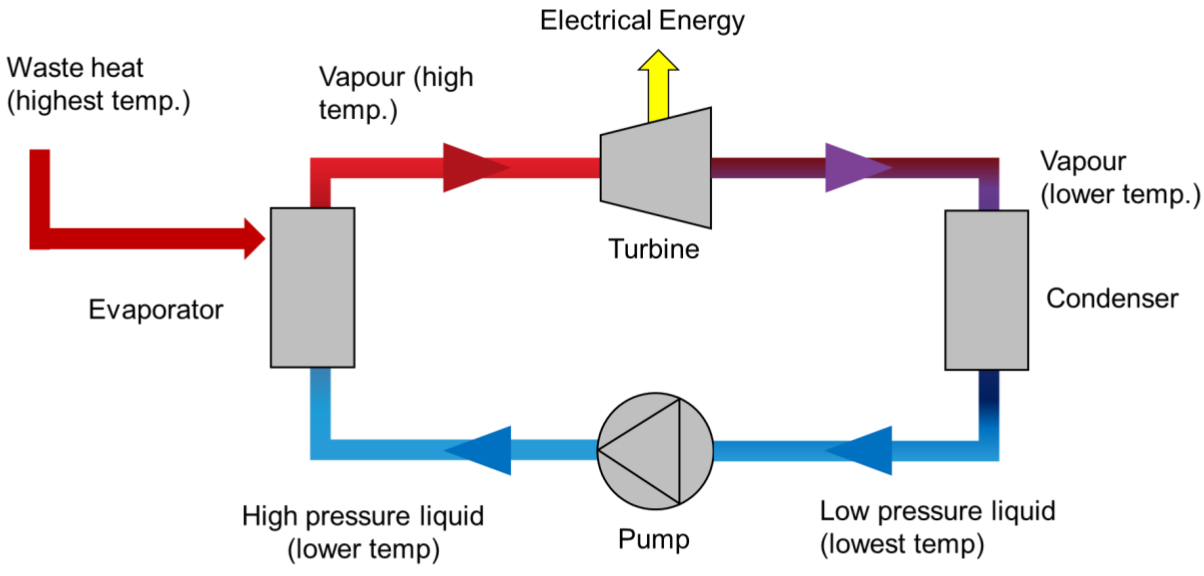


Figure 5: Typical waste heat recovery steam/ORC turbine

3.7.3 Thermoelectric generators

When a temperature difference exists between two semiconductors a voltage is generated (see Figure 6). This is the fundamental thermoelectric principle underpinning thermoelectric generators (TEG), which, unlike the devices described above, are solid state, with no moving parts.

TEGs (also known as Seebeck generators) are a flexible technology which can provide independent power at any location where waste heat can be used to create the necessary temperature difference. They have very low efficiencies, however, and are best suited to situations needing low amounts of power from a relatively maintenance free generator.

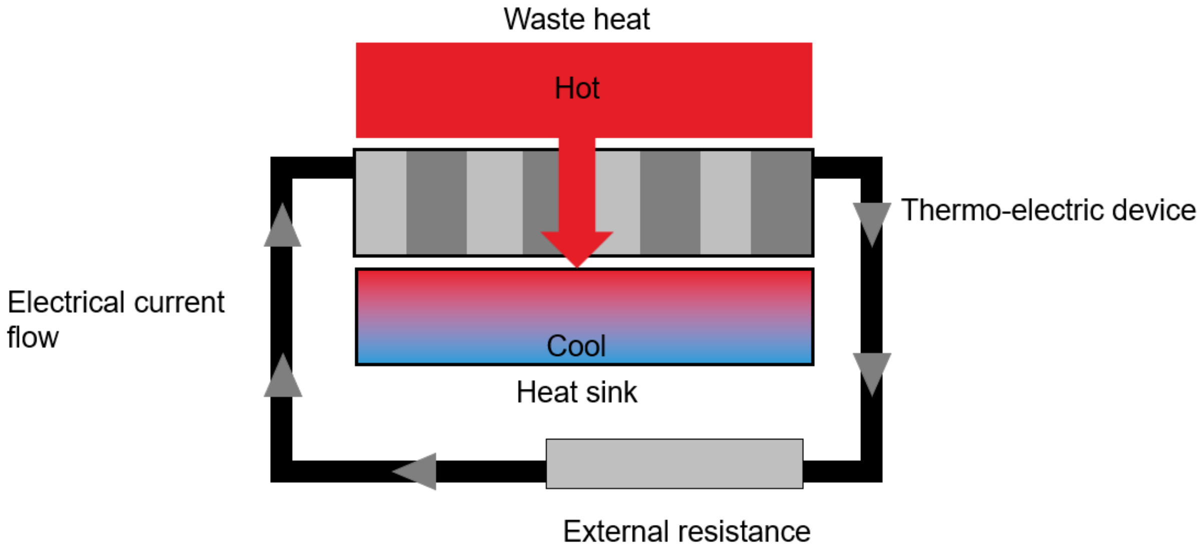


Figure 6: Simple schematic of a thermoelectric generator

3.8 Technologies to recover and raise the temperature of waste heat

There are a range of technologies or systems used to recover heat from different mediums and to raise its temperature if required, typically using heat pumps.

3.8.1 Using heat pumps to increase temperatures

In situations where heat transfer from waste or ambient heat sources does not create sufficiently high temperatures to suit the process or use for which it is intended, a heat pump can be used to boost the waste heat to higher temperatures.

As the electrification of heat expands as a major component of decarbonisation, the use of heat pumps will continue to increase. This is due to their ability to elevate waste and ambient sources to temperatures more suitable for a wider range of applications.

Heat pumps work in a way that is very similar to a domestic refrigerator. Refrigerant is evaporated using an ambient heat source and then compressed, which increases the refrigerant's temperature. This hot refrigerant transfers its heat to the medium (usually water) that will be used in another process or system. The cooled refrigerant condenses back into a liquid before expanding back into a vapour where the cycle repeats. This is shown in Figure 7 below.

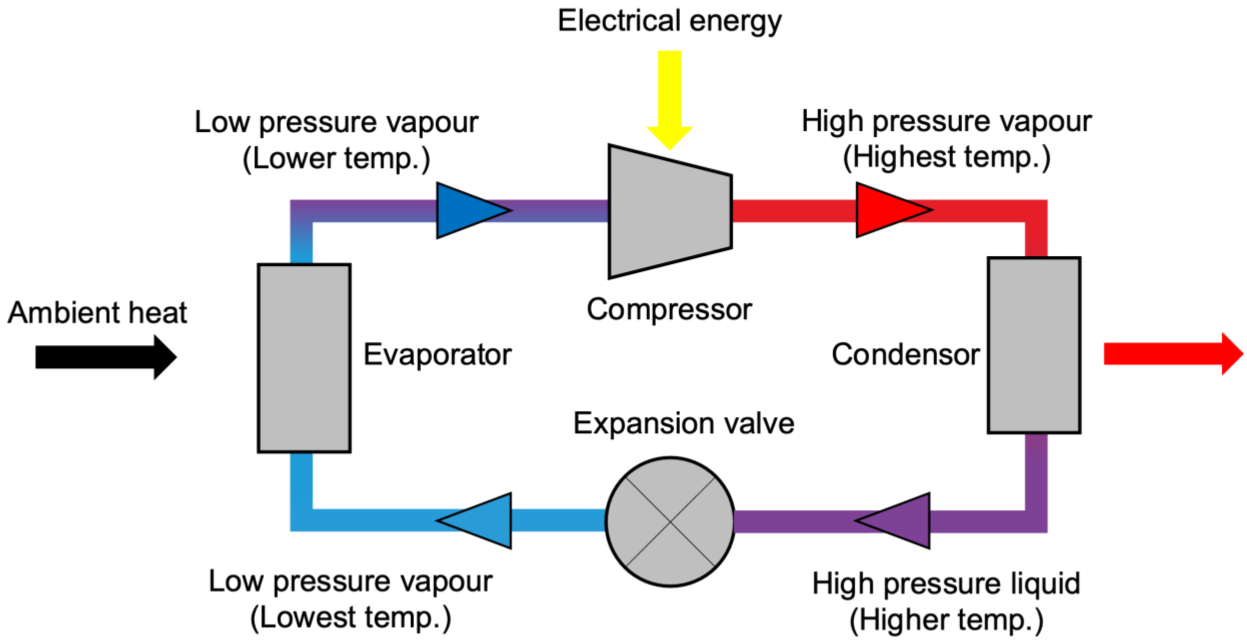


Figure 7: A typical heat pump's operation cycle

Heat pumps can be classified by the source of ambient or waste heat that is used to create useful heat. The three main types are air source heat pumps (ASHPs), ground source heat pumps (GSHPs) and water source heat pumps (WSHPs).

Whilst efficiencies of heat pumps vary as a function of factors such as the temperatures of the heat source, their minimum efficiencies are generally at least twice that of using electricity directly for heating, reducing the running cost and impact on grid capacity. In other words, a heat pump uses a unit of electricity (to drive the compressor) to create two or more units of heat.

Each type of heat pump system has different infrastructure requirements, depending on the heat source being exploited. Examples of these are shown in Table 4.

Table 4: Typical heat pump efficiencies and infrastructure requirements

Heat pump type	Typical efficiency (output vs. input energy)	Infrastructure requirements
ASHP	250% to 350%	• Units need to be located externally and unobstructed to allow for large amounts of air to be drawn through and the heat extracted. • Large units can be noisy, so need to be considered carefully.
GSHPs and WSHPs	400% (GSHPs) 350% (WSHPs)	• Extensive groundwork can be required to install boreholes or pipe coils. • If water is taken direct from a source, appropriate licenses will be required, and the technical complexity of the system can increase.

4. Commercial considerations

This section provides an introduction to some of the key non-technical issues associated with waste heat recovery and potential projects that use it, including the value of the heat, contract arrangements and sources of funding.

4.1 The value of waste heat

The potential value of waste heat depends on the following factors:

1. Temperature (i.e. grade) of the heat recovered and how suitable this might be for potential users.
2. Demand for the waste heat from parties who need it, known as heat offtakers. If there is higher demand, the potential value is usually higher. This can also vary seasonally.
3. Reliability of the waste heat supply. Without reliability in the short, medium and long terms, the offtaker will have to consider back-up alternatives to cover gaps in supply. This will negatively impact the potential value of the recovered heat.
4. The distance from the waste heat provider and the potential heat offtakers. Ideally, the offtaker would be as close as possible to the waste heat source to reduce infrastructure costs and heat losses in transit.

   In general, a heat network connection is considered viable if the linear heat density (LHD) is more than 4,000 kWh/m/year, although this depends on other factors such as the marginal cost of the heat, the type of offtaker and desired return on investment. It is still worth recording heat opportunities even if LHD does not show an immediate opportunity.

There are several drivers influencing the recovery of waste heat, these include:

- Technological advancements mean methods of recovering or reusing waste heat are becoming cheaper, increasing the economic viability of projects. For example, heat pumps are becoming more efficient and cost effective. This allows previously unviable sources of low-grade heat to be utilised, with the upgraded heat being available for use in a wider range of applications.
- Advancements in technology (including the use of new operating fluids) are allowing heat pumps to produce higher output temperatures than have been previously available. This opens the door to a wider range of higher temperature applications where waste heat can be used.
- Traditional primary sources of heat are becoming more expensive, with rising/fluctuating energy prices, meaning waste heat recovery now carries a greater value, due to its lower and more stable price.
- Growing demand for district heating is backed by a strong regulatory framework in Scotland and emerging policy elsewhere in the UK. This is supporting the diversification of sources of heat that can be integrated into heat networks, therefore facilitating waste heat distribution.
- Implementation of carbon taxes or similar legislation could further increase the importance of energy efficiency and reuse of heat.
- Grid balancing is becoming increasingly important. Waste heat recovery could support this, either through reducing demand at peak times or offering back-up supply options.

4.2 Contractual agreements

Contractual agreements will govern the ownership of assets and equipment, set out roles and responsibilities for operation and maintenance, and will cover financial aspects like payment tariffs.

Commercial energy contracts can be complex and will be bespoke to the specific context in which waste heat is being recovered and used. The main themes for contractual agreements are introduced in the following sections.

4.3 Heat supply agreements

The relationship between a waste heat producer and a party receiving the heat, such as a district heat network (DHN) operator or an individual heat user would typically be governed by a Heat Supply Agreement (HSA).

The objectives set out by different parties in an HSA will vary upon their interests. These are typically linked to the physical assets they own, their role in the contractual order and their financial perspective.

There is no standardised template to facilitate contract development, and agreeing an HSA can take a significant amount of time. A key consideration for the most appropriate HSA is the management of risks associated with the supply of recovered heat. The governing principle is that risks should be allocated to the entity most adept at dealing with them. Nevertheless, this can be a complicated process which requires agreement from all involved. In allocating these risks, each party receives clarity on their rights and obligations. Key elements captured in a typical HSA are shown in Table 5.

Table 5: Typical elements of a heat supply agreement

Aspect	Description
Annual heat supply availability	The amount of heat that is agreed to be supplied annually.
Peak heat supply availability	The peak heat that is agreed to be supplied at any given time.
Planned/unplanned interruptions	Agreed approach to outages and planned shutdowns.
Heat meter repair or replacement	Agreed approach and ownership of the heat meters and all their requirements.
Key performance indicators (KPIs)	Agreed service standards and the consequences of not meeting them.
Plant and ancillary plant ownership	Agreed management of plant and associated works.
Heat tariff derivation method	Agreed method of calculating the heat value and therefore price. Note, if the heat price can vary, how this would be reviewed and calculated within a defined time should be described.
Length of contract and exit clauses	The length of the agreement with a potential option for early termination of the agreement, and what circumstances could trigger this.
Complaint procedure	Agreed upon time and procedure to respond to a complaint from either party.

4.4 Ownership and procurement

There are three main types of HSA depending on who owns the assets (i.e. heat recovery system, heat distribution network, heat pumps and energy centres):

1. **Recovery and self-supply**: self-supplying heat to meet or supplement heat demand within the generation site. This is the simplest mechanism, as one organisation typically owns all the waste heat recovery assets. An example is a whisky distillery recovering heat to reuse in its own operations.
2. **Recovery then direct supply to third parties**: often relates to a single organisation owning the heat recovery assets as well as the heat distribution network to supply the heat either to operations or buildings owned by a third party. An example is the recovery of heat from a manufacturing plant which is used by another industrial facility nearby.
3. **Recovery then supplies to a network operator**: heat recovered is sold into a heat network to be used by consumers. This is the most typical situation for recovered heat to enter a district heating network. An example is the recovered heat from supermarkets being sold to a district heat network operator.

The boundary of asset ownership can vary from system-to-system depending on factors including:

1. What heat recovery and distribution equipment will be installed and where it will be located.
2. Whether any leases or wayleaves are required to install the equipment.
3. Whether reusing waste heat will impact an organisation’s existing operation from a technical or commercial perspective.

By way of an example, Figure 8 outlines the typical asset ownership boundaries between the waste heat producer, a district heat network operator, and the ultimate consumers of the heat.

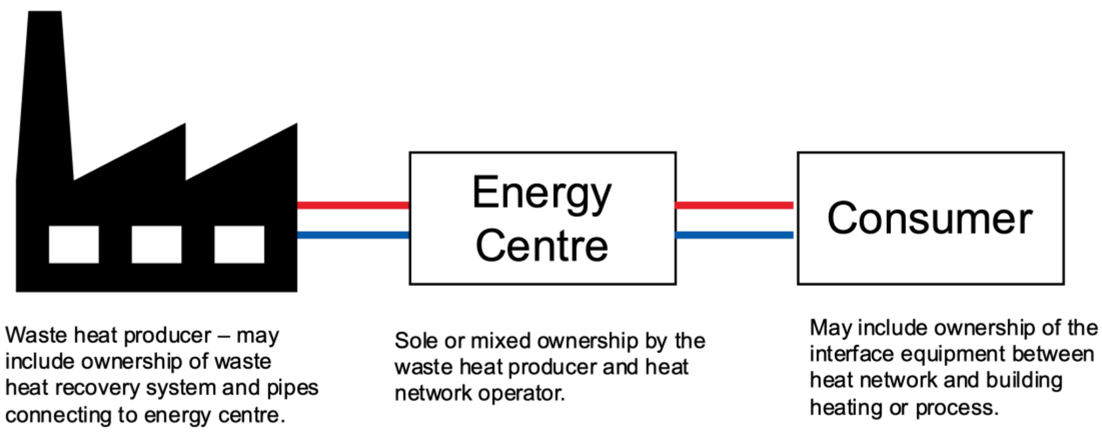


Figure 8: Typical ownership of waste heat and heat network assets

If the waste heat recovery system impacts an industrial or commercial process or is located on a site owned by the offtaker, the offtaker may want a degree of control and there will be boundaries of responsibility set out in an HSA. Producers often prefer to sell this heat wholesale without the need to upgrade to a higher temperature.

The diagrams and supporting text below briefly describe the advantages and disadvantages of various waste heat recovery asset ownership models.

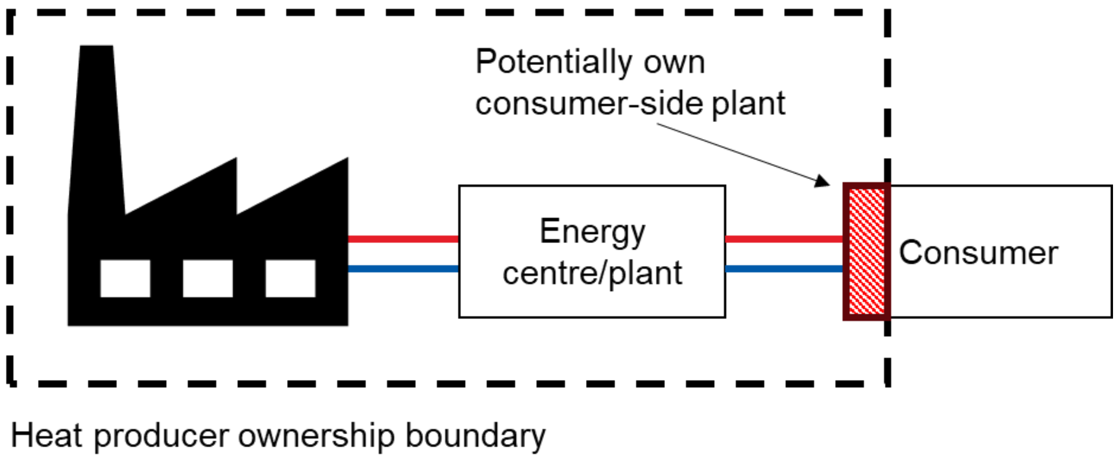


Figure 9: Option 1 - Maximum ownership model

Description: The waste heat producer owns all waste heat assets. An example of this is a manufacturing plant purchasing and then maintaining all heat recovery plant, including the distribution system.

This option is best suited to where there is a nearby offtaker.

Advantages:

- Contractual arrangements, if any, are simple.
- Potential risk reduction in areas such as maintenance, capital etc.
- Can make key decisions quickly (e.g. plant replacement).
- The waste heat producer has full control over the asset.

Disadvantages:

- Highest upfront capital cost for the heat producer compared to other options.
- Will have to source technical experts to design, select and maintain the plant.
- The producer bears all risk with this system.

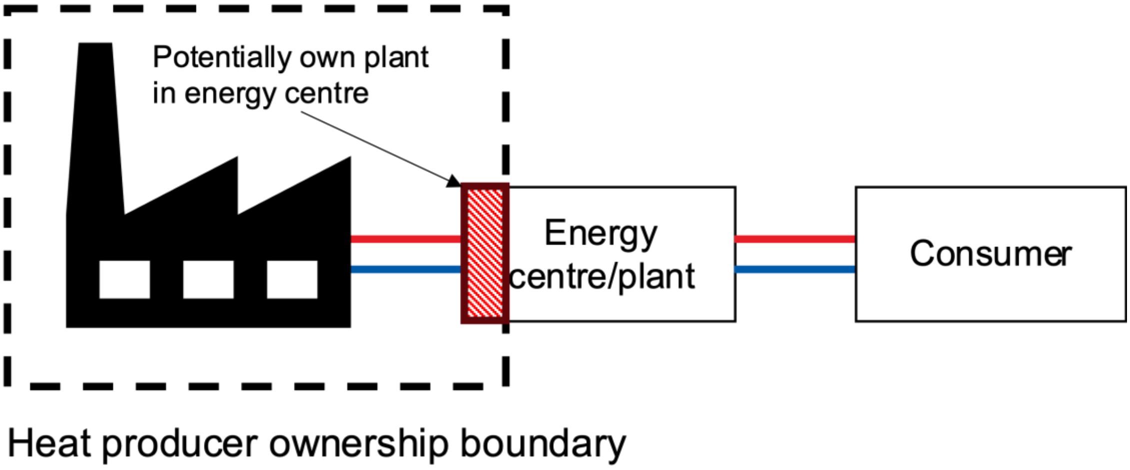


Figure 10: Option 2 - Mixed ownership model

Description: The waste heat producer partially owns some or all of waste heat assets. An example of this could be an energy from waste plant that sends excess heat to a DHN, via an energy centre. Here they own the waste heat recovery system but not the main energy centre plant, or the distribution system.

This option may suit where there is a nearby district heat network.

Advantages:

- Potentially lower financial investment as multiple stakeholders are present.
- Risk and liabilities can be shared by multiple parties.
- Stakeholders can bring their own expertise and specialists which no one side could provide.

Disadvantages:

- Stakeholder management can be more challenging the more there are.
- Reduced profit and return on investment due to profit being shared between stakeholders.
- Decisions could be slower due to having to involve more stakeholders.
- Allocation of responsibilities can be complex.

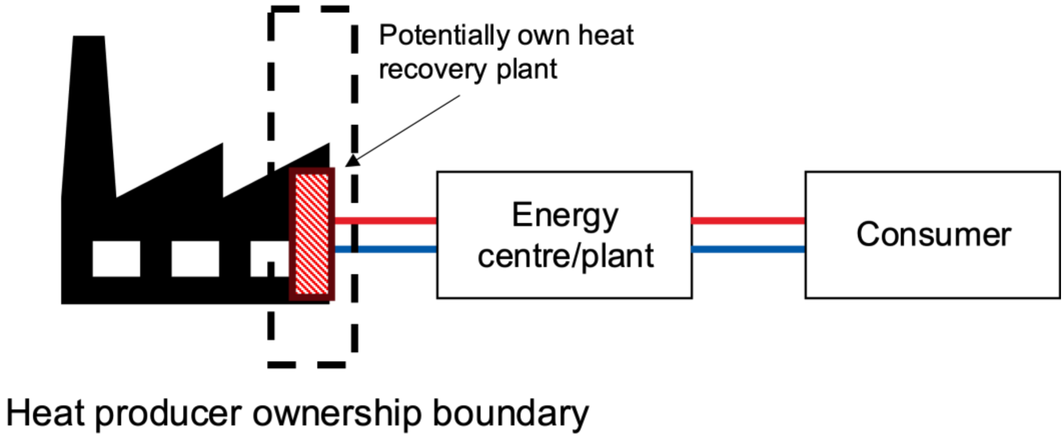


Figure 11: Option 3 - Minimal ownership model

Description: The waste heat producer owns the minimal amount of plant infrastructure.

This may suit waste heat producers with minimal capital funds and/or nearby offtaker with a large heat demand.

Advantages:

- This option requires the minimal amount of capital investment for the waste heat producer.
- Waste heat producers can focus on their day-to-day internal operations.
- Reduced commercial risk in the event of plant failure.

Disadvantages:

- Risk levels are very dependent on the offtaker competence.
- Risk of having an external contractor having access to business operations.

4.5 Common heat procurement methods

There is a range of ways in which waste heat can be procured:

1. A direct bi-lateral negotiation between the heat producer and the offtaker - ownership option 1.
2. The heat "producer" going out to tender to secure a pricing and volume offtake to sell their waste heat – can be ownership option 1, 2 or 3.
3. A district heating network operator or industrial consumer going out to tender for a waste heat supply agreement (i.e. looking to identify parties who can provide them with waste heat).

4.6 Heat tariff development

A heat tariff is the amount of money charged for heat, either by a producer to an offtaker or consumer, or by a heat network operator to a consumer, usually measured in cost per unit of energy (e.g. p/kWh). Much like typical gas and electricity energy tariffs. There are many ways to derive them, including:

1. A cost-plus reasonable profit mechanism where the price of heat is based on the underlying costs for the producer plus a reasonable degree of profit. The underlying costs are indexed to appropriate mechanisms (e.g. Consumer Price Indexes).
2. A competitive discount to alternative sources of heat (e.g. 10% to 20% reduction in the price of heat vs. the cost of procuring the heat from alternative technologies). Future price indexation is tied to the evolution in the alternative price of heat (typically either forward natural gas or wholesale electricity prices).
3. Based on the regulated price of heat (where there is a Regulatory Price Control mechanism which determines the price of heat).

Heat tariffs should be designed to be competitive with existing energy tariffs to incentivise uptake, whilst allowing the various costs involved in recovering and distributing the waste heat to be recouped.

4.7 Financial mechanisms/ support

There are various funding routes for financial support to install and implement waste heat recovery technologies.

Support has in the past been available for waste heat recovery to support industrial decarbonisation, without the need to supply a district heat network. At time of writing, most of these schemes have closed their latest calls[17,18]. However, it is likely further support may become available in the future.

4.7.1 Heat Network Support Unit (HNSU)

The HNSU offer guidance to support project identification and stakeholder engagement alongside stakeholder workshops and policy assessments[19]. In addition, funding can be granted for:

- Up to £50,000 for a detailed feasibility study.
- Up to £75,000 match funding for an Outline Business Case.
- Commercialisation costs, calculated on a case-by-case basis. Funding may be granted by the HNSU.

4.7.2 Scotland’s Heat Network Fund

The Scottish Government has made £300 million available to support the development of low or zero emission district heat networks[3]. Grant funding for this scheme must be drawn down by March 2026.

New low or Zero Direct Emissions district Heat (ZDEH) network projects are eligible, as well as the expansion of existing networks in a manner which continues to fulfil the ZDEH requirements. This includes supply from the recovery of energy / heat from industrial process, waste, or wastewater.

4.7.1 Capital allowances

Businesses can claim capital allowances and/or tax reductions to aid purchase of energy efficient, low, or zero-carbon technology from the UK government[20].

5. Next steps

5.1 Project decision tree

As with any construction project, preparation is needed for a waste heat project. Given the potentially large investment of time and money, it is important to diligently assess whether to proceed with the project. An example project decision tree is shown below:

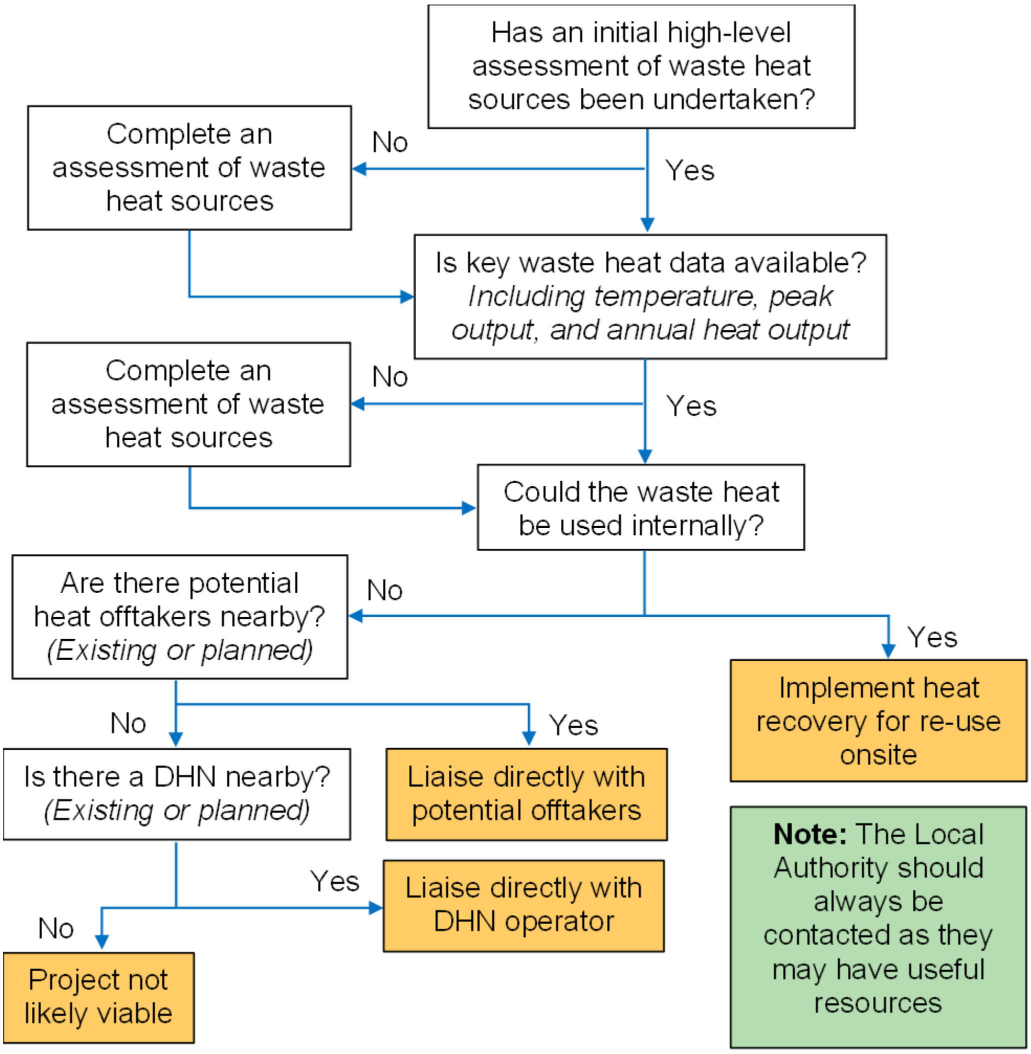


Figure 12: Project "Go/No-go" decision flow chart

5.3 Assessing feasibility

- **Initial assessment**

  An investigation that covers the fundamental questions of:

  A. Looking at plant operations, is there available waste heat?

  B. What is a high-level estimate of the amount and grade of heat available?

- **Data collection**

  A list of key data to gather, and methods of how to gather or estimate it, is shown in Table 6 below.

Table 6: Key data to assess project feasibility

Data	Description	How to gather it?
Peak waste heat supply	The maximum amount of heat that can be supplied over a timeframe (e.g. one hour).	Preferably derived from metered data taken directly at the waste heat recovery point. Alternatively: estimate based on similar case studies.
Annual waste heat supply	The amount of heat that can be supplied over the course of a year, in normal operations.	As above. Note that this should account for the usual number of disruptions (e.g. planned/unplanned outages).
Plant/ infrastructure capital costs	The initial purchase costs for all heat recovery and enabling equipment.	Ideally: gathered from equipment manufacturers. Alternatively: estimate using industry benchmarks based on peak heat supply.
Installation costs	The installation costs for all heat recovery and enabling equipment.	Ideally: Gathered from equipment manufacturers. Alternatively: Estimate using industry benchmarks based on peak heat supply.
Operational costs	Costs for operating and maintaining the equipment and systems	Estimated using input from maintenance providers, manufacturers and through using benchmarks from similar schemes
Fuel savings	The amount of fuel savings from reusing captured waste heat.	Calculated by comparing annual heat demand for a process and the annual waste heat supply.
Carbon emission savings	The carbon emissions saved from reusing waste heat or selling it to consumer.	Applying a carbon emission factor to the displaced fuel (either from selling to a consumer or using in a process).
Funding mechanisms	Potential additional project funding.	Research the funds that are available for the specific project.

Heat demand	The amount of heat an offtaker requires over the course of a year.	As above. Engagement with offtakers is very important for this. Uncertainty or unpredictability on heat demand can hurt economic viability.
Income	The income from selling heat to an offtaker.	Applying a heat tariff to the estimated waste heat that can be sold to offtakers.

5.4 Stages of project works

Waste heat projects are construction projects which should follow standard project models. The two most popular frameworks that concern waste heat recovery projects are:

- Royal Institute of Building Architects (RIBA) Stages
- Code of Practice - 1 (CP1)

Both frameworks have similar stages that guide a project from inception to completion and eventual handover. There are overlaps, but the key difference is RIBA stages are more general to any construction project, whilst CP1 only applies to district heat networks. The diagram below details the links between the two and shows key project milestones for each stage.

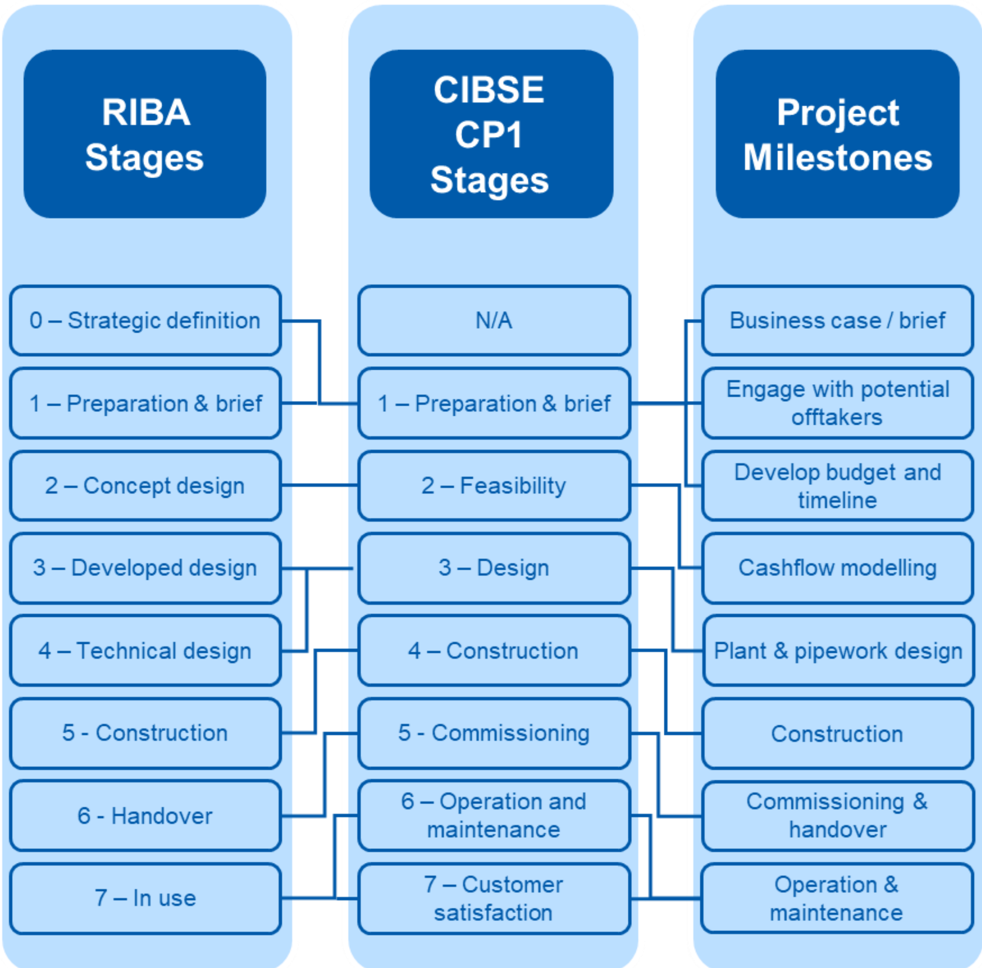


Figure 13: RIBA and CP1 links and project milestones

5.5 Additional resources

The following resources can provide further information:

- **Scotland Heat Map:** a map of estimated heat demand for domestic and non-domestic buildings in Scotland. This resource can be useful to identify potential offtakers, consumers and nearby waste heat providers. Most data is available to the public sector but more detailed information is available from the relevant local authority, subject to data sharing agreement.

  Scottish Government Website - Heatmap

- **Local Authority:** each Scottish Local Authority should already have, or be in the process of completing, their Local Heat and Energy Efficiency Strategy (LHEES). Each Local Authority should have a dedicated LHEES Officer (or similar) who can help give a local view of waste heat sources, possible demand, and plans for local Heat Network Zones.

- **Heat Network Support Unit (HNSU):** a Scottish focussed collaboration of organisations that provides funding, information and further signposting to support DHNs in Scotland.

  Heat Network Support Unit Website

- **Association for Decentralised Energy:** is a trade association supporting the growth of decentralised energy in the UK, with over 130 members. The group advocates for members through engagement with government and key decision makers on issues ranging from policy to industry standards.

  The Association for Decentralised Energy Website

- **Danish Board of District Heating (DDBH):** is an organisation representing the leading members of the Danish district energy sector. DBDH organise conferences, seminars, and exhibitions to foster global knowledge sharing.

  Danish Board of District Heating Website

- **Handbook for Increased Recovery of Urban Excess Heat:** consolidates information from low temperature waste heat recovery demonstration sites. It explores technical components, European urban waste heat potential, key stakeholders, and different business aspects.

  Euroheat Website - Handbook for Increased Recovery of Urban Excess Heat

Appendices

A. Technology Summary Table

A.1 Comparison of waste heat technologies

A high-level comparison between the different technologies is shown in Table 7 below. These technologies are applicable to a range of sectors and applications, with the key constraints being the recoverable grade of heat and the medium used to do so.

Some technologies will be more suited to specific industries, due to the constraints of their operations. An example of this would be the unsuitability of using some types of heat pumps in an explosive environment, such as a distillery.

Note these technologies are scored relative to each other.

Table 7: Waste heat recovery technology comparison

Technology	Cost	Typical heat recovery medium	Applicable grade of heat	Maintenance requirements	Typical efficiency (%)	Spatial impact
Heat exchanger	Low	Any fluid	All (depends on application)	Low	>90	Low
Waste heat recovery boiler	Low	Steam	Medium/ High	Low	90	Low
Economiser	Low	Steam	Medium	Low	90	Low
Absorption chiller	Medium	Flue gases	Medium	Medium	70 -140[21]	Medium
ORC	High	Flue gases	Medium	High	30[22]	High
Steam Rankine Cycle	High	Steam	Medium/ High	Medium/ High	50-60	High
Thermo-Electric Generator (TEG)	High	N/A	Medium	Low	5-15[23]	Medium

B. Individual sector overview

Waste heat recovery potential for key industrial sectors is described below. Where available, examples of operational schemes have been included.

B.1 Manufacturing

B.1.1 Cement production

The cement industry is one of the most energy intensive. Up to 45% of the total heat input to create clinker, an intermediate product to make cement, is lost[24].

The rotary kiln consumes the most energy, where minerals are heated to 1450°C. Exhaust gases typically pass through several chambers to recover heat before passing through the flue[24].

There is also potential to capture further heat from clinker grate cooling. Cold air treats passing clinker to cool it down to an appropriate temperature, causing a heat exchange. This is significantly cooler than in the kiln at ~360°C, but still medium grade[25].

Thyssenkrupp, a large German industrial engineering firm, use waste heat from the kiln and pre-heater to generate steam, which then drives electrical generators[26].

B.1.2 Paper & pulp manufacturing

Most processes involved in the production of paper and pulp are carried out at ambient temperature[4]. However, paper drying requires a significant amount of energy and usually uses steam generation. Energy consumption patterns vary by site but the available waste heat is usually consistent.

Heat recovery is often used in-house, typically focussing on recovery from steam and flue gas economisers. However, there is the opportunity to recover further medium-grade heat (>150°C) from these mills, by employing further heat recovery methods[4]. Scottish paper and pulp sites are usually located near areas of medium heat demand (>250 MWh), although not necessarily close to existing district heating networks[4].

UPM-Kymmene's facilities at Kaukas, Finland, comprises of two paper mills and a pulp mill. The Kaukas operations produce 590,000 tons of paper annually. Heat is recovered from cooling processes using a system of over 100 heat exchangers and recycled through the plant. Between 10-20% of energy recovered at the mill is used elsewhere on the site and the surplus is sold as process steam to the local paper and sawmills[27].

B.1.3 Food & drink manufacturing

Production processes and waste heat output vary significantly across the food and drinks sector. Dairy, baking, and brewing sectors are the predominant industries in Scotland[4].

Heat sources are mostly condensate arising from evaporation, distillation, and cooking processes, alongside boiler exhaust gases of a medium grade (typically between 120 -150°C)[4]. Food and drinks plants are often close to urban areas, offering the opportunity to reuse heat in the surrounding area, either for industrial or domestic use[4].

Tennent's brewery in Glasgow recovers waste heat from their Anaerobic Digestion (AD) plant and chimney stack. Heat exchangers upgrade heat from brewing process effluent to heat incoming material to the AD plant, reducing its heating demand by around 400 tCO_2/annum. A boiler economiser was also fitted to the flue, redirecting gases to pre-heat the water entering the boiler. This reduces the required increase in temperature and cuts carbon emissions by 500 tCO_2/annum[28].

B.1.4 Distilleries

Waste heat in distilleries is typically between 70-90°C. Seasonal and temperature variation is generally low, offering a consistent source of heat throughout the year[4].

The most considerable potential for heat recovery is from heat lost to the surroundings via a flue[4]. Utilising this heat in other steps of the distilling process is usually done using a heat pump. This can save up to two thirds of the heat energy used in the still house[29].

Micro-distilleries account for 90% of UK distilleries[30]. For micro-distilleries, specialist heat recovery systems are often too expensive and not designed for their needs[31]. As such, significant research and development is taking place to identify opportunities for small scale heat recovery. These methods are generally centred on the use of heat pumps and heat exchangers to capture waste heat from the various stages in the distilling process[32,33].

At Bowmore Distillery, on the Isle of Islay, waste heat from the drying process and stills is upgraded using a heat pump and reused in the visitor centre and the neighbouring community swimming pool[34].

B.1.5 Chemical manufacturing

Globally, the chemical industry is the largest industrial energy consumer. It is a diverse sector which requires heating for activities such as: distillation, curing, boiling, drying, cooling, transportation, and storage.

Typically, waste heat from chemical manufacturing is of a lower grade and arises from cooling water or exhaust gas from boilers. This is often recovered and used onsite.

Solutia UK, based in Wales installed a condensing economiser waste heat recovery unit on their Combined Heat & Power (CHP) facility. The predicted project savings were 1.1 MWh and 1400 tCO_2, with a payback period of 2 years[35].

B.2 Services

B.2.1 Energy from Waste

Energy from waste is the generation of energy in the form of electricity and/or heat from waste treatment. Scotland has the capacity to process over 1.4 million tonnes of waste per year at Energy from Waste (EfW) sites with another 1.1 million tonnes of capacity in planning or construction.

The majority of Scottish EfW plants are either conventional incineration or Combined Heat and Power (CHP). In these plants non-recyclable treated waste is burned in controlled conditions at high temperatures (often above 850°C), creating a high-grade source of heat[36].

There is also the opportunity to recover lower grade heat from incinerators, such as that which is residual in the outcoming bottom ash. However, this is generally overshadowed by the quantity of available high-grade heat.

The Scottish Government commissioned an independent review of the role of incineration in the waste hierarchy in Scotland. The review recommended deploying combined heat and power for as many existing incineration facilities as possible.

SEPA, Scotland's environmental regulator, requires all EfW permit applications to demonstrate at least 20% energy recovery. This must be accompanied by a Heat and Power Plan, to show how, within a period of seven years from commissioning, and where practicable, they will connect the facility to a heat network[37].

In Shawfair, Midlothian a joint venture by Midlothian Council and Vattenfall Heat UK known as Midlothian Energy Limited (MEL) will supply over 3,000 homes, as well as education and retail properties. This project is under construction and will be powered by waste heat from the Millerhill Recycling and Energy Recovery Centre. This initial phase is expected to save more than 2,500 tonnes of CO_2 a year[38].

B.2.2 Industrial laundries

The operations carried out at industrial laundry sites are energy intensive and there are several processes which produce waste heat.

For example, the washing and cleaning of textile products produces waste heat between 80-120°C with low seasonal and temperature variation[4].

Up to 40% of the energy used is to heat water for washing. Heat from wastewater produced as part of the washing process can be recovered and used to preheat incoming cold water, reducing energy consumption. This principle can also be applied to the warmed air used in the clothes driers[39].

Heat pump dryers are more energy efficient than traditional tumble dryers. Heat pump dryers use refrigeration cycles to capture and reuse heat from the drying process, instead of venting to the surroundings.

Heat can also be recovered from exhaust air from any part of the operations, including steam heat boilers and combined heat and power systems. This heat can either be used within the laundry operations or utilised as space heating for the site[40].

At the Victoria Hospital in Kirkcaldy, the laundry was losing the equivalent of £57,000 of heat a week from a wastewater tank before implementing heat recovery. Outgoing water is now used to preheat water coming into the washer. This reduces the need for steam in the washing process and therefore the level of moisture retained. As a result, drying times have reduced by 25%, increasing output, and saving energy. The payback period of this project was just over a year[41].

B.2.3 Electrical substations

Transformers require a cooling circuit, usually utilising oil, to function safely and efficiently. This is achieved by placing the transformer core in an oil bath to remove resistive heat generated by the coil windings, with typical waste heat around 45°C. A conservative estimate of waste heat potential across a year is more than 31 MWh for a typical substation transformer[4].

The higher the electrical load, the more heat energy the transformer will produce. The recovery of heat from the oil is relatively simple and just requires an additional heat exchanger and pump.

Substations are often spatially constrained sites and access is strictly controlled for safety reasons. Therefore, detailed planning is essential to ensure feasibility. As with other waste heat sources, it relies on suitable and reliable heat consumers to be nearby to be financially viable.

SSE has been collaborating on a trial scheme with the National Grid to use the waste heat from transformers to generate hot water and heating. Testing of the scheme began in 2021 in Deeside, Wales. If successful, this could be rolled out across the National Grid's 1300 substations[42].

B.2.4 Wastewater treatment plants

Wastewater Treatment Plants (WWTP) treat wastewater which is continuously available and in large quantities, allowing for low-grade heat recovery.

Whilst the flow rate tends to remain stable through the year, effluent water temperature can vary significantly. External conditions influence the temperature and consequently, the amount of waste heat captured in winter will be lower than during summer[4].

Many of these plants are near significant heat demand and/or heat networks. In urban areas, such as Edinburgh and Glasgow, the substantial heat demand, high capacity, and flow rates at WWTPs increase this sector's potential[4]. Modelled heat supply data for WWTP is provided by Scottish Water as part of the Scotland Heat Map dataset (please refer to section 5.5).

However, there are a range of technical challenges that arise from heat recovery from effluent water as flows can fluctuate greatly and a minimum temperature must be maintained within the effluent water to enable effective treatment[4].

In Renfrewshire, a fifth-generation, heat network converts treated water into low temperature heat. Treated water, otherwise flowing into the White Cart River, is directed into the Scottish Water Laighpark Energy Centre. Here heat from is extracted from the water before going through 3.7 km of underground pipes to the Advanced Manufacturing Innovation District Scotland (AMIDS). Heat pumps at each building upgrade this heat to suitable temperatures for use. This network supplies 90% greener heat and hot water than a traditional gas boiler facility[43].

B.2.5 Sewage pipe network

In this case, heat is taken from the sewage pipes upstream of any WWTP works. Scotland's sewers transport over 920 million litres of sewage every day and are estimated to contain enough heat to warm Glasgow for more than 4 months a year[44]. Sewage water temperatures tend to range through the seasons, between 10°C in winter and reaching peaks of 25°C in summer, averaging out across the year at 15°C[45].

Scottish Water publishes data on the flows within their waste water network which can be used to assess waste heat potential and is available here: Waste Water heat extraction opportunities (arcgis.com)

Borders College in Galashiels has installed a sewage heat recovery system. This project comprises of a heat pump connected to a district heating network. This provides 95% of the heat needed by the campus, equating to around 1 GW per annum[46].

B.3 Other

B.3.1 Hydrogen electrolysers

Electrolysers can be used to produce hydrogen. This method uses an electrical current to separate water into hydrogen and oxygen. The electricity used must come from renewable sources for the hydrogen to be considered 'green'.

Electrolyser efficiency can be up to 80%, however substantial waste heat is still generated. Electrolyser cooling is essential to improve efficiency and cell lifetime. Therefore, coolers are usually placed on the top of electrolyser containers, dissipating heat of 50-80°C into the surroundings[47].

As decarbonisation is an essential component of the development of electrolyser technology, waste heat reuse is being considered as an integrated part of plant design. In Hamburg a scheme expected to be operational by 2025 will harness waste heat from a 100 MW electrolysis plant for a DHN[48].

Waste heat reuse opportunities would be dependent on the electrolyser location. This could suit industrial offtakers located nearby, or the heat could be distributed further afield through a DHN.

B.3.2 Hydrogen fuel cells

Fuel cells can be applied to provide power across various sectors, including transport, industrial/commercial/residential buildings, and energy storage for the grid. A typical fuel cell has an efficiency of around 60%, where much of the lost energy is dissipated as heat[49].

Proton Exchange Membrane Fuel Cells (PEMFC) are the most common technology used in vehicles and vessels. PEMFCs typically reject heat at 75-80°C[49]. Other technologies have high grade exhaust heat, such as Solid Oxide Fuel Cells (SOFC), where temperatures are typically between 600-1000°C[50].

The Event Complex Aberdeen (TECA) hosts the largest fuel cell installation in the UK at 1.4 MW electrical generation capacity[51].

B.3.3 Supermarkets

Supermarkets offer a continuous flow of low-grade heat, typically between 20-40°C, which is rejected from the cooling / refrigeration systems in display cabinets. Furthermore, larger supermarkets may have a centralised refrigeration system which could offer low-grade heat between 60-90°C[4].

Heat pumps could be used to boost these temperatures to enable heat to be supplied to district heat networks. However, the development of newer DHNs operating at ambient temperatures, known as '5th Generation Networks', would allow for the direct re-use of low-grade heat.

Most supermarkets are located close to dense urban areas allowing waste heat recovered to be easily delivered to homes through a DHN.

Bals Elektrotechnik (BALs), an electronics supplier in Denmark, have equipped their store with CO_2 based refrigeration units and incorporated heat recovery. This technology recycles 95% of heat recovered and has saved the store 70% on its annual heating costs and 37% on its electricity. The recovered heat is used to heat the store, its hot water and supplies 15 homes via a DHN[52].

B.3.4 Data centres

The data centre industry is growing rapidly, and due to its energy intensive nature, so are calls for waste heat recovery to be an integral part of their design.

To prevent electronic components becoming damaged due to overheating, cooling systems are used to cool the circuits to around 25°C, with the waste heat exhausted into the atmosphere. For air cooled systems this heat can be recaptured at 25-35°C, whereas liquid submersion-cooled systems this is around 50-60°C[53].

In Stockholm, Sweden, an initiative was launched to attract data centres to the city and capture their excess heat for the city's DHN. Since 2022 more than 100 GWh of heat has been recovered. Heat pumps are used to boost the waste heat from cooling the processors to temperatures which can be delivered to the DHN. This system heats the equivalent of 30,000 modern apartments[54].

B.3.5 Edge computing

Edge computing uses decentralised data centres, some of which may be in households, rather than servers in a large central data centre.

As the need for increased processing speed grows, edge computing could offer a more self-sufficient way for buildings to incorporate communal heating – integrating the common need for heat and data. Through providing heat in-house, buildings would not need to be located on a DHN, presenting more sustainable growth opportunities outside a city centre.

In Devon a washing-machine-sized data centre provides 60% of the hot water needs of a public swimming pool. The oil used to cool the processing units is pumped through a heat exchanger, which in turn warms the pool water to 30°C[55].

Frequently asked questions

1) **What is “waste heat”?**

Waste heat is heat produced as a by-product of another process. This heat is not directly used in the process itself (hence “wasted”) and can often be captured and used to reduce overall energy consumption on-site or exported to a potential buyer.

2) **Why is it important to investigate recovering waste heat from our industrial and manufacturing processes?**

Waste heat recovery benefits are twofold. Firstly, depending on the grade and availability of waste heat and available offtakers, there is an economic incentive to save on fuel costs or generate an additional revenue stream. Secondly, depending on the source of waste heat, it could contribute to achieving UK’s decarbonisation goals by displacing carbon-intensive fuels.

3) **What are our options to turn our waste heat into something useful?**

This largely depends on the specifics of the process that results in waste heat, and the temperature of the heat. Options for reuse include either using a waste heat capture technology (e.g. a heat exchanger); converting it to electricity; reusing it on site; or exporting to a district heat scheme or nearby demand.

4) **Can we use the recovered heat within our facility or is it better suited for other purposes?**

There are a few options to reuse waste heat. The first, and most common, is capturing and utilising it in industrial processes to reduce fuel costs. An example of this is using an economiser to raise the temperature of boiler feedwater.

The second is using this heat to provide heating and hot water or electricity to a site. Note. converting to electricity requires waste heat to be at higher temperatures than for space heating.

The third is selling captured heat to a potential buyer, typically a DHN operator. It is also possible to export electricity to the National Grid or to another consumer if electricity generation is an option.

All options depend on the amount and grade of recoverable heat, the economics of fuel prices and if there are offtakers available nearby. Comparing these options often requires further investigation using lifecycle analysis.

5) **Are there any rules or environmental concerns we need to consider when recovering waste heat?**

Mainly, any concerns would be to ensure no damage comes to the immediate environment in the process of recovering this waste heat. For example, extracting heat from a river could reduce the water temperature to such a degree the local ecosystem suffers.

6) **What kind of equipment or changes would we need to make to start recovering waste heat?**

Typically, a pipe system is needed to divert the wasted heat to a new heat capture unit. In some processes this may already be available (e.g. flue stack). After the waste heat capture unit, an additional distribution network may be necessary to transport it to its desired location.

7) **Will incorporating waste heat recovery disrupt our current operations?**

This largely depends on the operation in question, but it would be likely some partial or complete shutdown would be required to install the required equipment and distribution network.

8) **How long will it take for us to see a return on investment from recovering waste heat?**

This is largely situation dependent and factors such as: the volume and grade of recoverable heat, the -economics of fuel prices and if there are offtakers available nearby.

9) **Is there any funding and general advice available?**

Yes, there are multiple funding schemes which may be applicable to a project. These include various funds to support heat networks, as well as advice from departments within the Scottish Government. Please see Section 4.7.

10) **Are there any downsides or risks we should be aware of?**

The two categories of risk are technical and commercial. Technically, it is important to ensure the waste heat recovery system does not impact usual operations.

Commercially, it is important to ensure the waste heat system will make a return and/or achieve carbon cutting objectives. This should be assessed via a lifecycle cost analysis. This activity is usually conducted in the feasibility stages (i.e. RIBA Stage 2 and/or CP1 Stage 2).

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