1. Executive summary

The core mission of Net Zero North West (NZNW) is to become the UK's first low carbon industrial cluster by 2030 and the world's first net zero industrial cluster by 2040. NZNW aims to save 38.5 megatonnes (Mt) of carbon dioxide emissions, deliver £206.9bn of investment, provide a social uplift of over £285 billion Gross Value Added (GVA) and develop a total workforce of 660,000 new and existing jobs.

Substantially decarbonising regional industry by 2030, and getting to net zero emissions by 2040, is an opportunity that presents significant economic benefits, both regionally and nationally. It will create and protect high value-added jobs and position the UK at the forefront of reducing global industrial emissions. The North West possesses the largest concentration of advanced manufacturing and chemical production in the UK and is home to a concentration of energy intensive users. Traditionally strong in textiles, shipping and engineering it is now home to leading information and communication technology, biotechnology, pharmaceuticals, aerospace, and telecommunications businesses.

This report aims to evaluate the characteristics of Industrial consumers by sector in the North West. In doing so, it considers current practical decarbonisation delivery and provides an assessment of future technologies when developing sectoral decarbonisation roadmaps. It creates a deliverable investment, technology, and infrastructure blueprint for the North West's transition to net zero carbon by 2040 and low carbon recovery post-COVID-19. This decarbonisation and clean growth vision will unlock huge opportunities across the supply chain for regional businesses to tap into, including engineering support; construction; parts provision; logistics and distribution; third party maintenance contracts and many other supporting work streams.

The analysis included in this report is based upon EQUANS' sector assumptions derived from Energy Savings Opportunity Scheme (ESOS) audits, European Union Emissions Trading System (EU ETS) emitters, UK National Atmospheric Emissions Inventory (NAEI) within the North West, across 27 industrial sectors with 181 manufacturing sites. It incorporates four common technology themes across the sectors; Energy Efficiency, Low Carbon Technologies, Renewable Generation and Hydrogen. Analysis has revealed that the application of these measures across the industrial sector is achievable and highlights the barriers to implementation:

Analysis 1 - It is estimated that the implementation of **Energy Efficiency technologies** could save up to 27% of emissions. These measures are usually easy to install, have low capital expenditure, and have respectable paybacks allowing the industry sectors to take advantage of the financial savings attributed to the measures, which can be instantaneous in some circumstances.

Analysis 2 - **Low Carbon Technologies** can achieve great financial savings through the implementation of Combined Heat and Power (CHP) technology which can be future proofed through the integration with hydrogen. Whilst Heat Pump technologies support the electrification of heat and provide the greatest decarbonisation potential.

Analysis 3 - The North West contains large land assets to enable **Renewable Energy Generation**. This report also highlights that through the deployment of Anaerobic Digestion plants, sectors such as the food and drink industry can take advantage of a circular economy producing biomethane from waste.

Analysis 4 – Converting fuels to **Hydrogen** is one of the most innovative technologies described in this report, most manufacturers are now aligning their technology for the potential change in fuel to meet the demands of industrial users. Manufacturers of equipment such as boilers and gas fired CHP systems have published figures around 25-30% blend of hydrogen with no change to existing equipment.

Based on analysis within this report, it is recommended that the industrial companies within the North West produce individual net zero carbon reports and action plans that align with the Net Zero North West 2040 ambitions to become the world's first net zero industrial cluster.

This can be achieved by taking a holistic approach to decarbonisation, focussing not just on individual technologies but integrated energy systems that tackle efficiency first, prior to the more complex infrastructure requirements.

The North West has immense breadth and diversity of decarbonisation activity, in fact it is the only region with all the elements required to deliver a low carbon industrial cluster by 2030. Contained within it are; Renewables, Hydrogen (e.g. enabling the Cheshire Salt Caverns for Hydrogen Storage), Carbon Capture Usage (e.g. enabling the Liverpool Bay gas fields for carbon capture) and Storage (CCUS), small and large scale Nuclear in Cumbria, Lancashire and Cheshire and developments in localised Smart Grids. The Net Zero North West decarbonisation strategy centres on growing regional economies in a coordinated fashion - delivering a decarbonised industrial cluster underpinned by energy security and an engaged workforce (2). Moreover, it has an advantage in building the region's key industrial strengths into innovative business models for clean energy and hydrogen, as evidenced by the HyNet project, which drives a regional hydrogen economy that has sustainable income streams.

The document 'Net Zero: Connecting Policy and Research for Climate Action' outlines that three main concepts – energy and resource efficiency, changing fuel and feedstock, and Carbon Capture and Storage (CCS) – must be married together and implemented in a full, holistic industrial decarbonisation system (3). This requires effective policy support from government to encourage industry buy-in and allow space for trialling innovative systems. Simultaneous innovation of policy and business models will ensure UK industry can decarbonise while maintaining competitiveness.

The Net Zero North West Cluster Plan will develop a deliverable investment, technology, and infrastructure blueprint to support the region's net zero transition and low carbon recovery post COVID.

The Cluster Plan has 7 underlying principles outlined below:

1. Defining the contribution that Hydrogen and CCUS can make to decarbonising industrial process emissions across the cluster geography to enable fuel switching in the energy intensive industries.

2. Developing future scenarios to forecast total regional demand for energy and energy mix by 2040.

3. Defining the baseline scenarios for growth, contraction, and transformation of industry.

4. Evaluating the impact of energy efficiency and investment in onsite generation on consumers.

5. Assessing the impact and opportunities of decentralised power generation and low carbon gas production.

6. Considering the production or manufacture of low carbon gases from within and near the cluster, including from nationally significant offshore wind, nuclear, tidal resources, and carbon capture opportunities for negative emissions.

7. Evaluating the impact of new energy infrastructure on the electricity and gas distribution.

Initially, these principles have been evaluated via four research work packages, listed below:

- Industrial Consumers (WP4) - led by EQUANS (this report)

- Electrolytic Hydrogen (WP5) - led by EQUANS

- Grid Scale Low Carbon Dispatchable Power (WP6) - led by Uniper

- HyNet and its role in Net Zero (WP7) - led by Progressive Energy and Cadent

These reports will be used to inform the remaining consortium partners in their assessment of the electricity distribution network impact, local education, skills requirements and the development and synthesis of the investment case for the North West.

This has been achieved by:

- Evaluating each sector including the distribution of industrial sites contained in the North West and calculating the respective carbon footprint produced by these consumers.

- Producing an Industrial Cluster Heat Map which shows the breadth of technologies used to generate energy at each location. Highly concentrated regions of these technologies within the North West indicate opportunities where energy and carbon saving measures should be focused.

- Reviewing the types of carbon emissions contained within the North West.

- Providing an overview of technologies that are most effective for decarbonisation by industrial consumers.

- Conducting a high-level assessment by sector to produce a decarbonisation roadmap and providing an indicative business case for recommended investment.

The aim of this report is to provide recommendations on the most effective technologies for investment when developing sectoral decarbonisation roadmaps.

2. Introduction

The UK's Industrial heartlands are integral to the UK economy. Contributing £170 billion each year to our economy, enabling 7.6 million jobs (1) directly and indirectly through the subsequent value chain, from manufacture of the COVID-19 vaccine through to the food that we eat.

The North West is situated in one of the most productive regions in the UK with a £185 billion GVA (economically the largest region outside of the South East of England) and a highly skilled and diverse workforce. The North West Industrial cluster holds the largest concentration of advanced manufacturing and chemical production in the UK, which is significantly energy intensive and currently produces ~50% of the UK Industrial Emissions (38 Mt CO_2e), the same as the Republic of Ireland. This is 20% more than the South East region which reflects the highly positive economic contribution to the UK, comes with a high environmental cost (2).

Net Zero North West is an industry-led cluster acting as a public and private sector investment accelerator for industrial decarbonisation and clean growth projects in the North West. It aims to unite businesses, regional leaders, academia, and is committed to delivering a co-ordinated net zero vision for the region. The core mission of Net Zero North West is to become the UK's first low carbon industrial cluster by 2030 and the world's first net zero industrial cluster by 2040.

£206.9 billion
Investment in
the North West

providing
social uplift
and benefit
of over
£285 billion GVA

Develop a total
workforce of
660,000

new and existing
jobs across the
North West with
over **½ million**
in our industrial
cluster

Save 38.5 mega-tonnes
of greenhouse gas
emmissions
(CO_2 equivalent) and
deliver the UK's first
net zero region by
2040

This bold vision for the North West will save 38.5 mega-tonnes of carbon dioxide emissions, turbocharge the UK economy by £285bn GVA and safeguard or create over 660,000 jobs.

Prior to conducting an energy survey, a request for information (RFI) form is submitted at the project initiation to start the data collection process. Afterwards an energy survey is carried out at site, where the ESOS assessor reviews the current energy consumption, existing processes, and potential improvements. Finally, an ESOS report is produced detailing the information captured from the RFI and energy survey.

There is no mandatory requirement for businesses to implement the energy saving opportunities identified by the ESOS audits. However, they do offer a valuable opportunity for businesses to reduce their energy use and costs. The measures identified could range from simple 'quick-fix, fast-return' solutions, such as installing LED lighting, through to longer-term investment programmes.

With this experience, EQUANS manages a depository of data on energy consumption and energy saving opportunities for industrial sites from a variety of sectors. Previously collected data for the purpose of compliance with ESOS has been collated for this study to generalise the variety of energy efficiency opportunities based on the sector of the industrial sites, protecting the identity of previous clients.

Energy saving opportunities for each sector have been aggregated to simulate the variety of solutions available. Where the same solution was proposed for different industrial sites within the same sector, the energy and carbon savings were averaged and compared to the baseline figures to attain a benchmark that can be applied to the whole sector in the North West. The results of this analysis are elaborated on in Section 5.2.

• The GHG inventory

The GHG inventory covers the seven direct greenhouse gases under the Kyoto Protocol, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). These gases contribute directly to climate change due to their positive radiative forcing effect. HFCs, PFCs, SF_6 and NF_3 are collectively known as the 'F-gases'. In general terms, the largest contributor to global warming is CO_2 which makes it the focus of many climate change initiatives. CH_4 and N_2O contribute to a smaller proportion, typically less than 20%, and the contribution of 'F-gases' is even smaller (despite their high Global Warming Potentials) at less than 5% of the total (10).

The GHG Protocol Corporate Standard classifies a company's GHG emissions into three 'scopes'. Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy. Finally, Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions.

For the purposes of this report, CO_2 emissions are classified by Scope 1 and Scope 2. Scope 3 emissions specify fifteen categories, including purchased goods, waste generated, fuel-related activities, use of sold products, investments, franchises, and employee commuting. These categories will require significant collaboration through stakeholder interviews with each of the sites and companies within the North West. To derive the most effective outcomes in the time available, a desktop assessment of Scope 1 and 2 was used to inform the analysis. Further development of Scope 3 emissions is recommended to be explored with sufficient time allowed for the significant organisational challenges in creating an effective data set.

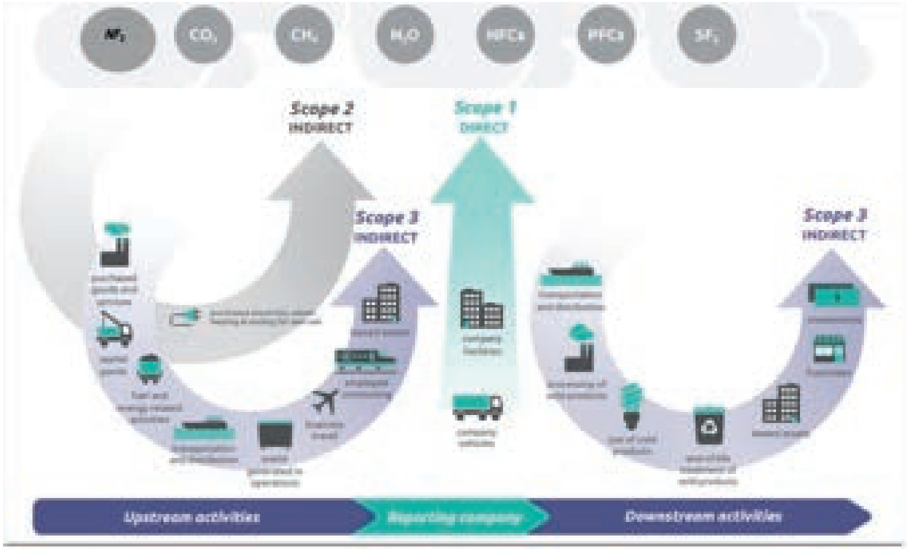

Figure 1 Overview of the GHG Protocol scopes and emissions across the value chain (151)

3. Industrial Emissions Data

To develop sectoral decarbonisation roadmaps for the North West, the first step was to benchmark current fossil fuel consumption. To do this we chose a base year that would act as a reference point to compare our emission reduction plan and was also representative of a non-COVID impacted period. A 2019 base year has been assumed as the most applicable full year considering COVID disruptions distorting more recent years.

Subsequently, available data sources were assessed to derive the most effective results. The data sets that were evaluated included:

- **European Union Emissions Trading System (EU ETS) (4)**

The EU ETS operates in all EU countries plus Iceland, Liechtenstein, and Norway (European Economic Area – European Free Trade Association states), limiting emissions from around 10,000 installations in the power sector and manufacturing industry, as well as airlines operating between these countries. This covers around 40% of the EU's Green House Gas (GHG) emissions.

The EU ETS works on the 'cap and trade' principle. A cap is set on the total amount of certain greenhouse gases that can be emitted by the installations covered by the system. The cap is reduced over time so that total emissions fall. Within the cap installations (or sites) buy or receive emission allowances, which they can trade with one another as needed. The limit on the total number of allowances available ensures that they have a value.

After each year, an installation must surrender enough allowances to fully cover its emissions, otherwise heavy fines are imposed. If an installation reduces its emissions, it can keep the spare allowances to cover its future needs or sell them to another installation that is short of allowances. Trading brings flexibility that ensures emissions are cut where it costs less to do so. A robust carbon price also promotes investment in innovative, low-carbon technologies.

It should be noted that since the departure from the European Union (EU), a UK Emissions Trading Scheme (UK ETS) replaced the UK's participation in the EU ETS on January 1st 2021. The UK ETS follows the 'cap and trade principle'. The UK ETS applies to energy intensive industries (EII), the power generation sector and aviation. It covers activities involving combustion of fuels in installations with a total rated thermal input exceeding 20MW (except in installations for the incineration of hazardous or municipal waste). The aviation routes covered by the UK ETS will include UK domestic flights, flights between the UK and Gibraltar, and flights departing the UK to the European Economic Area states for all aircraft operators, regardless of nationality. If an installation carries out an activity covered by the UK ETS, a greenhouse gas emissions permit will be required (5).

At the time of this report, the UK ETS database was in development and therefore EQUANS used the data contained within the EU ETS database to provide information on EU ETS installations, which included verified emissions and compliance status for the period 2005-2020.

- **UK National Atmospheric Emissions Inventory (NAEI) (6)**

There are several international commitments including, EU Directives and other national legislation aimed at reducing emissions of air pollutants and GHGs.

The NAEI provides a wide range of data necessary to support the reporting associated with these commitments. Full details of the UK's commitments can be found on the Department for Business, Energy and Industrial Strategy (BEIS) website for GHGs (7) and Department for Environment, Food and Rural Affairs (Defra) website for air pollutants (8).

The NAEI is funded by BEIS, Defra, the Scottish government, the Welsh government and the Northern Ireland Department of Agriculture, Environment and Rural Affairs.

The NAEI estimates annual emissions from 1970 to the most current publication year for most pollutants. Several pollutants are estimated from 1990 or 2000 to the most current publication year due to the lack of adequate data prior to the later date and the specific reporting requirements for each pollutant. To deliver these estimates, the NAEI team collect and analyse information from a wide range of sources – from national energy statistics through to data collected from individual industrial plants (9).

Energy Saving Opportunity Scheme (ESOS) and energy survey reports.

ESOS is a mandatory energy assessment and energy saving identification scheme typically delivered through an energy survey, introduced by the UK government for large organisations. The scheme applies throughout the UK and must be carried out by a qualified Lead Energy Assessor every 4 years. EQUANS has extensive experience in helping businesses to comply with ESOS, identifying savings through energy auditing and energy survey reports.

4.4.4 Sample

A representative sample of sectors from the ETS and NAEI list were selected to build an energy saving dedicated plan for those respective sectors. The sectors below represent 58% of the total number of EII sites in the North West, around 58.3% of the emissions and provide a good reflective range of manufacturing processes and auxiliary equipment in the North West England and North East Wales industrial cluster. The selected sectors are listed in Table 7 below.

Sector	% Represented in the NW	N. Of sites	% of emissions in the NW	Total Emissions ($teCO_2e$)
Automotive	3.91%	5	0.8%	153,256
Cement	4.69%	6	12.8%	2,579,166
Chemicals	27.34%	35	4.7%	957,762
Food and Drink	19.53%	25	4.8%	971,931
Glass	6.25%	8	2.8%	559,895
Iron and Steel	0.78%	1	0.3%	63,952
Paper and Pulp	16.41%	21	4.6%	926,812
Pharmaceuticals	5.47%	7	1.4%	276,272
Power producers	15.63%	20	17.3%	3,502,338
Total Analysed Sectors	**62.1%**	**128**	**49.5%**	**9,991,385**
Total North West	**100.0%**	**206**	**100.0%**	**20,189,634**

Table 7 Representative sample of the ETS and NAEI list

4.4.2 Scope 2

In Table 5, the ‘Other industries’ sector produces most of the Scope 2 emissions in the North West England and North East Wales industrial sector, while no Scope 2 emissions are produced by both the major and minor power producing sectors.

Sector	**Extrapolated Scope 2 Emissions (tCO_2e)**	**Extrapolated Scope 2 Emissions (%)**
Automotive	68,420	1.1%
Cement	322,708	5.2%
Chemicals	80,594	1.3%
Food and Drink	387,170	6.2%
Glass	86,637	1.4%
Iron and Steel	9,039	0.1%
Paper and Pulp	371,681	6.0%
Pharmaceuticals	137,152	2.2%
Power producers	00	0.0%
Other industries	4,745,018	76.4%
Total	**6,208,421**	**100%**

Table 5 Scope 2 Emissions per Energy Intensive Sector

4.4.3 Total Emissions

Table 6 below shows that the ‘Other industries’ sector is responsible for most of the total CO_2 emissions, with the cement and power producing sectors also contributing a large amount of the remaining emissions.

Sector	**Extrapolated Scope 2 Emissions (tCO_2e)**	**Extrapolated Scope 2 Emissions (%)**
Automotive	153,256	0.8%
Cement	3,057,649	15.1%
Chemicals	1,103,100	5.5%
Food and Drink	971,931	4.8%
Glass	559,895	2.8%
Iron and Steel	63,952	0.3%
Paper and Pulp	926,812	4.6%
Pharmaceuticals	276,272	1.4%
Power producers	3,502,338	17.4%
Other industries	9,574,429	47.4%
Total	**20,189,634**	**100%**

Table 6 Total emissions across industry

As can be seen from the references section and throughout this report, an extensive research exercise has been carried out to gather as much evidence to support the comparison study across the industrial sectors in North West England and North East Wales and the UK's emissions.

From investigative research, it is clear there is disparity between nationwide emissions data collection and transparency of reporting. In some circumstances, inconclusive evidence has been drawn due to several assumed factors:

- Emissions calculation methodology – different sectors require bespoke scientific applications.

- Reporting method of emissions – a sector may not have its own SIC code(s), and/or may be grouped by a wider categorical name.

- Consensus is that SMEs are behind in emissions reporting based on compliance activities such as SECR, ESOS, etc. where mandatory reporting is required for large organisations as defined by Companies Act 2006 (24).

4.4 Emissions Benchmark Assessment

This report assesses the extent in which companies in North West England and North East Wales produce emissions from Scope 1 and Scope 2. The following tables and figures illustrate the CO_2 emissions for the North West industrial sector and uses ETS 2019 data (25) and NAEI 2017 data (26).

The 'Other Industries' sector (in the tables below) is a combined figure of sectors not analysed within the report, whilst they contribute to 29.4%, individually these sectors have the least impact within the North West.

4.4.1 Scope 1

Most of the Scope 1 emissions come from power producing sites.

Sector	Scope 1 Emissions (tCO_2e)	Scope 1 Emissions (%)
Automotive	84,836	0.6%
Cement	2,734,941	19.6%
Chemicals	1,022,506	7.3%
Food and Drink	584,761	4.2%
Glass	473,258	3.4%
Iron and Steel	54,913	0.4%
Paper and Pulp	555,131	4.0%
Pharmaceuticals	139,120	1.0%
Power producers	3,502,338	25.0%
Other industries	4,829,410	34.5%
Public administration	198,464	1.42%
Lime	184,116	1.32%
Pharmaceuticals	139,120	1.00%
Panel board	136,959	0.98%
Other industries	136,152	0.97%
Oil and Gas	99,095	0.71%
Automotive	84,836	0.61%
Ceramics	77,501	0.55%
Non-ferrous metal	59,012	0.42%
Other mineral industries	56,319	0.40%
Total	**13,981,214**	**100%**

Table 4 Scope 1 Emissions per Energy Intensive Sector

4.3 Emissions Ranking

The below table ranks the highest emitters in the North West industrial cluster. The table illustrates that power producers, the cement industry and the oil refinery industry emit a total of 60% of the total industrial emissions within the North West. Therefore measures implemented across these sectors will have the largest impact to the overall cluster.

Sector	Scope 1 tCO_2e	Proportion %
Major power producers	3,467,587	24.80%
Cement	2,734,941	19.56%
Oil refinery	2,201,520	15.75%
Chemicals	1,022,506	7.31%
Ammonia	710,047	5.08%
Food and drink	584,761	4.18%
Waste collection, treatment and disposal	570,783	4.08%
Paper and pulp	555,131	3.97%
Glass	473,258	3.38%
Gas	258,793	1.85%
Public administration	198,464	1.42%
Lime	184,116	1.32%
Pharmaceuticals	139,120	1.00%
Panel board	136,959	0.98%
Other industries	136,152	0.97%
Oil and Gas	99,095	0.71%
Automotive	84,836	0.61%
Ceramics	77,501	0.55%
Non-ferrous metal	59,012	0.42%
Other mineral industries	56,319	0.40%
Iron and steel	54,913	0.39%
Aerospace	53,968	0.39%
Gypsum and plasterboard	38,414	0.27%
Minor power producers	34,751	0.25%
Mechanical engineering	11,836	0.08%
Textiles, clothing, leather and footwear	11,450	0.08%
Commercial	7,664	0.05%
Airport	6,648	0.05%
Asphalt	4,824	0.03%
Processing oil	3,930	0.03%
Water and sewerage	1,916	0.01%

Table 3 NZNW Emissions Ranking

4.2.9 Power Producers

There are several operational power stations in the UK categorised by generation type.
The following graph is cited from **www.statista.com:**

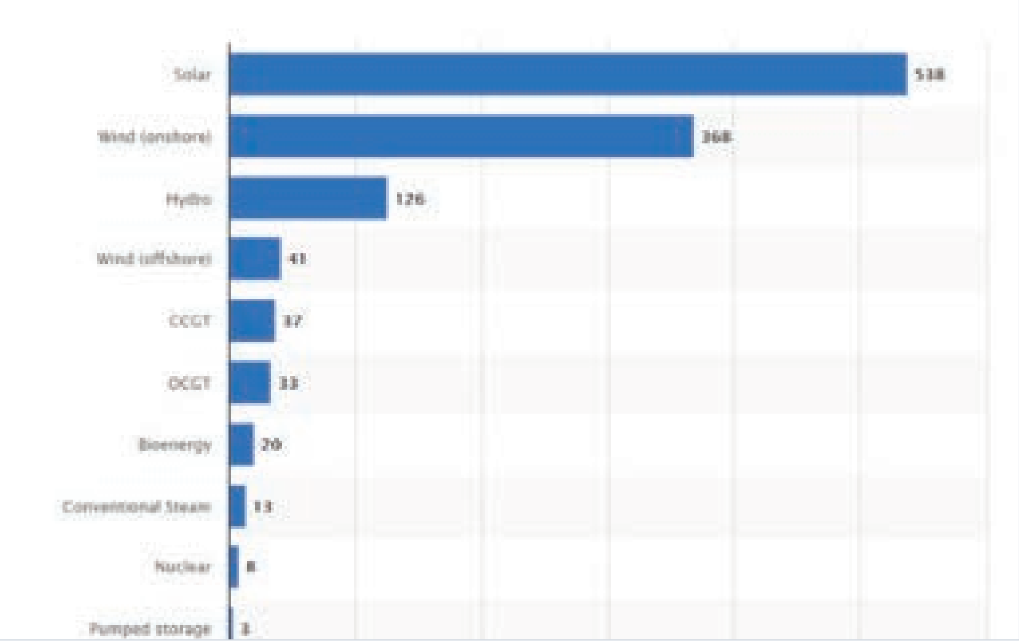

Figure 4 Number of operational power stations in the United Kingdom (UK) as of May 2020, by generation type (21)

According to the 2019 UK GHG Emissions, Final Figures, the report states:

"[this sector] is estimated to have been responsible for 21% of UK greenhouse gas emissions in 2019, with carbon dioxide being by far the most prominent gas for this sector (94%)". (23)

For comparison purposes, it should be noted that this categorisation includes emissions from electricity generation and other energy production activities such as mining, refining, and manufacturing fuels.

From our data set we identified 20 power producers based in the North West, collectively these sites emit 3,502,338 tCO_2e, equivalent to 25% of total cluster emissions – the highest emitting sector. Aforementioned emissions for power producers in North West also include emissions from Fiddlers Ferry power station which closed in 2020. Total emissions have not been adjusted to take into account the closure of Fiddlers Ferry power station as this report does not investigate the net zero strategy for power producers (as this has been covered in the WP6 report).

4.2.6 Iron and Steel

In 2020, the UK steel industry contributed £2 billion to the UK economy in terms of GVA. This was equivalent to 0.1% of total UK economic output and 1.2% of manufacturing output. There are 1,100 businesses in the UK steel industry and in 2019 they produced 7 million tonnes of steel.

The steel industry is a significant contributor and is responsible for 13.5% of GHG emissions from manufacturing and 2% of total UK GHG emissions (19).

From our data set we have only identified one site in the North West which manufactures approximately 500,000 tonnes of metallic coated and pre-finished steel per year. This site emits 54,913 tCO_2e, equivalent to 0.4% of total cluster emissions.

4.2.7 Paper and Pulp

The paper and pulp industry comprises of companies that use wood as raw material and produce pulp, paper, paperboard, and other cellulose-based products.

BEIS has projected that the paper, pulp and print industry will reduce emissions from 1.4 $MtCO_2e$ in 2020 to 1.3 $MtCO_2e$ by 2040 (20).

From our data set we identified 21 sites operated by 15 businesses in the North West providing a variety of pulp, paper, and paperboard. Collectively they account for 555,131 tCO_2e, equivalent to 4% of total cluster emissions (eighth highest).

4.2.8 Pharmaceuticals

The pharmaceutical industry plays a pivotal role in the health of all lives. In 2019, the annual turnover of pharmaceutical wholesalers in the UK was over £51 billion. The UK pharmaceutical market is among the global top 10 national markets, holding 2.5% of the global pharmaceutical market (21).

The pharmaceutical industry has its own unique decarbonisation challenges: a new drug can take significant time and resources to develop, test and take to market. In addition, the varying number of chemical components means they have complicated supply chains. There is inconclusive evidence at this time to demonstrate whether the pharmaceutical industry understood its UK impact on climate change in the form of tonnes (t) or Mega tonnes (Mt) CO_2e from any baseline year, as findings indicate emission tools have been developed and rolled out but returned no high-level figure. Results indicate that this industry is greater than that of the automotive industry. The NHS estimates medicines account for 25% of total emissions from the health service, currently equivalent to 4% of England's total carbon footprint (22).

From our data set we identified 5 companies operating across 7 sites in the North West, collectively they emit 139,120 tCO_2e, equivalent to 1% of total cluster emissions.

4.2 Sector based overview

This section provides a broad outline of how each analysed sector operates, what their function is within the UK economy, and statistics reported of their impact on global warming. Further information on all sectors can be found within Section 9.2. The high-level information has been cross-examined against the industrial large emitting sites contained within the EU ETS and NAEI data sets represented in this report and existing in the NZNW. The following section focuses on Scope 1 emissions as the data has been taken from EU ETS and NAEI.

It should be noted that the total output of emissions for the NZNW industrial cluster is 16,687,296 tCO_2e, equivalent to 0.02% of UK total emissions (2018) (14), with 10,478,876 tCO_2e for Scope 1 emissions and 6,208,420 for Scope 2 tCO_2e emissions, excluding power producers.

4.2.1 Automotive

The automotive sector is a vital part of the UK industry attributing £15.3 billion value to the economy. More than 30 manufacturers build more than 70 different models in the UK which accounts for 13% of total UK export of goods (15). With the future of EV vehicles on the increase, the automotive industry is needed more than ever to help meet the UK's net zero targets.

From our data set we have identified 6 automotive sites in the North West which makes up 0.6% of total cluster emissions, with 84,836 tCO_2e.

4.2.2 Chemicals

The chemical industry is one of the largest in the UK and is a top manufacturing exporter. It adds almost £25 billion of value to the economy with 3,700 business providing over 500,000 jobs. It also has the one of the highest labour productivity rates of £123k GVA per employee (16).

From our data set we have identified 35 sites associated to the chemical sector in the North West at 1,022,506 tCO_2e, this sector is the fourth highest contributor to the overall cluster emissions representing a 7.3% contribution.

4.2.3 Food and Drink

Food and drink accounts for 20% of total UK manufacturing. The Food and Drink Federation (FDF) organisation has stated that in 2018, the sector contributed almost £29 billion to the UK economy, equivalent to 2.3% national GVA. Over 440,000 people are directly employed by the industry across every region and nation in the UK, and it has a very complex supply chain (17).

From our data set we have identified 25 sites across the North West cluster producing a variety of human and pet food and beverages.

This sector emits 584,761 tCO_2e, representing 4.2% of total cluster emissions (sixth highest).

4.2.4 Cement

Cement is used in construction to bind other materials together. Cement emissions contribute to climate change as approximately 50% of emissions of cement production come from limestone ($CaCO_3$) calcination, which happens at high temperatures in a cement kiln to produce lime (CaO). This leads to a release of waste in the form of CO_2, called process emissions. A further 40% of cement emissions come from burning fossil fuels to heat kilns for the calcination process, and around 10% from fuels needed to mine and transport raw materials.

There are 12 manufacturing and 2 grinding/blending plants in the UK cement industry contributing £1 billion to the UK economy.

From our data set we have identified 6 cement sites in the North West accounting for the second highest sector contributor of CO_2 emissions, 2,734,941 tCO_2e; 19.6% representative total emissions.

4.2.5 Glass

The UK large scale glass manufacturing industry includes 10 companies with 17 sites throughout England, Scotland, and Northern Ireland.

The glass industry employs around 6,000 direct staff and indirectly around 150,000 (18).

The glass industry is split into three categories:

1. **Container** – food and drink and pharmaceutical products.
2. **Flat glass** – used in commercial and residential buildings for glazing.
3. **Fibre** – used in numerous manufacturing applications such as wind turbine blades.

Emissions are reported as 1.5m tCO_2 of Emission Trading Scheme (ETS) (site emissions reported under the ETS).

From our data set we have identified 8 glass sites based in the North West. Collectively they account for 473,258 tCO_2e, equivalent to 3.92% total cluster emissions, which is the ninth highest.

Figure 3 Sector breakdown of industrial sites in the North West, shows the breakdown of sectors contained within the data set of industrial sites studied in this analysis. Industrial sites are colour coded to illustrate the variety of sectors and their distribution in the North West. Cheshire contains the greatest number of industrial sites whereas, Greater Manchester and Merseyside are the most densely populated areas considering the size of their respective regions. Cumbria contains the least number of industrial sites even though it has the biggest land area.

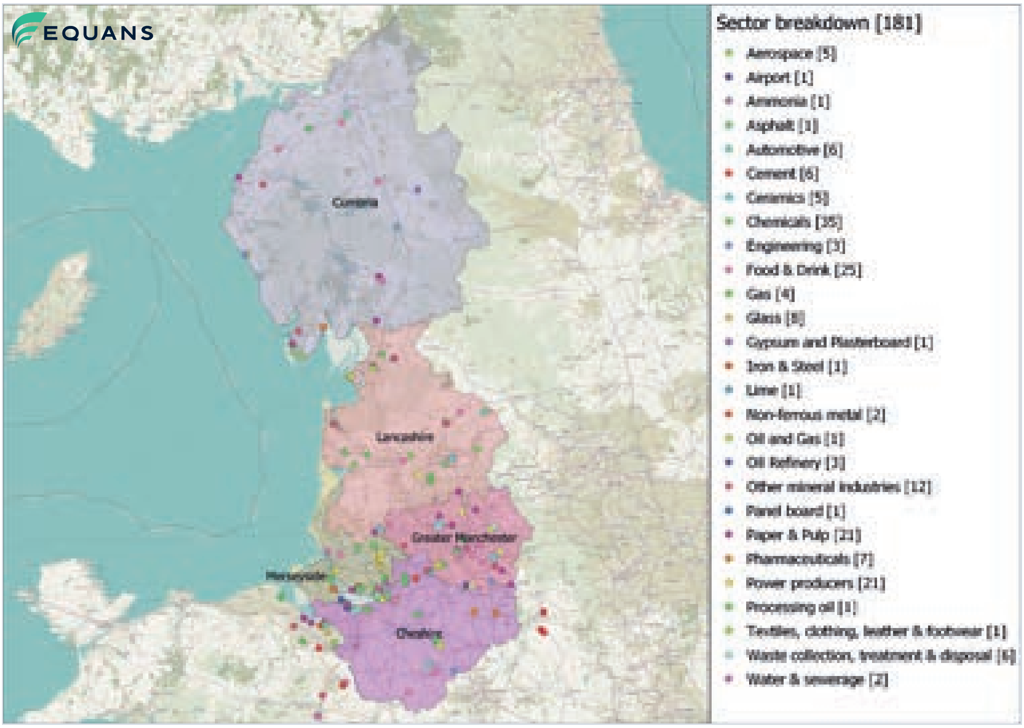

Figure 3 Sector breakdown of industrial sites in the North West

Paper and pulp and the food and drink industry are the most common sectors within Cumbria. Most of the sites in Lancashire are located around Preston and Blackburn and include chemical, power producers and other mineral industries. The main sectors in Greater Manchester are paper and pulp, food and drink, and power producers. Around half of the industrial sites are located within a 5-mile radius of Manchester city centre and the rest are sparsely spread.

Chemicals, glass, and pharmaceuticals are the most common sectors within Merseyside. Liverpool city contains half of the industrial sites whereas St. Helens contain a small cluster. Over 50% of pharmaceuticals sites in the North West are located within Merseyside. Chemicals is the most common sector within Cheshire and 60% of all chemicals sites within the North West are in Cheshire. Food and drink, paper and pulp and power producers also have a strong presence in the region.

4.1 Sectors represented

The analysis included in this report is based upon EU ETS and NAEI emitters in the North West as mentioned in Section 3. The list of industrial sites is broken down into 27 sectors with 181 industrial sites. The table below outlines the number of sites against each sector.

Sector	Number of Sites
Aerospace	5
Airport	1
Ammonia	1
Asphalt	1
Automotive	6
Cement	6
Ceramics	5
Chemicals	35
Engineering	3
Food and Drink	25
Gas	4
Glass	8
Gypsum and Plasterboard	1
Iron and Steel	1
Lime	1
Non-ferrous metal	2
Oil Refinery	3
Oil and Gas	1
Other mineral industries	12
Panel board	2
Paper and Pulp	21
Pharmaceuticals	7
Power Producers	20
Processing oil	1
Textiles, clothing, leather and footwear	1
Waste Collection, Treatment and Disposal	6
Water and sewerage	2
Total	**181**

Table 1 EU ETS 2019 and NAEI 2017 sites in the North West Industrial Cluster

Sector	Number of Sites %
Aerospace	2.8%
Airport	0.6%
Ammonia	0.6%
Asphalt	0.6%
Automotive	3.3%
Cement	3.3%
Ceramics	2.8%
Chemicals	19.3%
Engineering	1.7%
Food and Drink	13.8%
Gas	2.2%
Glass	4.4%
Gypsum and Plasterboard	0.6%
Iron and Steel	0.6%
Lime	0.6%
Non-ferrous metal	1.1%
Oil Refinery	1.7%
Oil and Gas	0.6%
Other mineral industries	6.6%
Panel board	1.1%
Paper and Pulp	11.6%
Pharmaceuticals	3.9%
Power Producers	11.0%
Processing oil	0.6%
Textiles, clothing, leather and footwear	0.6%
Water and sewerage	3.3%
Waste collection, treatment and disposal	1.1%
Total	**100%**

Table 2 ETS 2019 and NAEI 2017 % sites in the North West Industrial Cluster

The four industrial sites featured in the figure have been awarded grant funding as part of IETF Phase 1. The details of the sites are as follows (13):

- **Encirc Ltd – Glass sector**

The project involves the implementation of a new control system for the furnace forming-section which will integrate two separate areas of production processes into one system. This in turn will enable the operators to maximise process efficiency through optimising the energy safety-margin and will result in energy savings. The new control systems will also enable the deployment of future decarbonisation measures such as hydrogen fuels and light-weighting containers. The project has received a £2.5m grant for the total project cost of £6.2m.

- **James Cropper Plc – Paper and pulp sector**

This project entails a feasibility and engineering study into advanced waste heat recovery at the paper mill site. It is aimed to reduce reliance on natural gas through understanding key technologies in recent commercial heat recovery applications. The project has received £74k for the total project cost of £148k.

- **Essar Oil (UK) Ltd – Oil refinery sector**

The project aims to upgrade a major distillation unit with a new, net-zero ready furnace which will be able to deliver energy efficiency improvements through heat recovery, eliminating oil firing and reduction in other pollutants such as NOx. The furnace will also be designed for 100% hydrogen firing and ready to utilise carbon-free hydrogen from the proposed Hynet project. The site is thought to be the first UK oil refinery furnace specifically designed to run on 100% hydrogen. The project has received £7.2m for the total project cost of £24.2m.

- **Rick Bestwick (North West) Ltd – Food and drink sector**

The project aims to maximise energy efficiency opportunities at the site through upgrades and enhancements of equipment. Through this project the next generation of cold storage technology may be applied to the existing building infrastructure. The project will provide a guide to practical implementation for retrofitting energy efficiency measures in this sector. The project has received £250k for the total project cost of £766k.

Cumbria and Lancashire lie outside of the proposed Hynet project, with 50 out of the 181 sites within the North West equating to 27% share. Hence, Cumbria and Lancashire regions as well as industrial sites within Merseyside, Greater Manchester and Cheshire that are not able to connect to the hydrogen network will require a different path for decarbonisation of combustion of fossil fuels such as on-site solutions.

In addition to Hynet, there are other enabling projects in the region to replace fossil fuels (2). Leyland CNG fuelling station in Lancashire currently uses 100% renewable certified gas. A pilot project is being carried out in Cheshire to consider the storage of green (renewable derived) hydrogen. Pilkington Glass at St. Helens, Merseyside has successfully manufactured architectural glass using hydrogen power in a world-first trial in 2021. At the same time, Tata Chemicals Europe site at Winnington, Cheshire has implemented the first large-scale carbon capture project of its kind in the UK. The project captures and purifies the CO_2 from the gas-fired CHP plant generation and utilises it as a key raw material in later processes. The project cost £18 million and it was 25% part funded by BEIS. It will save an estimated 40,000 tCO_2e every year. Several key organisations have already committed to and are undertaking suitable measures to address energy efficiency and low carbon heating for the industrial and commercial sectors in the North West (2).

The creation of Protos, an energy resource hub, near Ellesmere Port further demonstrates the actions taken to decarbonise energy supply in the North West. Protos is being developed by Peel NRE, part of Peel L&P as a cluster of complementary businesses with the aim of providing access to energy, skills, support and resources, and a co-located supply chain in the region. Protos brings together innovative technologies in energy generation and resource management that are leading the way on the clean growth agenda such as energy from waste, timber recycling and plastic to hydrogen facilities and bio-substitute natural gas (BioSNG) plants. They will deliver low carbon energy direct to the industrial and domestic customers through a local energy grid which can result in substantial reduction of cost and carbon emissions (11).

The North West has a substantial potential for, and examples of, renewable energy generation in the region. The high tidal range in Liverpool Bay and the Mersey estuary provides a unique opportunity to reliably generate abundant and predictable long-term renewable energy. Therefore, Mersey tidal power project is seen as an important part of the whole energy system integration of electricity, storage, and hydrogen, providing resilience in the wider regional network (2).

Large scale solar PV application examples in the region include Bentley’s factory in Crewe with an installed capacity of 7.7 MW. The panels are installed on the rooftop and carport, and the generation output is able to meet all in house operational demand. Onshore wind in the North West has a significant role to play in decarbonisation. However, the deployment rate needs to be accelerated despite the current challenging planning constraints for new onshore wind farms. The North West should use its links to construction and supply chain for offshore wind farms to sustain a growth for onshore wind farms as well (2).

Figure 2 Regional breakdown of the North West and industrial sites also illustrates the industrial sites which have been awarded grant funding by the Industrial Energy Technology Fund (IETF), managed by BEIS. The UK government announced £315 million of funding in 2018 which will be available until 2025. IETF is aimed to help businesses with high energy use to cut their bills and carbon emissions through investing in energy efficiency and low carbon technologies. It is divided into two phases where Phase 1 supports the development of energy efficiency and decarbonisation studies, and Phase 2 expands the scope to support the deployment of decarbonisation technologies (12).

4. North West Industrial Cluster Overview

The North West industrial cluster stretches from Cheshire in the South, Manchester in the East, and Cumbria in the North, covering the entirety of the North West of England. The region contains the cities of Liverpool and Manchester and the suburban areas that are surrounding, as well as a significant number of industrial zones, electricity generators, offshore wind farms and gas storage sites (including Stublach). Several projects and consortiums in the region have been funded through recent government funding schemes, to support the development of hydrogen, CCUS and industrial decarbonisation.

Figure 2 Regional breakdown of the North West and industrial sites, illustrates the breakdown of regions in the North West of England into Cumbria, Lancashire, Greater Manchester, Merseyside, and Cheshire as well as the geographical spread of industrial sites studied in this analysis. Data sources of these industrial sites were discussed in Section 3. Cumbria, Lancashire, Greater Manchester, Merseyside, and Cheshire represent the following number of industrial sites respectively; 20, 30, 31, 30 and 70. The figure also demonstrates the geographical extent of the proposed Hynet project in terms of indicative hydrogen and CO$_2$ network. Data sources, year of origin and proximity of industrial sites to indicative hydrogen network is further discussed in the WP5 Electrolytic Hydrogen report.

The proposed Hynet umbrella of projects, led by Progressive Energy, is a significant project in the North West as it collectively drives the region to meet its net zero target through over £1bn of investment. Main workstreams within the proposed Hynet are the development of a blue (gas derived) hydrogen and CCUS network. It is the UK's leading low carbon hydrogen and CCUS project, offering a low-cost, low risk route to decarbonising North West industrial cluster as well as other sectors of the regional economy.

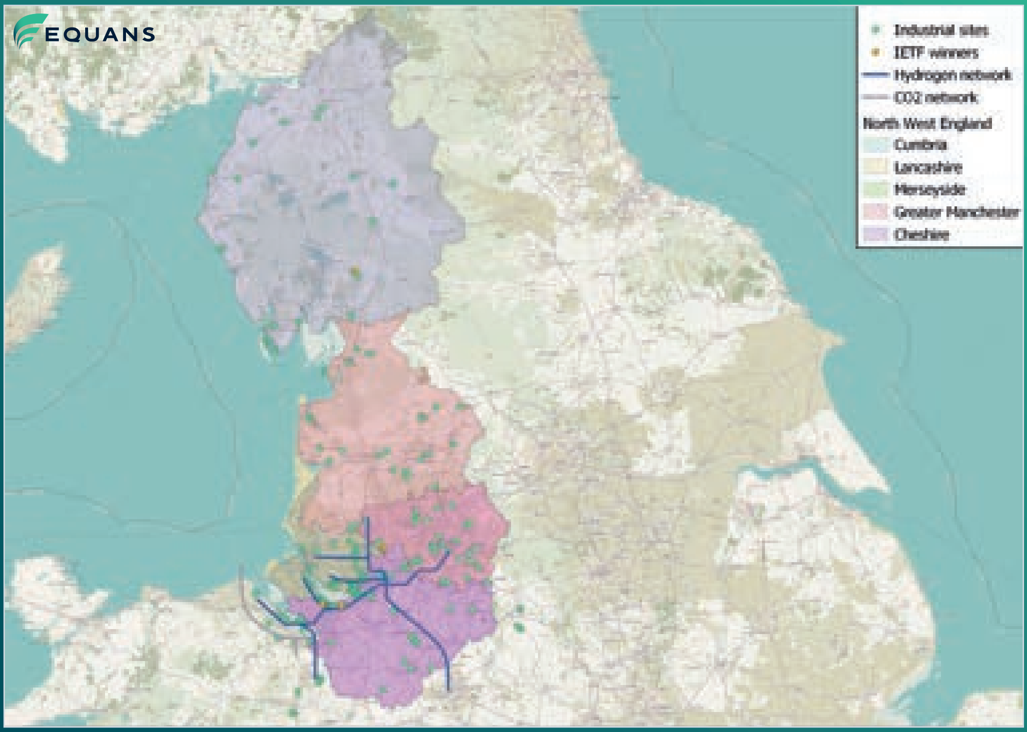

Figure 2 Regional breakdown of the North West and industrial sites

EQUA

5.7 Funding Available

The government recently consulted on two significant support mechanisms to support hydrogen producers, namely the Net Zero Hydrogen Fund which will provide CAPEX support, and the Hydrogen Business Models, which will provide revenue support. These producer-led support schemes are further explained within *EQUANS' Electrolytic Hydrogen Recommendations Report*. However, demand side support will also be important to support consumers with the CAPEX associated with converting plant equipment, such as the Industrial Energy Transformation Fund (IETF).

5.7.1 Industrial Energy Transformation Fund (74)

The IETF is a grant which supports high energy consuming industrial sites with aspirations to achieve a low carbon future. The IETF is aimed at industrial processes which will help companies:

- cut energy bills by investing in more efficient technologies, and

- reduce emissions by bringing down the costs and risks associated with investing in decarbonising technologies.

BEIS manage the UK government's £289m grant commitment through the IETF which is split across two phases.

PHASE 1 (2021 – Q1 and Q2)

Up to £40m of funding was made available for all companies with SIC codes between 10-33 and data centres for:

- projects deploying technologies that improve the energy efficiency of industrial processes, and
- feasibility and engineering studies into energy efficiency and deep decarbonisation measures for industrial processes.

The grant thresholds were:

Funding applied for	Minimum threshold per application	Maximum threshold per project
Energy efficiency deployment projects	£100,000	£14 million
Engineering studies	£50,000	£14 million
Feasibility studies	£30,000	£7 million

Table 30 IETF Phase 1 Grant Threshold

PHASE 2 (2021 – Q3 and Q4)

Up to £60m of funding was made available specifically for companies with; mining and quarrying processes (SIC codes between; 05101-05200, 07100-08990 and 09900); manufacturing processes (SIC codes between 10000-33200); recovery and recycling of materials processes (SIC code 38320); and data centres (SIC code 63110) for:

- studies - feasibility and engineering studies to enable companies to investigate identified energy efficiency and decarbonisation projects prior to making an investment decision,

- energy efficiency - deployment of technologies to reduce industrial energy consumption, and

- deep decarbonisation - deployment of technologies to achieve industrial emissions savings.

The grant application window opened on 27/9/2021and closed on 6/12/2021.

The grant thresholds available were:

Funding applied for	Minimum threshold per application	Maximum threshold per project
Energy efficiency deployment projects	£100,000	£14 million
Deep decarbonisation deployment projects	£100,000	£30 million
Engineering studies	£50,000 (total eligible cost)	£14 million
Feasibility studies	£30,000 (total eligible cost)	£7 million

Table 31 IETF Phase 2 Grant Threshold

Further details can be found here

CO_2 can be captured from a range of sources, including the air, and transported by pipeline or ship for use or permanent storage. Different terminology is often adopted when discussing CCS technologies, as detailed below.

- Carbon capture and storage: includes applications where the CO_2 is captured and permanently stored

- Carbon capture and utilisation (CCU) or CO_2 use: includes where the CO_2 is used, for example in the production of fuels and chemicals

- Carbon capture, utilisation and storage: includes CCS, CCU and also where the CO_2 is both used and stored, for example in EOR or in building materials where the use results in some or all of the CO_2 being permanently stored.

As discussed previously, the HyNet project is exploring low carbon energy generation for the North West cluster, and includes carbon capture and storage as part of the project proposal, demonstrated below in figure 41.

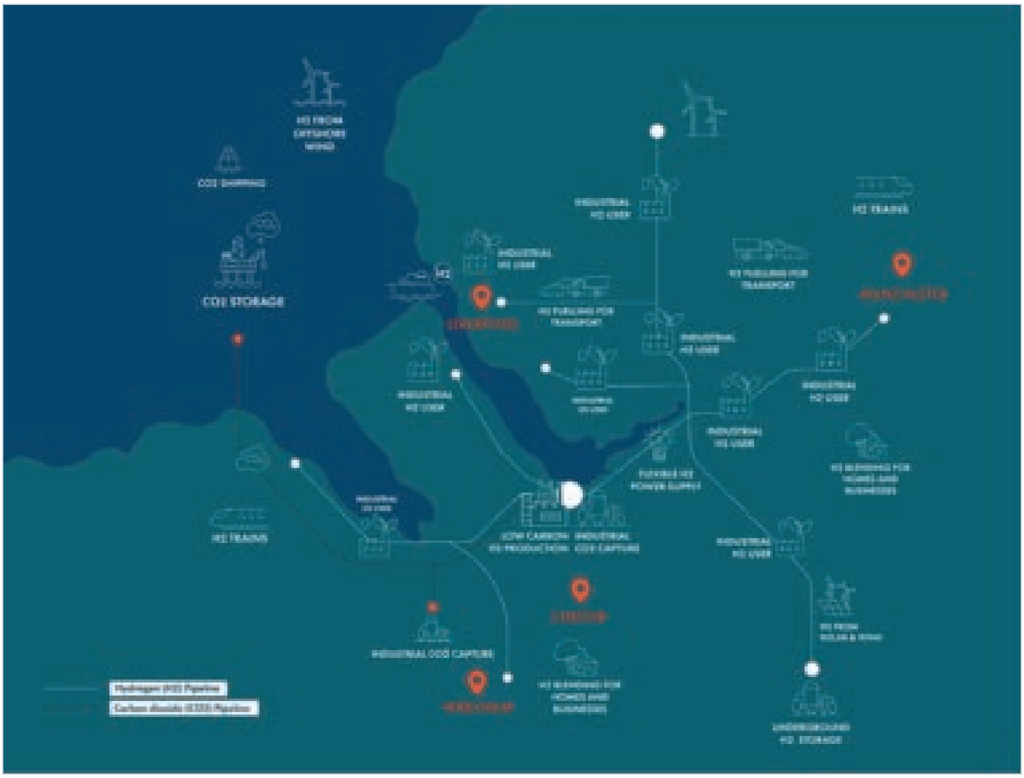

Figure 41 Proposed HyNet Project including Industrial CO2 Capture and Storage (63)

Phase 1 of the proposed HyNet project includes development of the infrastructure for capture and storage of CO_2 (63). There are also numerous pilot and demonstration scale projects in operation as well as significant CCS RandD activity.

5.6 Carbon Capture and Storage (CCS)

CCS will need to form a key pillar on the path to net zero emissions. A net zero energy system requires a profound transformation in how we produce and use energy that can only be achieved with a broad suite of technologies. Alongside electrification, hydrogen and sustainable bioenergy, CCS will need to play a major role. It is the only group of technologies that contributes both to reducing emissions in key sectors directly and to removing CO_2 to balance emissions that cannot be avoided – a critical part of net zero. (72)

CCS facilities have been operating for decades in certain industries, but they are still a work in progress in the sectors that need them the most. CCS has primarily been used in areas such as natural gas processing or fertiliser production, where the CO_2 can be captured at relatively low cost. But in other areas, including cement and steel, CCS remains at an early stage of development. These are the sectors where CCS technologies are critical for tackling emissions because of a lack of alternatives.

CCS refers to a suite of technologies that involves the capture of CO_2 from large point sources, including power generation or industrial facilities that use either fossil fuels or biomass for fuel. The CO_2 can also be captured directly from the atmosphere. If not being used on-site, the captured CO_2 is compressed and transported by pipeline, ship, rail or truck to be used in a range of applications or injected into deep geological formations (including depleted oil and gas reservoirs or saline formations) which trap the CO_2 for permanent storage. The extent to which CO_2 emissions are reduced in net terms depends on how much of the CO_2 is captured from the point of source and how the CO_2 is used. The use of the CO_2 for an industrial purpose can provide a potential revenue stream for CCUS (Carbon Capture, Utilisation and Storage) facilities.

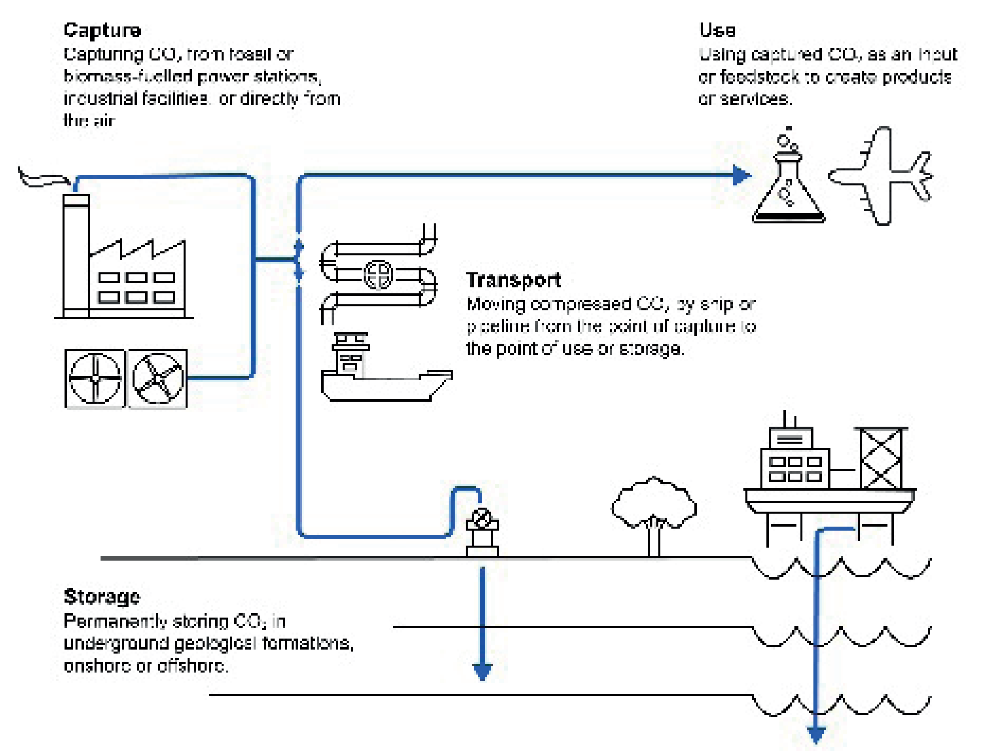

Figure 40 CCS Schematic (73)

As a result of utilising an electrolyser to produce hydrogen rather than through steam reforming, the carbon input can be reduced to zero. Further requirement for the input of renewable energy is needed for the Haber-Bosch process to fully decarbonise the system (70). See figure 39.

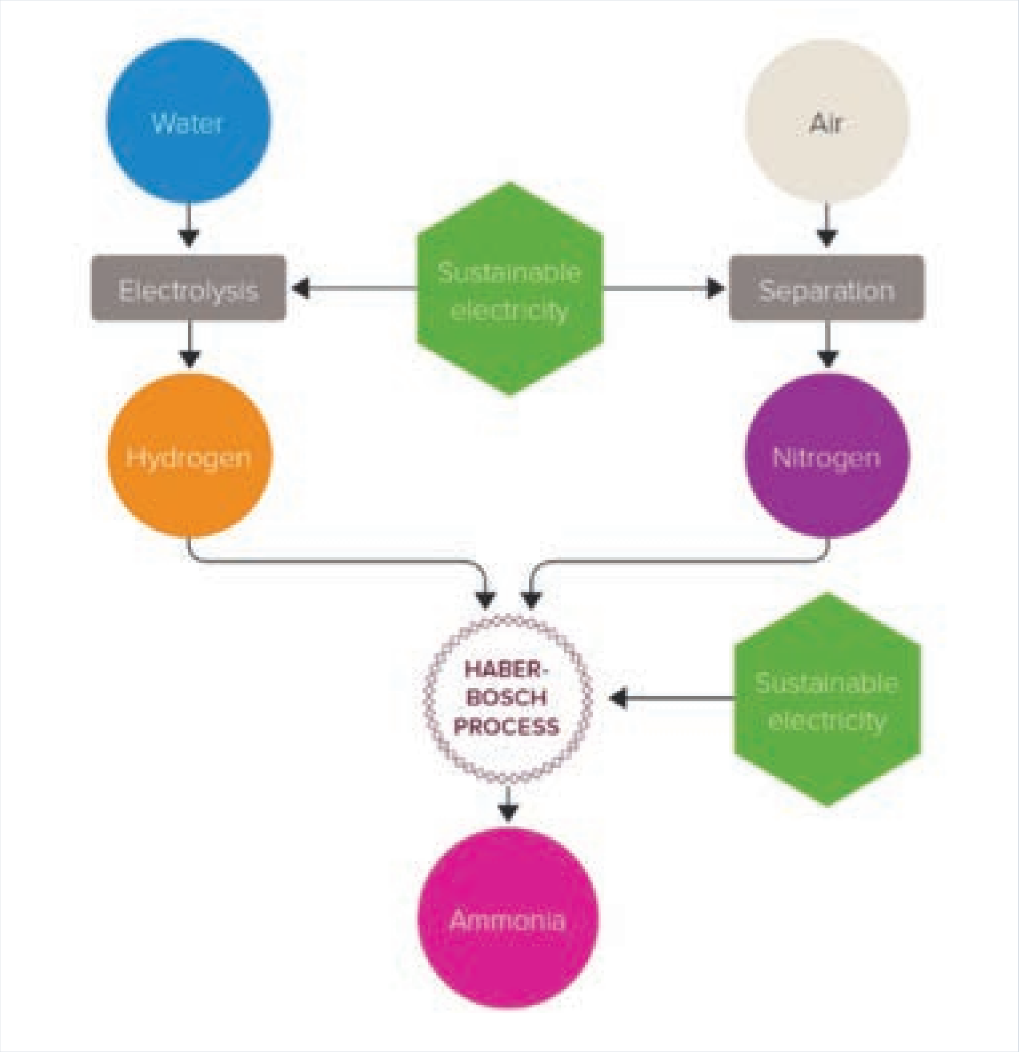

Figure 39 Green Ammonia Process (152)

5.5.5.3 Glass Industry

As stated previously, the glass industry's carbon emissions are produced from direct fired equipment which are part of the manufacturing process rather than through conventional combustion equipment.

The glass industry has recently undertaken successful trials to operate using hydrogen gas rather than natural gas within the glass manufacturing float process. The glass float process already applies hydrogen to stop molten tin from oxidising whilst the molten glass is undertaking its curing process.

However, the recent testing used hydrogen fuel gas to the heating process which takes place before curing, heating the glass to approximately 1000°C over a heating cycle process (71). The makes the glass turn to a liquid state so it can be then fed onto a molten tin pool where working takes place to form the final thickness of the sheet of glass. Because this process is widely used throughout the industry and is a considerable output to emissions for the glass sector, the fuel change presents significant carbon reduction.

5.5.5 Hydrogen Utilization - Manufacturing Processes

The difficulty presented for the industrial user is being able to move certain processes away from the existing use of natural gas or oil to hydrogen fuel with little to no interruption upon manufacturing and production. Certain industries such as glass and ceramics require natural gas for direct fired processes as part of the manufacturing of the product. The fuel is applied directly into kilns and furnaces with the product responding to the temperature and combustion characteristics. Other industries such as vehicle manufacturing require a large portion of their gas use for space heating. The food and drink sector, which accounts for 14% of the emissions produced in North West England and North East Wales, predominantly uses natural gas for steam, high and/or low temperature hot water production. These are simpler to resolve the issue of decarbonisation through switching fuels. Therefore, sector and government road maps for decarbonisation rely heavily on the implementation of hydrogen used within existing combustion equipment. This would be a *'do nothing'* scenario due to the changes being significantly reliant on external parties and the influence of technological developments.

Section 6 of this report details the current emissions generated for each sector. These roadmaps illustrate what the indicative carbon producers are and ways to mitigate these towards a net zero carbon future. This highlights that a large portion of some industries are using natural gas to produce heat and therefore rely on the integration of hydrogen fuel to achieve the set targets for the industry. Another consideration is the requirement for green electricity to fully support industrial processes embarking on a net zero carbon future. Hydrogen fuel can reduce the carbon emissions, however, further consideration is required to allow for complete decarbonisation in certain industries and processes.

5.5.5.1 Oil Refineries

Hydrogen can be used in several hydrodesulphurisation (HDS) and hydrocracking processes. The first being a catalytic chemical process to remove any sulphur from natural gas or refined petroleum products e.g., petrol, kerosene, and diesel, while the latter takes the heavier products of the refinery industry and cracks large molecules into smaller more desirable ones. The oil refinery industry in the UK produces a significant amount of hydrogen which could be utilised both onsite and transported for use off-site (67). These processes centre around the generation of hydrogen through steam reforming, which is common within oil refineries throughout the refinement process of crude oil. Existing refineries throughout Europe are undertaking research around the integration of green hydrogen within certain processes, removing the need for methane from steam methane reformation (SMR) process to produce hydrogen. This has led to the integration of a 'behind the meter' (like the diagram shown in Figure 37) approach with onsite hydrogen production plants feeding into the existing processes. This would result in a significant drop in natural gas input to the site and therefore, a reduction in carbon emissions.

5.5.5.2 Ammonia Production

The Haber Bosch process, the main method used for ammonia production, combines both hydrogen and nitrogen at a ratio 3:1. Usually hydrogen used in these plants is produced via the SMR method. The ammonia industry accounts for approximately 55% of global hydrogen consumption (68). The manufacturing process for ammonia produces hydrogen through steam reforming to enable the production of ammonia. This process is shown below (Figure 38).

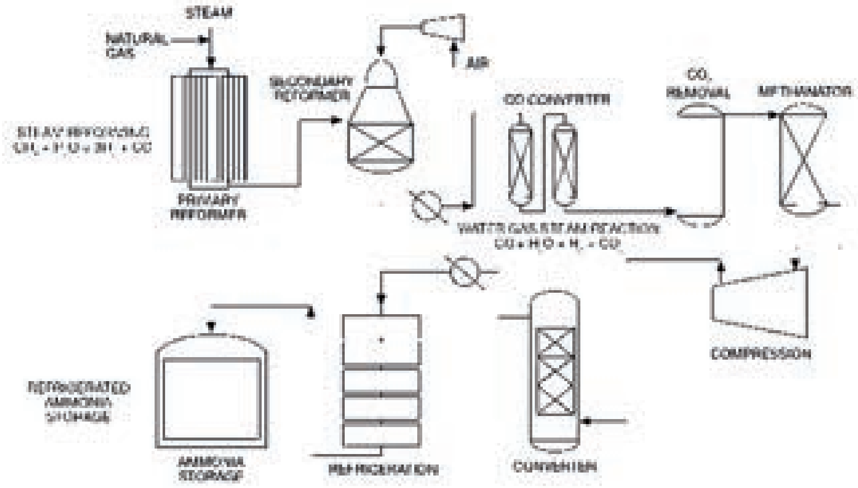

Figure 38 Ammonia Production Schematic (69)

as it is appreciated that space can often be a commodity on industrial sites. This provides a required energy input of 39 kW for the nine hours of hydrogen production due to 0.71 kWh/kg energy input to compress per kg. The required storage is calculated to a total of 100,000 L storing hydrogen at a pressure of 100 barg, storing approximately 25 MWh of hydrogen fuel.

Once the renewable technology no longer produces electricity after the nine hour period, the system assumes switching to a CHP system. The CHP selected is based on existing technology which is commercially available to run on 100% hydrogen fuel (66). This CHP system has an output of 750 kWe and 747 kWth and requires a supply of 54.6 kg/hr of hydrogen, thus allowing for a total of eleven hours of continuous operation.

It is found that with this process, applying existing technology, and the site being able to fully utilise the electrical and thermal energy generated by the CHP system, an overall efficiency of approximately 52.5% can be found. This would require further review and a detailed analysis of the process on a site-by-site basis. Also, with ongoing improvements with the technologies applied, this efficiency will increase providing a lower payback.

Figure 37 shows a diagram of a similar process of an engine gas turbine hydrogen conversion demonstration project

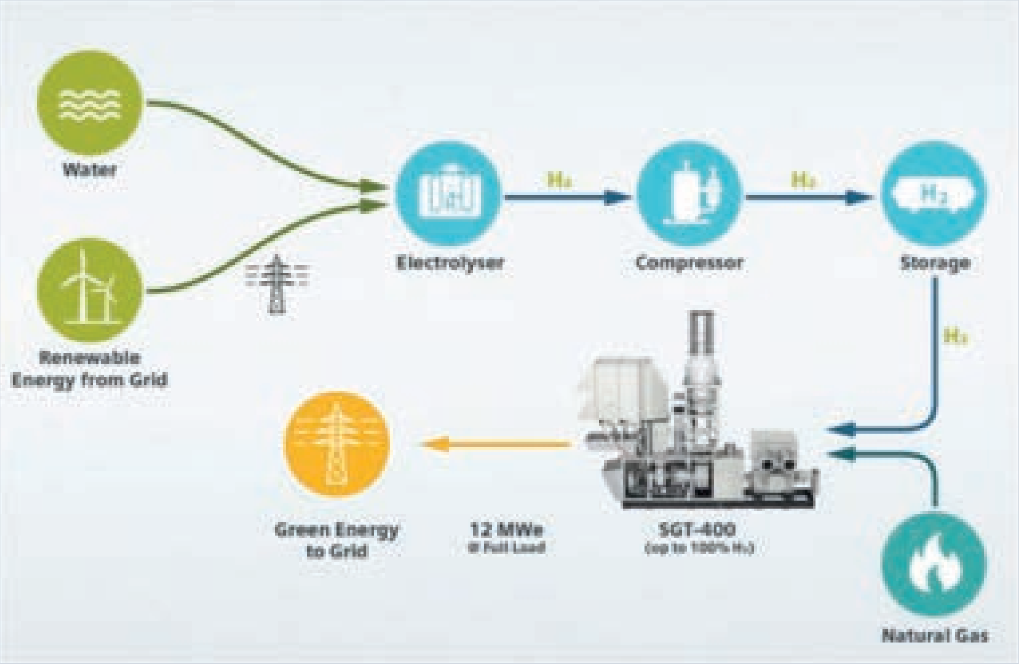

Figure 37 Hydrogen production with CHP integration (157)

5.5.3 Hydrogen Utilisation

This report details areas of decarbonisation through electrification and lower carbon technologies all considering the application of hydrogen fuel.

The review of hydrogen fuel used with existing technologies and low carbon alternatives has been explored within this report, comparing the use of hydrogen within a CHP and HP system. The analysis conducted within work package 5 specifies the generation of hydrogen throughout various locations in the North West, with the input of electricity from renewables and other low carbon technology such as Small Modular Reactors (SMR) using nuclear technology. This is to allow for sufficient distribution of the fuel to maintain the same amount of combustion plant within the area for industrial processes, and therefore allowing other areas of the industry such as peaking plants to become fully decarbonised when used to support the National Grid. However, the process of converting electricity into hydrogen fuel, then combusting it in a boiler or CHP system for power and heat is not particularly efficient. Due to the existing equipment, within the entire process a site can expect approximately 50-55% overall efficiency. This is considering the initial electrical generation equipment such as wind turbines, the process of electrolysis, transmission losses and pressurisation of the gas for storage and finally combustion within an industrial site.

However, *EQUANS' Electrolytic Hydrogen Recommendations* emphasises the ability to produce hydrogen fuel with a high degree of versatility, unlike oil and natural gas which are governed by location, thus creating a monopoly. The key motivation for the application of hydrogen gas is the ability to become carbon neutral when utilising combustion plant. This would enable existing older methods of heat generation and onsite electrical generation to continue operating within a future market.

Hydrogen fuel provides a feasible application for energy storage beyond battery storage. The significant difference hydrogen storage offers is the ability for it to be produced at a location, transported, and then used in another location. It should be noted that there are restrictions on how much hydrogen can be transported in bulk.This is something battery storage is not able to facilitate which emphases the versatility of the fuel type. Fuel switching allows for a completely carbon neutral solution to existing combustion fuels. It will enable industrial sites to remove the use of conventional combustion methods of producing thermal energy, alleviating the demand of hydrocarbon fuels. It is understood that certain direct firing processes currently do allow for fuel switching, however, ongoing research has proven benefits to moving away from natural gas.

5.5.4 Hydrogen Behind The Meter

As well as network connected solutions, behind the meter solutions are also available for hydrogen production. In this case, an electrolyser would be installed behind the meter allowing a consumer, or a group of consumers, to produce the necessary hydrogen on site. In *EQUANS' Electrolytic Hydrogen Recommendations Report*, three behind the meter sites were modelled to understand how different variables would impact the cost of producing hydrogen on site. These variables included the amount of hydrogen needed, the demand profile, the availability of renewables and wider system constraints. As was demonstrated in this report, these factors can significantly impact the cost of hydrogen, demonstrating the requirement to consider them early in the feasibility process. This is further discussed in the Project Blueprints section of that report.

Drawing upon this work, in this report, EQUANS examines an application for a behind the meter solution, discussing some practical implications of the system design. This application involves incorporating renewable electrical production, used for balancing fluctuating grid power, in the form of gas to power systems (64), providing an alternative to energy storage beyond battery technology.

This process requires a renewable electricity source; wind turbines and solar panels have been selected for the review. The system is designed so that a portion of the output of the renewable generation is fed to the site, supplementing the electrical demand with the remaining feeding into an electrolysis plant.

The average modelled data illustrates an average operation of nine hours per/day for wind turbine generation. Therefore, this has been the selected figure to support the model at a constant output of 4,200 kW. From this 4,200 kW, only 720 kW shall feed into the site demand with the rest being used to power the hydrogen production process. Based on the input requirements, the turbine shall provide enough electricity to produce approximately 600kg of hydrogen fuel.

A further parasitic load for the system is the compression of the hydrogen fuel to ensure its suitability for storage. Pressurising the gas minimises the required footprint on site

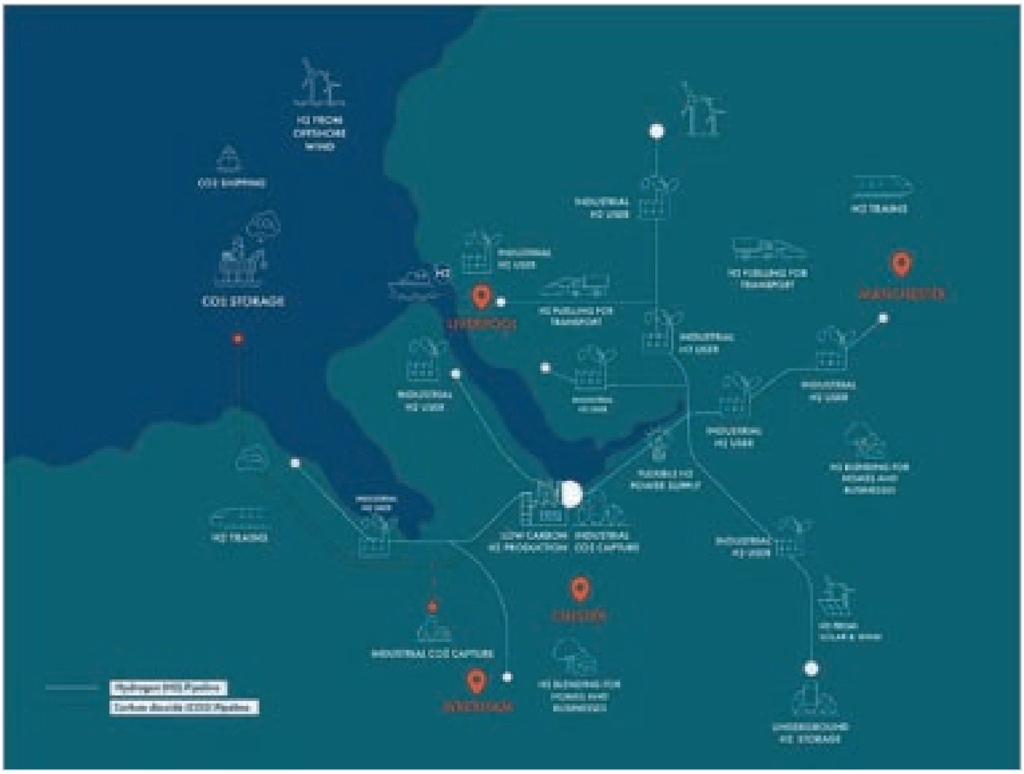

Figure 36 proposed HyNet project (63)

The review of the generation and distribution has been undertaken within this document, specifying locations which would be ideal for hydrogen generation based on consumption. Therefore, this report shall not repeat the work carried out in that section but will refer where required.

5.5.1 Grey and Blue Hydrogen

Grey and blue hydrogen account for approximately 80-90% of hydrogen generated worldwide. This is produced typically from the process of steam reforming which requires temperatures between 700 -1100ºC. A metal-based catalyst, normally nickel, causes steam to react with methane to yield carbon monoxide (CO) and hydrogen. The endothermic process of steam reforming can be improved to produce more hydrogen by using a process called the 'water-gas shift reaction', in which CO and steam are reacted with a catalyst.

The significant difference between the two processes is that blue hydrogen uses carbon capture to reduce the carbon emissions emitted from the system.

5.5.2 Green Hydrogen

The process of green hydrogen production centres around the application of electrolysis which can be classified as an entirely carbon free process. There are a range of different methods of electrolysis systems used with the most common being Proton Exchange Membrane (PEM) which does not require additional electrolytic solution. This is due to the polymer electrolyte membrane being the catalyst for ion transfer.

5.5 Hydrogen

Hydrogen is one of the most abundant elements throughout the universe and is one of the most common elements on Earth. One of the significant benefits of utilising hydrogen as a fuel is that it produces no carbon emissions during the process of combustion as no hydrocarbons are present in the fuel. Hydrogen, unlike fossil fuels, is not available within nature in its usable form (60), processes including steam reforming and electrolysis can be used.

This section discusses the implications for hydrogen use at a local point with further considerations for generation and distribution to industrial consumers upstream of a site. This is covered in detail within *EQUANS' Electrolytic Hydrogen Recommendations* document which shall be referenced to provide a holistic view on the landscape of the new fuel. Industrial site integration is one of the key areas for review of specific sites when hydrogen fuel becomes available.

Most manufacturers are now aligning their technology to a potential change in fuel to meet the demands of industrial users. Manufacturers of equipment such as boilers and gas fired CHP systems (61) have published figures that state a 25-30% blend of hydrogen with existing fuels requires no change to the equipment. This would include boiler burners or gas engine ignition systems. When a site looks to carry out a full fuel change from natural gas to hydrogen, a review of the combustion equipment would be needed. This would include items such as a gas train and burner for boiler equipment with additional auxiliary equipment such as gas boosters.

- Existing gas engines would require a gas train change, modifications to injection systems and currently would require de-rating to 75% output, due to the poor knock resistance of the hydrogen fuel when switching from natural gas. Additional equipment such as turbo bypass valves may need to be changed depending on the manufacturer.

- Existing boiler equipment can be modified as mentioned with a new burner and ignition systems, however, beyond 20-30% this is not sufficient. New boiler plants installed will have to be specified as hydrogen ready which means current technology will have to be oversized to account for a larger heat transfer area. This is the largest change to existing equipment but means that an existing boiler shell and tube arrangement would not produce the required output.

- Safety equipment such as gas leak detection would need to be upgraded to account for the different type of gas, in addition to this, further risk assessments governed by current gas regulations would need updating for a site. With existing practices for testing piping systems using nitrogen gas, the same system can leak when hydrogen gas is used (62). This is due to hydrogen having a much lower kinetic diameter than methane, therefore it possesses the ability to leak past joints that would hold natural gas.

- The Hynet scheme includes the use of underground storage of hydrogen fuel and has been considered within the modelling for the feasibility for the network infrastructure. However, if there is a need for onsite storage, local systems would need to be purpose built for hydrogen gas. Aside from leakage, hydrogen embrittlement can occur which can lead to high strength metals failing at stresses below yield stress. As such, 316 stainless steel is becoming popular for hydrogen storage applications with higher pressure systems using composite materials.

Hynet is undertaking the review and research of a fully integrated hydrogen network spanning the North West of the UK. This is not conducted as a theoretical report but as a system that can be implemented forming part of the UK's commitment to achieving a 100% carbon emission reduction by 2050. Figure 36 proposed HyNet project illustrates the plan for the hydrogen network being implemented as detailed within WP5 *EQUANS' Electrolytic Hydrogen Recommendations*.

5.4.6 Rankine Cycle

Rankine cycle is a process where heat is converted into mechanical work, which in turn can be used to generate electricity. A common example for this process is steam Rankine cycle which is used in power stations to convert high temperature steam into electricity. Organic Rankine Cycle (ORC) can do the same with low-grade heat (90-500°C). Hence, ORC is an important energy generation opportunity at industrial sites with waste heat from industrial processes or from internal combustion engines, gas turbines and fuel cells operating on open cycle.

ORC is fuel flexible which means that the site can be fuelled by natural gas, biomass, residual waste, or hydrogen. This flexibility allows the technology to be adapted to the changing fuel type over the lifetime of the plant in decarbonising its energy demand. Figure 34 illustrates the working principle of ORC. The ORC process enables electricity and steam generation on site which can be consumed on site or exported to the grid or nearby users.

There are numerous plug-and-play models readily available as commercially viable solutions within the market. Implementation of ORCs are not complex and can very easily be adopted where a feasibility study is carried out and funding is provided. ORCs are particularly suitable for energy intensive industries such as cement, steel, glass, ceramics and, non-ferrous metals sectors. Figure 35 shows the breakdown of industrial sites per sector and region in the North West where the ORC technology may be suitable for energy generation. Estimated nominal cost of ORC per kW is between £2,000 - 3,000 with a payback of under five years depending on application, operating temperatures, and size of installation (58) (59).

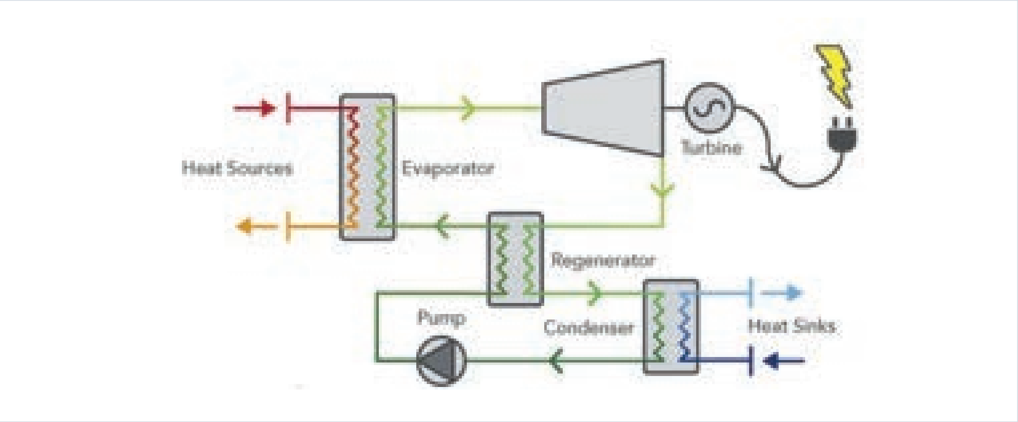

Figure 34 Working principle of ORC (57)

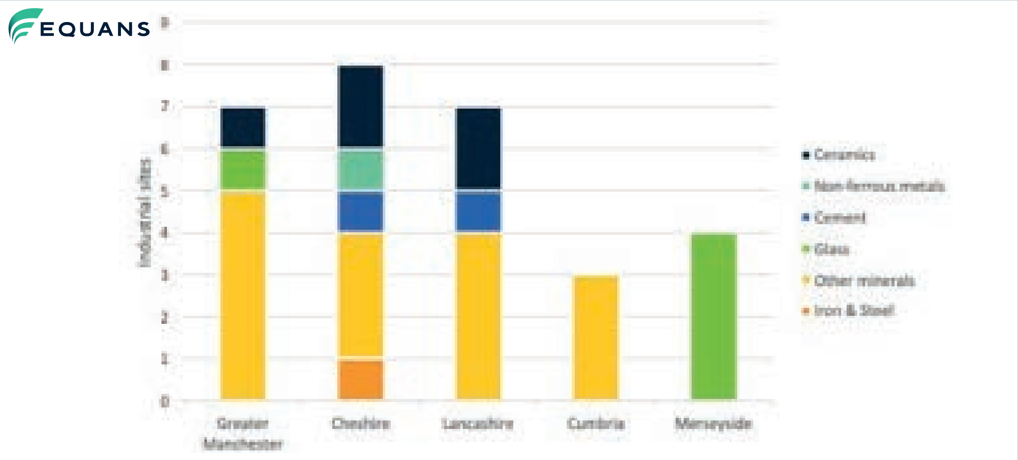

Figure 35 Breakdown of sectors in regions where ORC opportunities may be applicable in the North West

Recuperation of waste heat will not result in energy or carbon savings for the industry. However, sale of waste heat could offer a great financial benefit for waste heat producers. Cost of heat produced at a district heat network utilising waste heat has been estimated to be £30/MWh whereas a natural gas fired boiler would be £40/MWh (52). Besides financial benefits for the industry and heat users, waste heat could help decarbonise the building stock in North West England and North East Wales. Local governments and waste heat producing industrial sites can play an important role in coupling supply and demand for waste heat in the region with the help of central government. The proposed Oldham district heat and Alderley Park ambient loop networks are some examples of current district heat networks in the region. Figure 33 illustrates the heat networks in the North West that are operational or in the pipeline for development. The future of hydrogen production is expected to increase the amount of waste heat generation in the region. Whether it is blue or green hydrogen, its production will result in substantial amounts of energy being lost as heat. Hence, hydrogen production projects should consider ways in which associated waste heat can be utilised via district heating at an early stage (55).

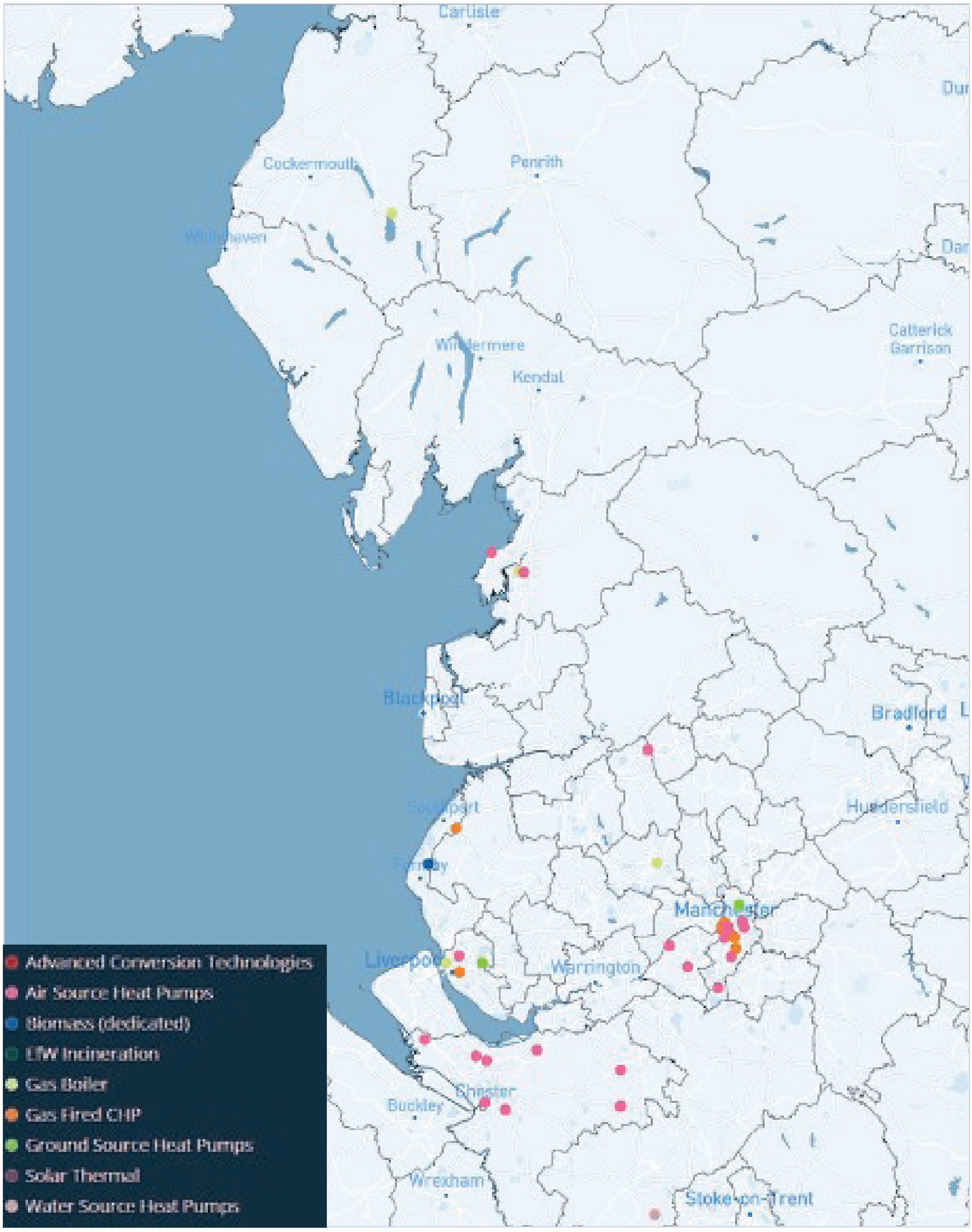

Figure 33 Heat network planning database in the North West (56)

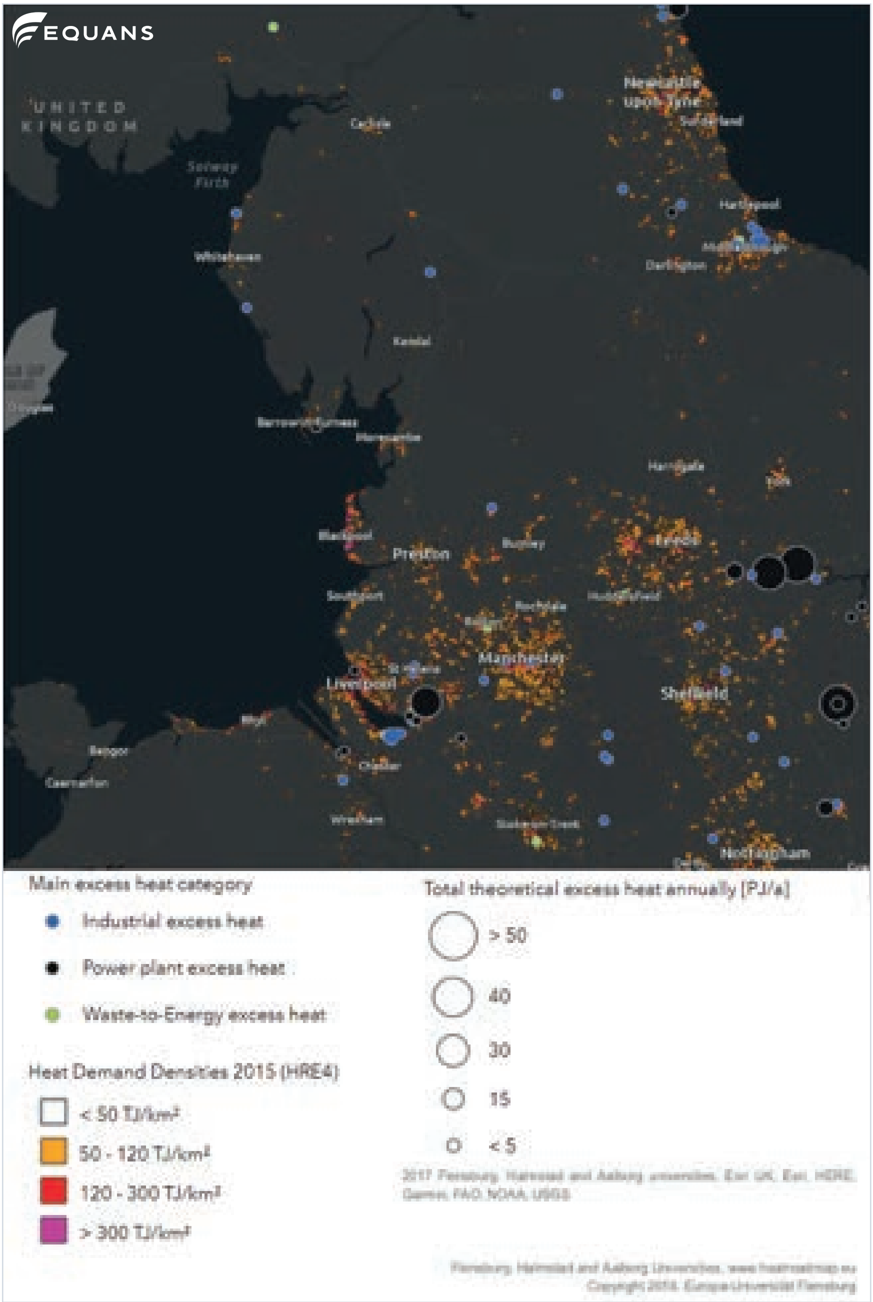

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Figure 31 Heat demand density and excess heat from industrial sector in North West

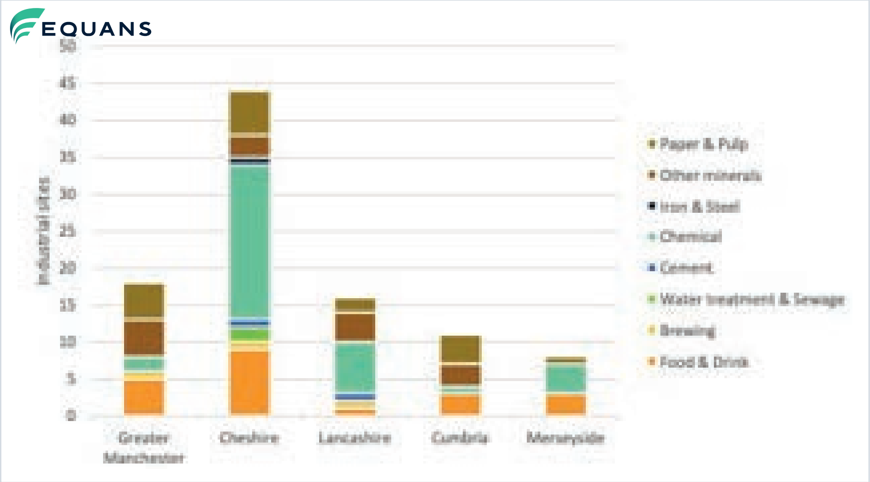

Figure 32 Breakdown of sectors in regions where district heating opportunities may be applicable in the North West

5.4.4 Waste Heat Reuse

In the UK, 20% of the total energy consumed can be accounted for by industry, which produces 32% of heat related CO_2 emissions, with 73% of industrial energy demand being for heating. The Digest of UK Energy Statistics (DUKES) states that almost half of this demand is for low temperature processes while 22% is for high temperature processes, with drying and separation processes (42 TWh/yr) and space heating (36 TWh/yr) making up the remainder (52). Cement, ceramics, steel and iron, glass, chemicals, refineries, paper and pulp, and food and drink are heat intensive sectors that also generate substantial waste heat. It should be noted that considerable amount of waste heat is suitable to be used directly on site, through integration with existing processes or other energy efficiency measures. As with AD plants, the brewing sub-sector has been separated from food and drink sector to highlight the available opportunities.

This section aims to focus on additional energy generation or utilisation opportunities that are not covered and cannot be obtained through energy efficiency improvements. Depending on the sector and the processes in place, waste heat generated between 90-500°C can be used in an Organic Rankine Cycle to generate electricity on-site. Additionally, waste heat from one or more industrial sites can be fed into a network to meet the hot water and space heating demand for commercial and residential buildings that are near the industrial sites. Both examples unlock additional revenue generation potential for the industry as well as advancing the decarbonisation of energy for the wider region.

5.4.5 District Heating

Currently, district heating meets 2% of the heating demand of buildings in the UK and the UK government aims to reach 18% by 2050. This ambitious target can only be achieved by unlocking access to waste heat opportunities from industrial process, data centres and geothermal heat. The majority of waste heat from industry is available between 100°C - 200°C excluding metallic, mineral and chemical sectors. Currently, it is estimated that 9 TWh of waste heat within this temperature range is being lost to the atmosphere within the UK (53). District heating utilises this waste heat to provide space heating and hot water for nearby commercial and residential premises. Waste heat from this specific temperature range can be captured and transferred to end users via heat exchangers. Waste heat below 100°C may require an additional generation technology such as heat pumps to increase the required temperature.

According to a study, around 14% of the hot water and heating demand for residential buildings in the UK could be supplied through the reuse of waste heat from buildings and industrial processes (54). The quality and quantity of waste heat, practicality of heat recovery, demand of heat users and distance between the heat source and heat users are important considerations for realising viable schemes. UK examples of waste heat as a heat source in district heating has been limited to energy from waste, mines water and wastewater treatment. However, industrial waste heat opportunities have also been tried and found to be economically viable low-carbon options in Europe.

Figure 31 illustrates the heat demand of buildings which are concentrated in urban areas and excess heat from various sources. Industrial regions such as Ellesmere Port, Runcorn, St. Helens, Trafford Park, Clitheroe, Sellafield and Siddick are located close to heat sinks in the form of towns and cities. These regions should be prioritised to couple waste heat utilisation from industry with decarbonisation of heat for homes and businesses. Figure 32 shows the breakdown of sectors and regions where waste heat from industry can be recuperated as a heat source for district heating.

revenue opportunities, cost savings from waste treatment, management, disposal, and utilisation of the biogas produced, whether it is used on site to meet the heat and electricity demand via a CHP or upgraded to be injected to the gas grid. Therefore, associated costs are normalised through biogas production of the plant. Despite high capital cost, the payback period can be relatively short due to incentives and reduced cost of waste disposal. An AD plant would be expected to have a payback period of 5-6 years or even less and the lifetime of the plant is 20 years.

Industries that would be able to utilise biogas production through AD plants in the North West England and North East Wales include food and drink manufacturers, in particular breweries due to their continual production line and waste by-products that require treatment and disposal. Brewing is a sub-sector of the food and drink sector, however, it is separated here to highlight its potential. Wastewater and sewage treatment facilities also utilise AD plants in their treatment process. Figure 30 shows the breakdown of industrial sites per sector and region in the North West England and North East Wales where AD sites may be a suitable energy generation opportunity.

Deployment of AD plants are relatively common in water treatment and sewage sector. Therefore, it was assumed that there are no further installation opportunities within that sector. On the other hand, around 70% of food and drink and brewing sectors were assumed to deploy AD plants to generate on-site green heat and power. As mentioned before, the capital cost, financial benefits and payback period are heavily influenced by various parameters. EQUANS' experience in AD feasibility studies and ESOS reporting for these sectors were utilised to evaluate the potential opportunity at North West England and North East Wales and this is tabulated below.

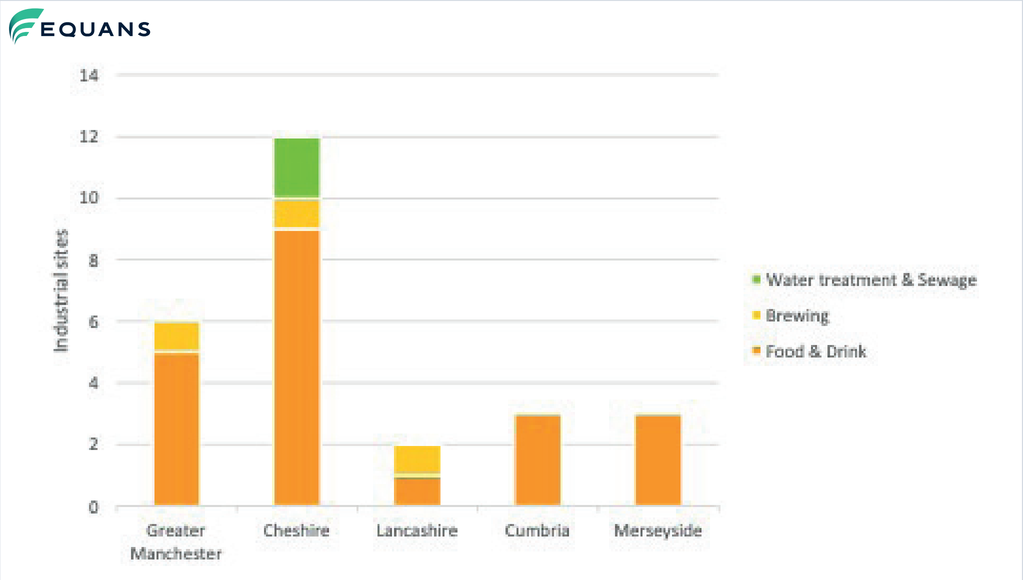

Figure 30 Breakdown of sectors in regions where AD opportunities may be applicable in the North West England and North East Wales

	Food & Drink	Brewing	Total
Estimated no. of sites applicable	15	2	17
Estimated electrical savings (MWh)	49,248	5,699	54,610
Estimated thermal savings (MWh)	45,298	16,859	62,157
Estimated CO_2 savings (te)	33,720	14,720	48,440
Estimated net financial benefit (£)	11,281,080	1,722,110	13,003,190
Estimated budget capital cost (£)	81,750,000	7,750,532	89,500,532
Estimated payback period (years)	7.3	4.5	6.9

Table 29 Estimated energy, carbon, and financial benefits of AD plants in North West England and North East Wales

5.4.3 Anaerobic Digestion (AD)

AD is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen and is widely used to treat wastewater. The organic pollutants in the wastewater are converted by anaerobic microorganisms to a gas containing methane and carbon dioxide, known as "biogas". The process is classed as a renewable energy source because the methane and carbon dioxide rich biogas is suitable for energy production, helping reduce the use of fossil fuels. Also, the nutrient-rich digestate or excess sludge can be used as fertiliser. Anaerobic digesters can be designed and engineered to operate using several different process configurations depending on the application.

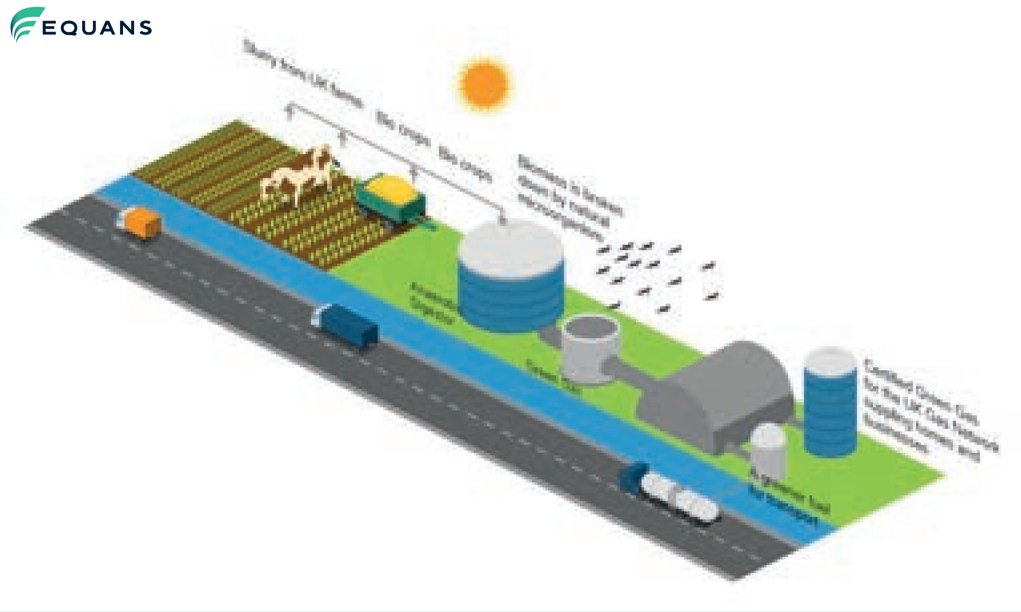

Figure 29 Biogas production from an anaerobic digestion plant

There are numerous financial benefits of an AD plant. A digester degrades waste that would otherwise need to be disposed of, often at a cost. For example, industrial wastewater from food manufacturing has organic contaminants that need to be treated. f the waste is fed to sewer, the site needs to pay to discharge it so that it can be treated at the local municipal treatment works. This charge can reach over £1/m3 so a large site could be paying more than £2,000 per day in effluent charges. Reducing the contaminants prior to discharge can reduce effluent bills significantly.

The biogas produced by an AD system can also be used to offset the import of natural gas and can therefore create a direct saving in utility bills associated with creating steam for process and heating. As mentioned in section 5.3.1, biogas can also be used in CHP to generate electricity which creates a direct saving against import electricity. Green Gas Support Scheme (GGSS) will also replace the previously available Renewable Heat Incentive (RHI) for AD plants.

GGSS will provide financial incentives for new AD biomethane plants to increase the proportion of green gas in the gas grid. However, the biogas produced at an AD plant needs to be upgraded to biomethane before it can be injected to the gas grid. The scheme will run for four years with applications opening in autumn 2021. Registered AD plant will receive quarterly payments over a period of 15 years.

AD plants require a constant and good quality supply of feedstock to ensure a smooth, viable and sustainable operation. Feedstock can be obtained through food and drink waste, processing residues, agricultural residues, crops, and sewage sludge streams. The yield of biogas production depends on several factors such as dry matter content, length of time in digester, type of AD plant, digester conditions and purity of feedstock.

The capital cost, operational cost and payback period of a new AD plant depends on multiple factors. These include the type of AD plant, administration of the plant, Ground-mount systems are applicable in industrial areas with various land use such as landfill, contaminated land, or land not in use. As highlighted in the North West Industrial Energy Zone Prospectuses, all the energy zones defined have solar PV deployment opportunities. However, some promising areas that should be mentioned are Fleetwood, Trafford Park, Knowles business park, Manchester science park, Speke industrial area and business parks, Alderley Park and Ellesmere port area.

Six industrial clusters were identified for ground-mount systems and three of these clusters were chosen as a sample to estimate the average generation potential to be 15 GWh/year per industrial cluster, amounting to 90 GWh/year in total. Roof-mount systems are, in principle, applicable to every cluster

In the analysis, four industrial clusters of various sizes were chosen to estimate the available roof space for roof-mount solar PV deployment. Roof space considered in these sample clusters included manufacturing sites, warehouses, and distribution centres. This was later compared to the area of industrial cluster to obtain a ratio between available roof space and size of cluster. As a result, 5% of the cluster roof area is estimated to be suitable. To consider equipment on the roof such as HVAC and skylights, a factor of 0.75 was applied. A further factor of 0.75 was applied to omit roofs that may not be structurally sound to carry roof-mount solar PV system. A conservative figure of 878 kWh/m^2/year was assumed as the GHI at North West. Table 26 shows the estimated roof area and energy generation potential for each industrial cluster whereas Table 27 shows the estimated total solar energy generation through various systems.

Estimated Energy Generation Potential (MWh/year)	
Ground-mount	90,380
Roof-mount	168,955
Floating	458
Total	**259,793**

Table 27 Estimated energy generation potential via solar PV in the North West

The estimated average cost of generating 1 kWh of energy assuming a lifetime of 35 years for ground-mount and floating systems, and 30 years for roof-mount system would be 3.72p. The projected price and carbon factor of electricity from the grid is used from 2020 to 2054. Table 28 summarises savings offered by the proposed installations.

Savings Summary	
Estimated installed capacity (MW)	301.4
Estimated electrical savings (MWh/year)	259,793
Estimated CO_2 savings (te)	393,540
Estimated annual financial benefit (£)	47,641,214
Estimated budget capital cost (£)	306,825,880
Estimated simple payback period (years)	6.4

Table 28 Estimated savings summary for solar energy generation in North West

Industrial Cluster	Estimated cluster area (km^2)	Estimated roof area (m^2)	Estimated energy generation potential (MWh/year)
1 Sellafield to Siddick	18	900,000	21,819
2 Furness Business Park	2.6	92,640	2,246
3 Red Marsh and ICI Fleetwood	2	124,009	3,006
4 Leyland Area Business Park	2	100,000	2,424
5 Trafford Park Area	11	550,000	13,334
6 Knowles Business Park	5.6	280,000	6,788
7 St Helens	4	200,000	4,849
8 Manchester Science Park	0.1	5,790	140
9 Wirral Waters to Port Sunlight	9.5	475,000	11,516
10 Speke Industrial Area and Business Parks	5	250,000	6,061
11 Sealand and Deeside	27	1,350,000	32,729
12 Alderley Park	0.2	16,555	404
13 Ellesmere Port	49.5	2,475,000	60,003
14 Weston Point	3	150,000	3,637
Total	**13,945**	**6,969,094**	**168,955**

Table 26 Breakdown of industrial clusters, estimated roof area and energy generation potential

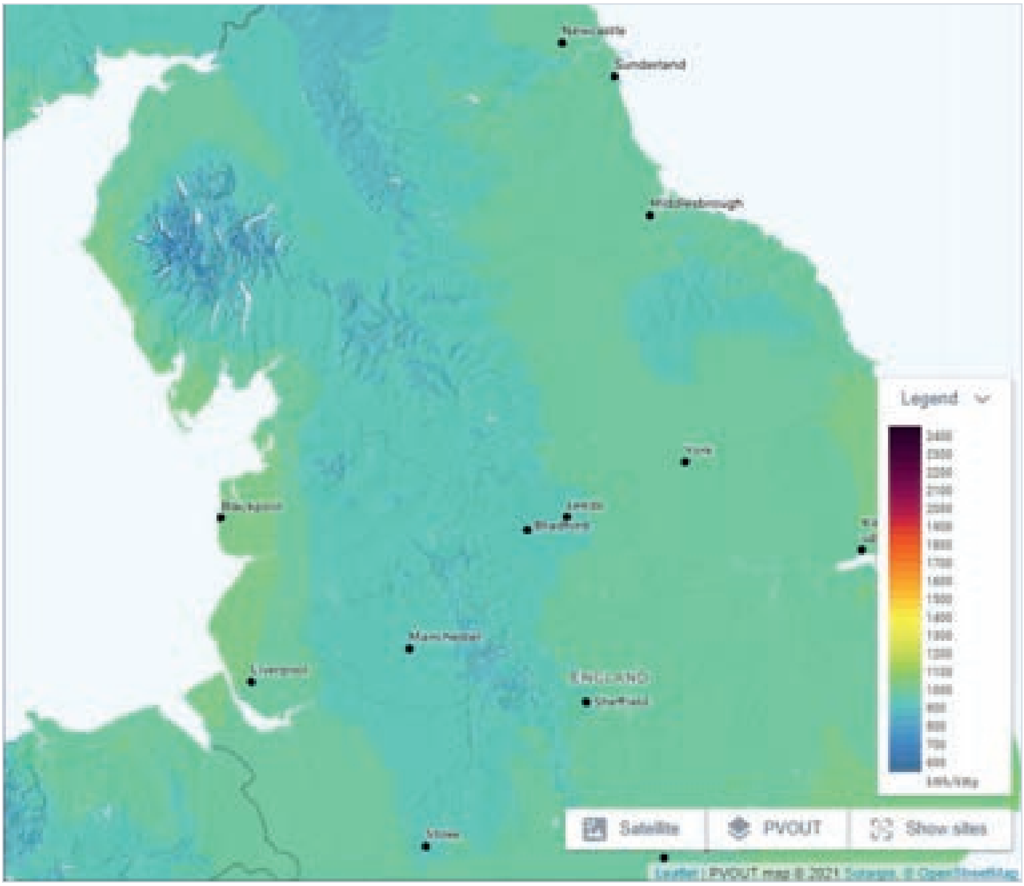

Figure 28 Specific photovoltaic power output map of North West of England (51)

Table 25 illustrates the industrial clusters and the types of solar PV systems identified in the North West Industrial Energy Zone Prospectuses. Industrial clusters in various sizes (i.e., small, medium, and large) were chosen to be studied in detail to estimate average energy generation. In each sample cluster, available area - land, roof, and water - were studied to estimate an average installation size. This analysis includes industrial sites outside of the ETS and NAEI data collected because all the industrial sites within sample clusters were considered.

Industrial Cluster	**Ground Mount**	**Roof Mount**	**Floating**
1 Sellafield to Siddick	✓	✓	✗
2 Furness Business Park	✗	✓	✗
3 Red Marsh and ICI Fleetwood	✓	✓	✗
4 Leyland Area Business Park	✓	✓	✗
5 Trafford Park Area	✗	✓	✗
6 Knowles Business Park	✗	✓	✗
7 St Helens	✗	✓	✗
8 Manchester Science Park	✗	✓	✗
9 Wirral Waters to Port Sunlight	✓	✓	✗
10 Speke Industrial Area and Business Parks	✗	✓	✗
11 Sealand and Deeside	✗	✓	✗
12 Alderley Park	✓	✓	✓
13 Ellesmere Port	✓	✓	✗
14 Weston Point	✓	✓	✗

Table 25 Breakdown of industrial clusters and Solar PV systems applicable

Based on the available land and local restrictions, twenty four units of 4 MW wind turbines with a total installed capacity of 96 MW could be deployed at Red Marsh, ICI Fleetwood, Furness business park and Buccleuch dock clusters. This scale of installation would have the potential to generate 336 GWh/year of energy assuming 3,500 full load hours. Various costs for the deployment of wind turbines were estimated based on normalised figures (i.e., £/MW or £/MWh) from BEIS electricity generation costs (2020) (50).

The estimated costs are summarised in Table 23. Assuming a lifetime of 25 years the estimated cost of generating 1kWh of energy would be 2.54p. The projected price and carbon factor of electricity from the grid is used from 2020 to 2044.

Table 24 summarises the savings offered by the proposed installation.

Cost type	Estimated cost (£)
Pre-development cost	£11,520,000
Construction cost	£96,000,000
Infrastructure	£3,500,000
Fixed O&M (annual)	£2,256,000
Variable O&M (annual)	£2,016,000
Insurance (annual)	£153,600
Connection and use of system charges (annual)	£393,600

Table 23 Associated capital and operational cost of the proposed wind farm installation

Savings Summary	
Estimated no. of wind turbines	24
Estimated installed capacity (MW)	96
Estimated electrical savings (MWh/year)	336,000
Estimated CO_2 savings (te)	493,417
Estimated annual financial benefit (£/year)	36,335,040
Estimated budget capital cost (£)	231,500,000
Estimated simple payback period (years)	6.37

Table 24 Estimated savings summary for wind energy generation in North West

5.4.2 Solar Photovoltaics (PV)

Solar PV is a renewable energy technology that converts energy from the sun into electricity. Solar PV systems can be installed on a building rooftop, as a large-scale ground-mount system, floating on a body of water or building integrated system which replaces traditional materials in the envelope of a building.

The increase in solar generation production and deployment globally has reduced the price, especially utility-scale solar PV, to very low levels when compared to fossil-fuel alternatives such as coal and CCGT (46). Solar PV has a significant role to play in decarbonising the electricity grid and lowering the demand on the grid through decentralised production. Battery storage and EV charging stations add flexibility to solar PV maximising financial gains.

Large buildings with substantial roof space are ideal for rooftop installation. Within industrial areas warehouses have significant space availability without shadows during the day. Carports are another example where solar PV panels can be integrated, and electricity generation can be coupled with electric charging stations to contribute towards decarbonisation of transport.

South-facing and flat roofs are ideal locations for solar PV installation. However, east, and west facing roofs can be utilised if shading can be avoided. It is important to consider the structural integrity of the roof to ensure it can bear the weight of the panels intended for installation. Access to the roof and sufficient space for installation should be considered at an early stage.

Coastal regions of England have a slightly higher solar potential compared to in land areas. This can be seen in Figure 28 in terms of specific photovoltaic power output. The average specific photovoltaic power output in the North West is between 862 and 1,008 kWh/kWp whereas global horizontal irradiation (GHI) is between 868 and 989 kWh/m^2/year. These figures were estimated based on the area captured by the North West.

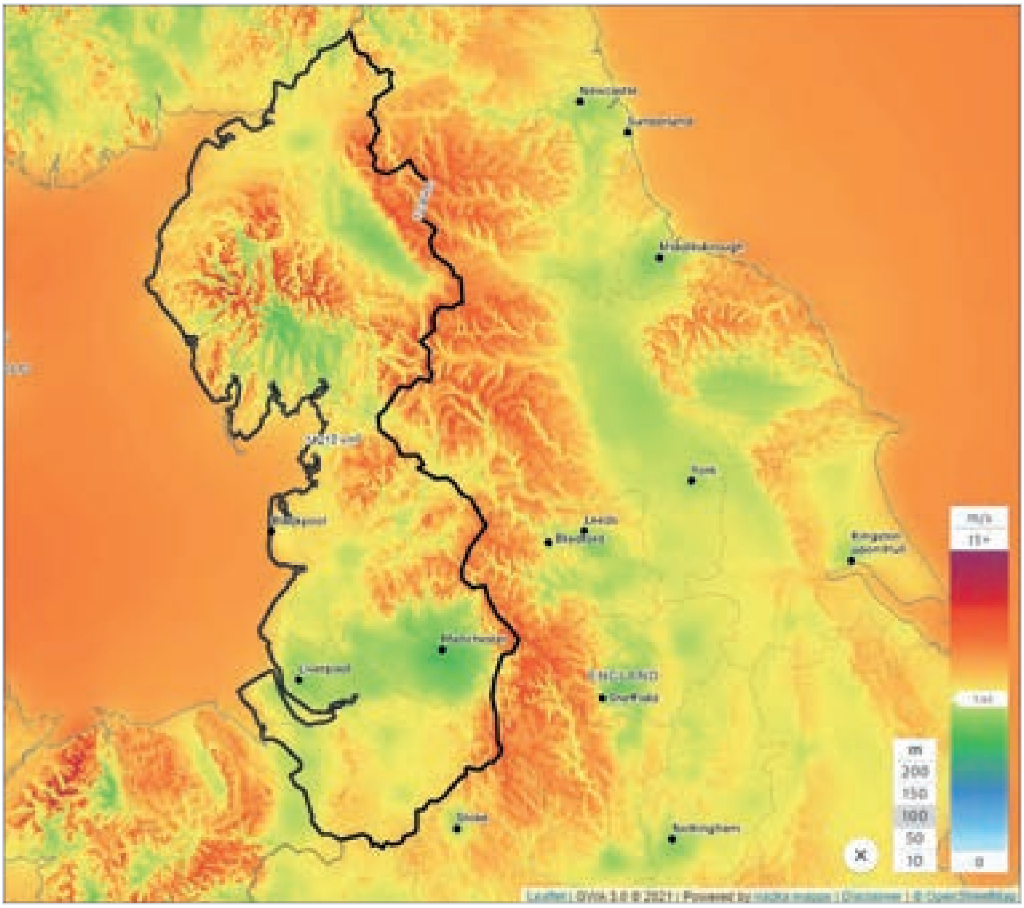

Figure 26 Mean wind speed map of North West of England (48)

Figure 26 illustrates the mean wind speed for the North West of England at 100m height in Global Wind Atlas. This area covers roughly 1,413 km^2 of land. For this study, only onshore wind energy generation is considered. According to this tool, the mean wind speed at 100m within this area is 10.56 m/s. Figure 27 shows the distribution of the mean wind power density in North West of England in W/m^2. This is calculated based on the mean wind speed at 100m. The mean power density for the 10% windiest areas in the region are estimated to be 1,34 9W/m^2.

The windiest areas in the North West are within Lake District National Park and Forest of Bowland which are due to the topography of the area. However, these areas do not contain industrial sites and would not be eligible for wind farm development due to environmental constraints. Regions where wind farms can be developed are Red Marsh, ICI Fleetwood, Furness business park and Buccleuch dock as highlighted in North West Industrial Energy Zone Prospectuses (47).

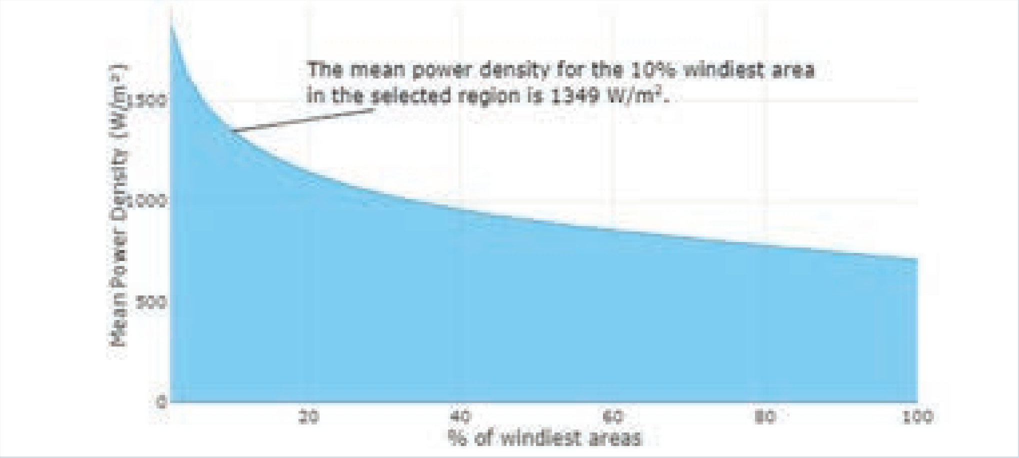

Figure 27 Mean power density distribution in North West of England (48)

Onshore wind farm development is ongoing in the North West. A total of 15.3 MW of capacity for two wind farms located in Lancashire have been granted planning permission and they are awaiting construction. A further 35.8 MW of capacity over two wind farms is also awaiting approval on their planning application in Lancashire and Cumbria according to the quarterly renewable energy planning database published by BEIS (47).

Wind speed is one of the most important parameters in determining the wind energy generation potential of a site. The average wind speed varies from one year to the next. Figure 25 shows the wind speed variability in the North West of England. Wind speed measurements on site are cross-examined with historical data from a meteorological station. This ensures that extremities of a particular year can be averaged to provide a more realistic generation potential over the lifetime of the windfarm.

Wind speed is affected by the friction against the surface of the earth which is determined by roughness length. The higher the roughness length, the larger the decrease in wind speed magnitude. For example, water surface poses negligible influence on wind speed unlike large cities with tall buildings. Therefore, locations with minimal built-up environment and obstacles are preferable, especially considering the prevailing wind direction.

Environmental Considerations

Noise is a very important constraint, particularly in the more populated parts of the country. In general, the perceived noise from a wind farm will depend on the noise power output from each turbine and its distance from dwellings, the frequency (pitch) of the noise, the ground absorption and blockage or reflection by obstacles. For wind farm design purposes, a common requirement is that the noise from the turbines should not exceed given threshold values at the dwellings. Guidelines indicate ETSU-R-97 as a recommended method to be used in the UK (49).

Shadow flicker is the flashing effect when moving turbine blades pass between the sun and the observer, which is perceived as an annoyance. The effect is more likely to be an issue if the turbines are built relatively close to dwellings. The occurrence depends very sensitively on the latitude of the location and the time of year. Guidelines for the assessment of shadow flicker typically require the maximum potential to be calculated assuming standard conditions.

Visibility can also be a vital part of a wind farm design. Therefore, accurate assessment of the extent of visibility of wind farms from sensitive areas is important. Inter-visibility between radar facilities and proposed turbines should be assessed in the planning stage of a wind farm development project. This is to ensure minimal disruption to important services such as civilian aviation, military radar, or weather radar systems. Optimisation of penetration can locate areas where turbines will be below radar sweep or provide information as a basis for discussion when turbines intersect the radar.

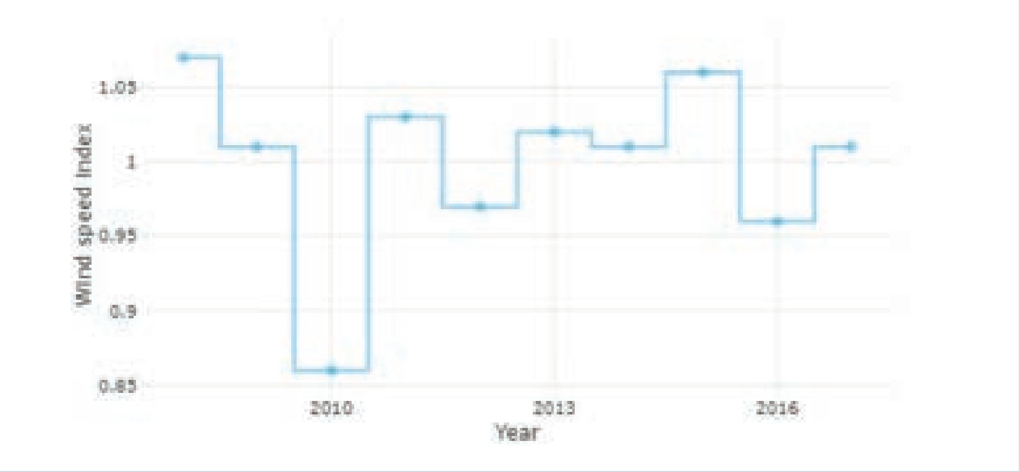

Figure 25 Annual wind speed variability in North West (48)

Another future technology which is currently undergoing trials is the Grid Scale High Temperature Energy Store (GSHTES). GSHTES is electrification of heat and heat storage. The basic concept is that the GSHTES is using renewable energy to heat steel elements to store the energy and provide heat on demand for processes up to ~550ºC. This technology is currently being trialled within the UK. Additional to the environmental benefits the technology has other benefits and barriers, a selection of which is illustrated in table 22 below.

Benefits	Barriers
Easy to retrofit	Large footprint
Easily scalable	Likely to require planning permission
Can be used to balance the grid	Price of electricity
OPEX minimal	Continuity of subsidies

Table 22 GSHTES benefits and barriers

5.4 Renewable Energy Generation

This section deals with on-site energy generation and utilisation technologies. Deployment of these technologies are considered for specific industrial sites as behind the meter assets, as well as for the areas available within the industrial clusters as in front of the meter assets. Fourteen industrial clusters in the North West England and North East Wales were analysed to assess the overall potential for renewable energy generation. These clusters were defined in the North West Industrial Energy Zone Prospectuses by Buro Happold in 2020 as part of Net Zero North West Cluster Plan Phase 1 (44). In this way, utility scale generation opportunities, within the boundaries of industrial clusters, were included in the analysis. A holistic approach was taken to capture the dynamic energy potential of industrial sites with the rest of the region including domestic and commercial energy demand.

An important constraint for the deployment of renewable energy generation will be the available capacity in the electricity grid network. Electricity North West, who supply a large portion of the North West, has unveiled their ambitions to lead the North West to net zero carbon (44). It is stated that the growth of renewable generation and storage across the region is encouraged by the DNO. They are investing in the network to ensure that the potential of decarbonisation of the grid is met by 2038. Similarly, Scottish Power Energy Networks, which supplies the rest of the North West around Merseyside and Cheshire, has announced their plans to invest £3.2 billion between 2023 and 2028 to aid critical upgrades to connect an additional 5 GW of renewable generation (45).

5.4.1 Wind

Wind energy utilises aerodynamic forces of the wind acting on blades of a wind turbine to convert wind energy into rotary motion, kinetic energy. This energy is later used to drive a generator, housed within the hub of the turbine, to generate electricity. Generally, numerous wind turbines are deployed within a wind farm. Wind energy is a prominent renewable energy generation technology in the UK, both on and offshore. Futher deployment of wind energy has the potential to help achieve a net zero grid. Wind energy can be coupled with other technologies to increase flexibility. Adding flexibility to intermittent energy sources like wind energy can help reduce curtailment – turning down of wind turbines when wind energy generation is higher than the electrical demand in the grid – and increase penetration. Examples of such technologies are battery storage or hydrogen production. Cost of wind energy has been reducing over the years and it is at a competitive state with combined cycle gas turbine (CCGT) plants, without any subsidies (46).

The decarbonisation of heat is a major challenge for the UK. For this report the focus is industrial heat, including space and process heating. The Sixth Carbon Budget from the climate change committee (42) highlights the necessity for electrification, especially in the industrial sector, and indicates the pathway for the manufacturing and construction sector.

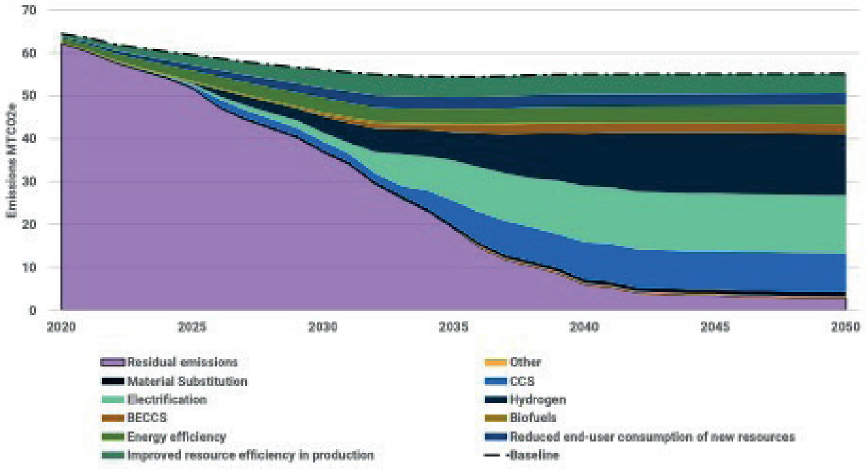

Figure 24 CCC 6th budget net zero pathway for manufacturing and construction sector (43)

In the industrial decarbonisation strategy (1), which the government released in March of 2021, it indicates that electrification of industry could reduce emissions by between 5 $MtCO_2e$ and 12.3[ii] $MtCO_2e$ per annum by 2050. Based on current technology[iii], electrification may not be suitable for industrial processes that require higher temperatures, for example, processes that can be found in industries such as cement, ceramics, steel production or chemical. For these processes, it is currently more cost effective to investigate alternatives such as hydrogen or CHPs. However, as stated in section 5.3.4.2, as technology develops and electricity prices fall, electrification for industrial processes would become a more attractive proposition.

5.3.4.1 Potential Barriers

Most of the heat that electrification would be replacing is produced by natural gas. The current main barrier to electrification is the cost disparity between gas and electricity. Another barrier to electrification is that the infrastructure may not be able to support the increased electrical demand. The government is working with Ofgem, National Grid and DNOs to plan and deliver a robust, future proof electrical network.

5.3.4.2 Future of Electrification

In the 10-point plan published by the government (41) investment in research and development (R&D) for a net zero future is a priority. A significant component of the future of net zero will be innovation which includes electrification.

Taking the food and drink sector as an example, electrification can play a big part in their route to decarbonisation.

Pasteurisation is an energy intensive process, electrifying this process through non- thermal or cold pasteurising can reduce carbon and can occur in several forms including ultra violet (UV) pulsed light or ultrasound. Non-thermal or cold pasteurising can occur in several forms including ultra violet (UV) pulsed light or ultrasound. These have applications in dairy, fruit juices and brewing. In addition to the environmental benefits, there are other benefits and barriers electrification can bring, a selection of which is illustrated in table 21 below.

Benefits	Barriers
Taste of product unaffected	Requires a change of process
Extends shelf life	High CAPEX charge
No heat required	Price of electricity

Table 21 Electrification of pasteurisation benefits and barriers

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[ii] Please note that these figures include the use of HPs

[iii] This references to technology that is commercially readily available

5.3.3.4 Future Roadmap

In Figure 23 Fuel Cells Roadmap, is a pictorial representation of the fuel cell road map for Europe.

The information presented is from *'HYDROGEN ROADMAP EUROPE: A SUSTAINABLE PATHWAY FOR THE EUROPEAN ENERGY TRANSITION'* (38). The sections highlighted in blue are aspirational and those highlighted in green are industrial expectations. For example, the aspirational hydrogen fuel cell for aviation is 2035 but the industrial expectation is 2045.

5.3.3.5 Cost of Fuel Cell CHP

Due to the variations in material and maturing manufacturing process prices, the cost of fuel cell technology fluctuates widely. To give a sense of the scale of cost for a fuel cell CHP, the following table 20 has been generated from Battelle analysis on behalf of the US Department of Energy (39). Table 20 highlights the influence of how large-scale production can influence the cost of the fuel Cells.

5.3.4 Electrification

Fuel switching, in the context of this report, is replacing a fossil fuel with a low carbon alternative. Fuel switching is an important step towards Net Zero 2050 as highlighted in the government released literature (1) (40) (41) (42). The three low carbon alternatives highlighted in the government literature in reference to fuel switching are electrification, hydrogen, and biofuels. The two mainstream low carbon alternatives are electrification and hydrogen. For more on hydrogen see Section 5.5.

As stated above, electrification is one of the main steps towards Net Zero 2050. Electrification is the process of moving away from fossil fuel-based energy sources such as natural gas and replacing that with low-carbon sources of electricity, such as electricity generated via a wind turbine. One example of a market where electrification is prevalent is in transportation.

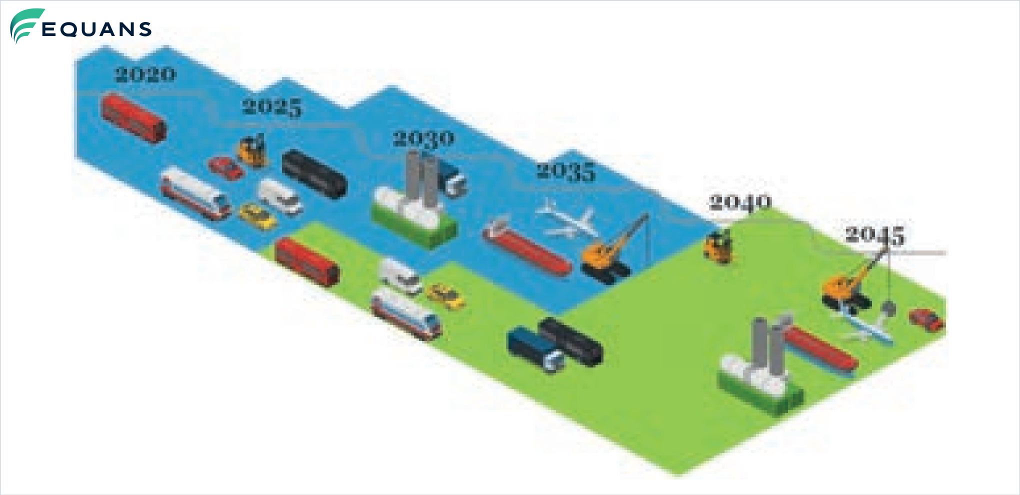

Figure 23 Fuel Cells Roadmap

Type of Fuel Cell	System Size kW	100 Units/ Yr	1,000 Units/ Yr	10,000 Units/ Yr	50,000 Units/ Yr
Solid oxide fuel cell	100	£162,124	£128,647	£112,604	£103,667
		£1,621	£1,286	£1,126	£1,037
	250	£318,724	£262,915	£230,451	£211,339
		£1,275	£1,052	£922	£845
Proton-exchange membrane	100	£258,173	£215,915	£191,413	£177,285
		£2,582	£2,159	£1,914	£1,773
	250	£460,168	£384,676	£338,680	£311,039
		£1,840	£1,539	£1,355	£1,244

Table 20 Cost of fuel cell CHP from Battelle 2017 analysis of the fuel cell market

The two main applications for hydrogen fuel cells are backup power and transport. Backup power is used when the primary source of power is disrupted, and transport is used to move people or goods by the means of a vehicle. Backup power and transportation have both traditionally used the combustion engine to satisfy demand. Typically, the backup power has been provided by diesel generators and transportation has used combustion engines fuelled by diesel or petrol. Batteries (usually lithium-ion or lead-acid batthers) have been used as a lower carbon alternative for both backup power and transportation.

Below, Table 19 shows a summary of the advantages and disadvantages of hydrogen fuel cells as a low carbon alternative compared to combustion engines and batteries.

5.3.3.1 Combustion Engines

Fossil fuelled vehicles and diesel fuelled backup power has been the norm for many years, providing stability and reliability, but ultimately eroding reserves of fossil fuels and generating significant carbon emissions. This traditional method has the flexibility to cope with high power demands, which is essential for large generators and larger vehicles such as large goods vehicles (LGV) and heavy goods vehicles (HGV). Applications for generators include, but are not limited to, industrial sites, hospitals, and data centres. The fuelling time is relatively short and if the system is maintained, the degradation is minimal. However, the use of fossil fuels means that they have high pollutants levels particularly CO_2 and NOx.

5.3.3.2 Batteries

Batteries are a well-known and well-established lower carbon alternative[i] to generators and traditional combustion engines.

The advantage of using batteries is that the technology is mature and integrated in everyday life. Additionally, the infrastructure largely already exists, for charging in both applications, transport and backup power, the 'well-to-tanks' is simple. Electricity is generated and transported through the national grid to charge the batteries. The main disadvantages are the time it takes to charge the batteries, the degradation of power, limited charging cycles and storage capacity. The time it takes to charge a battery back for backup power or a vehicle's battery is substantially longer than fuelling using fossil fuels or hydrogen. The power charge degrades over time, therefore, if the battery remains dormant over time it will need recharging, which causes issues with reliability. A batteries charge capacity degrades over time and has a finite number of cycles; in time, a battery system will require a costly replacement.

5.3.3.3 Fuel Cells

As a direct comparison to the two technologies above the hydrogen fuel cell has advantages and disadvantages. The main advantage of a fuel cell is that due to the lack of moving parts it is completely reliable; if hydrogen is supplied, the cell will generate electricity. Another advantage is the process of fuel cells generating electricity is very quiet compared to combustion engines. A fuel cell also requires considerably less space than a battery system. The fuel cell combines the lower carbon nature of a battery with the speed and reliability of fuelling a combustion engine. The main disadvantage of the hydrogen fuel cell is access to the fuel; the infrastructure and market is not as advanced as needed for hydrogen to be a cost-effective alternative to batteries and combustion engines. Additionally, the fuel cells themselves can be expensive due to the use of precious metal as a catalyst.

	Zero Carbon	Fuelling Time	Well-to-Tank Process	Infrastructure	Running Costs
Combustion Engine	✕	✓	✕	✓	✕
Batteries	✓	✕	✓	✓	✓
Fuel Cell	✓	✓	✕	✕	✕

Table 19 Representation of advantages and disadvantages of each technology

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[i] Please note for the purpose of this document it is assumed that the batteries are charged using renewable electricity

A clear comparison between 2030 and 2040 hydrogen prices against electricity prices shows that both the high and low temperature HPs provide a benefit financially in energy savings during 2030. However, due to the drop in hydrogen production price and the increase in electricity purchased from the district network operator (DNO), high temperature HPs do not present the same saving in 2040. Therefore, with changes to pricing throughout that decade high temperature HPs will become less profitable. This analysis is based solely on utility pricing and does not consider any incentives or schemes offered by the government, giving the reader an understanding of the market if there were no CFD mechanism in place. Low temperature HPs do, however, offer a financial benefit due to the larger system performance with greater COPs bridging the gap between hydrogen and electricity costs.

The figure below shows the savings possible through carbon offset from a reduction in emissions. Due to the nature of the system only low temperature HPs have been shown, providing an insight into the financial savings possible through HP implementation with carbon offset.

The review offers insight into how HP technology can retain its value within industrial processes. This analysis only considers existing technology; with continuous development HP systems could achieve higher efficiencies and secure their foothold within the industry. Further to this, HP technology has been proven to be beneficial to users that are able to electrify their thermal processes. A detailed review would be required to understand the costs for connection onto the network and appreciate the savings through the implementation of HP technology.

5.3.3 Fuel Cells

A fuel cell is a device that converts chemical energy (in this case hydrogen and oxygen) into electricity with by-products of heat and water. A typical fuel cell consists of three main components, a positive and negative electrode separated by an electrolyte. The positive electrode is called a cathode and the negative electrode is called an anode. Hydrogen passes through the anode while oxygen passes through the cathode. At the anode the hydrogen molecules are separated into protons and electrons. The protons can pass through the membrane while the electrons cannot, and the electrons are forced through a circuit which generates an electric current and heat. The hydrogen protons and electrons combine with oxygen to create water (H_2O). See Figure 22 Fuel Cell Diagram below for reference.

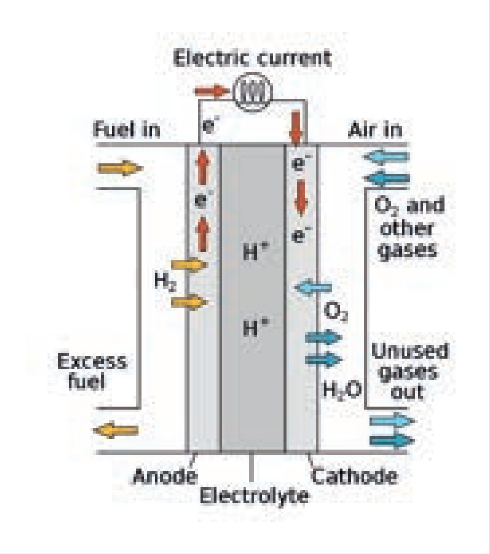

Figure 22 Fuel Cell Diagram (37)

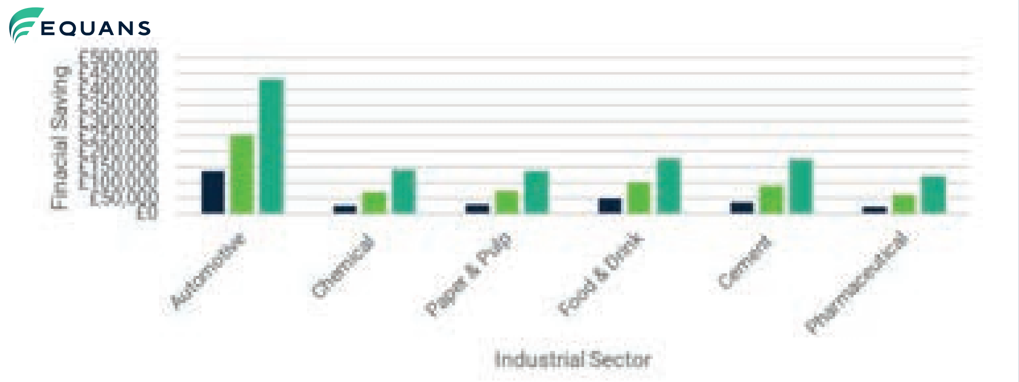

Figure 21 Heat Pump Saving Through Carbon Offsetting

5.3.2.3 The Future of Heat Pumps

A further review of HPs within the industrial sector against predicted hydrogen prices shows a significant reduction in cost when utilising HPs within a site process. Industries that typically use large amounts of gas such as the Automotive industry can benefit from the use of a HP to reduce the gas usage on site.

Figure 19 Heat Pump Savings with Hydrogen Usage Offset 2030 and Figure 20 Heat Pump Savings with Hydrogen Usage Offset 2040 show that with no supplement of hydrogen prices there can be a comparative saving found. However, due to incentives placed by the government to reduce the cost of hydrogen to natural gas prices through CFD, HPs shall still present a poor return on investment.

Figure 21 illustrates the possible savings for HP technology when applying a carbon offset due to the reduction in carbon from site processes. This is comparative against the use of conventional hydrocarbon fuels and electrification.

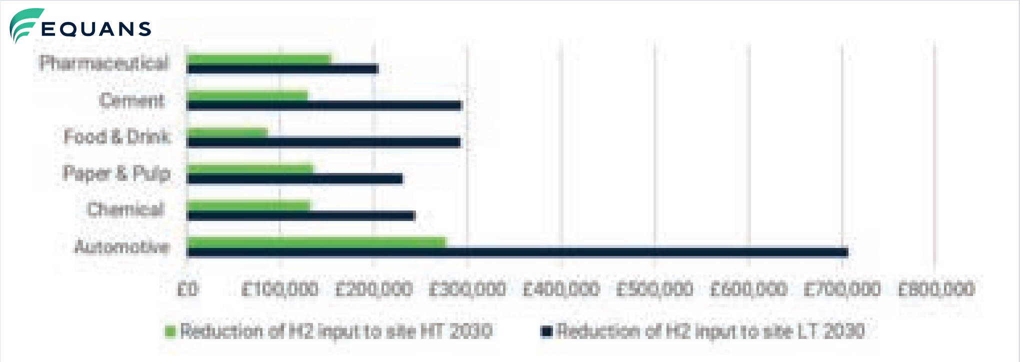

Figure 19 Heat Pump Savings with Hydrogen Usage Offset 2030

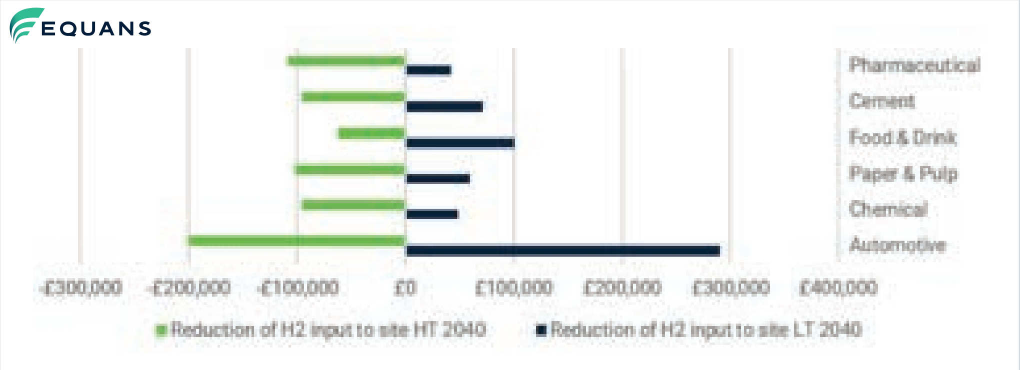

Figure 20 Heat Pump Savings with Hydrogen Usage Offset 2040

A benchmark figure for gas and electricity prices were used across all sectors as shown in Table 17 and Table 18. These prices have been used to align with Work Package 5 of this report, however, standing charges and CCL taxes have been added to represent a more realistic financial outcome. Table 18 shows the grid carbon figures applied to the model to understand the carbon savings from a HP installation.

Fuel	£/kWh
Electricity	0.108
Gas	0.023

Table 17 Utility Costs

Fuel	mg/kWh
Electricity CO_2	255.6
Natural gas CO_2	183.53

Table 18 Carbon Factors

5.3.2.2 Heat Pump Considerations

The review of HP technology within industries adopts the same approach as a CHP system regarding a consistent heating load profile. Therefore, it is critical when sizing a HP that it can satisfy the base load requirements for the site process and / or heating loads. HPs will also increase the electrical consumption for that site which is considered when calculating the potential savings.

Due to the existing gas and electricity prices for industrial users, the installation of a HP in some circumstances can in fact be detrimental to any financial savings. This difference in price can be referred to as the 'spark spread'. To allow for an offset against the spark spread energy prices, certain government incentives can be sought when applying to the installation of HP technology. Currently non-domestic Renewable Heat Incentive (RHI) supports the installation of certain low carbon technologies, with a grant awarded for the installation of the technology and generation of heat. However, a new scheme is expected in April 2022.

The installation for a large-scale HP for an industrial user must consider the carbon savings available when removing the requirement for combustion plant. This ensures the installation of a HP is more attractive against conventional cheaper combustion plant, as it is a critical step towards a carbon neutral industry.

With the available ESOS data, ASHPs have been modelled against the thermal profiles for each of the industrial sectors. ASHPs were chosen as they are simplest to model and understand given the data available for this report. ASHPs are also the easiest to install within an industrial application due to the smaller space requirements when compared with GSHPs and can be installed within a land locked location when compared with WSHP. Further GIS mapping would be required to understand the thermal energy available within both ground and water sources for a specific site.

The following sections detail the findings from the modelling of each sector with the application of the most suitable HP model. The graphs included within each section detail the sector demand for heat and the base operation of the HP selected. This is plotted against the outside ambient temperature conditions to calculate the SCOP for the HP. In addition to this is the requirement for additional back up heat supplied by a boiler which should be implemented to satisfy the peak loads only. During modelling of the HP for a sector, the gas reduction, thermal output, carbon savings, and operational performance towards 100% full load running have been priority. This ensures a fair benchmark when comparing between high and low temperature models and between the various industrial sectors.

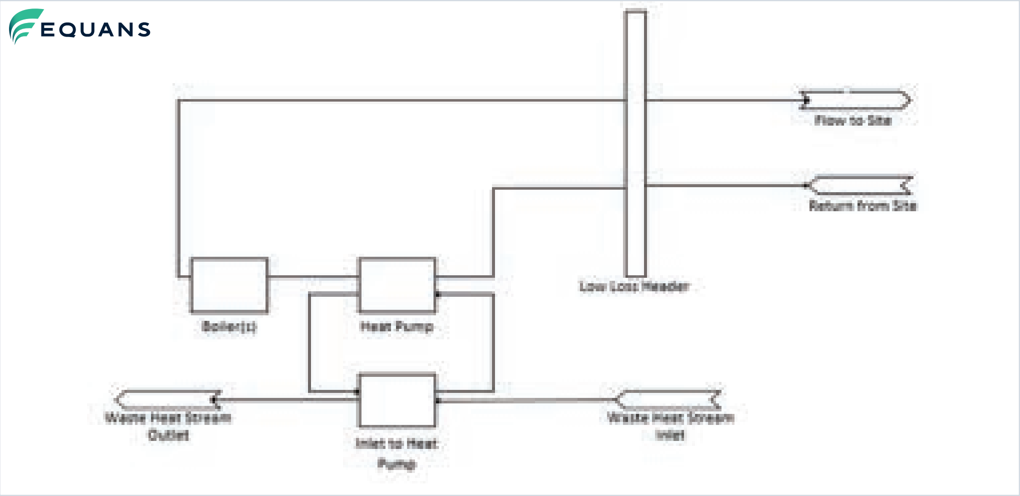

Figure 18 Heat Pump System Arrangement

Industrial HP installations need to account for space for both the heat pump unit and the cooler/condenser. Typically, these range from 6m(L) x 2.5m(H) x 1.5m(W) for the HP and 5m(L) x 1.2m(H) x 3.7m(W) for smaller systems around 150 kW output to 10.5m(L) x 2.6m(H) x 1.5m(W) for the HP and 9.5m(L) x 2.75m(H) x 18.5m(W) for the cooler/condenser unit for a 2.7 MW. The HP unit increases accordingly due to the increase in output however, the cooler for the system increases dramatically. This needs to be included when evaluating the scope of a HP installation.

5.3.2.1 Heat Pump Methodology

Heat pumps are affected by the external energy sources, which are adversely affected by the environment and weather conditions. Therefore, the initial requirement for ASHP design is to understand the weather conditions for the local area. This was achieved by choosing an area close to the North West England and North East Wales which had accurate weather data for a 12-month period. This could then be used in a calculation process to ascertain the SCOP, calculated with the method set out in BS EN 14825:2018, which covers air conditioners, heat pumps and liquid chilling packages. Once this was understood, the maximum and minimum required energy input for that industry would be applied and using the data sheet information for different heat pump models, a SCOP could be calculated. Based on this information an indicative operation for the HP throughout the year could be derived. This would allow for an understanding of operating hours, electricity requirements, gas offset and additional heat input required in the event of the heat pump not satisfying site load.

From this, the payback and potential financial savings could be obtained, however, it is common for HPs that as the output temperature increases the COP for the HP decreases. This is due to the compression and expansion cycle of the HP; the greater the difference in temperature from the source to the sink the more work is required from the compressor (36). Therefore, a decision would need to be made during the feasibility and concept design stage of a project on how a HP would work within an existing system.

For the sake of the analysis carried out by EQUANS, a comparison for both higher and lower temperature HPs have been shown in Section 6 for each industry. These are working to a flow and return of 85°C/60°C for high temperature and 60°C/35°C for low temperature. The units selected shall match as close as possible to offer the best comparison, as the high temperature and low temperature HPs operate with slightly differing output duties. This offers the comparison between system flow and return temperatures, efficiency, and potential savings both for financial and emissions output.

GSHP require the use of boring into the ground to extrapolate the thermal energy, as is shown in Figure 17, they can also extrapolate heat through buried coils. When reviewing this type of HP application, ground heat conditions must be understood during the feasibility of the system. Ground temperatures can fluctuate respective to ambient temperatures above a ground level of 10m, up until this depth the latency between ambient temperatures and ground temperature increases (34). Below a depth of 10m the temperature remains effectively constant respective to the annual mean air temperature (35).

HPs work best under similar conditions to CHP systems, meaning a consistent flat base load and fixed flow and return temperature is needed for optimum performance. Therefore, a process load connected to a district heating scheme, for example, would favour the use of heat pumps as this can ensure a constant base load throughout a 24-hour period. The use of a pre-heat for other equipment such as boilers is a useful method to reduce the gas consumption for a process or site. This allows a HP to pre-heat the return water from site before entering a boiler, offsetting the requirement for burning more gas to produce the same process system temperatures. An example this type of arrangement is shown below.

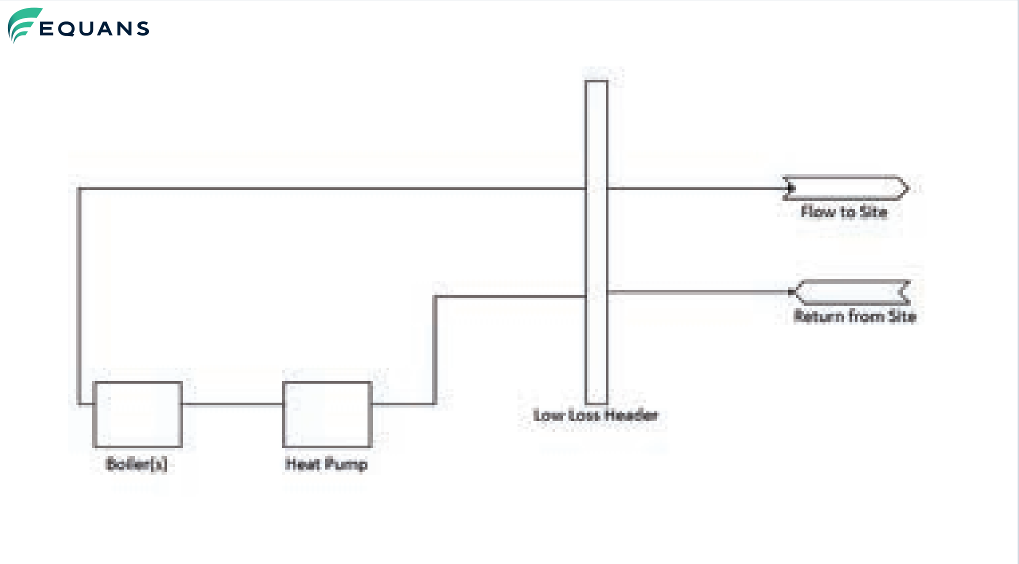

Figure 17 Heat Pump System Arrangement

Waste heat recovery can also be utilised, making use of the wasted energy from a process whether it be air or process water as an energy source. This inlet energy stream to the HP will allow for a higher temperature output to a site process. This will again offset the need for combustion plant and increase the efficiency of the process as that energy would then not then be rejected to the atmosphere.

The savings presented for each industry throughout Section 6 Decarbonisation Opportunities are for a hydrogen fuelled CHP system. The savings that would be presented per sector are shown in Figure 16 Savings from Hydrogen Fuel Carbon Offset. This comparison is assuming the use of hydrogen fuel, completely eliminating the carbon produced from the equivalent CHP system using natural gas fuel.

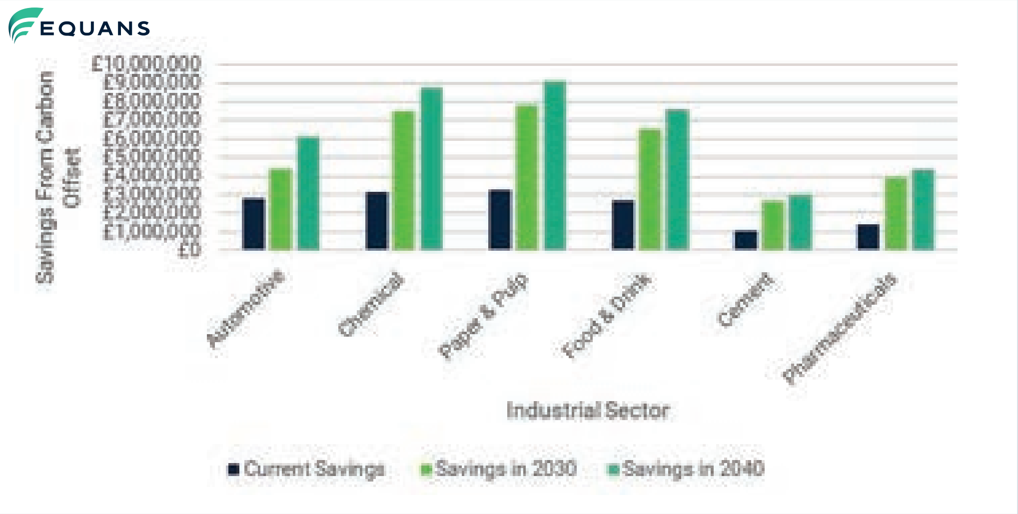

Figure 16 Savings from Hydrogen Fuel Carbon Offset

The CHP plant does produce a spectrum of benefits within the existing market, and with the introduction of hydrogen fuel further savings would be apparent for industrial users, including reducing costs from fines and taxes imposed through carbon emissions emitted. Section 6 discusses the savings presented to a sector by using hydrogen for combustion plant when considering the same analysis undertaken for a CHP. It identifies the potential benefits to end users of fuel switching in conjunction with the implementation of CHP technology. When the fuel switch occurs from natural gas to hydrogen, an industrial site can change fuels with little impact on their existing infrastructure.

5.3.2 Heat Pumps

Heat pump (HP) technology utilises energy from a source (air, ground or water) and transfers it to a sink, process or space heating. This is achieved by the transfer of energy through an intermediate system using a compression and expansion cycle. This cycle requires the input of electrical energy, with the ratio of electrical energy input to useful heat energy output being measured as COP. For the cycle to be effective the COP must be greater than 1 with a typical COP between 2 and 3, with some systems as high as 5 (32). As the COP is the result of the energy output divided by the energy input, a COP of 3 would mean 3 kW of heat energy is produced compared with 1 kW of electrical energy consumed. The intermediate system contains a specific media such as CO_2 or Hydrocarbons (HC) which classify as natural refrigerants. Previously environmentally harmful gases such as hydrofluorocarbons (HFCs) were used which have been phased out of use due to their detrimental effect on the environment.

Different energy sources can be utilised in a HP application, such as ground source (GSHP), air source (ASHP) and water source (WSHP). The fundamental characteristics of a HP work the same with different sources of energy.

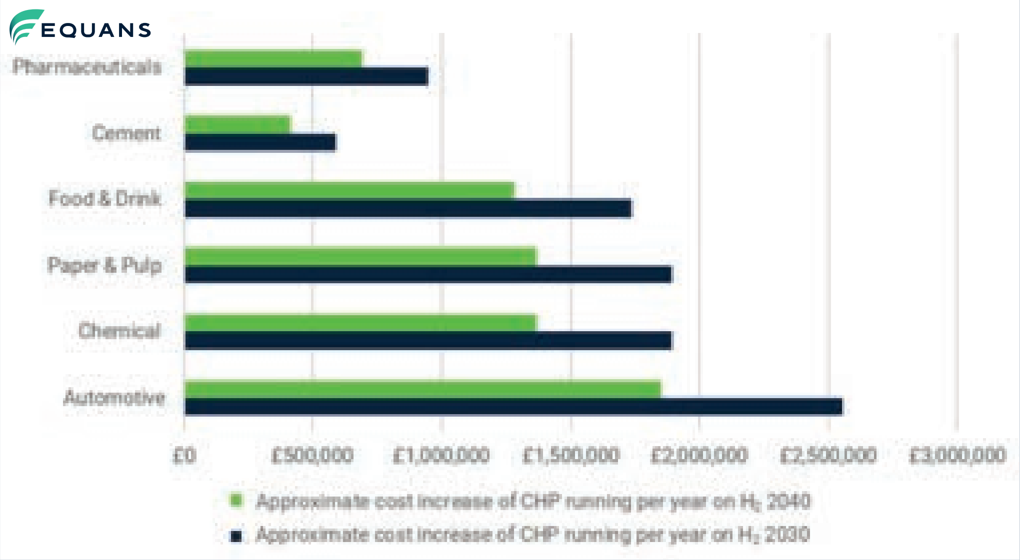

Figure 14 H2 Cost Increase 2030 and 2040 Comparison

Figure 14 H_2 Cost Increase 2030 and 2040 Comparison illustrates that the initial application of hydrogen gas can cause an increase in cost of over £2,500,000 per year in certain sectors, with a reduction in cost by approx. 28% 10 years later in 2040 (if unsubsidised). However, we recognise that the hydrogen business models consultation is set to benchmark the cost of hydrogen to the counterfactual fuel of natural gas. Therefore, the cost increase delta would be covered by the Contract for Difference (CFD) mechanism, meaning the consumer sees no additional cost.

Figure 15 simply illustrates the importance of the CFD mechanism in ensuring technologies such as CHP are viable. With significant savings presented when considering the offsetting of carbon production from onsite generation. This increase in potential financial savings is from the combination of the utility price gap and carbon reduction savings. Therefore, the integration of CHP technology operating with hydrogen fuel would provide a significant financial benefit when comparing to the existing climate. This scenario is only viable with a CFD mechanism in place, otherwise these savings would be unachievable.

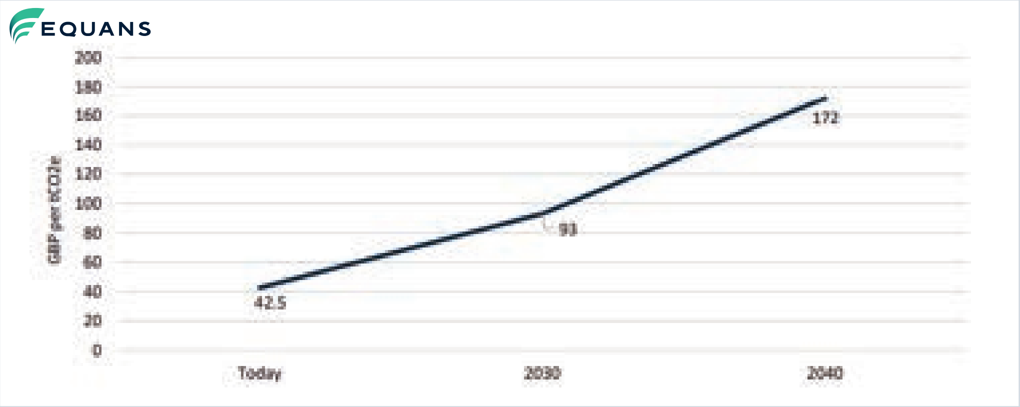

Figure 15 Carbon Pricing Per Tonne

5.3.1.3 CHP Review

For this stage of the analysis each sector was reviewed to understand its suitability to support the operation of a CHP system. A specific criterion had been defined for thermal and electrical utilisation and payback so an understanding could be reached as to whether the site would benefit from the installation of a CHP system. This has been applied to a range of industries contributing to approx. 40% of the carbon output for the North West England and North East Wales industrial users. This has allowed for a clear comparison between various industries with differing processes and operating profiles. Due to the type of review undertaken, assumptions have been made regarding the thermal energy usage on site. Modelling has considered only a LTHW system, which does not exceed an operating temperature of 90°C.

It is appreciated that this does not make a true reflection of circumstance, so a feasibility study would be required at each site to understand the appropriate system to install. This section of the report does not detail the operating intricacies of each industry, a more detailed review of each industry is in section 6.

5.3.1.4 The Future of CHP

The current forecast for the industrial landscape has shown that natural gas combustion equipment is not viable to achieve net zero carbon by 2050. However, the narrative for the report is to appreciate the carbon savings available through hydrogen integration. Therefore, a huge investment is being placed within research and development to produce an alternate solution moving away from natural gas combustion to hydrogen gas. Currently hydrogen gas engines are commercially viable up to 1 MW with a view to expand this to a larger scale output matching the market's existing system offering.

The characteristics of a hydrogen engine differ slightly from a conventional natural gas engine due to the nature of the fuel type. This is expected as hydrogen fuel has a higher calorific value than natural gas when comparing mass, but is much lower on a volumetric basis. Hydrogen in a gas form needs to be pressurised before combustion, this allows for a comparative energy output from the CHP when changing from natural gas to hydrogen gas.

Current legislation restricts CHPs from being classified as low carbon solutions. However,, the installation of the system can still contribute to a significant cost reduction to site from the offset of electrical and thermal energy.

If we assume that there are no changes in the current legislation, natural gas CHP modelling has been applied to understand the operation of the CHP and that when hydrogen is introduced it is possible to reduce carbon further, thus savings could be vast across each industrial sector. The model for the CHP system includes the assumption there is an existing boiler working at 75% efficiency. It is understood that newer boilers can operate up to an approximate efficiency of 86%. Therefore, the benefit of a CHP installation will be different for each site.

Another parameter for modelling a CHP system within an industrial site is the thermal and electrical utilisation rate. A minimum of 90% thermal utilisation is required to ensure the system does not reject too much energy during a yearly operation profile. Electrical utilisation rates need to be as close to 100% as possible to enable the greatest benefits through displacing site power and national grid constraints, as previously mentioned.If this does not occur, then the CHP shall need to de-rate to suit the site requirements which is illustrated below in Figure 13 in a load duration curve. This curve shows the CHP can run for 7,884 hours of the year with a utilisation rate of 99.93%. This type of system is an electrically-lead system.

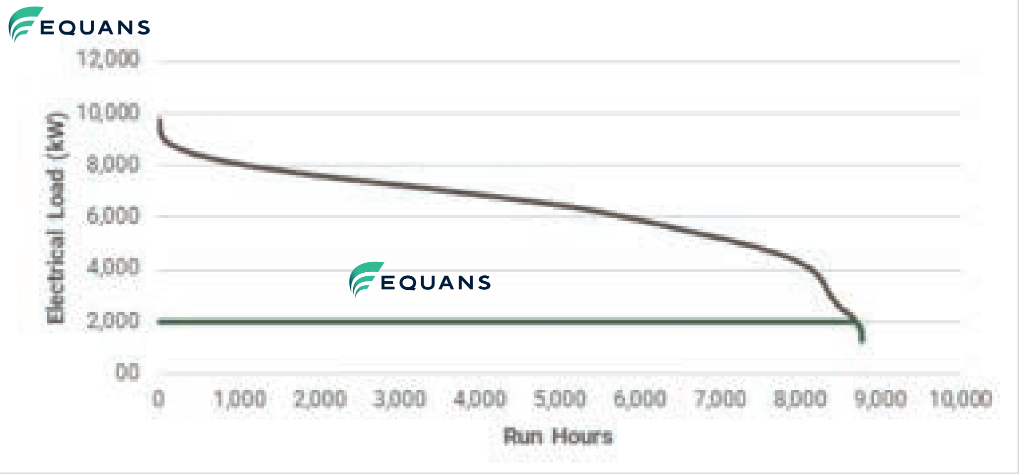

Figure 13 CHP load duration curve

The payback for the installation of the system is a key input to the overall report as this is the most attractive motivation behind a CHP installation. For the calculations carried out within this report, the electricity and gas prices used for all costings and savings are shown in Table 15. Table 16 shows the grid carbon figures applied to the model to understand the carbon savings from a CHP installation.

Fuel	£/kWh
Electricity	0.108
Gas	0.023

Table 15 Utility Costs

Fuel	mg/kWh
Electricity CO_2	255.6
Natural gas CO_2	183.53

Table 16 Carbon Factors

As previously stated, the advantage of this system is the generation of multiple energy outputs for a site. However, it should be recognised that for this to be a feasible solution for a site, termination points for each respective system need to be in relative proximity to each other. The viability of a CHP installation needs to be explored with a feasibility study.

Due to space constraints within most installations, modern CHP systems are designed to be supplied as a modular assembly, removing the need for additional construction works on a site. This would be within a container of an approximate size of 3m(w) x 3m(h) x 12m(l) including the respective equipment within the supply of the assembly. Systems exceeding 2.5 MW would require a more bespoke container or enclosure design specifically for that installation.

5.3.1.1 CHP Feasibility

CHP systems work best when installed within a system that operates with a consistent base load, avoiding the need to modulate between full and part load conditions and reducing start/stop operation. This will allow for the most optimised and efficient system with the quickest payback and will reduce premature wear to components.

In the event the CHP exceeds the site thermal requirements, it will have the capacity to eject the energy to the atmosphere via a dry air cooler. This is not a desired situation as the efficiency of the system will decline dramatically below the potential savings available. If the site's electrical requirement drops below the CHP output, then certain constraints shall be in place to de-rate the system to suit. This is largely due to recent constraints with network operator issues with 'back feeding' electricity onto the National Grid. Local control systems must ensure the CHP does not exceed the required site electrical output.

Consideration of the future of hydrogen fuel within the horizon of CHP applications would enable CHP technology to count towards a significant carbon reduction for industrial sites. The review that has been undertaken within this report is to understand the technology of CHP being implemented within an existing infrastructure. Further review is needed to demonstrate how the technology can be future proofed with the introduction of low carbon fuels such as hydrogen. Hydrogen fuels are discussed further in Section 5.5 of this report. Existing fuel types such as biogas from anaerobic digestion (AD) plants can be shown to reduce carbon further within power generation applications. The process of biogas production is through the anaerobic decomposition of organic material. Biogas can then be utilised within a CHP plant to produce electricity. This process and the application is explained further in Section 5.4.3 of this report.

5.3.1.2 CHP Methodology

Considerations were made for the selection of the CHP system with existing CHP data sheets acquired by EQUANS, ensuring the most accurate selection for the industry. This allows for an understanding of carbon reduction, quality index (QI) score, which determines the quality of the CHP through the CHP Quality Assurance (CHPQA) standard, and a total saving for the installation and operation of the equipment. The QI score for a CHP installation is defined by the energy output from a system compared with the fuel input. This is calculated against an equal alternative power supply from electrical and thermal sources. The alternative values are published values from government guidelines for CHP installations. With the threshold for good quality CHP being over 100, this has been considered within the analysis as a parameter for the modelling of CHP within the industrial sectors.

Rather than being combined with the engine hot water circuit the exhaust gas energy can be recovered separately for steam applications. This is shown in Figure 11. The advantage of this application is the versatility of the system; if a site has multiple mechanical processes requiring both steam and hot water, then a CHP can supplement both simultaneously.

Both configurations shown in Figure 10 and Figure 11 are referred to as cogeneration, whereby two separate energy streams are being generated from a single fuel source. In addition to this, trigeneration systems have presented significant benefits for industrial sites that require cooling in tandem with thermal and electrical energy. This requires the CHP system to be used in conjunction with an absorption chiller. The process would then utilise some or all the hot water generated by the engine within the chiller through a condensing and evaporation process. The typical chiller system outlet temperatures would be between 4°C to 10°C, however, this can change subject to system design and manufacturer. A typical arrangement for this type of system is shown in Figure 12.

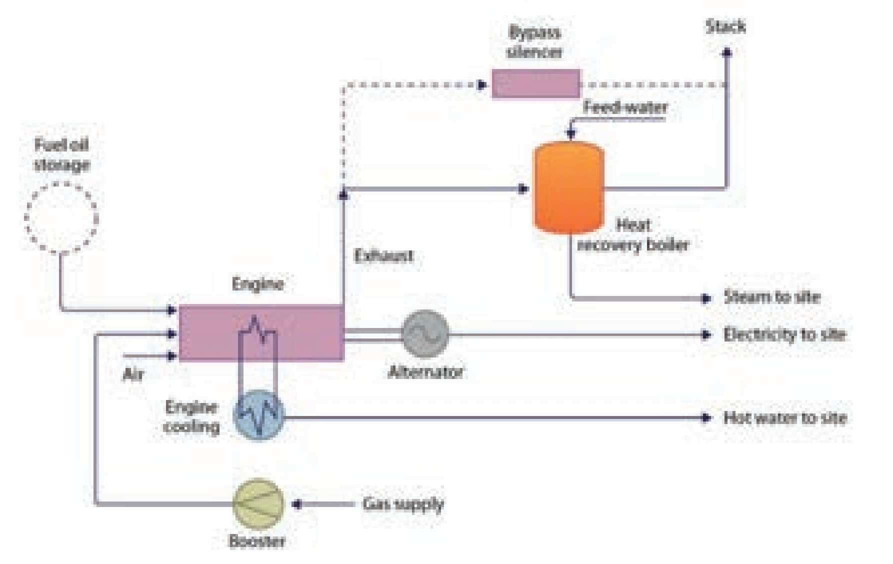

Figure 11 CHP custom steam and hot water generation (30)

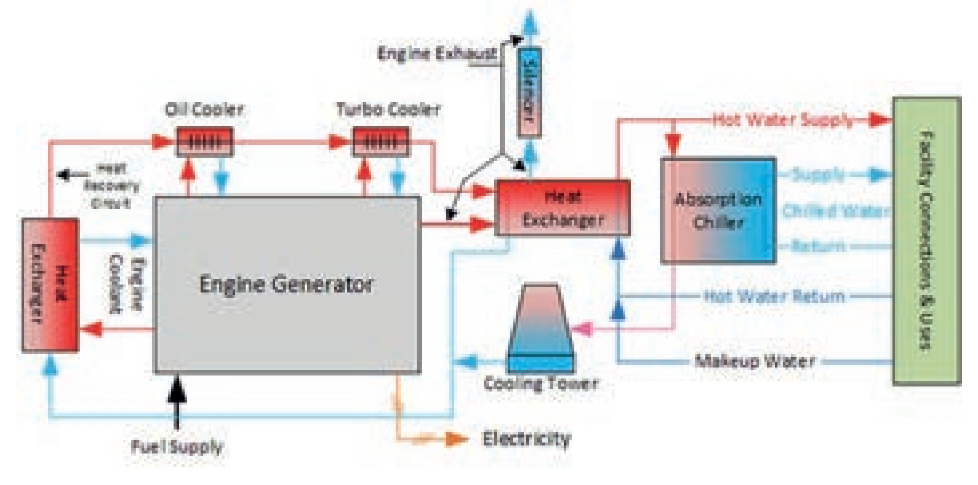

Figure 12 Trigeneration System (31)

The arrangement shown in Figure 9 is of a typical thermal energy flow diagram through the engine assembly. This arrangement is shown as an illustrative aid for the internal heat recovery system for a particular configuration. The flow arrangement for this system may differ depending on the application and manufacturer.

Figure 10 shows a CHP system typically used for LTHW application. The system beyond the limits of the engine arrangement is shown in Figure 10 illustrating the interface into the site. The advantage in utilising this type of arrangement is to offset the sites' water demand of temperatures up to approx. 100°C. However, the most common thermal conditions for this type of arrangement would be providing water at 90°C returning at 70°C. The capital expenditure of this type of arrangement is much higher in comparison due to the additional equipment needed to produce steam. However, if a CHP is sized appropriately for a site, then a significant saving can be made against the use of natural gas for the use of conventional hot water boilers.

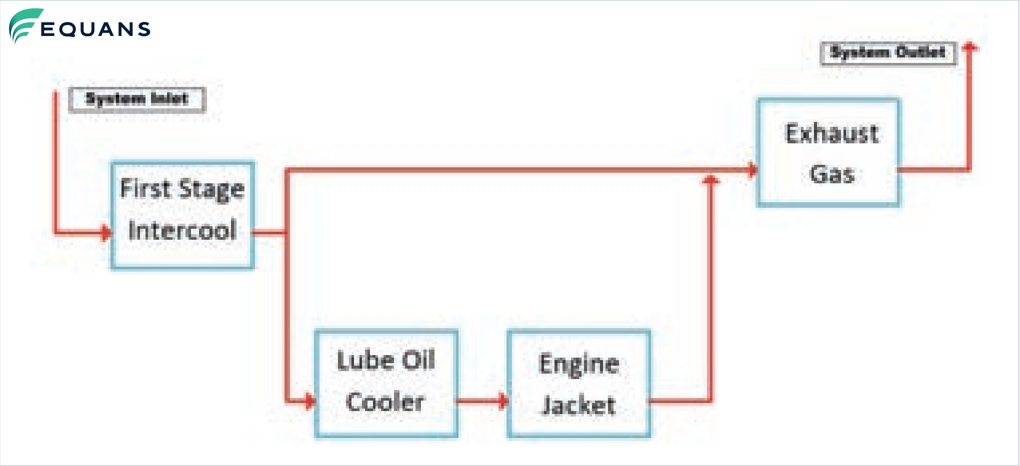

Figure 9 Typical thermal energy flow

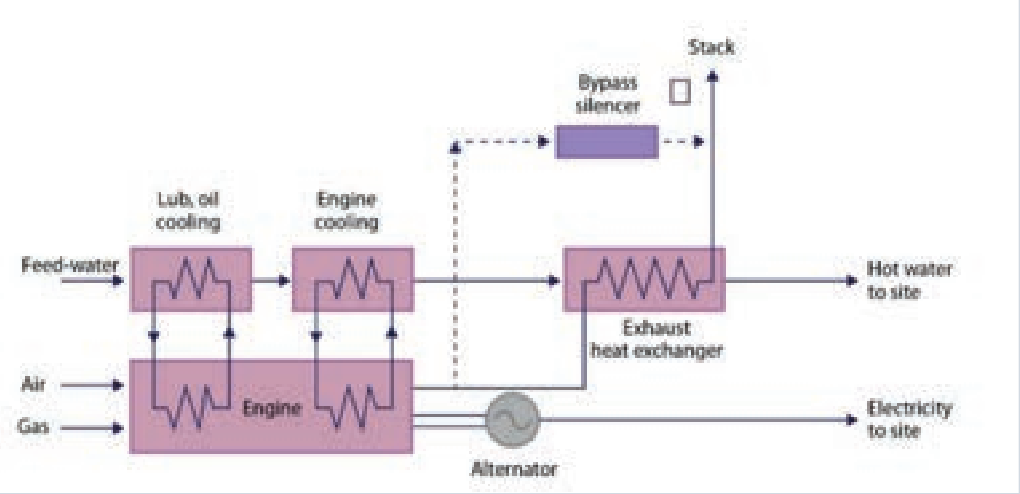

Figure 10 Low Temperature Hot Water (LTHW) CHP system (30)

5.2.7 Smart Metering And Targeting System (SMT)

SMT products are specifically designed to measure energy consumption, record, distribute metered energy data, and analyse and report on energy consumption. This enables organisations to identify ways to reduce energy costs, to pinpoint energy wastage, to be notified of instances of exceptionally high energy consumption, and to put in place robust and long-term energy management practices. SMT systems can be started at a high level i.e., measuring main utilities, and then move on to sub-metering by fitting meters on individual end-users. The information/data from a SMT system can be used to create an awareness programme and behaviour change campaigns for staff by analysing the performance against production throughput, looking at energy consumption per floor area or understanding which asset is working the most efficiently.

It is estimated that this technology can help the sectors identify energy savings of 4 - 20% or more, with average cost savings of 10-15% (29).

5.3 Low Carbon Technologies

The approach for analysing low carbon technologies shall consist of the review of clustered data of the industrial sites, grouped by their specific sector, then an average figure calculated to gauge a typical thermal energy operating profile for that industry. Electrical data has been used from various industrial sectors to understand how the electrical consumption behaves. This has allowed for a characteristic profile for that sector to be developed, which complements the thermal profile used throughout a normal year of operation.

5.3.1 Combined Heat and Power (CHP)

CHP systems produce both electrical and thermal energy from a single fuel input. This is achieved using an internal combustion engine or a gas turbine as the prime mover for the system, driving an alternator. The thermal energy is then recovered from the engine as a by-product of the mechanical work being carried out from combustion.

The most common types of CHP systems use a gas-fired internal combustion engine fuelled by natural gas. The engine assembly is directly coupled to an alternator producing electricity. There are two types of alternators typically used within a CHP application; synchronous, over 100 kW systems, and asynchronous, sub 100 kW systems.

Electrical energy is produced via the alternator coupled to the engine crankshaft. The rotation of the engine rotates the alternator which in turns produces an electromagnetic force (EMF). This EMF is the voltage generated for the site in the form of an alternating current distributed over three phases. This can be generated at 430/440 V (Low Voltage) or 11 kV (Medium Voltage). The requirement of either depends on the size of the CHP output and the site’s electrical requirement.

The thermal energy is recovered from a series of separate streams (engine jacket water, oil system, intercooler and the exhaust stream) within the engine assembly and can be combined depending on the application. The operation of the engine produces heat through mechanical work and combustion of fuel. If this heat was not removed from the engine assembly, it would suffer from catastrophic failure.

5.2.6 Heating, Ventilation and Air-Conditioning

HVAC is an important utility for industrial companies as it Is required for both human comfort conditions and certain manufacturing processes. If a poorly designed and controlled HVAC system is in operation a drop in manufacturing output and product loss may be seen. This can be because specific products and materials are being stored at the wrong temperature conditions. For example, with recent technological development of lithium-ion batteries, particularly within the automotive sector, set temperature conditions must be met. This is to reduce the degradation rate of the maximum charge capacity. Additionally, HVAC design and operation is critical for human comfort as deviation to an individual's surrounding temperature conditions will be detrimental to their output.

The equipment used within a HVAC system can also suffer from poor design and operation, as premature wear to components can occur. This could all contribute to a system that will be more expensive to run and maintain. AHUs are the most common equipment used to achieve the distribution of both hot and cool air, with other applications used for air purification. These typically contain a distribution fan and motor, heating and cooling coils, filtration, and sound attenuation. Air will be distributed through the AHU from a source to the sink, which is the area being heated or cooled, achieved via ductwork.

In the most basic explanation, the AHU is simply a heat exchanger, where energy is transferred from the media within the heating or cooling coils to the air being circulated. It is therefore crucial the specification for the coils is correct for the duty required, as over or under sizing of the effective heat transfer area will detriment the efficiency of the system. For heating applications, the most common temperature required is 20°C - 22°C. Therefore, it is more efficient to operate a heating system with low temperature hot water conditions rather than a system maintaining temperature at 90°C and above. Controls for a HVAC system are critical to achieving a fully optimised system configuration.

Pre- Heat The Combustion Air

In a common boiler, where the combustion air is taken from the boiler house, temperatures can vary from 10°C to 30°C, depending on the size of the system, boiler house insulation, etc. The combustion air needs to be heated up to the combustion temperature, which is normally achieved in the burner by burning fuel. Pre-heating the combustion air using heat rejected from the stack will result in fuel savings.

5.2.5 Refrigeration

Refrigeration is widely used in different types of industry for process cooling, cold storage, and comfort cooling. The most common refrigeration systems that can be found within manufacturing facilities are listed below:

- Package Chillers
- Refrigeration Compressors
- Adiabatic Coolers
- Absorption Chillers

Opportunities for cooling improvements in a typical manufacturing facility are listed below.

Replace Old Refrigeration Equipment with High Efficiency Equipment

The efficiency of a refrigeration system is measured by the Coefficient of Performance (COP), which is the cooling load capacity divided by the electrical load consumed by the equipment.

For example, a refrigeration system with a COP of 3, will consume one kW of energy per each 3 kWc produced.

During the operational time of the equipment, depending on the maintenance and external conditions, the COP will decrease resulting in low operation conditions. For example, an old chiller poorly maintained can have a COP of less than two, compared to a new highly efficient refrigeration system (with controls or a free cooling coil) which can have a COP over four.

Set-Point Review

Increasing the cooling temperature where possible will result in energy savings as the cooled load required from the refrigeration system will be reduced.

Free Cooling

Free cooling is the opportunity to use external air at low ambient temperatures to cool a space, allowing refrigerant cooling systems such as air conditioning to be turned off during cold periods of the year. A control system can be introduced to determine whether the ambient temperature is sufficiently low enough to use the free cooling, or high enough to use the traditional refrigerant system.

Free cooling can also be used to assist chillers. During periods of low ambient temperature, a valve will allow the cooling water to bypass the chiller and run through an air blast cooler. This may provide the entire cooling demand or be used as a pre-cooler before the chiller, reducing the energy used at the chiller.

VSD Installation

Installation of VSDs on chillers and distribution pumps to modulate the site cooling load for different times of the day or for different processes will result in significant energy savings.

Refrigeration Heat Recovery

Heat recovery equipment can be fitted to existing plants or can be integrated into new plant. In both cases, the technology allows waste heat to be re-used for space heating or hot water.

The refrigeration process includes a heat rejection stage to cool the refrigerant for re-use in the cycle. The heat is given up at the condenser, this provides the opportunity for it to be recovered.

5.2.4.2 Boiler Specific Energy Efficiency Technology Economiser

Flue gas (or exhaust gas) is generated through the combustion process. A proportion of this gas contains useful heat which is wasted if the gas is released into the atmosphere via a stack. An economiser can recover some of this waste heat and use it to pre-heat the feed water, resulting in a lower energy input to achieve the same output.

Blowdown

Blowdown is required for steam boilers to control total dissolved solid (TDS) and the build-up of sludge solids.

There is potential to recover water and heat through the blowdown process. The quality of water dictates the the amount of blowdown required to maintain the required boiler water TDS. Automating this process with TDS sensors has the potential to save energy. Furthermore recovering heat from the flash vessel can limit further wasted heat.

This can be achieved by installing TDS sensors and automating the process, so the blowdown will only occur when necessary.Once the blowdowns are limited this way, further heat waste can be minimised via the use of a flash vessel for heat recovery.

As the water in the boiler is at saturation temperature when it is released into atmospheric pressure, it will flash off as steam. This steam can be recovered and put back into the system, either to heat the feed tank or to be used for other heating applications.Further opportunities for heat recovery may also be available from the sensible heat in the remaining blowdown stream.

Combustion Controls

Each combustion process needs to respect a ratio between fuel and air. The theoretical amount of air needed to completely burn the fuel during a combustion process is known as stoichiometric air.

However, due to practical reasons, it is not possible to achieve 100% fuel combustion with only stoichiometric air, therefore, some percentage of excess air is provided to assure that all the fuel is burned and is not transported to the stack. Heat loss through the stack depends on the mass flow and temperature of the gas leaving the boiler. Reducing the gas temperature by reducing the surrounding air temperature can improve system efficiency. The boiler efficiency will depend on the excess air so improving the excess air rate will improve boiler efficiency.

Table 14 shows indicative combustion efficiencies for different excess air rates in gas fired equipment.

Combustion Efficiency (%)						
Excess (%)		**Net Stack Temperature (°C)**				
Air	**Oxygen**	**93.3**	**149**	**204**	**260**	**316**
9.5	2	85.4	83.1	80.8	78.4	76
15	3	85.2	82.8	80.4	77.9	75.4
28.1	5	84.7	82.1	79.5	76.7	74
44.9	7	84.1	81.2	78.2	75.2	72.1
81.6	10	82.8	79.3	75.6	71.9	68.2

Table 14 Combustion efficiency per excess air rate in a gas fired equipment

As per the table above, a combustion system with a 9.5% excess air and 2% of oxygen will have an efficiency of 85.4%. As a rule of thumb, the boiler efficiency can be increased by 1% for 15% reduction in excess.

5.2.3 Motors And Drives

Most moving applications and modern-day devices are powered by electric motors. These range in size from large industrial pumps to small office ventilation fans. In industry they are expected to consume 70% of all electrical consumption. Opportunities for improvements in efficiency through motors and drives are listed below:

- Many assets are fitted with electrical motors such as boiler burners, blowers, chilled water/ cooling tower recirculation pumps, air handling units (AHU) and ventilation fans, etc. They run most of the time to maintain the requirements for the end-user. These motors can be replaced with high efficiency motors or fitted with VSDs and feedback signal for better control.

- VSDs and variable frequency drives (VFDs) (also called adjustable speed drives (ASDs)) vary the speed of a fixed speed motor. In HVAC systems, they are used primarily to control fans in variable air volume systems. Instead of devices such as inlet vanes, pumps and discharge dampers, VSDs provide effective speed control of AC motors by manipulating voltage and frequency. Controlling the speed of a motor provides users with improved process control, reduced wear on machines, increased power and energy savings.

- Belt drives can incur considerable efficiency losses. The efficiency depends on the calculation of the belt gear, the type of belt, and the complete gear adjustment. Normally an expected efficiency of a belt drive is 90% at medium power (3–15 kW), but it can easily slip to 60–70% if the gear adjustment is incorrect. Belt driven systems are more common in extraction and ventilation systems, however, they can be found in various manufacturing dedicated processes. The newly designed systems must avoid belt-driven applications and should always use direct drives where transmission efficiency is 100%.

5.2.4 Heating

Heating is used widely in every sector within the North West England and North East Wales, either for space or process heating.

Heating systems vary for different applications and heat loads. The most common heating systems that can be found within a manufacturing facility are listed below:

- Hot water Boiler
- Steam Boiler
- Radiant heaters
- Cabinet heaters
- Direct burners for process or AHUs

Opportunities for heating improvements in a typical manufacturing facility are listed below, the list is separated into two categories; general energy efficiency opportunities and boiler specific opportunities.

5.2.4.1 General Energy Efficiency

Equipment Efficiency

Over time efficiency of combustion or heating equipment will degrade. This is mainly atributed to fouling/scaling and poor air fuel ration control. Although a good maintenance strategy will mitigate some of the degradation it cannot stop the inevitable. When paired with new efficient technology, it can be more cost effective to replace the heat provider (see heat pumps and CHP for low carbon alternatives).

Maintenance

A good maintenance programme not only increases shelf-life and decreases risk of faults/breakdown, it also maintains efficiency. Cleaning fouling off fans and/or heat exchangers is an example of how a good maintenance routine can maintain a heating system to run as efficiently as possible.

Controls

This refers to controls on the heating generator, whether that is boiler controls or controls on a direct heating system, such as a cabinet or radiant heater (see HVAC for more on point of use control). Timers, heating zones and lock-outs to stop simultaneous heating and cooling are the top efficiency opportunities.

Set-Point Review

Reducing heating temperature where possible will result in energy savings as the thermal load produced by the heating system will be reduced.

Install Thermostatic Radiator Valves (TRV) to Heating Radiators

Smart TRVs are devices that are designed to provide an individual, room-by-room heating control, by working in conjunction with the thermostat kit and creating a so-called zoned heating system, which can be easily managed through an app on smartphones, tablets, or computers.

5.2.2 Lighting

Lighting improvements are the most common energy efficiency opportunity and can be implemented with quick payback periods. Examples of opportunities for energy reduction are listed below:

- **LED upgrades:** LEDs are semiconductors; as electrons pass through this type of semiconductor, it turns into light. Compared to incandescent and compact fluorescent lamp (CFL) bulbs, LED lights are more efficient at turning energy into light.

- Improved **lighting controls** can result in significant savings. This can be through daylight detectors, occupancy sensors, LUX level control or CO_2 sensors. Where smart controls are put in place these should be set up so that lights are controlled in logical groups. For example, lights in an area can be banked so that outer roofs can be switched off when there is sufficient daylight through windows, or halls can be set up so different levels of lighting can be switched on to suit the activity being undertaken.

- **Maximising use of daylight.** Daylight should become the primary light source in buildings for health, productivity, and sustainability reasons. Architects should be designing buildings to maximise the use of daylight, which is measured in lumens, and illumination in lux. Lux levels reveal how many lumens you need to light a given area. A lux (symbol: lx) is equal to an illumination level of one lumen per square metre. In non-SI units, one footcandle is equal to approximately 10 lux. The below table provides a summary of the lux level for different applications (27).

Lux Level (28)	Area of Activity
20-30	Car parks, roadways
<100	Corridors, stores, and warehouses, changing rooms and rest areas, bedrooms and bars
150	Stairs, escalators, loading bays
200	Washrooms, foyers, lounges, archives, dining rooms, assembly halls and plant rooms
500	General lighting e.g., offices, laboratories, retail stores and supermarkets, counter areas, meeting rooms, general manufacturing, kitchens, and lecture halls
750	Detailed lighting e.g., manufacturing and assembly (detail), paint spraying and inspection
1,000	Precision lighting e.g., precision manufacturing, quality control, examination rooms
1,500	Fine precision lighting e.g., jewellery, watch making, electronics and fine working.

Table 13 Recommended lighting levels for different areas

Furthermore, each compressor is designed with an optimum running temperature range; any heat recovery system should not over-cool the compressor which would impose an unnecessary burden on its performance. A typical air compressor heat recovery system is demonstrated below.

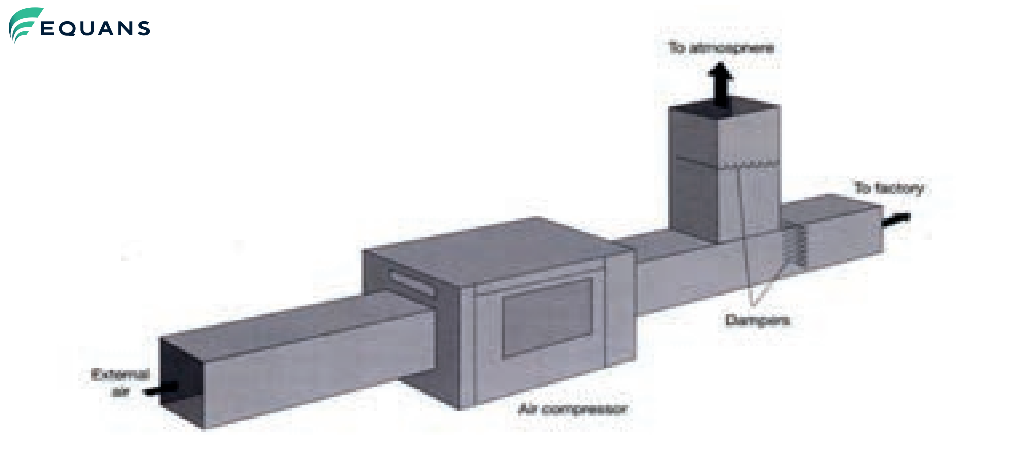

Figure 8 Typical compressed air heat recovery system

Table 12 below shows examples of recoverable heat from a range of screw compressors.

Capacity (l/s)	Nominal Motor Rating (kW)	Cooling Air Flow (l/s)	Available Heat (kW)
40	15	450	12
60	22	810	21
159	55	1,600	54
314	110	3,700	107
450	160	5,600	157
585	200	8,900	197
725	250	8,900	246

Table 12 Recoverable Heat from a range of screw compressors

Compressor Control Systems

A compressor control system should allow the user to select how each compressor will operate in relation to the others given its range of operational options. The compressor control solutions are built around integrated high-speed Programmable Logic Controller (PLC) and local Human Machine Interface (HMI) systems to monitor, log and oversee the connected compressor systems. The compressor controllers have extensive communications capabilities to allow the connection of remote third-party systems. The compressor control system may be connected to host systems to permit data to be made available throughout the plant.

Control systems are often overlooked within compressed air systems. As a site grows or evolves the air compressors are replaced or new air compressors are added to the system to meet the demand. Often the compressor will run on a 'duty and standby' system with the larger compressors meeting most of the demand and smaller compressors coming online as required.

A combination of one or multiple fixed load compressors producing the compressed air base load and a VSD compressor modulating the extra demand peaks is the most cost-effective solution for almost every compressed air system.

A compressor management control system ensures that the most efficient compressors are employed in the most efficient combination to suit a given demand for compressed air.

This is done by installing multiple independent control pressure transmitters in the air distribution system to monitor the demand and communicate to a sequence controller. The controller harnesses the most efficient combination of compressors and optimises the fixed and variable speed air compressors to orchestrate the most efficient control strategy available.

Heat Recovery

This is achieved by reusing the heat from the air compressors for space heating or process heating. The recovered heat can be supplied to heat exchangers to offset heating energy at different locations. A properly designed heat recovery unit can recover over 80% of this heat for heating air or water. Although compressors can be purchased with a heat recovery kit, a retrofitted unit would also be a good investment. The best payback is achieved when the compressed air and heat recovery systems can be designed as integral parts of the plant. For example, if the heat is used for space heating, it is beneficial to incorporate the design within the existing heating system.

Typical applications for air heating include:

- Space heating
(e.g., warehouse or factory areas)

- Pre-heating boiler combustion air.

Typical applications for water heating include:

- Pre-heating boiler feed water

- Pre-heating process water
(e.g., bottle washing)

- Water heating in laundries.

The potential savings from heat recovery should be evaluated carefully as they are highly dependent on the load cycle of the compressor being able to generate sufficient heat at the right times.

Reduction In The Compressed Air Inlet Temperature

In many industrial sites the compressor will take its inlet air from within the compressor house, which is often a warm environment due to the heat released from the compressors themselves. The warmer the inlet air the more energy required to compress it. Thus, efficiency of the compressor can be greatly improved by providing cooler air at its intake. This can be as simple as ducting air from outside the compressor house or another location on-site.

Another important consideration is where the waste heat from your compressor is discharged to, whether it is discharged into the compressor house or into the atmosphere. Best practice would ensure that waste heat does not find its way back into heating the inlet air to the compressor. The table below illustrates energy savings arising from reducing the air inlet temperature to a compressor.

Air Intake Temperature Reduction	3°C		6°C		10°C		20°C	
4	80	9	160	18	264	29	528	58
7.5	150	17	300	33	495	54	990	107
11	220	24	440	48	725	79	1,450	157
15	300	33	600	65	990	107	1,980	214
22	440	48	880	96	1,450	157	2,900	314
30	600	65	1,200	130	1,980	214	3,960	428
37	740	80	1,480	160	2,440	264	4,880	528
55	1,100	119	2,200	238	3,625	392	7,250	783
75	1,500	162	3,000	324	4,950	535	9,900	1,070
110	2,200	238	4,400	476	7,260	785	14,520	1,569
160	3,200	346	6,400	692	10,550	1,140	21,100	2,279

Table 11 Energy Savings from reducing air inlet temperature

Compressors Speed Control

Compressors can be fitted with their own individual control system to control the site demand. The traditional way of controlling a compressor is by running the motor at full speed and then stopping it when the air has been compressed to the correct pressure. It is then stored in a reservoir at a slightly higher pressure than is needed, to allow a hysteresis in the pressure.

Modulation control schemes proportionally adjust the inlet valve from open to closed, altering the compressor discharge according to demand. Whilst this yields a consistent discharge pressure over a wide range of demand, power consumption is significantly higher than with load/unload mode schemes, resulting in approximately 70% of full-load power consumption when the compressor is at a zero-load condition.

A VSD controlled air compressor uses an alternative current (AC) drive to control the speed of the unit, which in turn saves energy compared to a fixed speed equivalent. VSDs reduce the energy output of a compressor, by controlling the speed of the motor, ensuring it runs no faster than necessary for the required compressed air demand.

Compressor manufacturers often sell compressors for worst case scenarios that are essentially too large for the applications. These oversized compressors can easily be identified by the unload running hours when compared to load running hours. Compressors with high run hours and low load hours are ideal for a VSD installation.

Pressure Optimisation

Pressure optimisation is achieved through reviewing and resetting compressed air pressure to match the demand and activation of setback mode when not in peak demand. Historically, sites will maintain their compressed air pressure regardless of whether it is required or not. As a site evolves over time and equipment changes, the compressed air distribution may not be re-assessed. The higher the pressure to be generated in the compressor, the more expensive it is to provide that air, thus, generating less pressure requires less energy input from the compressor, consequently saving energy. If the pressure can be reduced without detriment to the system or the equipment it serves, the energy savings are immediate at no cost. Even small reductions in pressure setpoints can result in significant energy cost reductions; for every 0.5 barg reduction in the compressor set-point pressure, 3% of energy required by the compressor is saved.

It is important to notice that higher pressures increase compressed-air leakage and consumption at open air lines. If an end of use application requires a different pressure than the output of the compressed air plant, it is more efficient to run a local dedicated system as a booster or a small compressor close to the relevant process than it is to run the whole system at the highest pressure.

Consideration should be given to:

i. Ensuring low pressure requirements where possible when specifying new equipment.

ii. Installing air pressure boosters to specific users.

iii. Installing dedicated air compressors to specific users.

iv. Pressure drop between compressor house and end-user should not be more than 10% .

The use of VSDs and a good control system are both likely to enable more effective optimisation of compressed air delivery due to being able to offer tighter controls of the pressure.

5.2.1 Compressed Air

Compressed air is used in almost all manufacturing processes as a source of motive power for actuators, tools, etc. However, it is one of the most expensive and inefficient utilities in manufacturing plants. In fact, over the lifespan of a typical compressor, energy typically used costs several times more than the purchase price of the compressor. For this reason, maximising energy efficiency in compressors is crucial to achieve savings. Compressed air is an inefficient form of energy, with only 8-10% of input energy converted into useful energy output, the remainder being dissipated as heat.

There are two common applications of compressed air, namely instrument air and process air. Instrument air is used for actuation (pneumatics) such as a robotic arm for packaging machines, while process air is used in the process itself, such as the delivery of raw material from silos to production machinery.

Opportunities for compressed air improvements in a typical manufacturing facility are outlined below.

Leak Reduction

Leaks in the compressed air system can be a further source of wasted energy; a typical compressed air system loses 20-40% of the compressors output through leaks. Therefore, frequent checks are required on generation and distribution networks to avoid loss of compressed air from the system The table below demonstrates the typical impact of compressed air losses at varying hole and system pressure sizes.

Leaks can occur in any part of the system, however, the most common problem areas are pipe joints, fittings, valves, and filters. Leaks can be difficult to detect if the system is at a high level or if the leaks are within a noisy environment. The most common equipment used in a leak detection survey is the ultrasonic equipment which converts the air leak ultrasound to an audible frequency that normally can be heard through a set of headphones. A single survey and fix is not enough to maintain an efficient system; a leak prevention program will take a holistic approach to the facility's operations, and include:

- Identification
- Tagging
- Tracking
- Repair (budget)
- Verification
- Employee engagement

If this is implemented effectively the wasted compressed air would realistically reduce from 20-40% to 5-15%.

Air Pressure (barg)	**Leakage (l/s) through various sized holes (mm)**							
	0.5	1	2	3	4	10	12.5	4.2%
2.5	0.14	0.58	2.3	5.5	14.6	58.6	91.4	2.1%
5.0	0.25	0.97	3.9	8.8	24.4	97.5	152.0	1.0%
7.0	0.33	1.31	5.9	11.6	32.5	129.0	202.0	3.0%

Table 10 Estimated Air Leakage rate for different range of pressures

Table 8 and Table 9 show the average percentage savings achievable by implementation of the most common energy efficiency opportunities within an industrial site, for each of the analysed sectors. Further manufacturing process related savings within each sector are explored individually in section 6.

Technology	Automotive	Cement	Chemical	Iron and Steel	Food and Drink	Glass	Pharma	Paper and Pulp	Average Electricity Savings (%)
Compressed Air	2.4%	5%	4.0%	5.0%	3.9%	–	5.1%	4%	**4.2%**
Heat Recovery	0.0%	10%	-0.1%	0.0%	0.4%	–	–	–	**2.1%**
Heating Systems	3.0%	–	0.0%	0.0%	1.0%	–	–	–	**1.0%**
HVAC	3.5%	4%	5.0%	–	5.0%	–	4.5%	–	**4.3%**
Lighting	2.5%	1%	3.0%	2.0%	1.9%	1.0%	5.9%	3%	**2.7%**
Motors and Drives	3.0%	4%	1.0%	3.5%	2.0%	3.0%	4.0%	5%	**3.2%**
Pumping Systems	2.9%	1%	1.7%	2.7%	1.0%	2.0%	–	–	**1.9%**
Refrigeration	1.9%	–	3.5%	2.9%	5.7%	2.0%	10.3%	–	**4.9%**
SMT	3.0%	3%	3.0%	3.0%	3.0%	1.0%	2.8%	3%	**3.0%**

Table 8 Electricity savings per Sector

Technology	Automotive	Cement	Chemical	Iron	Food	Pharma	Glass	Paper	Average Gas Savings (%)
Compressed Air	5.0%	0%	0.0%	1.2%	0.8%	2.0%		1%	**1.5%**
Heat Recovery	10.0%	10%	7.5%	7.5%	5.0%		5.8%		**8.0%**
Heating Systems	7.0%	10%	4.0%	2.5%	2.5%		11.6%		**5.2%**
HVAC	0.0%	2%	0.0%		2.5%	1.0%			**1.1%**
SMT	3.0%	1%	3.0%	3.0%	5.0%	3.0%	1.2%	3%	**3.0%**

Table 9 Natural Gas savings per Sector

5.2 Common Energy Efficiency Opportunities

In its simplest form, energy efficiency is the measure of how much energy is required to perform an action. Strategies that enable organisations to use less energy are one of the easiest, lowest-investment, and often simplest approaches to lowering carbon emissions. However, these are sometimes overlooked for larger transformations that come with corresponding risks. In our experience, reduction through energy efficiency is the first step in addressing the net zero challenge.

The higher the energy efficiency the lower the amount of energy needed to perform the same action. The goal of energy efficiency is to use the least amount of energy without diminishing the performance of the work required. The following section will introduce common energy efficiency measures that can be utilised in an industrial setting across all the sectors. Sector specific opportunities can be found in Section 6.

Energy efficiency opportunities enable an organisation to utilise existing processes and equipment, optimising a systems' performance through new technology implementation or through energy recovery. The following subsections detail areas where this is commonplace within an industrial site, such as improvements within a compressed air or hydraulic pumping system. Typically, the capital expenditure for such improvements is small when compared to implementing a solar array or heat pump installation.

Therefore, to assist an industrial site in reducing carbon emissions and operating costs it can be beneficial to explore these opportunities.

Each of the following areas are commonly used within all industrial sectors, and the respective data is taken from Net Zero Carbon Roadmaps, ESOS reports, and other analysis conducted on industrial sites. This has allowed for a review of specific systems and process areas that can present a carbon and cost reduction through efficiency optimisation.

The following is a short introduction on typical energy saving opportunities across these technologies, which can be found in multiple sectors but are the most common to industrial sites. This is explored in more detail in the each of the respective subsections. The technologies explored in this section include:

- Compressed Air
- Lighting
- Motors and drives
- Heating
- Refrigeration
- Heating, ventilation, and air conditioning (HVAC)
- Smart Metering and Targeting System

Figure 6 Emission types and technologies used in the North West England and North East Wales illustrates the link between the emission sources on the left and the energy generation technologies on site on the right, weighted using Scope 1 emissions. The category "Manufacturing Process" represents the actual emissions produced as a result of production processes. For example, when producing cement, the Clinker (cement raw material) goes through a chemical process that produces carbon emissions.

Figure 6 Emission types and technologies used in the North West England and North East Wales

Whilst the North West England and North East Wales has a high concentration of Heaters and LTHW in the region, the associated emissions are much lower when compared to technologies such as gas turbines, which are employed at only five industrial sites. Hence the comparison of Figure 5 Industrial cluster technologies with Figure 6 Emission types and technologies used in the North West demonstrates the number of sites utilising a technology is not representative of the volume of Scope 1 emissions. One of the important factors of consideration includes the scale of operations in relation to the technology and processes in place at the site. For instance, a CHP will tend to be deployed at larger sites with the highest overall consumption. According to the data, biogas is used only within a CHP plant whereas biomass and coal are used exclusively within a kiln. The majority of emissions from the Manufacturing Process are from kilns, with a small amount from CHP plants and furnaces.

Figure 7 Breakdown of emissions based on technology utilised in the North West illustrates the concentration of Scope 1 emissions in relation to energy generation technologies used. Gas turbine has the highest share of Scope 1 emissions (28%) with only five sites which are power producers. These are followed by CHP plants with 20% utilisation at thirty eight industrial sites. This technology can be found throughout a variety of sectors including paper and pulp, food and drink, and chemicals. This is largely due to the ability of CHP technology to produce both electricity and heat on site. Kilns produce 20% of Scope 1 emissions within the cement and ceramics sectors exclusively. Despite the high utilisation of Heaters and LTHW at seventy five sites, Scope 1 emissions for this technology only total 9%.

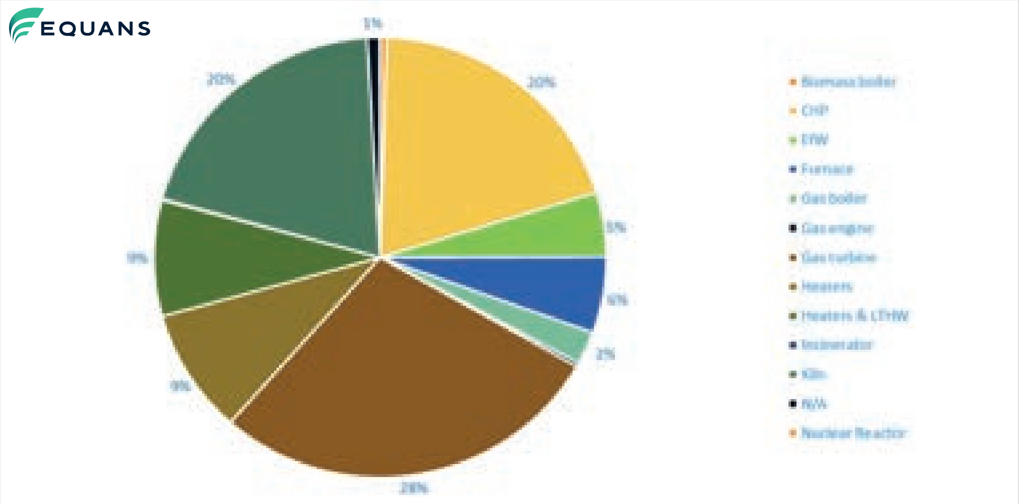

Figure 7 Breakdown of emissions based on technology utilised in the North West England and North East Wales

5. Technology Overview

5.1 North West Cluster Technologies for Scope 1

Figure 5 Industrial cluster technologies demonstrates the breadth of technologies used to generate thermal energy at each industrial site, based on data collected via EU ETS and NAEI.

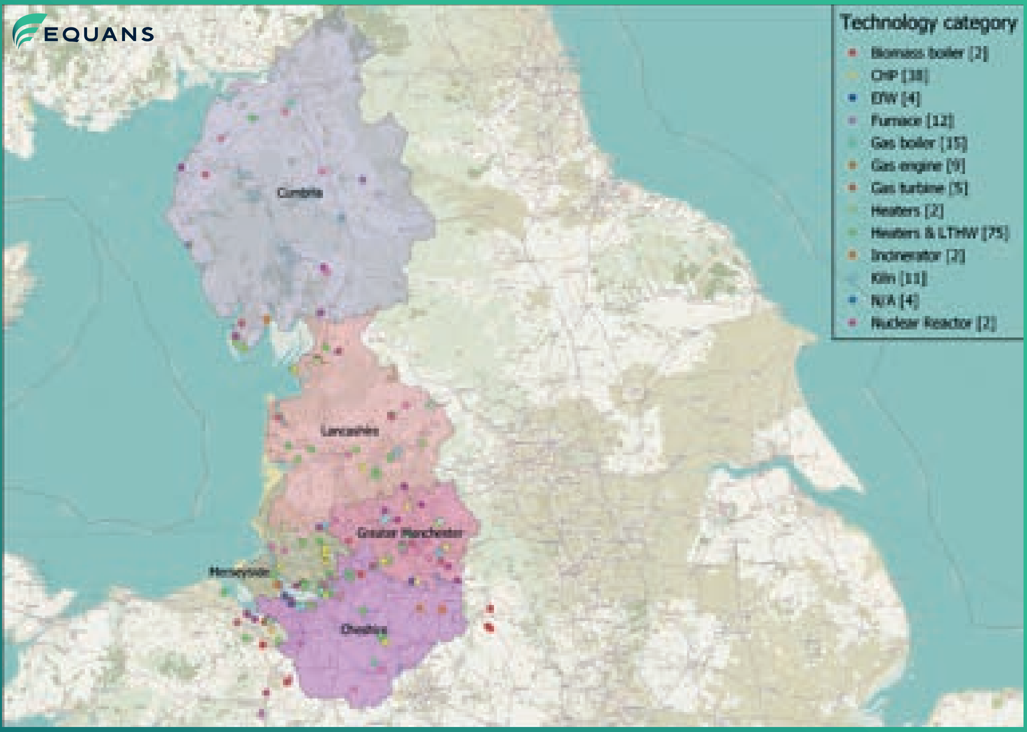

Figure 5 Industrial cluster technologies

Industrial heaters and Low Temperature Hot Water (LTHW) are the most common technologies, identified at 75 out of 181 North West England and North East Wales sites, which is representative of the heat demand in industrial processes and space heating requirements. This is followed by CHP, gas boiler, furnace, and kiln, respectively. Highly concentrated regions of these technologies within the North West England and North East Wales indicate opportunities where energy and carbon saving measures could be deployed.

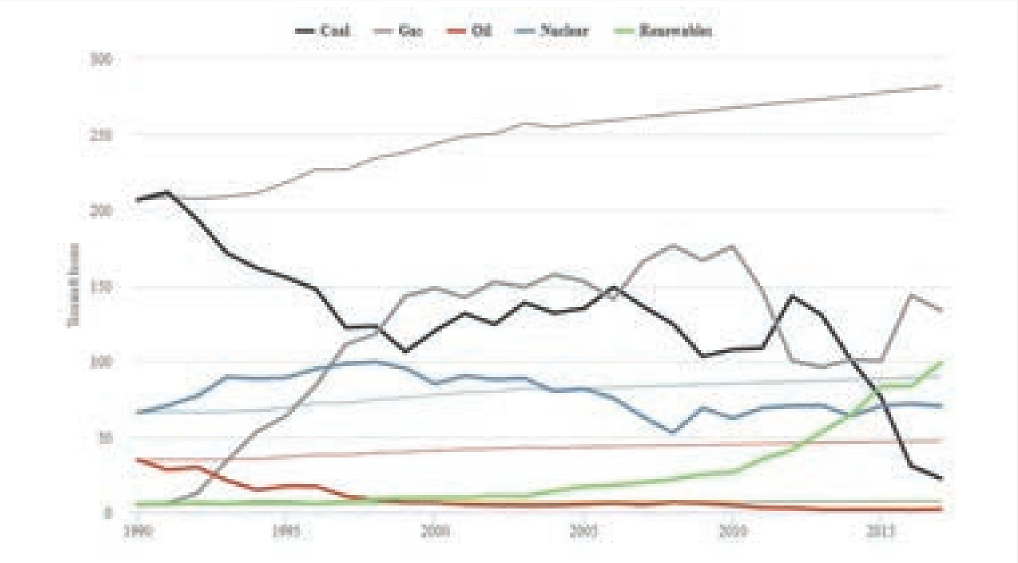

Figure 123 UK electricity Production (109)

The UK government has confirmed plans to eliminate fossil fuels from UK electricity generation by 2035. More than half of the electricity generated in the UK is already from renewables and nuclear.

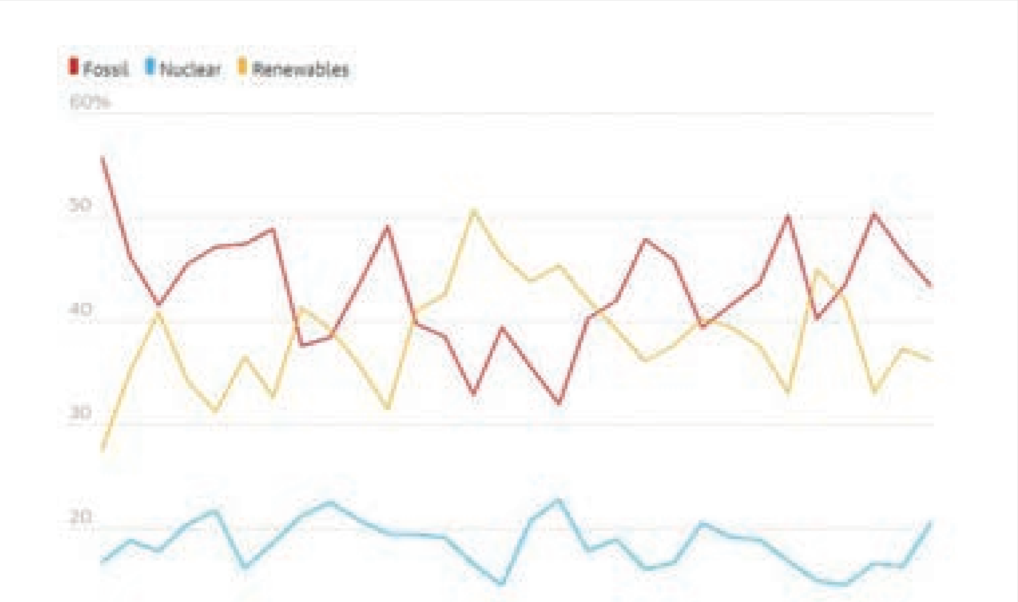

Figure 124 Percent share of electricity production (110)

This report briefly discusses the availability of Hydrogen Network (HyNet) in section 5.5.

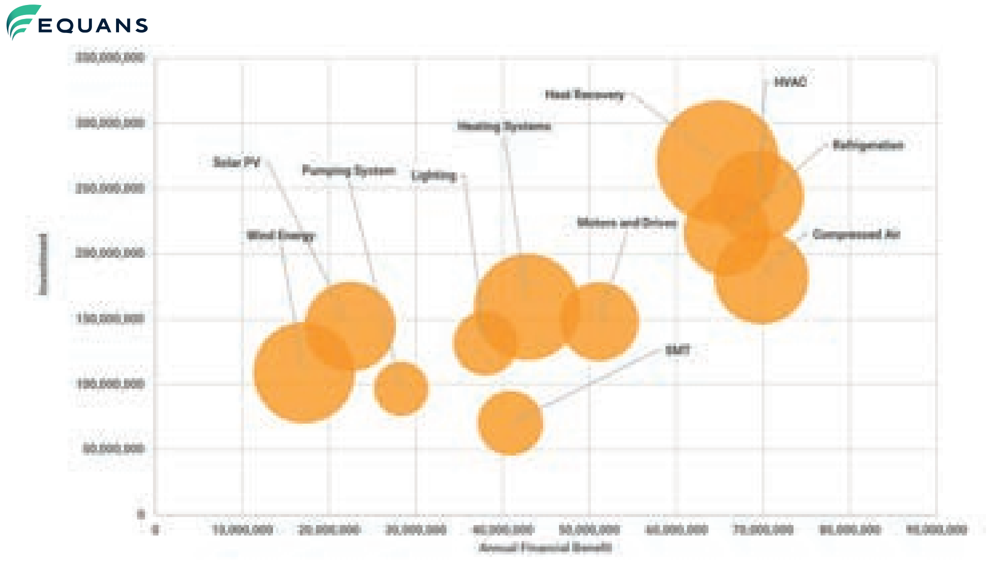

Figure 122 Other Sector Opportunities Bubble Chart

This chart demonstrates the relative cost effectiveness of each opportunity to reduce carbon. This chart can help prioritise opportunities with the ones in the bottom right quadrant of the graph with larger bubble size will have the greatest return on investment with the largest CO_2e savings.

It should be noted that above bubble chart does not include decarbonisation technologies/opportunities like conversion, procurement of renewable electricity, procurement of hydrogen or green gas and CCS as they have no payback.

6.12 Power Producers

Total emissions from power producers are approximately 1,554,407 tCO_2e for the year 2019, which is approx.19.8% of total estimated emissions in North West England and North East Wales. Emissions from Fiddlers Ferry power station, which closed in 2020, have been included .

As this sector does not have control on the end-user side, it is very difficult to reduce power production. In contrast energy consumption in coming decades is estimated to rise sharply due to growth in population, industrial manufacturing and IoT, making it more important for this sector to decarbonise power generation.

This sector can achieve net zero via adoption of renewable energy sources for power generation such as biomass, hydrogen (HyNet in North West England and North East Wales), solar, wind, tidal, waste, etc.

6.11.4 Other Sector Roadmap

Based on the technologies discussed above a pathway to net zero for the remaining sectors is proposed below. Most of the carbon reduction is through green electricity procurement and energy conservation measures as with all the opportunities stated above the sector can reduce the carbon emissions by 22%.

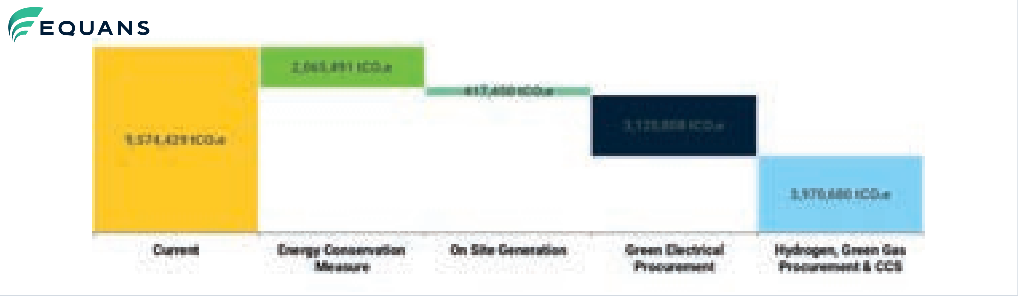

Figure 120 Other Sectors Carbon Waterfall

For net zero, total CAPEX has been estimated at **£1,816,997,514** with a financial benefit of **£524,629,055**, giving a simple payback of **3.5 years**. There is no CAPEX and therefore no payback against green electricity procurement and green hydrogen procurement as it is assumed that grid will be decarbonised by 2035 and green hydrogen will cost same as natural gas.

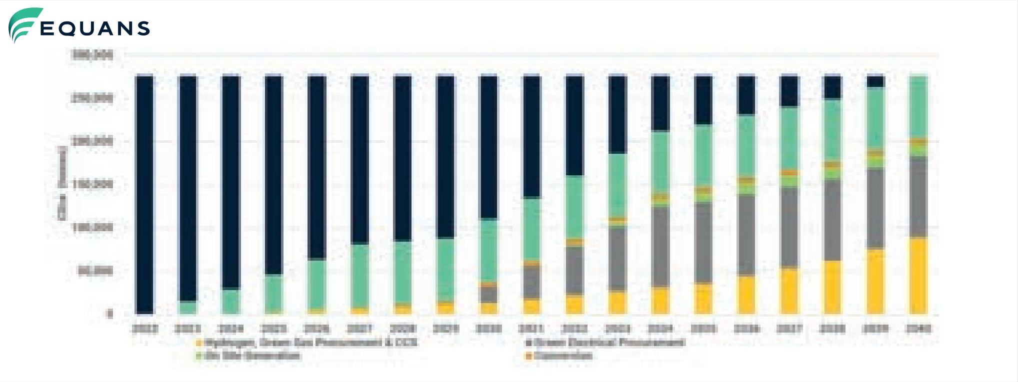

Figure 121 Carbon Neutral Delivery Plan

The timeline is an indication of when these opportunities can be implemented to achieve a carbon neutral position. It is assumed that energy efficiency opportunities will be prioritised and implemented in a 5-year interval. The total implementation of the energy efficiency opportunities will help to define a new energy consumption profile for the site.

Therefore, when low carbon technologies and renewable sources are implemented, the site will be already the most efficient that can be. It is assumed that UK electricity grid will be carbon free by 2035 as stated by UK Government. On the next page is a bubble chart for the opportunities identified above the size of the bubbles coincides with the amount CO_2e saved.

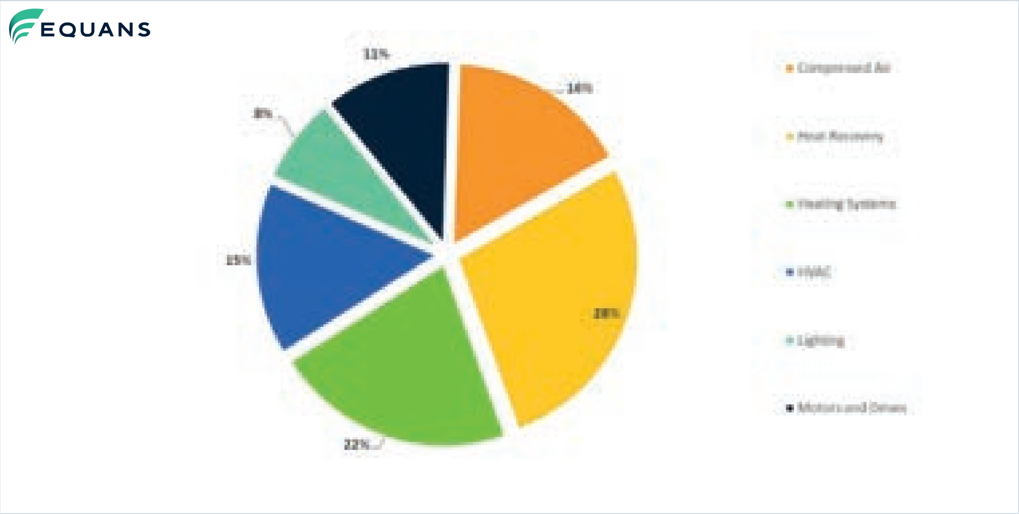

Figure 119 Other Sector Carbon Savings

Total carbon savings of approximately 22% are achievable that can enable remaining sectors to accelerate their sustainability targets and pave the way for net zero future.

6.11.3 On-Site Generation

6.11.3.1 Wind Generation

Wind energy generation can offer savings to the whole of North West England and North East Wales regardless of sector. The energy and carbon savings calculated in this section are based on the entire region of North West. The overall savings from wind energy generation in the region is applied as a ratio to the total emissions from remaining sectors to estimate specific savings. The results are illustrated in Table 101.

6.11.3.2 Solar Photovoltaics (PV)

Solar PV energy generation can offer savings to the whole of North West England and North East Wales regardless of sector. The energy and carbon savings calculated in this section are based on the entire region of the region. The overall savings from solar PV energy generation in the region is applied as a ratio to the total emissions from remaining sectors to estimate sector specific savings. The results are illustrated in Table 102.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
9,574,429	2.79%	267,193	19,676,012	125,360,997	6.4

Table 101 Other sector wind energy savings

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
9,574,429	2.23%	213,108	25,798,180	166,151,181	6.4

Table 102 Other sector solar PV savings

6.11.2 Energy Efficiency Opportunities

The table below shows the average savings or the remaining savings that have been estimated using the average savings from analysed sectors.

	Electricity		**Natural Gas**				
Technology	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
Compressed Air	759,833	82,061,939	385,899	8,875,673	90,937,612	237,542,033	2.6
Heat Recovery	317,394	34,278,595	2,006,059	46,139,347	80,417,942	335,647,560	4.2
Heating Systems	185,642	20,049,372	1,647,175	37,885,021	57,934,393	215,268,526	3.7
HVAC	775,527	83,756,929	288,950	6,645,857	90,402,786	318,129,572	3.5
Lighting	458,561	49,524,625	37,526	863,098	50,387,723	174,772,506	3.5
Motors and Drives	570,855	61,652,303	217,651	5,005,970	66,658,273	193,354,825	2.9
Pumping System	814,805	87,998,923	00	00	37,257,160	127,093,982	3.4
Refrigeration	814,805	87,998,923	00	00	87,998,923	289,050,392	3.3
SMT	493,696	53,319,162	00	00	53,319,162	91,908,605	1.7
Total Savings	**5,191,118**	**560,640,772**	**4,583,259**	**105,414,967**	**615,313,976**	**1,982,768,001**	**3.2**

Table 99 Other Sector Energy savings, Investment and Payback

The overall payback period for all energy saving measures is 3.2 years which lies within the criteria of payback periods for most industrial sectors.

	Electricity Savings		**Gas Savings**		**Total Carbon Savings**	
Technology	**Carbon (te)**	**%**	**Carbon (te)**	**%**	**Carbon (te)**	**%**
Compressed Air	194,213	4.1%	70,948	1.5%	265,161	2.8%
Heat Recovery	81,126	1.7%	368,814	7.6%	449,940	4.7%
Heating Systems	47,450	1.0%	302,833	6.3%	350,283	3.7%
HVAC	198,225	4.2%	53,124	1.1%	251,348	2.6%
Lighting	117,208	2.5%	6,899	0.1%	124,107	1.3%
Motors and Drives	145,910	3.1%	40,015	0.8%	185,926	1.9%
Pumping System	88,175	1.9%	00	0.0%	88,175	0.9%
Refrigeration	208,264	4.4%	16,098	0.3%	224,362	2.3%
SMT	126,189	2.7%	00	0.0%	126,189	1.3%
Total Savings	**1,206,761**	**25.4%**	**858,730**	**17.8%**	**2,065,491**	**21.6%**

Table 100 Other Sector Carbon Savings

Figure 117 shows a bubble chart for the opportunities identified above the size of the bubbles coincides with the amount CO_2e saved. This chart demonstrates the relative cost effectiveness of each opportunity to reduce carbon. This chart can help prioritise opportunities with the ones in the top left quadrant of the graph with larger bubble size will have the greatest return on investment with the largest CO_2e savings. This shows that steam systems energy efficiency opportunities would be the most beneficial to implement.

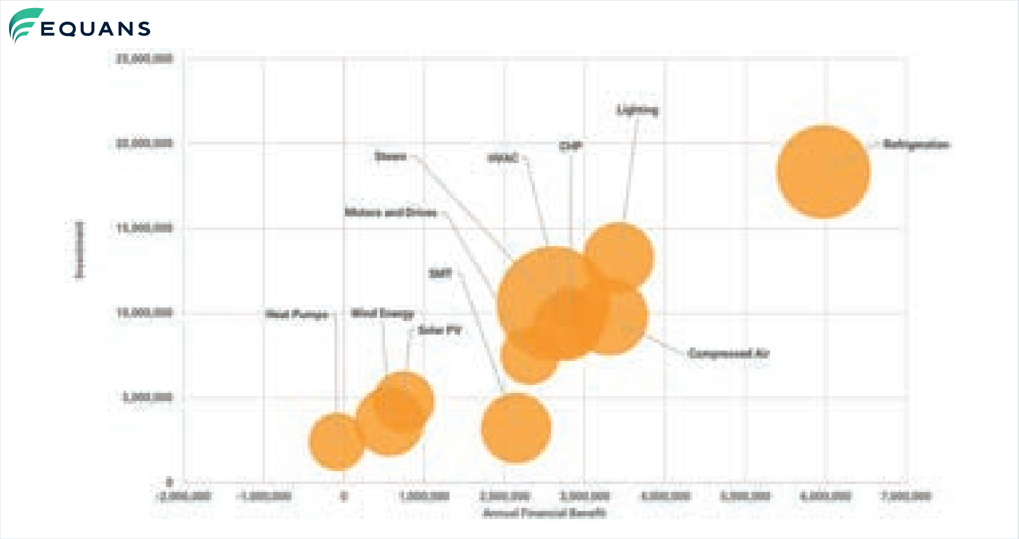

Figure 117 Pharmaceutical Sector Opportunities Bubble Chart

6.11 Other Sectors

Other sectors include all the remaining sectors that were not analysed due to absence of adequate data. However, it has been assumed that energy efficiency opportunities identified in analysed sectors are also viable for the remaining sectors. These energy saving measures have been extrapolated and presented in this section for remaining sectors.

6.11.1 Energy Consumption

The following graph shows the total energy consumption for the remaining sectors within North West England and North East Wales.

Total energy consumption for remaining sectors is approx. 44,832,443 MWh with total carbon emissions of 9,574,427 $teCO_2e$.

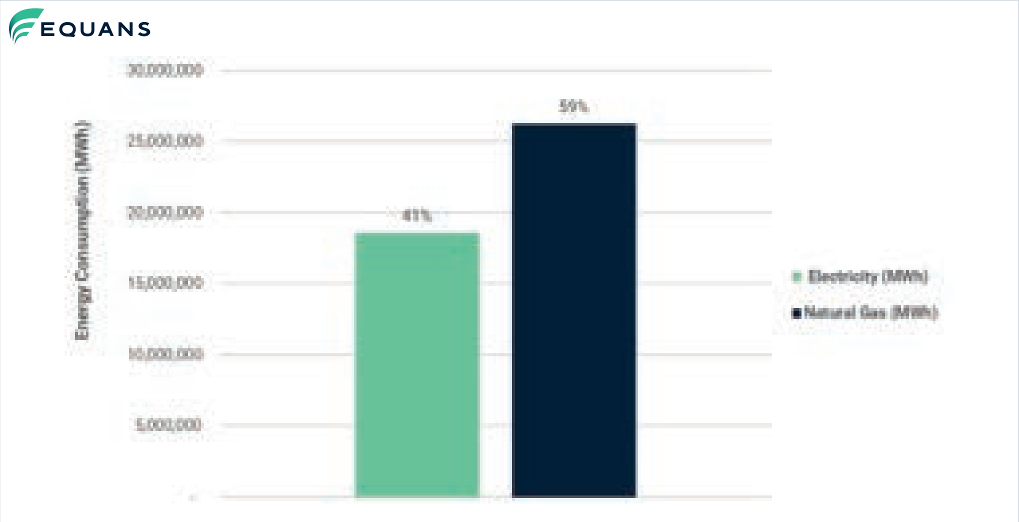

Figure 118 – Other Sectors Energy Consumption

6.10.5 Sector Roadmap

Based on the technologies discussed above a pathway to net zero for the North West Pharmaceutical sector is proposed in Figure 115.

Most of the carbon reduction is through green electricity procurement and energy conservation measures as with all the opportunities stated above the sector can reduce the carbon emissions by 26.8%.

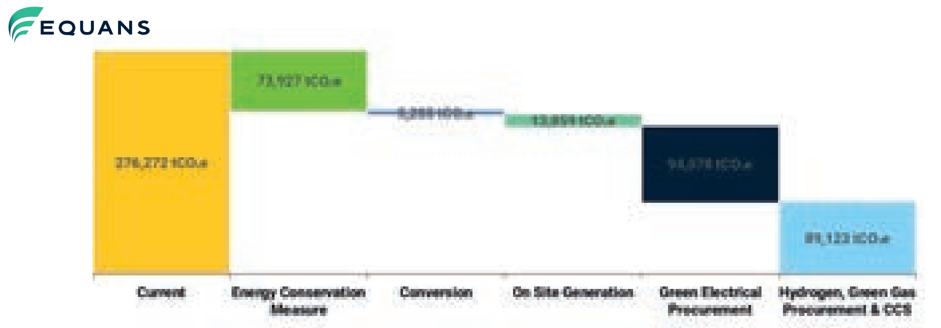

Figure 115 Pharmaceutical Sector Carbon Waterfall

For net zero, total CAPEX has been estimated at **£82,809,492** with a financial benefit of **£23,777,854**, giving a simple payback of **3.5 years**. There is no CAPEX and therefore no payback against green electricity procurement and green hydrogen procurement as it is assumed that grid will be decarbonised by 2035 and green hydrogen will cost same as natural gas.

The timeline in figure 116 gives an indication of when these opportunities can be implemented to achieve a carbon neutral position. It is assumed that energy efficiency opportunities will be prioritised and implemented in a 5-year interval. The total implementation of the energy efficiency opportunities will help to define a new energy consumption profile for the site. Therefore, when low carbon technologies and renewable sources are implemented, the site will be already the most efficient that can be. It is assumed that UK electricity grid will be carbon free by 2035 as stated by UK Government.

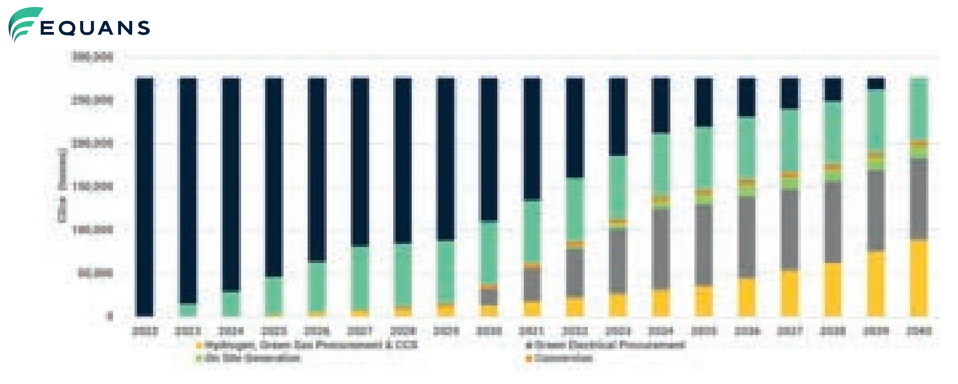

Figure 116 Pharmaceuticals Sector Carbon Neutral Delivery Plan

6.10.3.2 Heat Pumps

The HPs modelled offer a viable solution for carbon reduction, offsetting gas usage through heat electrification largely reducing the gas usage on site. With the low temperature model showing a good operation throughout the year of 93% at 100% output, with a slightly optimised COP the system would present a good financial offering.

6.10.3.3 Electrification

Electrification of space and processes heating is a key part of decarbonising industry. In addition to heat pumps there are other mature technologies that can be applied such as steam generators, electric ovens, and irradiation heaters. There are more process specific and storage solutions being researched and developed within the electrification technology sector, including several government funded trials. It is advised to periodically review sector specific literature or the industrial net zero literature to keep up to date with industrial developments for your specific sector.

An additional review of the potential for a site to electrify its thermal process was conducted. This review does not consider the other operational parameters above and only looks to cover 100% of the thermal requirement. This can provide an indictive cost per kg of CO_2 produced by that sector, which can be carried out by the site if the scope 1 emissions are known. Only scope 1 emissions can be calculated as this figure for the industrial site only accounts for direct emissions for thermal energy generation.

Scope 1 Industry Avg Emissions Tons/CO_2	Cost per kg CO_2	Percentage of Scope 1 Emissions being Electrified
19,874	£0.9785	6.04%

Table 96 Scope 1 emissions electrified

6.10.4 On-Site Generation

6.10.4.1 Wind Generation

Wind energy generation can offer savings to the whole of the North West regardless of sector of industrial sites. The energy and carbon savings calculated in this section are based on the entire region of North West. The overall savings from wind energy generation in the North West is applied as a ratio to the total emissions from pharmaceuticals sector to estimate sector specific savings. The results are illustrated in Table 97.

6.10.4.2 Solar Photovoltaics (PV)

Solar PV energy generation can offer savings to the whole of North West England and North East Wales regardless of sector. The energy and carbon savings calculated in this section are based on the entire region of the region. The overall savings from solar PV energy generation in North West England and North East Wales is applied as a ratio to the total emissions from pharmaceuticals sector to estimate sector specific savings. The results are illustrated in Table 98.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
276,272	2.79	7,710	567,755	3,617,316	6.37

Table 97 Pharmaceuticals sector wind energy savings

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
276,272	2.23	6,149	744,411	4,794,325	6.4

Table 98 Pharmaceuticals sector solar PV savings

As stated previously the modelled data used showed a low electrical requirement, therefore a smaller CHP system has been selected. This is to ensure an accurate electrical utilisation to avoid derating the system from 100% operation. However, due to a good electrical and thermal utilisation throughout the year, the payback period is below 4-years even though the savings are not as high as other industries within the report.

This is due to a smaller system being modelled. It is understood that much larger sites will draw a greater amount of electricity from the grid and therefore a specific site review will illustrate the need for a larger CHP system with greater savings. This review only details that the pharmaceutical industry would be suitable for the installation of a CHP system.

High Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
2,707,252	6,419,411	8,559,215	881.64	2.37	1041.7	76%	-£90,107

Table 94 Pharmaceutical Heat Pump High Temperature Data

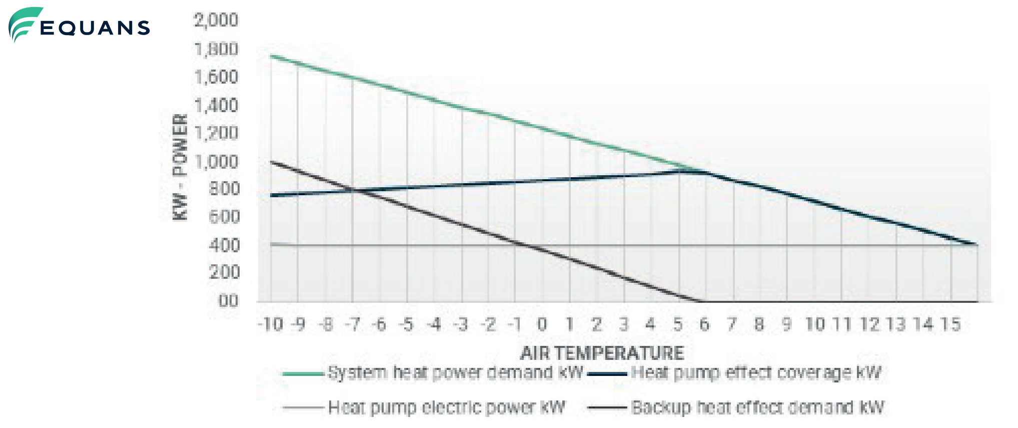

Figure 113 Pharmaceutical Heat Pump Low Temperature Data

Low Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
1,433,171	4,574,444	6,099,259	755.03	3.19	629.5	93%	-£11,633

Table 95 Pharmaceutical Heat Pump Low Temperature Data.

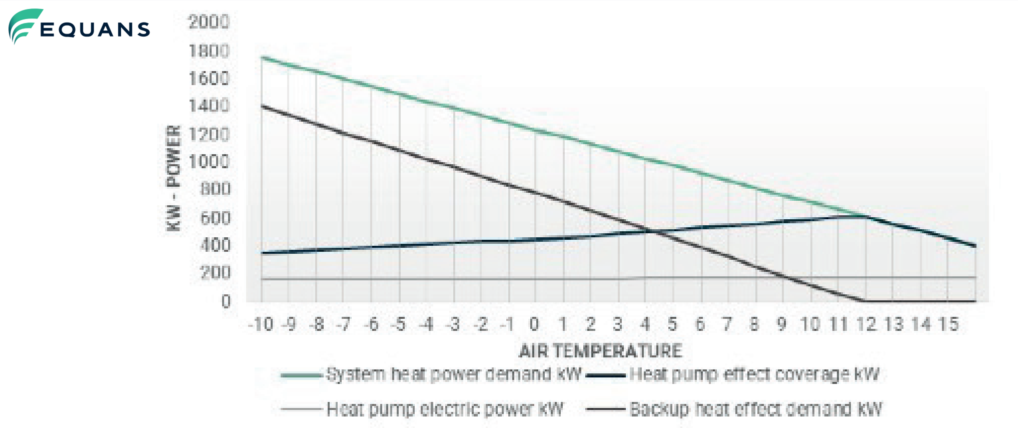

Figure 114 Pharmaceutical Heat Pump Low Temperature Operation Profile

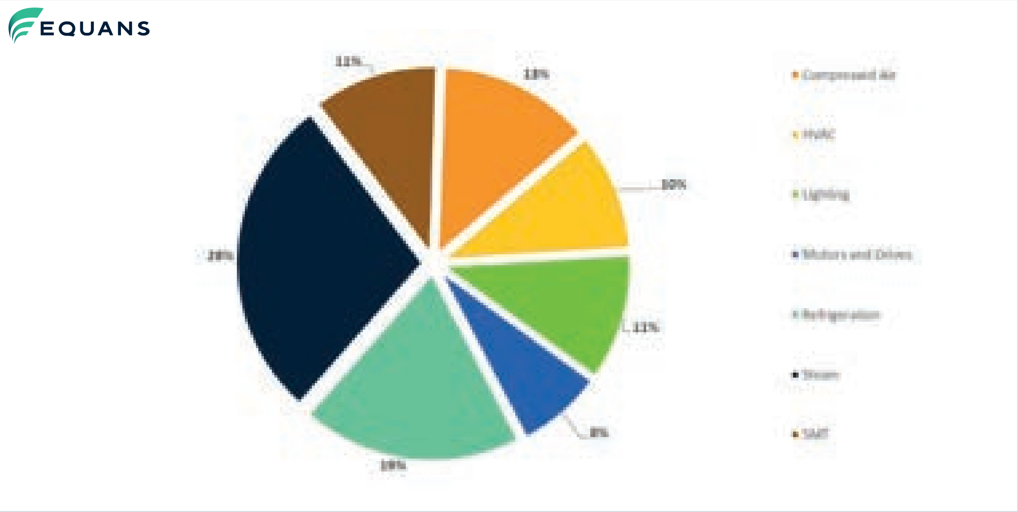

Figure 112 Pharmaceutical Sector Carbon Savings

Total carbon savings of approximately 27% are achievable that can enable this sector to accelerate their sustainability targets, help maintain drug costs and pave the way for net zero future.

Steam system, refrigeration, lighting, and compressed air are the large energy and carbon saving areas followed by lighting, motors and drives and metering and monitoring. As heating and cooling is the key utility in this sector, the savings potential is higher for refrigeration and steam/hot water.

It would be ideal to start with the implementation of a SMT system followed by compressed air optimisation and other projects. SMT would enable the confirmation of savings post implementation and can even provide more accurate data before implementation.

The common sources of cooling within the sector are air-cooled and water-cooled chilled water chillers, cooling towers and dry coolers. Thermal fluids such as glycol is also used as a heat transfer medium especially when providing sub-zero chilling for the process.

6.10.3 Low Carbon Technologies

6.10.3.1 CHP

The Pharmaceutical industry typically relies on a range of mechanical systems and processes to carry out the manufacture of its products. The ETS 2019 data shows that pharmaceutical companies are already utilising CHP technology as part of its onsite energy generation, albeit with older gas turbine systems. Industry reports also state the usage of steam and LTHW is commonplace within processes on site, which further compliments the use of such technology as a CHP.

Review of different energy reports highlight pharmaceutical manufacturers typically import more gas than electricity. This confirms the requirement as a high thermal user, as a large portion of the processes on site resemble that of the chemical industry. Requiring the use of systems such as LTHW, low pressure steam and chilled water for the manufacturing process, making it a good viable option for onsite generation in the form of CHP or HPs.

Current Emissions for Sector Avg T/Yr	New Emissions with CO_2 Offset T/Yr	Existing Gas Usage for Sector Avg kWh	Gas increase Natural Gas Engine kWh	Carbon Saving (te) p/a	Comparison of gas increase	Gas Engine input
276,272	275,897	108,100,548	123,779,162	375	15%	15,678,614

Table 92 Pharmaceutical CHP data

Indictive CapEx Cost + 1st Yr Service	Electrical cost reduction	Savings per Year	Approx. Payback Years	Electrical Utilisation	Thermal Utilisation
£1,485,715	£741,361	£402,035.0	2.65	95%	95%

Table 93 Pharmaceutical financial data

6.10.2 Energy Efficiency Opportunities

In pharmaceutical manufacturing, energy consumption can vary depending on various factors such as ambient weather conditions and type of product (e.g., liquid solution, tablet/capsule, Gel, and cream, etc.). Optimisation of HVAC and associated utilities with respect to ambient weather will reduce the energy consumption. This sector can benefit from several simple and proven energy saving measures which may still need to go through approval process due to the nature of production.

The table below shows the potential energy and carbon savings for pharmaceutical sector with required investments and associated payback periods.

	Electricity		Natural Gas				
Technology	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
Compressed Air	27,366	2,955,534	15,134	348,084	3,303,618	1,637,576	0.5
HVAC	24,147	2,607,825	7,567	174,042	2,781,866	9,257,661	3.3
Lighting	31,659	3,419,148	00	00	3,419,148	13,268,240	3.9
Motors and Drives	21,464	2,318,066	00	00	2,318,066	7,497,368	3.2
Refrigeration	55,269	5,969,021	00	00	5,969,021	18,335,238	3.1
Steam	00	00	113,506	2,610,628	2,610,628	10,576,244	4.1
SMT	15,025	1,622,646	22,701	522,126	2,144,772	3,217,158	1.5
Total Savings	**174,928**	**18,892,240**	**158,908**	**3,654,880**	**22,547,120**	**63,789,485**	**2.8**

Table 90 Sector Energy savings, Investment and Payback

Individual project payback periods are between six months and four years with most of the project payback periods under four years. The overall payback period for all energy saving measures is 2.8 years which lies within the criteria of payback periods for most pharmaceutical industries.

	Electricity Savings		Gas Savings		Total Carbon Savings	
Technology	**Carbon (te)**	**%**	**Carbon (te)**	**%**	**Carbon (te)**	**%**
Compressed Air	6,995	5.1%	2,782	2.0%	9,777	3.5%
HVAC	6,172	4.5%	1,391	1.0%	7,563	2.7%
Lighting	8,092	5.9%	00	0.0%	8,092	2.9%
Motors and Drives	5,486	4.0%	00	0.0%	5,486	2.0%
Refrigeration	14,127	10.3%	00	0.0%	14,127	5.1%
Steam	00	0.0%	20,868	15.0%	20,868	7.6%
SMT	3,840	2.8%	4,174	3.0%	8,014	2.9%
Total Savings	**44,712**	**32.6%**	**29,215**	**21.0%**	**73,927**	**26.8%**

Table 91 Sector Carbon Savings

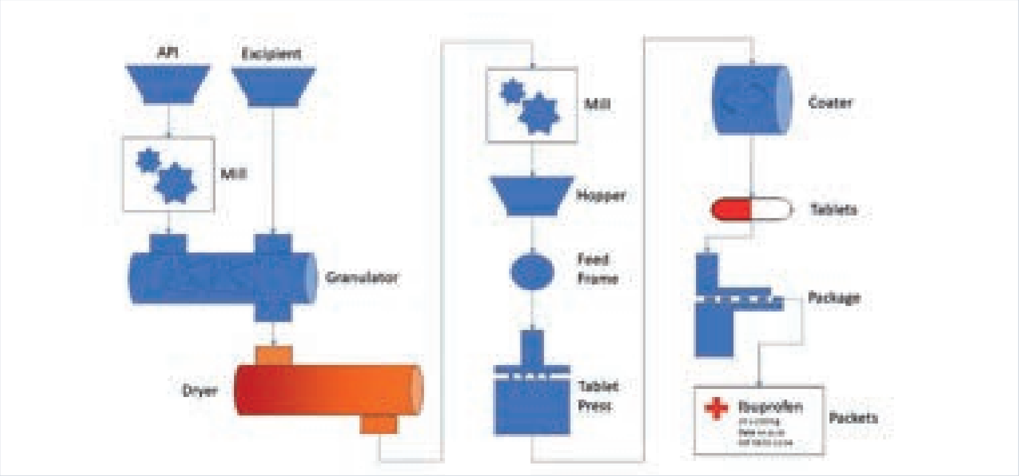

Figure 110 Typical pharmaceutical tablet production line (108)

6.10.1.1 Energy Consumption

As previously mentioned, the pharmaceutical industry is an energy intensive industry with a different range of technologies. Sub-zero cooling in API and HVAC for clean rooms, laboratories and RandD booths are one of the most significant energy users within the industry. HVAC includes heating (steam and hot water), cooling, dehumidification, filtration, room pressurisation and extract system. Most laboratories and clean rooms maintain full fresh air system, making it very energy intensive compared to HVAC in other sectors.

Electricity is used throughout the facility for many different purposes, e.g., chillers, air compressors, HVAC, lighting, and packaging lines. Steam and hot water boilers, direct fired heating batteries and gas fired dehumidification units are energy intensive users in terms of natural gas. Energy intensity and distribution of different energy sources is dependent on the adopted technologies and type of manufacturing such as whether the factory is API or non-API.

Some large pharmaceutical companies including UK based companies have already committed to achieving net zero by 2030. As a result, this sector has invested in energy efficiency to not only meet their sustainability targets but also to remain competitive due to rising energy costs. Total energy consumption for the pharmaceutical sector in North West England and North East Wales is shown in Figure 111.

Total energy consumption for this sector is approx. 1,293,293 MWh with total carbon emissions of 276,272 $teCO_2e$.

The below graph shows a typical distribution between electricity and gas where gas consumption is higher than electricity. This is due to the application of reheating supply air to its required set-point after dehumidification via cooling of the air to its dewpoint. Regeneration of desiccant wheels using steam is also common in this sector for very low humidity areas.

The ratio between electricity and gas can change if the chillers are fitted with heat recovery units, generating hot water to offset gas and desiccant wheel regeneration is done via electric heating.

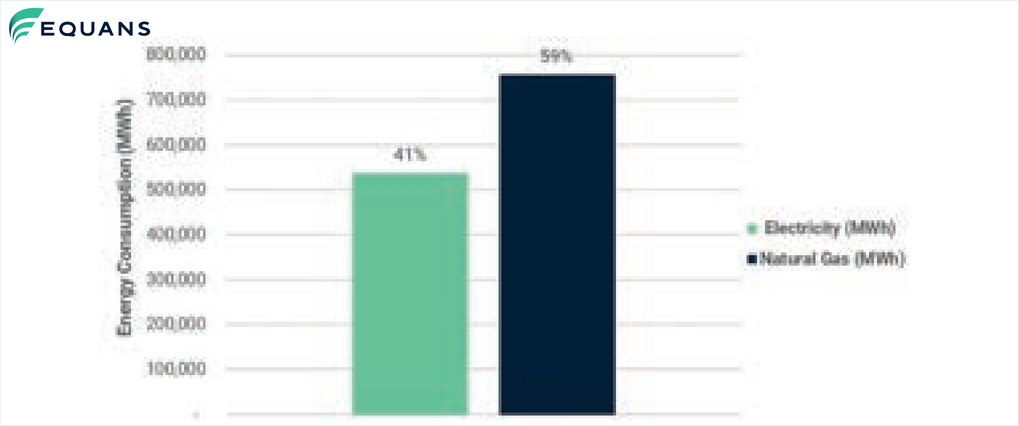

Figure 111 Pharmaceuticals Sector Energy Consumption

Figure 109 UK pharmaceutical Sector Output & Turnover by Region (106)

All drugs are made up of two core components—the Active Pharmaceutical Ingredient (API), which is the central ingredient, and the excipient, the substance other than the drug that helps deliver the medication to your system. Excipients are chemically inactive substances, such as lactose or mineral oil. Manufacturers use certain standards to determine how strong the API is in each drug. However, the standard can vary widely from one brand to another. Each brand might use different test methods, which can result in different potencies (107).

The tablet formation process consists of a series of steps:

- **Weighing** – To maintain the ratio of API and Excipient ingredients.

- **Milling and Mixing** – Reduction in size of API for compact and consistent particle size and mixing with Excipient.

- **Granulation** – Granulation process transforms fine powders into free-flowing, dust-free granules that are easy to compress

- **Drying** – Removal of moisture using different drying techniques. Spray dryer is one of the most common technologies used for this process.
- **Compaction** – Powder compression for the development of the tablets.

- **Coating** – Application of coating materials to the surface of the tablet to achieve the desired properties of dosage form over the uncoated variety.
- **Packaging** – Packaging of tablets or capsules in desired packaging type.

Regardless of the method used the standard processes – weighing, milling, and mixing, are the same; subsequent steps differ.

Figure 108 shows a bubble chart for the opportunities identified above the size of the bubbles coincides with the amount CO_2e saved. This chart demonstrates the relative cost effectiveness of each opportunity to reduce carbon. This chart can help prioritise opportunities with the ones in the top left quadrant of the graph with larger bubble size will have the greatest return on investment with the largest CO_2e savings. This shows that the heat recovery and heating systems opportunities would be the most beneficial to implement.

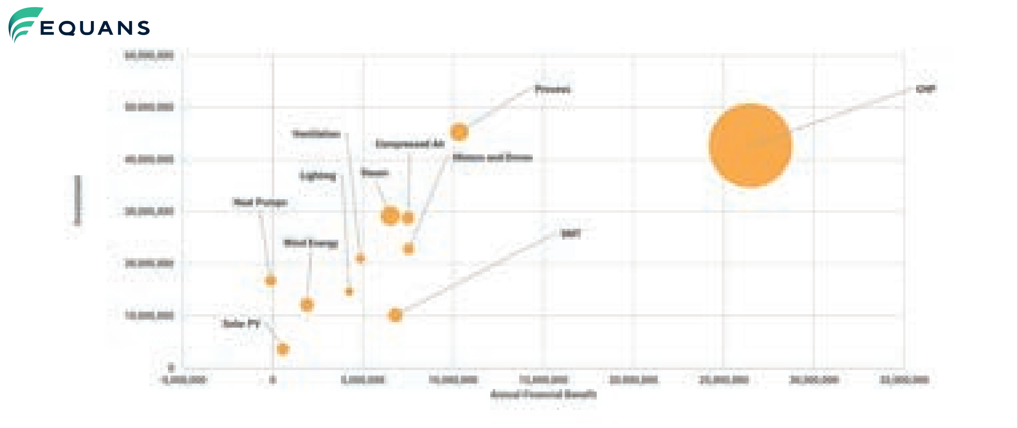

Figure 108 Paper and Pulp Opportunities Bubble Chart

It should be noted that above bubble chart does not include decarbonisation technologies/opportunities like conversion, procurement of renewable electricity, procurement of hydrogen or green gas and CCS as they have no payback.

6.10 Pharmaceuticals

The Pharmaceutical sector is an important industry in our modern society. The Pharmaceutical industry is also an energy intensive industry as it needs to maintain critical environment for production in terms of temperature, humidity, room pressurisation, cleanliness, and containment.

The Pharmaceutical industry is highly regulated, and all the manufacturing areas are validated, making it difficult for change compared to other industries where changes can happen rapidly. Medicines are manufactured in different form such as tablets, liquid solutions, creams, and gels.

Though the Association of the British Pharmaceutical Industry (ABPI) has supported UK government ambition of net zero by 2050, there is no published net zero strategy from ABPI for the entire sector. However, several UK pharmaceutical factories have committed to net zero before 2050.

North West England and North East Wales is the manufacturing hub for UK pharmaceutical, with 38% of the output and 43% of the UK pharmaceutical turnover being generated there. The North West England Pharmaceutical sector has the highest output and turnover compared to other regions in the UK.

6.9.4 Sector Roadmap

Based on the technologies discussed above a pathway to net zero for the North West England and North East Wales Chemical sector is proposed below. Most of the carbon reduction is through energy conservation measures as with all the opportunities stated above the sector can reduce the carbon emissions by 20%.

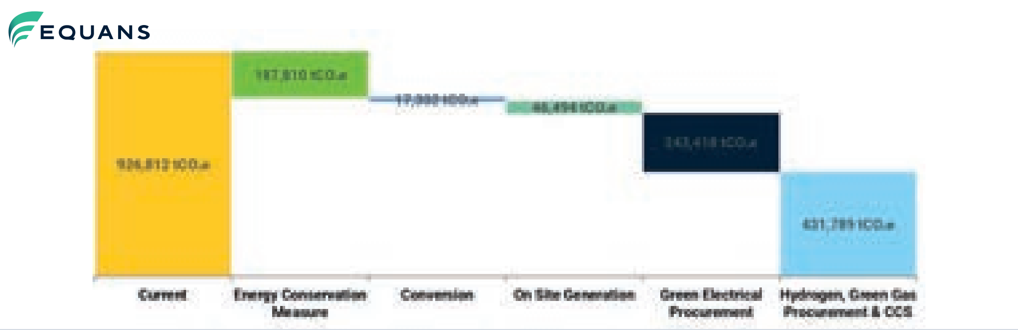

Figure 106 Paper and Pulp Sector Carbon Waterfall

For net zero, total CAPEX has been estimated at **£204,859,095** with a financial benefit of **£50,170,175**, giving a simple payback of **4.1** years. There is no CAPEX and therefore no payback against green electricity procurement and green hydrogen procurement as it is assumed that grid will be decarbonised by 2035 and green hydrogen will cost same as natural gas.

The timeline in Figure 107 is an indication of when these opportunities can be implemented to achieve a carbon neutral position. It is assumed that energy efficiency opportunities will be prioritised and implemented in a 5-year interval. The total implementation of the energy efficiency opportunities will help to define a new energy consumption profile for the site.

Therefore, when low carbon technologies and renewable sources are implemented, the site will be already the most efficient that can be. It is assumed that UK electricity grid will be carbon free by 2035 as stated by UK Government.

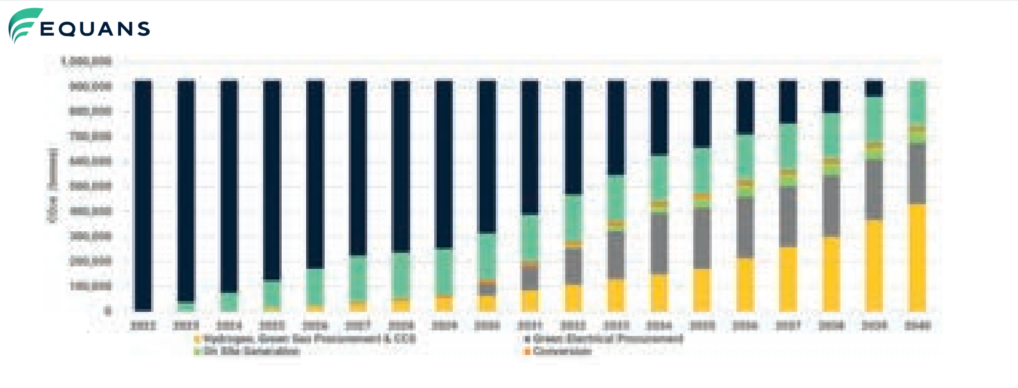

Figure 107 Pulp and Paper Carbon Neutral Delivery Plan

6.9.3 On-Site Generation

6.9.3.1 Wind Generation

Wind energy generation can offer savings to the whole of the North West England and North East Wales regardless of sector. The overall savings from wind energy generation in the region is applied as a ratio to the total emissions from Paper and Pulp sector to estimate sector specific savings. The results are illustrated in Table 88.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
63,952	2.79%	1,785	131,424	837,339	6.4

Table 88 Paper and Pulp wind energy saving

6.9.3.2 Solar Photovoltaics (PV)

Solar PV energy generation can offer savings to whole of North West England and North East Wales regardless of sector. The overall savings from solar PV energy generation in the North West is applied as a ratio to the total emissions from Paper and Pulp sector to estimate sector specific savings. The results are illustrated in 89.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
63,952	2.23%	1,423	172,317	1,109,794	6.4

Table 89 Paper and Pulp solar PV savings

6.9.3.3 Anaerobic Digestion

Anaerobic digestion is applicable for sectors that produce organic waste and requires treatment or disposal. Therefore, AD is not applicable for the Paper and Pulp sector.

High Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
2,462,140	5,790,928	7,721,237	790.23	2.35	1041.7	69%	-£83,398

Table 86 Paper and Pulp Heat Pump High Temperature Data

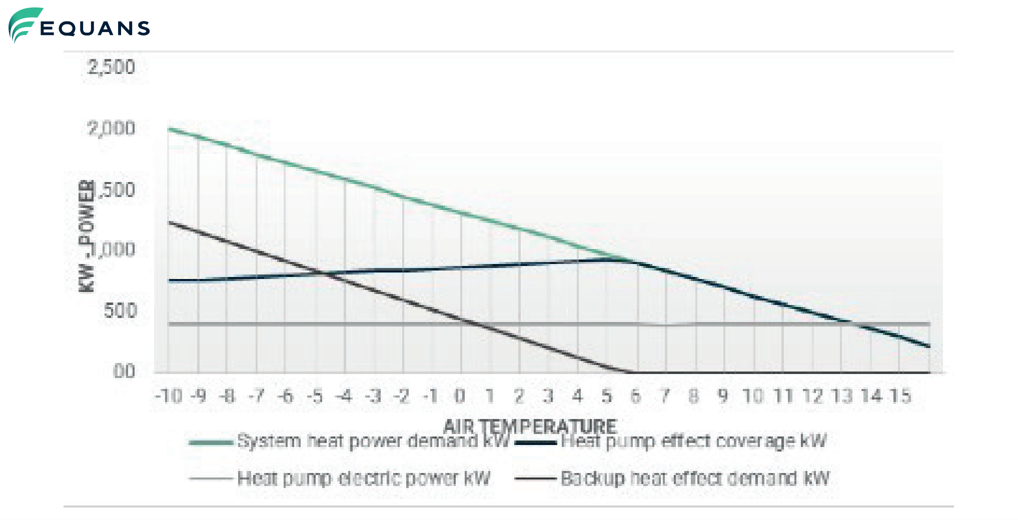

Figure 104 Paper and Pulp Heat Pump High Temperature Operation Profile

Low Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
1,468,792	4,892,553	6,523,404	823.90	3.33	810.6	78%	-£5,654

Table 87 Paper and Pulp Heat Pump Low Temperature Data

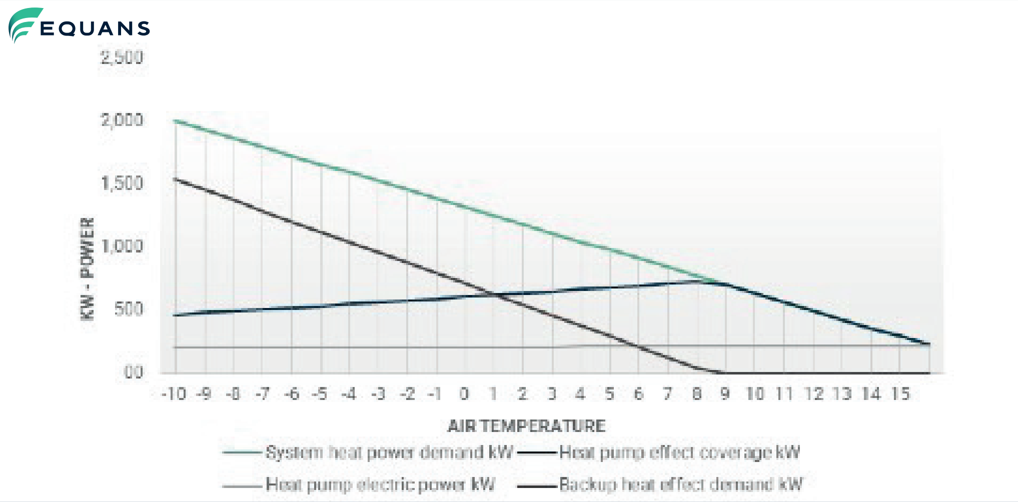

Figure 105 Paper and Pulp Heat Pump Low Temperature Operation Profile

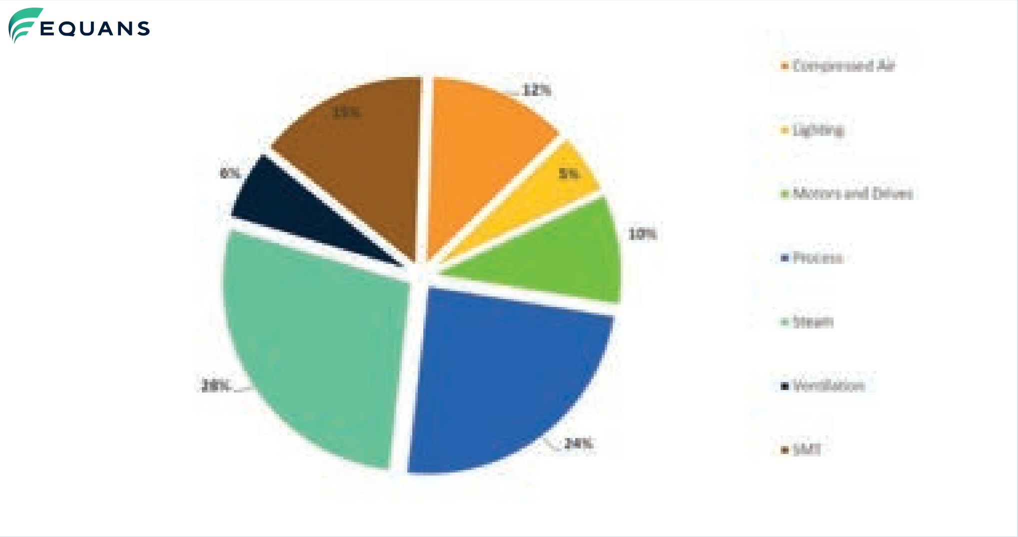

Figure 103 Paper and Pulp - Emissions Savings

Most of the emission savings are from heat i.e., steam and process followed by compressed air. Therefore, heat recovery and maximum efficiency of power generation and steam systems is key to this sector. Heat recovery from on-site power generation (e.g., CHP) is discussed in later sections.

6.9.2 Low Carbon Technologies

6.9.2.1 CHP

Differing from other industries, Paper and Pulp do not produce any carbon from processes; all carbon emitted is from heat and power used within the site, with direct emissions for thermal processes coming from onsite steam boilers and gas turbines. CHP technology is commonplace within a Paper and Pulp manufacturing site with approx. 65% of production coming from sites with a CHP installed, and thermal processes such as drying, bleaching, and de-inking all requiring hot water below 100ºC. Due to the large import of electrical energy onto a site, the installation of a CHP can alleviate strain placed on the network reinforcing the advantage with the installation of the system.

Current Emissions for Sector Avg T/Yr	New Emissions with CO_2 Offset T/Yr	Existing Gas Usage for Sector Avg kWh	Gas increase Natural Gas Engine kWh	Carbon Saving (te) p/a	Comparison of gas increase	Gas Engine input
926,812	2.79%	25,865	1,904,654	12,135,045	6.4	926,812

Table 84 Paper & Pulp CHP data

Indictive CapEx Cost + 1st Yr Service	Electrical cost reduction	Savings per Year	Approx. Payback Years	Electrical Utilisation	Thermal Utilisation
£2,035,000	£1,784,805	£1,261,177.0	3.05	100%	95%

Table 85 Paper & Pulp CHP financial data

6.9.1 Energy Efficiency Opportunities

It was estimated that this sector emitted 3.3 million tonnes/year of CO_2 of which 2.4 million tonnes/year of CO_2 was from combustion of fossil fuels, with a further 0.9 million tonnes/year emitted in grid electricity production for use within the sector. (105) The following savings are estimated for this sector from the review of different energy audit reports including ESOS Phase 2 reports. Identified savings are extrapolated to estimate the total potential savings for this sector within the region. The table below depicts the extrapolated savings.

	Electricity		**Natural Gas**				
Technology	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
Compressed Air	61,074	6,596,037	39,308	904,081	7,500,118	28,802,969	3.8
Lighting	39,262	4,240,310	00	00	4,240,310	14,722,097	3.5
Motors and Drives	69,799	7,538,328	00	00	7,538,328	22,906,205	3.0
Process	61,074	6,596,037	163,052	3,750,191	10,346,228	45,361,089	4.4
Steam	00	00	283,831	6,528,110	6,528,110	29,239,665	4.5
Ventilation	45,079	4,868,504	00	00	4,868,504	21,090,050	4.3
SMT	43,625	4,711,455	90,584	2,083,439	6,794,895	10,192,342	1.5
Total Savings	**319,914**	**34,550,672**	**576,775**	**13,265,821**	**47,816,493**	**172,314,417**	**3.6**

Table 82 Sector Energy savings, Investment and Payback

Considerable energy and cost savings are achievable with an approximate payback period of under 3.6 years which fits within the payback criteria for most of the manufacturing industries. SMT, motors and drives improvement and lighting upgrades are among the top candidates for energy efficiency and carbon savings.

	Electricity Savings		**Gas Savings**		**Total Carbon Savings**	
Technology	**Carbon (te)**	**%**	**Carbon (te)**	**%**	**Carbon (te)**	**%**
Compressed Air	15,611	4.2%	7,227	1.3%	22,837	2.5%
Lighting	10,035	2.7%	00	0.0%	10,035	1.1%
Motors and Drives	17,841	4.8%	00	0.0%	17,841	1.9%
Process	15,611	4.2%	29,977	5.4%	45,588	4.9%
Steam	00	0.0%	52,182	9.4%	52,182	5.6%
Ventilation	11,522	3.1%	00	0.0%	11,522	1.2%
SMT	11,150	3.0%	16,654	3.0%	27,804	3.0%
Total Savings	**81,770**	**22.0%**	**106,040**	**19.1%**	**187,810**	**20.3%**

Table 83 Sector carbon Savings

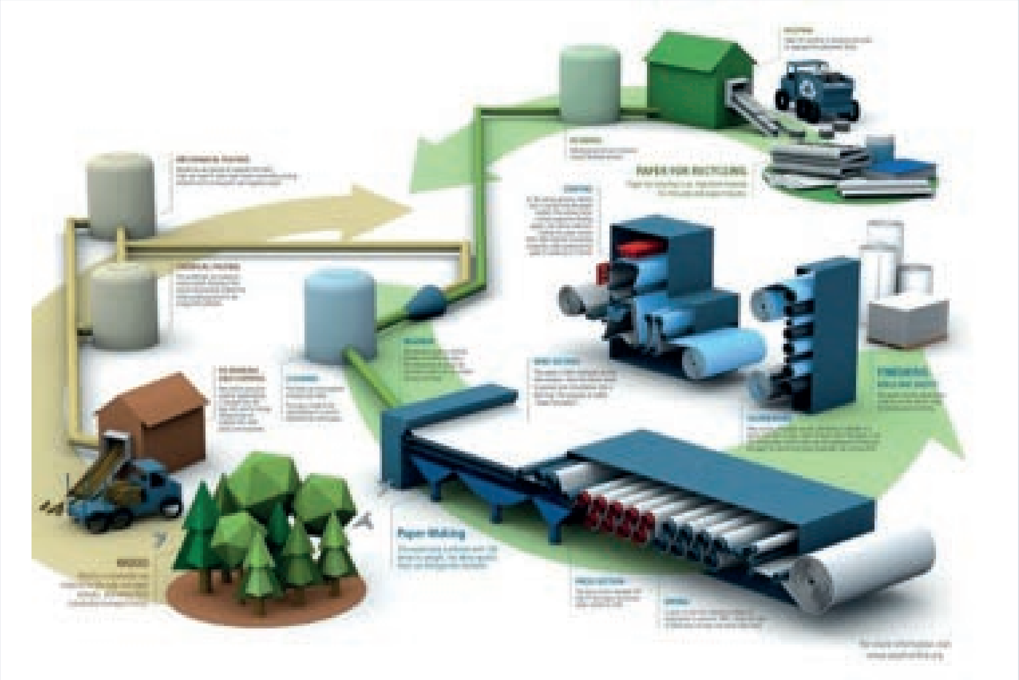

Figure 101 Paper and Pulp Process flow (103)

In the UK, the total fossil fuels used in 2008 in the pulp and paper industry amounted to 16,718 GWh (104), being mostly natural gas. Biomass is mostly used by four installed biomass CHP plants. Sludge from wastewater treatment plants is also used as fuel source in some mills. Since 2012, the sectors use of coal has decreased to well below 1%, due to the replacement of a coal CHP by a biomass CHP. Total energy consumption for Paper and Pulp sector in North West England and North East Wales is shown below.

As can be seen in the graph, gas consumption is higher than electricity due to the nature of process.

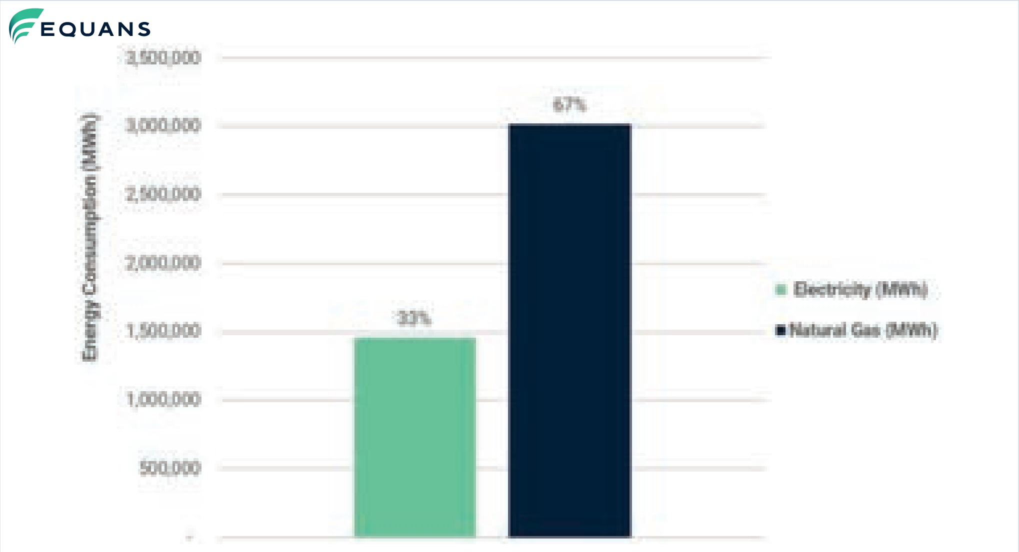

Figure 102 Pulp and Paper Sector Energy Consumption

Figure 100 shows a bubble chart for the opportunities identified above the size of the bubbles coincides with the amount CO_2e saved. This chart demonstrates the relative cost effectiveness of each opportunity to reduce carbon. This chart can help prioritise opportunities with the ones in the bottom right quadrant of the graph with larger bubble size will have the greatest return on investment with the largest CO_2e savings. This shows that the heat recovery and heating systems opportunities would be the most beneficial to implement.

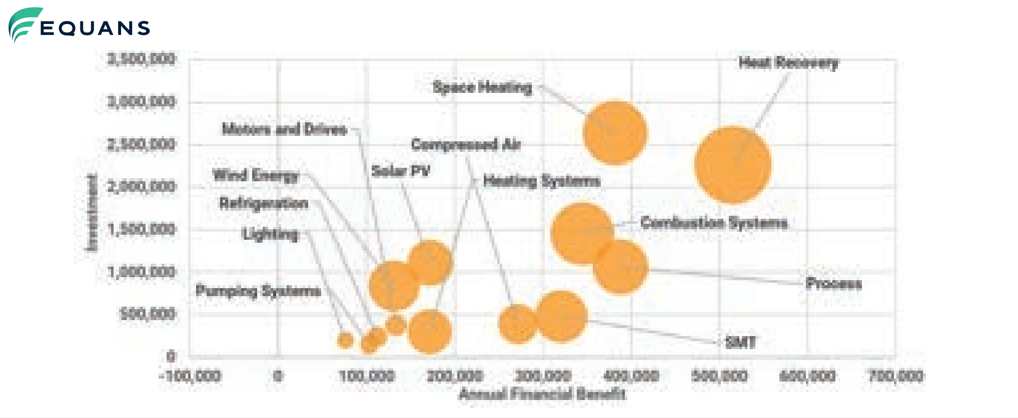

Figure 100 Iron and Steel Sector Opportunities Bubble Chart

6.9 Paper and Pulp

The paper-based industries are widely spread throughout the UK, but with concentrations in the North West and far South East of England, Wales and Scotland.

UK papermaking acts as the foundation for a paper-based sector representing a collective turnover of £11.5 billion per annum and directly employing 56,000 people (ONS Annual Business Survey 2015, SIC code 17); an additional 232,000 jobs are supported through the wider supply chain. Outputs from the industry are declining, with the UK producing 3.7 million tonnes of paper and board in 2016, down from 6.6 million tonnes in 2000. Of this amount, 1 million tonnes were exported (at a value of £1 billion), while the UK imported £6 billion worth of products, making it the world's largest net importer of paper and board. 11.5 million tonnes of paper and board were placed on the domestic market in 2016 (102).

Papermaking uses the circular economy concept. In the UK around 73% of all fibre used to make paper is recovered from collected paper and card, with several sites also recovering energy from otherwise waste materials. The UK Paper and Pulp sector is dominated by multi-national organisations, with nine of the ten largest sites headquartered outside the UK and making up more than 75% of capacity (102).

In the papermaking process, either paper for recycling or wood fibres serve as the raw material to the pulp production. The pulp is then processed, dewatered, and dried into paper in the paper machine. Depending on the quality of the paper depends on how many processes it goes through after the paper is formed. The paper machine accounts for about two thirds of all energy use in a typical UK pulp and paper mill, using mainly steam produced by natural gas or biomass in the drying process (102).

6.8.4 Sector Roadmap

Based on the technologies discussed above a pathway to net zero for the North West England and North East Wales Chemical sector is proposed below. Most of the carbon reduction is through energy conservation measures as with all the opportunities stated above the sector can reduce the carbon emissions by 27%.

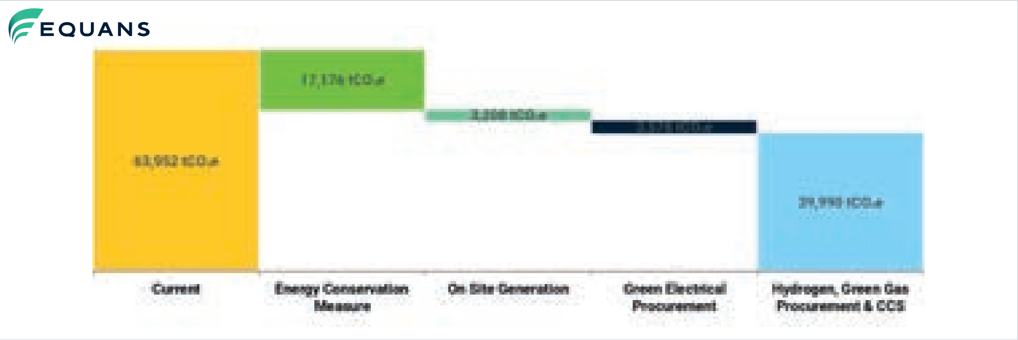

Figure 98 Iron and Steel Sector Carbon Waterfall

For net zero, total CAPEX has been estimated at £11,505,395 with a financial benefit of £3,122,436, giving a simple payback of 3.7 years. There is no CAPEX and therefore no payback against green electricity procurement and green hydrogen procurement as it is assumed that grid will be decarbonised by 2035 and green hydrogen will cost same as natural gas.

The timeline below is an indication of when these opportunities can be implemented to achieve a carbon neutral position. It is assumed that energy efficiency opportunities will be prioritised and implemented in a 5-year interval. The total implementation of the energy efficiency opportunities will help to define a new energy consumption profile for the site.

Therefore, when low carbon technologies and renewable sources are implemented, the site will be already the most efficient that can be. It is assumed that UK electricity grid will be carbon free by 2035 as stated by UK Government.

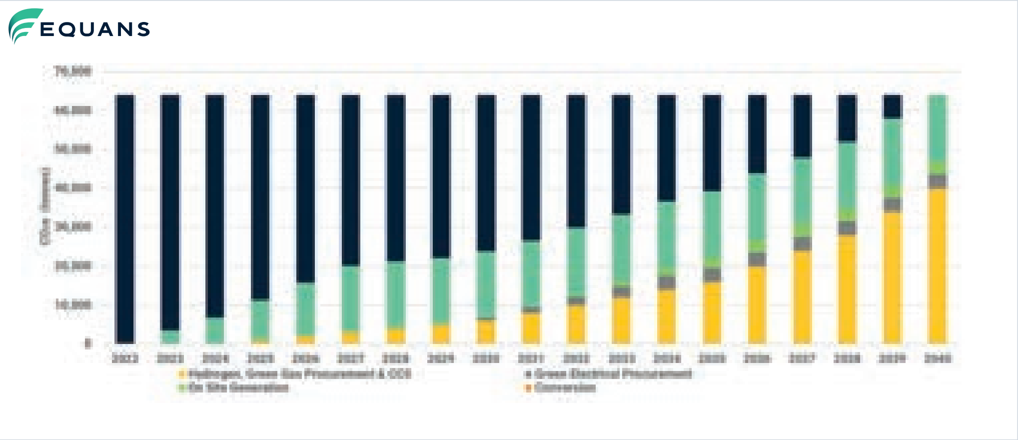

Figure 99 Iron and Steel Sector Carbon Neutral Delivery Plan

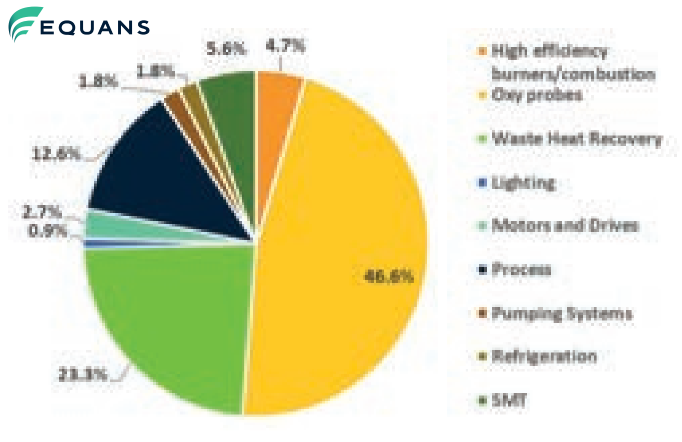

Figure 97 Iron and Steel carbon saving breakdown

Total carbon savings of 27% are achievable that can enable this sector to achieve net-zero.

6.8.2 Low Carbon Technologies

No data available therefore no analysis carried out for CHP, HP within this sector.

6.8.3 On-Site Generation

6.8.3.1 Wind Generation

Wind energy generation can offer savings to the whole of North West England and North Wales regardless of sector. The overall savings from wind energy generation in the region is applied as a ratio to the total emissions from the Iron and Steel sector to estimate sector specific savings. The results are illustrated in Table 80.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
63,952	2.79%	1,785	131,424	837,339	6.4

Table 80 Iron and Steel wind energy saving

6.8.3.2 Solar Photovoltaics (PV)

Solar PV energy generation can offer savings to the whole of the region regardless of sector. The overall savings from solar PV energy generation in the region is applied as a ratio to the total emissions from Iron and Steel sector to estimate sector specific savings. The results are illustrated in Table 81.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
63,952	2.23%	1,423	172,317	1,109,794	6.4

Table 81 Iron and Steel solar PV savings

6.8.3.3 Anaerobic Digestion

Anaerobic digestion is applicable for sectors that produce organic waste and requires treatment or disposal. Therefore, AD is not applicable for the Iron and Steel sector.

6.8.3.4 Waste Heat reuse

Iron and Steel sector can utilise heat recovery systems to improve their energy efficiency and save 4,119 tCO_2e every year which amounts to 6.4% of sector emissions. Heat recovery savings are estimated for the whole sector. Further investigation is required to assess the viability of waste heat recovery systems at each site due to various criteria such as site-specific processes, use of heat on site, and existing heat recovery systems. Waste heat utilisation may be appropriate for various applications such as improving the efficiency of a certain process, generating electricity through organic Rankine cycle or recuperating waste heat to be used as a heat source in a heat network.

6.8.1 Energy Efficiency Opportunities

Every ton of steel produced in 2018 emitted on average 1.85 tons of carbon dioxide, equating to about 8% of global carbon dioxide emissions. Consequently, steel players across the globe, especially in Europe, are increasingly facing a decarbonization challenge (101).

As this sector is one of the most energy intensive sectors and requires high grade heat for its processes, this sector has several energy reduction opportunities including heat recovery.

The table below shows estimated savings from the implementation of energy saving measures which were estimated from the review of past energy audit reports carried out for this sector.

	Electricity		**Natural Gas**				
Technology	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
Combustion Systems	10	1,109	14,934	343,486	344,596	1,455,288	4.2
Compressed Air	1,768	190,957	3,510	80,739	271,697	393,491	1.4
Heat Recovery	0	0	22,401	515,229	515,229	2,264,644	4.4
Heating Systems	0	0	7,467	171,743	171,743	300,666	1.8
Lighting	707	76,383	0	0	76,383	197,394	2.6
Motors and Drives	1,238	133,670	0	0	133,670	372,909	2.8
Process	1,683	181,743	8,961	206,092	387,835	1,062,390	2.7
Pumping Systems	955	103,117	0	0	103,117	150,433	1.5
Refrigeration	1,038	112,079	0	0	112,079	239,714	2.1
Space Heating	354	38,191	14,934	343,486	381,678	2,640,324	6.9
SMT	1,061	114,574	8,961	206,092	320,666	480,999	1.5
Total Savings	**8,813**	**951,825**	**81,168**	**1,866,868**	**2,818,693**	**9,558,252**	**3.4**

Table 78 Sector Energy savings, Investment and Payback

Compressed air systems, pumping systems and SMT are the top energy saving opportunities in this sector. Payback periods are very attractive, meeting industrial criteria with considerable energy and cost savings.

	Electricity Savings		**Gas Savings**		**Total Carbon Savings**	
Technology	**Carbon (te)**	**%**	**Carbon (te)**	**%**	**Carbon (te)**	**%**
Combustion Systems	03	0.0%	2,746	5.0%	2,748	4.3%
Compressed Air	452	5.0%	645	1.2%	1,097	1.7%
Heat Recovery	00	0.0%	4,118	7.5%	4,118	6.4%
Heating Systems	00	0.0%	1,373	2.5%	1,373	2.1%
Lighting	181	2.0%	00	0.0%	181	0.3%
Motors and Drives	316	3.5%	00	0.0%	316	0.5%
Process	430	4.8%	1,647	3.0%	2,078	3.2%
Pumping Systems	244	2.7%	00	0.0%	244	0.4%
Refrigeration	265	2.9%	00	0.0%	265	0.4%
Space Heating	90	1.0%	2,746	5.0%	2,836	4.4%
SMT	271	3.0%	1,647	3.0%	1,919	3.0%
Total Savings	**2,253**	**24.9%**	**14,923**	**27.2%**	**17,175**	**26.9%**

Table 79 Sector Carbon Savings

The iron and steel sector produced over nine million tonnes of diverse products in 2012, including plates, coils, sheets, pipe products and coated steel products. The largest sources of CO_2 emissions in this industry are the process-related emissions; the direct emissions from on-site combustion of fossil fuels; and the indirect emissions from electricity consumed during the production process (99). Total sector emissions (sum of direct and indirect) were 16.6 million tonnes CO_2 in 2011, 18.4 million tonnes in 2012 and 22.8 million tonnes in 2013. EAF (Electric Arc Furnace) sites accounted for 6%, 6% and 4% of these emissions respectively (100).

In the UK, the total amount of energy used in 2012 in the iron and steel industry was 53,963 GWh, coming mostly from coal and coke (77.8%). At integrated (BF-BOF) sites, coal and coke are used both for their energy content and as a chemical reductant in the iron-making process. Purchased natural gas was the second most commonly used fuel at 9.7% due to its usage in steam production; reheating of secondary processes; and EAF ancillary heating requirements. At integrated sites, gases arising from the coke ovens, BF and BOF are collected and used as energy sources throughout the site (6.8%), including use for electricity generation.

A negligible amount of propane and LPG is also used for smaller combustion processes and for cutting of material. The share of purchased electricity in the energy consumption of the sector is limited (5.5%), although about half of the energy on EAF sites is provided by the electricity grid. EAF sites tend to use electricity and natural gas instead of coal. Total energy consumption for the Iron and Steel sector in the North West of England and North East Wales is shown below.

Due to the nature of the process, approx. 90% of energy consumption is direct fired fossil fuel such as gas and only 10% is grid electricity.

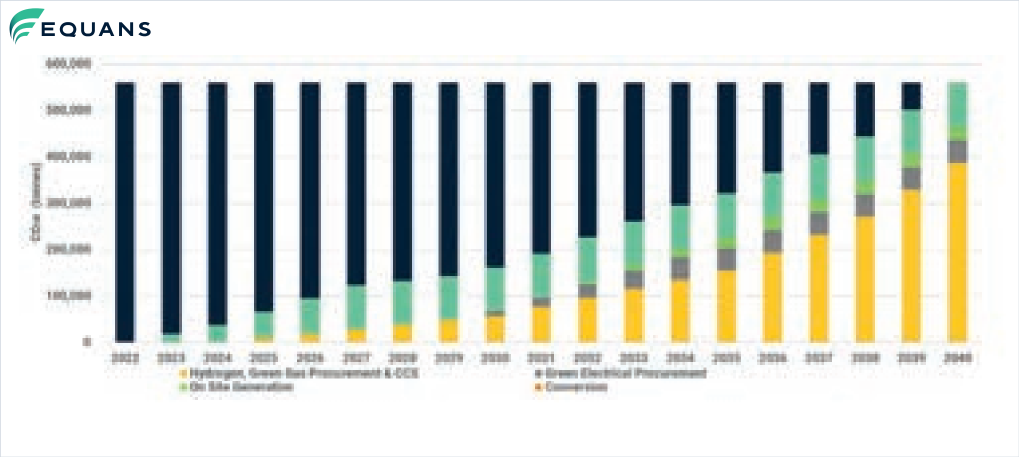

Figure 96 Iron and Steel energy breakdown

Figure 94 shows a bubble chart for the opportunities identified above the size of the bubbles coincides with the amount CO_2e saved. This chart demonstrates the relative cost effectiveness of each opportunity to reduce carbon. This chart can help prioritise opportunities with the ones in the bottom right quadrant of the graph with larger bubble size will have the greatest return on investment with the largest CO_2e savings.

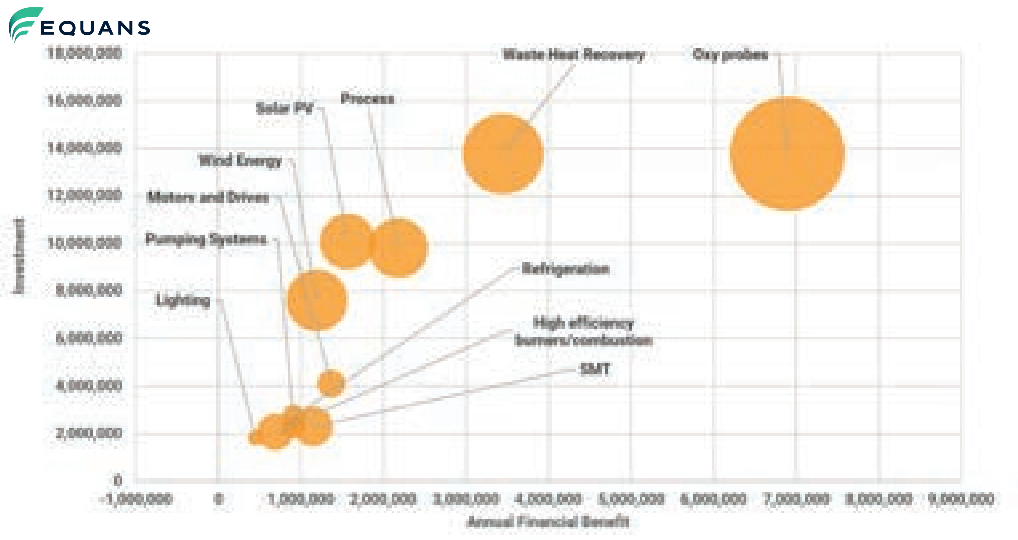

Figure 94 Glass Sector Opportunities Bubble Chart

It should be noted that above bubble chart does not include decarbonisation technologies/opportunities like conversion, procurement of renewable electricity, procurement of hydrogen or green gas and CCS as they have no payback.

6.8 Iron and Steel

Steel is one of the core pillars of today's society and, as one of the most important engineering and construction materials, it is present in many aspects of our lives. Iron and Steel is one of the most heat intensive industries.

The UK iron and steel industry is a highly mature and consolidated industry. Steel is globally traded and highly price sensitive. UK steel revenues in 2013 were £9.9 billion, with a profit of £672.8 million (98).

Steel can be manufactured either by the primary BF-BOF (blast furnace – basic oxygen furnace) or by the secondary EAF (electric arc furnace) route. The primary BF-BOF route accounts for 79% of crude steel production in the UK, and includes coke production, sintering, BF, BOS, casting and rolling. The secondary EAF route accounts for the remainder of UK crude steel production, and includes scrap preparation, electric arc furnaces, casting and rolling.

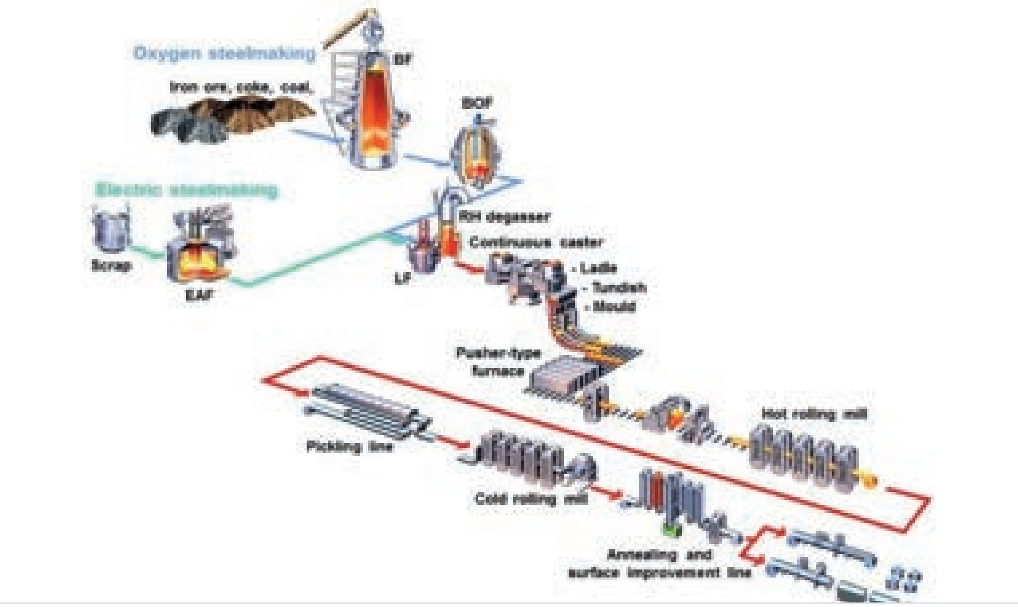

Figure 95 Iron and Steel Process flow (79)

6.7.4 Sector Roadmap

Based on the technologies discussed above a pathway to net zero for the North West England and North East Wales Glass sector is proposed below. Most of the carbon reduction is through energy conservation measures as with all the opportunities stated above the sector can reduce the carbon emissions by 17%.

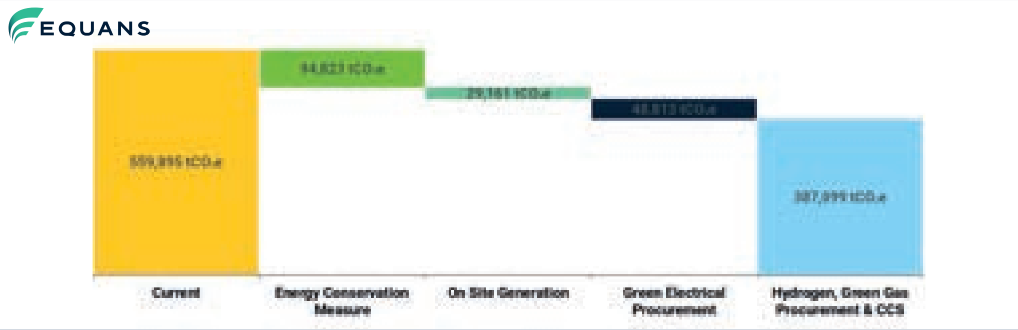

Figure 92 Glass Sector Carbon Waterfall

For net zero, total CAPEX has been estimated at **£70,392,506** with a financial benefit of **£20,766,393**, giving a simple payback of **3.4 years**. There is no CAPEX and therefore no payback against green electricity procurement and green hydrogen procurement as it is assumed that grid will be decarbonised by 2035 and green hydrogen will cost same as natural gas.

The timeline in Figure 93 is an indication of when these opportunities can be implemented to achieve a carbon neutral position. It is assumed that energy efficiency opportunities will be prioritised and implemented in a 5-year interval. The total implementation of the energy efficiency opportunities will help to define a new energy consumption profile for the site.

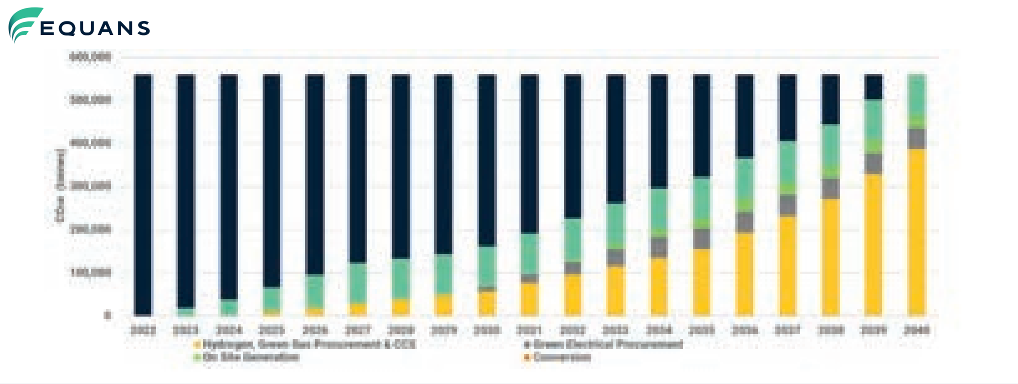

Figure 93 Glass Sector Carbon Neutral Delivery Plan

6.7.3 On-Site Generation

6.7.3.1 Wind Generation

Wind energy generation can offer savings to the whole of North West England and North East Wales regardless of sector. The overall savings from wind energy generation in the region is applied as a ratio to the total emissions from Glass sector to estimate sector specific savings. The results are illustrated in Table 76.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
559,895	2.79%	15,625	1,150,617	7,330,877	6.4

Table 76 Glass wind energy saving

6.7.3.2 Solar Photovoltaics (PV)

Solar PV energy generation can offer savings to the whole of North West England and North East Wales regardless of sector. The overall savings from solar PV energy generation in the region is applied as a ratio to the total emissions from Glass sector to estimate sector specific savings. The results are illustrated in Table 77.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
581,291	2.23%	12,938.42	1,566,282	10,087,521	6.4

Table 77 Glass solar PV savings

6.7.3.3 Anaerobic Digestion

Anaerobic digestion is applicable for sectors that produce organic waste and requires treatment or disposal. Therefore, AD is not applicable for the Glass sector.

6.7.3.4 Waste Heat reuse

The glass sector can utilise heat recovery systems to improve their energy efficiency and save 22,092 tCO_2e every year which amounts to 3.9% of sector emissions. Heat recovery savings are estimated for the whole sector. Further investigation is required to assess the viability of waste heat recovery systems at each site due to various criteria such as site-specific processes, use of heat on site, and existing heat recovery systems. Waste heat utilisation may be appropriate for various applications such as improving the efficiency of a certain process, generating electricity through organic Rankine cycle or recuperating waste heat to be used as a heat source in a heat network.

Considerable energy and cost savings are achievable with an approximate payback period of three years. As can be seen from the table below, this sector offers approx. 17% of carbon savings. Figure 91 shows carbon savings by project.

	Electricity Savings		Gas Savings		Total Carbon Savings	
Technology	**Carbon (te)**	**%**	**Carbon (te)**	**%**	**Carbon (te)**	**%**
High efficiency burners/combustion	00	0.00%	4,418	1.16%	4,418	0.8%
Oxy probes	00	0.00%	44,184	11.64%	44,184	7.9%
Waste Heat Recovery	00	0.00%	22,092	5.82%	22,092	3.9%
Lighting	866	1.00%	00	0.00%	866	0.2%
Motors and Drives	2,599	3.00%	00	0.00%	2,599	0.5%
Process	866	1.00%	11,046	2.91%	11,912	2.1%
Pumping Systems	1,733	2.00%	00	0.00%	1,733	0.3%
Refrigeration	1,733	2.00%	00	0.00%	1,733	0.3%
SMT	866	1.00%	4,418	1.16%	5,285	0.9%
Total Savings	**8,664**	**10.0%**	**86,159**	**22.7%**	**94,823**	**16.9%**

Table 75 Sector Carbon Savings

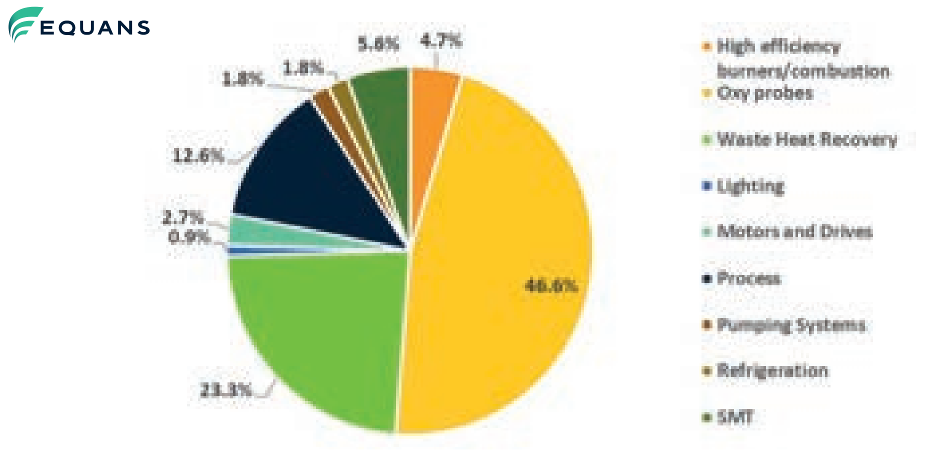

Figure 91 Glass Sector Carbon Savings (teCO2e)

6.7.2 Low Carbon Technologies

No data available therefore no analysis carried out for CHP, HP

The following graph shows the total energy consumption of this sector within North West England and North East Wales.

The total energy consumed for the Glass sector is estimated to be 2,403,281 MWh with total carbon emissions of 466,163 $teCO_2e$.

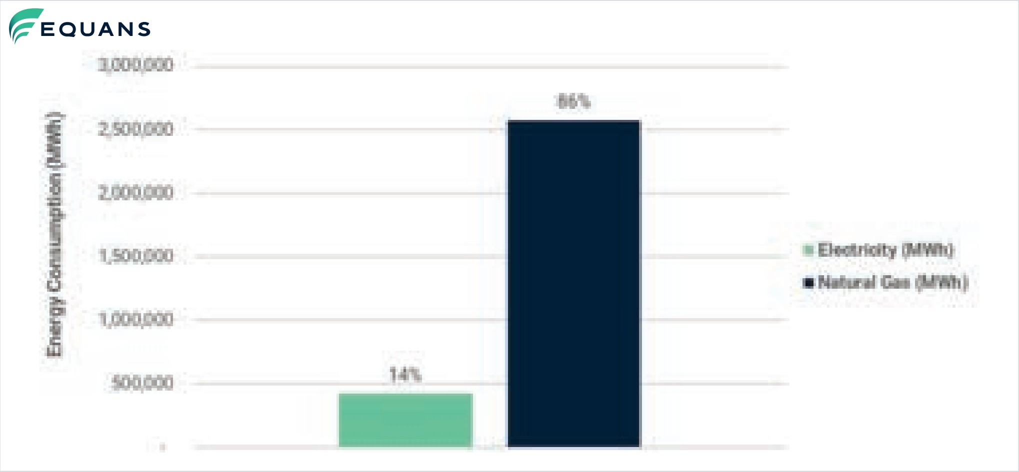

Figure 90 Glass Sector Energy Consumption

6.7.1 Energy Efficiency Opportunities

The glass industry has a key role to play in helping the UK reach net zero by 2050 by providing a circular economy solution to the packaging industry (container glass), providing high efficiency glazing to improve energy efficiency in buildings (flat glass) and continuous filament glass fibre to be incorporated into wind turbines for renewable energy and lightweight vehicles.

This sector has lowered its emissions by an increase in energy efficiency mainly via improved energy performance of furnaces and heat recovery.

The overall energy savings via improved utility energy performance and heat recovery can be as high as 17% excluding on-site power generation and renewables. The table below depicts the extrapolated savings.

	Electricity		Natural Gas				
Technology	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
High efficiency burners/ combustion	00	00	24,033	552,755	552,755	1,658,264	3.0
Oxy probes	00	00	240,328	5,527,546	5,527,546	11,055,091	2.0
Waste Heat Recovery	00	00	120,164	2,763,773	2,763,773	11,055,091	4.0
Lighting	3,390	366,071	00	00	366,071	1,464,283	4.0
Motors and Drives	10,169	1,098,212	00	00	1,098,212	3,294,636	3.0
Process	3,390	366,071	60,082	1,381,886	1,747,957	7,865,807	4.5
Pumping Systems	6,779	732,141	00	00	732,141	1,830,353	2.5
Refrigeration	6,779	732,141	00	00	732,141	2,196,424	3.0
SMT	3,390	366,071	24,033	552,755	918,825	1,837,650	2.0
Total Savings	**33,895**	**3,660,707**	**468,640**	**10,778,714**	**14,439,421**	**42,257,599**	**2.9**

Table 74 Sector Energy savings, Investment and Payback

The below figures show the container and flat glass manufacturing processes. The first three stages of this process – raw materials, batch house and furnace – are common to each of the glass sectors and utilise similar batch preparation and furnace technologies. Once the glass leaves the furnace the forming and downstream processes are unique to each sector.

In the batch house, the high purity raw materials are weighed and mixed along with the other materials. The batch is then fed into the furnace which can operate up to temperatures of 1,700°C. The furnace is normally heated by gas burners which fire above the surface of the melt and heat the glass by radiation. A furnace may also have submerged electrodes (within the glass) that heat the glass via resistive heating. Depending on the product the glass is either formed by iron moulds, using compressed air for shaping, or the molten glass floats on top of a molten tin to form a solid ribbon of glass. The annealing stage of the process is to remove any stresses formed within the glass during the formal stage. This involves heating and cooling. The last phases are inspection, packaging, storing and dispatching (97).

Figure 88 Container glass manufacturing process (96)

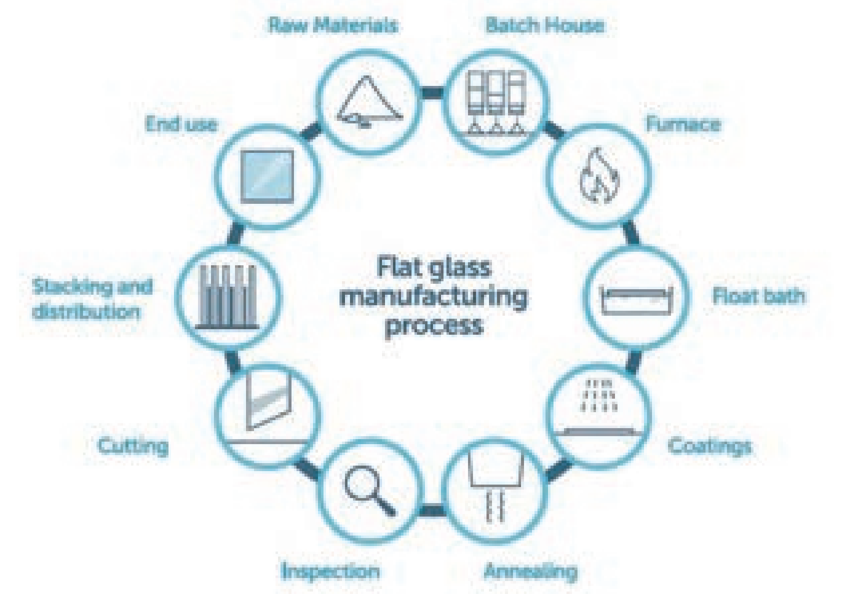

Figure 89 Flat glass manufacturing process (96)

Figure 87 shows a bubble chart for the opportunities identified above the size of the bubbles coincides with the amount CO_2e saved. This chart demonstrates the relative cost effectiveness of each opportunity to reduce carbon. This chart can help prioritise opportunities with the ones in the bottom right quadrant of the graph with larger bubble size will have the greatest return on investment with the largest CO_2e savings.

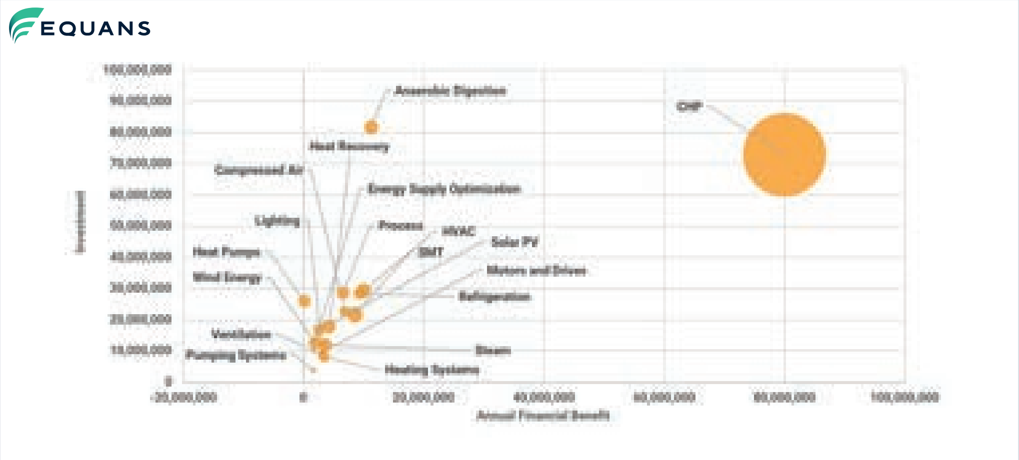

Figure 87 Food and Drink Sector Opportunities Bubble Chart

6.7 Glass

The UK largescale glass manufacturing industry includes 10 companies across 17 sites throughout England, Scotland, and Northern Ireland (95). Approximately 6,000 staff are directly employed by the industry, with indirect employment figures around 150,000. There are three main glass manufacturing processes:

Container – Food, drink, and pharmaceutical products. There are currently six companies across 12 manufacturing sites in the UK.

Flat – Flat glass is used in commercial and residential buildings for glazing. Sophisticated coatings enable high efficiency glazing installation to reduce building CO_2.

Fibre – Continuous filament fibres of glass are incorporated into reinforced plastic materials used in numerous applications in manufacturing, and predominantly for wind turbine blades and light weighting of vehicles. Approximately 3.5 million tonnages of glass melted per year in the UK (18).

6.6.4 Sector Roadmap

Based on the technologies discussed above a pathway to net zero for North West England and North East Wales Food and Drink sector has been proposed below. Most of the carbon reduction is achieved through hydrogen, green gas procurement and CCS, as with the utilisation of all the opportunities stated above the sector can reduce their carbon emissions by 26%.

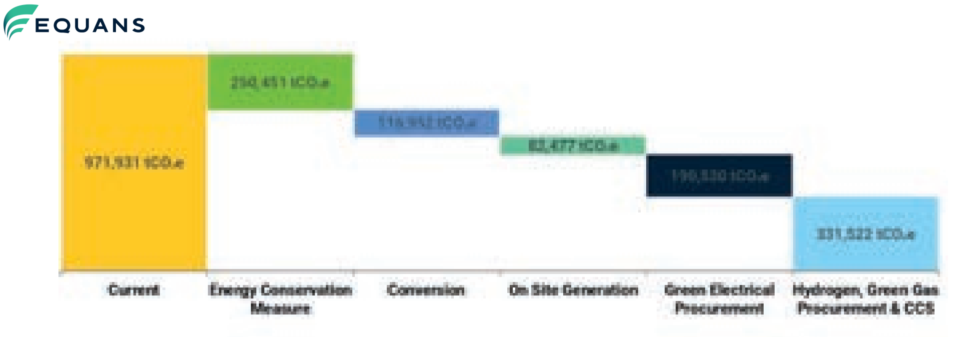

Figure 85 Food and Drink Sector Carbon Waterfall

For net zero, total CAPEX has been estimated at **£350,923,191** with a financial benefit of **£81,366,430**, giving a simple payback of **4.3** years. There is no CAPEX and therefore no payback against green electricity procurement and green hydrogen procurement as it is assumed that grid will be decarbonised by 2035 and green hydrogen will cost same as natural gas.

Figure 86 below gives an indication of when these opportunities can be implemented to achieve a carbon neutral position.

It is assumed that energy efficiency opportunities will be prioritised and implemented in a 5-year interval. The total implementation of the energy efficiency opportunities will help to define a new energy consumption profile for the site. Therefore, when low carbon technologies and renewable sources are implemented, the site will be already the most efficient that can be. It is assumed that UK electricity grid will be carbon free by 2035 as stated by UK Government.

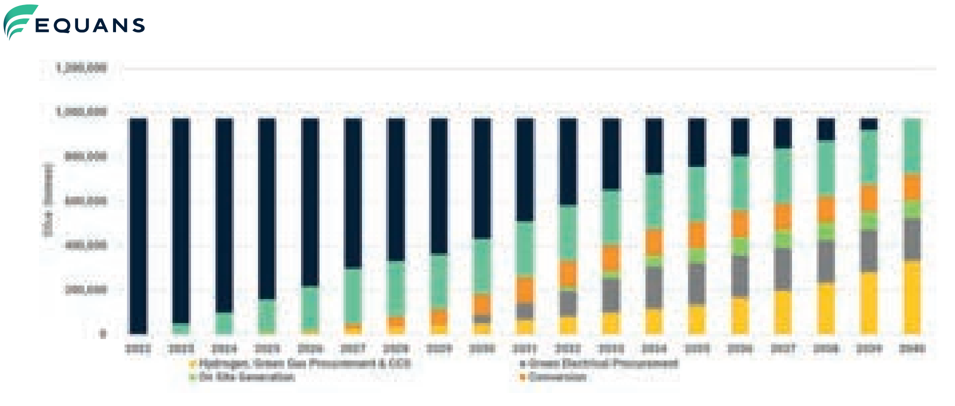

Figure 86 Food and Drink Sector Carbon Neutral Delivery Plan

6.6.3 On-Site Generation

6.6.3.1 Wind Generation

Wind energy generation can offer savings to the whole of the North West England and North East Wales regardless of sector. The overall savings from wind energy generation in the region is applied as a ratio to the total emissions from the Food and Drink sector to estimate sector specific savings. The results are illustrated in Table 71.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
971,931	2.79%	27,123.65	1,997,375.22	12,725,797.53	6.4

Table 71 Food and Drink wind energy saving

6.6.3.2 Solar Photovoltaics (PV)

Solar PV energy generation can offer savings to the whole of the region regardless of sector. The overall savings from solar PV energy generation in the region is applied as a ratio to the total emissions from Food and Drink sector to estimate sector specific savings. The results are illustrated in Table 72.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
971,931	2.23%	21,633.31	2,618,856	16,866,540	6.4

Table 72 Food and Drink solar PV savings

6.6.3.3 Anaerobic Digestion

As this sector has organic waste that can be treated using Anaerobic Digestion, savings have been estimated from the use of biogas generated by AD and shown in Table 73.

Description	Food & Drink
Estimated electrical savings (MWh)	49,248
Estimated thermal savings (MWh)	45,298
Estimated CO_2 savings (te)	33,720
Estimated net financial benefit (£)	11,281,080
Estimated budget capital cost (£)	81,750,000
Estimated payback period (years)	7.3

Table 73 Food and Drink AD savings

6.6.3.4 Waste Heat reuse

The Food and Drink sector can utilise heat recovery systems to improve their energy efficiency and save 30,661 tCO_2e every year which amounts to 3.2% of sector emissions. Heat recovery savings are estimated for the whole sector. Further investigation is required to assess the viability of waste heat recovery systems at each site due to various criteria such as site-specific processes, use of heat on site, and existing heat recovery systems. Waste heat utilisation may be appropriate for various applications such as improving the efficiency of a certain process, generating electricity through organic Rankine cycle or recuperating waste heat to be used as a heat source in a heat network.

6.6.2.3 Electrification

Heat is used within the food and drink sector in many forms. Typical processes include but are not limited to: pasteurising, baking, drying, and evaporating. Most of the processes generate heat using fossil fuels. This can be directly such as gas fired ovens or indirectly such as gas fired boilers to generate hot water or steam. Due to the wide scope of heat used within the food and drink sector there is not a simple 'plug in and play' solution. Figure 84 shows a simple heat map for an industrial bakery.

Figure 84 shows that natural gas is used for both indirect and direct heating. With current technology it is possible to electrify all these processes. Table 70 shows the alternatives that are commercially available. As stated previously, net zero is more complicated than just electrifying all the processes, there are several other considerations. These considerations include, but are not limited to quality, reliability, capital, and operational expenditure. Bespoke solutions will be the key to the food and drink industry reaching net zero. Electrification will be an important part to all bespoke solutions, whether that is fuel switching with the currently available technologies or technology that is in development.

Current Technology	Commercially available Electric alternatives
Oven	Electric convection ovens; Electric infra-red ovens; Electric ceramic
Boiler (steam)	Immersion steam boiler; Electrode steam boiler; Electric steam generator
Wash (hot water)	Electric heater; Immersion heater; Electric process heater
Office Heating	Electric heater; Electric infra-red heaters; Heat pumps

Table 70 Commercially available electric alternatives

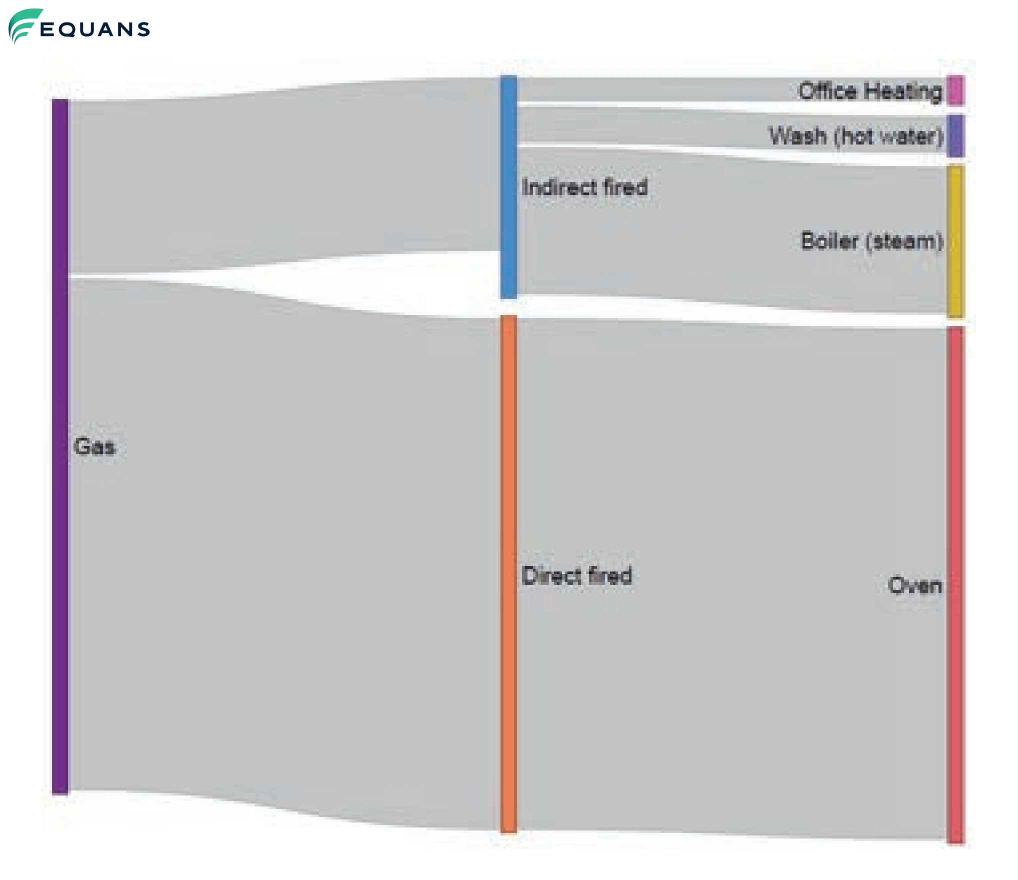

Figure 84 Industrial Bakery heat map

6.6.2.2 Heat Pumps

Heat pump technology can offer savings to the whole of the region regardless of sector. These savings are shown in the tables and figures below.

High Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
1,530,653	3,619,954	4,826,605	496.14	2.36	481.5	86%	-£51,237

Table 68 Food & Drink Heat Pump High Temperature Data

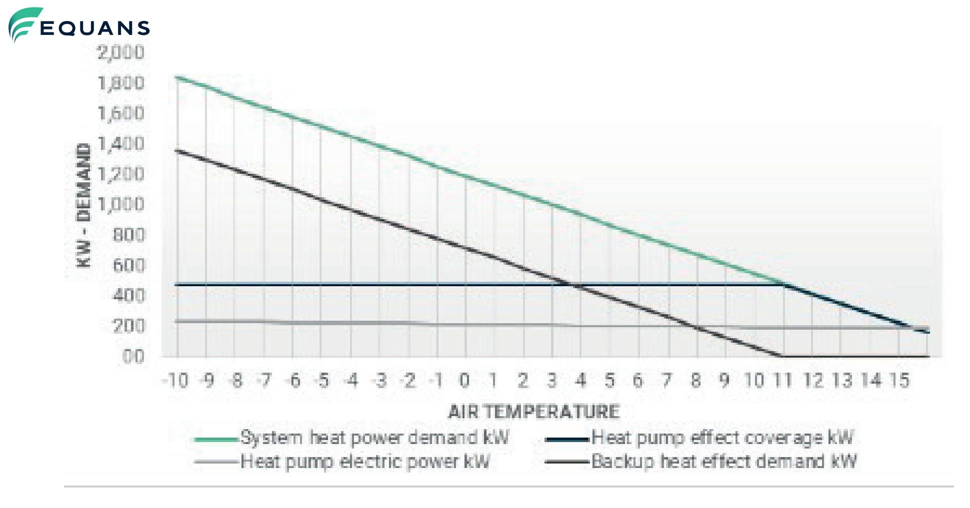

Figure 82 Food & Drink Heat Pump High Temperature Operation Profile

Low Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
1,577,178	5,687,776	7,583,702	991.14	3.61	1928.4	40%	£7,244

Table 69 Food & Drink Heat Pump Low Temperature Data

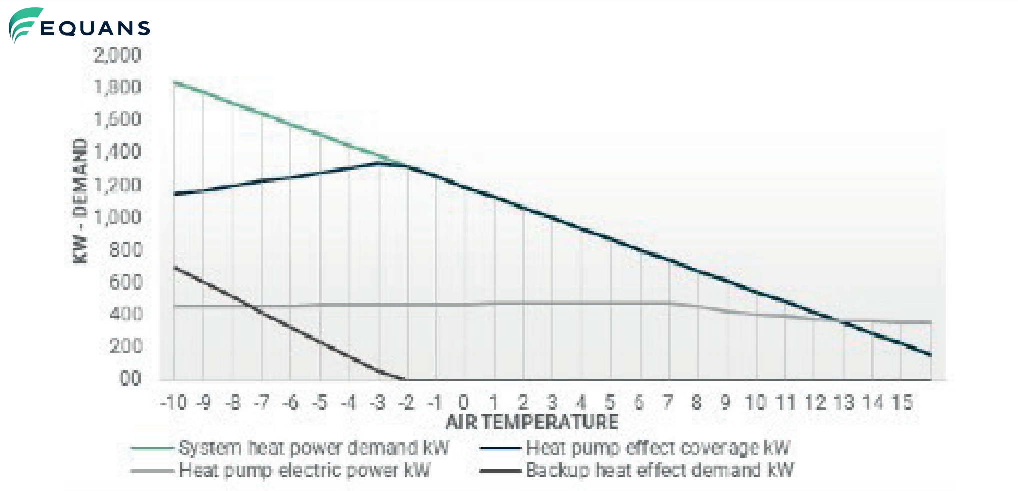

Figure 83 Food & Drink Heat Pump Low Temperature Operation Profile

6.6.2 Low Carbon Technologies

6.6.2.1 CHP

Current projections for the food and drink industry suggest a growth of up to 2% to account for population growth. The food production industry typically runs various processes requiring both thermal and electrical energy input. Thermal processes make use of different media such as LTHW and steam generated from combustion plants including direct fired ovens, boilers or CHPs (93). These can include pasteurisers, blanching, spray driers and clean in process (CIP), hence why this industry has been selected to model as an attractive option for a CHP system.

Chilled water systems and chiller plants present a viable option for electrical consumption due to their flat, consistent load all year round, typically for storage of product. The installation of a CHP system would reduce the electrical energy imported to the site thus reducing the electricity consumption of the process. The current financial benefit would be governed by the spark spread, where a site can benefit from electricity at the price of gas per/kWh.

The brewing industry falls into the food and drink industry sector, but as there are specific processes which are unique to this industry, the analysis for brewing has been carried out in isolation. Brewing processes make use of LTHW, HPHW, and steam for thermal energy requirement with onsite generation from conventional fired boilers and older gas turbine CHP systems. This includes processes such as kegging and CIP. Electrical processes such as fermenting, brewing, and kegging are some of the larger consumers on a site used within the brewing industry. Because of continuous production, these processes allow for a substantial base load of electrical and thermal loads throughout the year creating a typical profile not greatly affected by seasonal changes.

Current ETS Emissions for Sector Avg T/Yr	New Emissions with CO_2 Offset T/Yr	Existing Gas Usage for Sector Avg kWh	Gas increase Natural Gas Engine kWh	Carbon Saving (te) p/a	Comparison of gas increase	Gas Engine input
971,931	31,451	174,713,858	206,201,779	670.5	30%	31,487,921

Table 66 Food & Drink CHP data

Indictive CapEx Cost + 1st Yr Service	Electrical cost reduction	Savings per Year	Approx. Payback Years	Electrical Utilisation	Thermal Utilisation
£2,915,000	£1,436,754	£1,015,681.3	2.23	98%	95%

Table 67 Food & Drink CHP financial data

Considerable energy and cost savings are achievable with an approximate payback period of 3.3 years, which is within the payback criteria for most of the food processing factories. Compressed air system, HVAC, steam system and heat recovery are among the top candidates for energy efficiency and carbon savings.

	Electricity Savings		**Natural Gas Savings**		**Total Carbon Savings**	
Technology	**Carbon (te)**	**%**	**Carbon (te)**	**%**	**Carbon (te)**	**%**
Compressed Air	14,969	3.87%	4,715	0.81%	19,684	2.0%
Energy Supply Optimization	3,872	1.00%	00	0.00%	3,872	0.4%
Heat Recovery	1,423	0.37%	29,238	5.00%	30,661	3.2%
Heating Systems	3,872	1.00%	14,619	2.50%	18,491	1.9%
HVAC	19,359	5.00%	14,619	2.50%	33,978	3.5%
Lighting	7,292	1.88%	00	0.00%	7,292	0.8%
Motors and Drives	7,743	2.00%	00	0.00%	7,743	0.8%
Process	11,228	2.90%	14,619	2.50%	25,847	2.7%
Pumping Systems	3,872	1.00%	00	0.00%	3,872	0.4%
Refrigeration	22,069	5.70%	00	0.00%	22,069	2.3%
SMT	11,615	3.00%	29,238	5.00%	40,853	4.2%
Steam	00	0.00%	29,238	5.00%	29,238	3.0%
Ventilation	6,852	1.77%	00	0.00%	6,852	0.7%
Total Savings	**114,164**	**29.5%**	**136,287**	**23.3%**	**250,451**	**25.8%**

Table 65 Sector Carbon Savings

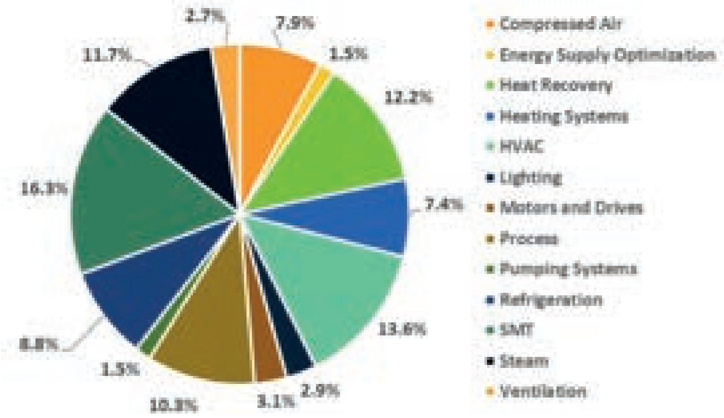

Figure 81 Food and Drink Carbon Savings (teCO$_2$e)

Heat recovery is an imperative and a common opportunity within this sector which plays a vital role to achieving energy efficiency.

Example heat recovery opportunities include:

- Heat recovery from boiler flue gases
- Heat recovery from air compressors
- Heat recovery from process end-users e.g., Retorts
- Heat recovery from refrigeration system and HVAC

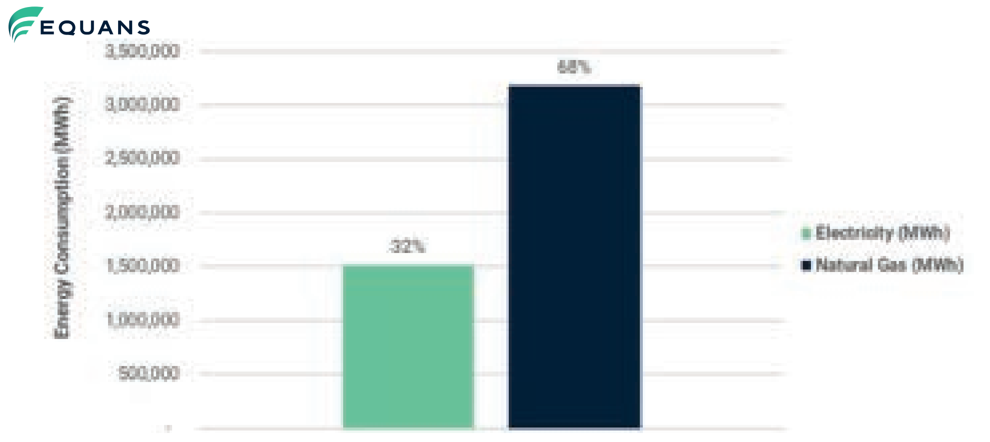

Figure 80 Food and Drink Sector Energy Consumption

Total energy for the Food and Drink sector is estimated to be 4,695,393 MWh with total carbon emissions of 971,931 teCO$_2$e.

6.6.1 Energy Efficiency Opportunities

This sector has lowered its carbon footprint considerably – with a 42% emissions reduction in 2015 from a 1990 baseline (94). Around 98% of the food and drink sectors CO$_2$ emissions are covered by EU ETS and/or the Climate Change Agreement Scheme (CCA).

This sector has a considerable number of potential energy saving opportunities with adequate paybacks. The overall energy savings via improved utility energy performance can be as high as 26% excluding on-site power generation and renewables .

Several energy efficiency reports including ESOS Phase 2 were analysed for energy efficiency opportunities identified within this sector. Identified savings are extrapolated to estimate the total potential savings for this sector within North West England and North East Wales. The table below depicts the extrapolated savings.

	Electricity		**Natural Gas**				
Technology	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
Compressed Air	58,564	6,324,925	25,649	589,918	6,914,843	22,671,046	3.3
Energy Supply Optimization	15,148	1,635,931	00	00	1,635,931	10,337,098	6.3
Heat Recovery	5,567	601,221	159,032	3,657,738	4,258,959	17,879,337	4.2
Heating Systems	15,148	1,635,931	79,516	1,828,869	3,464,800	8,082,723	2.3
HVAC	75,738	8,179,657	79,516	1,828,869	10,008,526	29,386,546	2.9
Lighting	28,527	3,080,965	00	00	3,080,965	12,006,291	3.9
Motors and Drives	30,295	3,271,863	00	00	3,271,863	9,856,928	3.0
Process	43,928	4,744,201	79,516	1,828,869	6,573,070	28,617,768	4.4
Pumping Systems	15,148	1,635,931	00	00	1,635,931	3,834,872	2.3
Refrigeration	86,341	9,324,809	00	00	9,324,809	28,443,578	3.1
SMT	45,443	4,907,794	159,032	3,657,738	8,565,532	21,633,737	2.5
Steam	00	00	159,032	3,657,738	3,657,738	11,961,800	3.3
Ventilation	26,806	2,895,047	00	00	2,895,047	8,935,374	3.1
Total Savings	**446,651**	**48,238,274**	**741,293**	**17,049,739**	**65,288,013**	**213,647,099**	**3.3**

Table 64 Sector Energy savings, Investment and Payback

It is assumed that UK electricity grid will be carbon free by 2035 as stated by the UK Government and the following bubble chart, for the opportunities identified above the size of the bubbles coincides with the amount CO_2e saved. This chart demonstrates the relative cost effectiveness of each opportunity to reduce carbon. This chart can help prioritise opportunities with the ones in the bottom right quadrant of the graph with larger bubble size will have the greatest return on investment with the largest CO_2e savings.

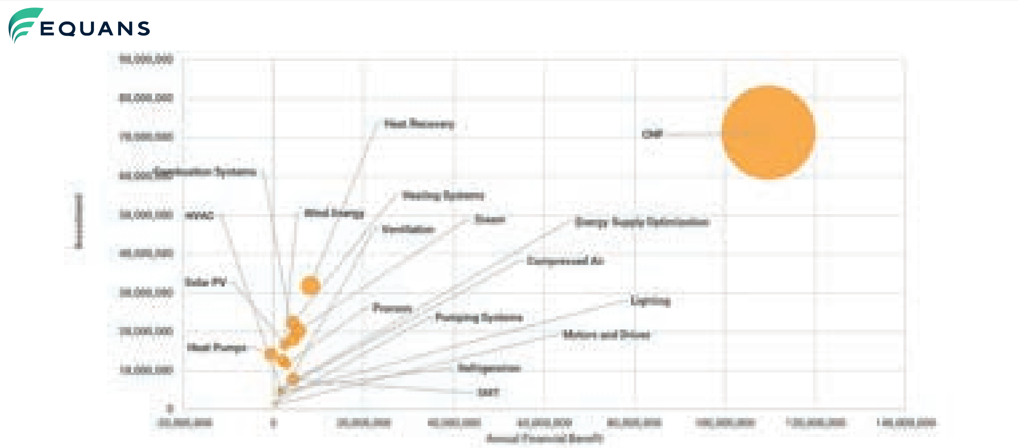

Figure 79 Chemical Sector Opportunities Bubble Chart

It should be noted that above bubble chart does not include decarbonisation technologies/opportunities like conversion, procurement of renewable electricity, procurement of hydrogen or green gas and CCS as they have no payback.

6.6 Food and Drink

The UK food and drink sector is highly diverse and has a number of subsectors, including dairy, brewery, distilling, sugar, bakery, rendering, meat processing, fish and seafood, poultry, malting, soft drinks, animal feed, oil and fat, glucose, canned food, and pet food (93). The main processing techniques outlined below can be applied to the sector.

- Materials reception and preparation
- Size reduction, mixing and forming
- Separation techniques
- Product processing technologies
- Heat processing
- Concentration by heat
- Chilling and freezing
- Post-processing operations
- Utility processes

Typical electricity consumers in food and drink sector include:

- Lighting
- HVAC
- Refrigeration
- Compressed Air
- Motors and Drives
- Process machines
- Packaging

There are high, medium, and low-grade heat requirements within the Food and Drink sector.

6.5.5 Sector Roadmap

Based on the technologies discussed above a pathway to net zero for the North West England and North East Wales Chemical sector is proposed below. Most of the carbon reduction is through energy conservation measures as with all the opportunities stated above the sector can reduce the carbon emissions by 27%.

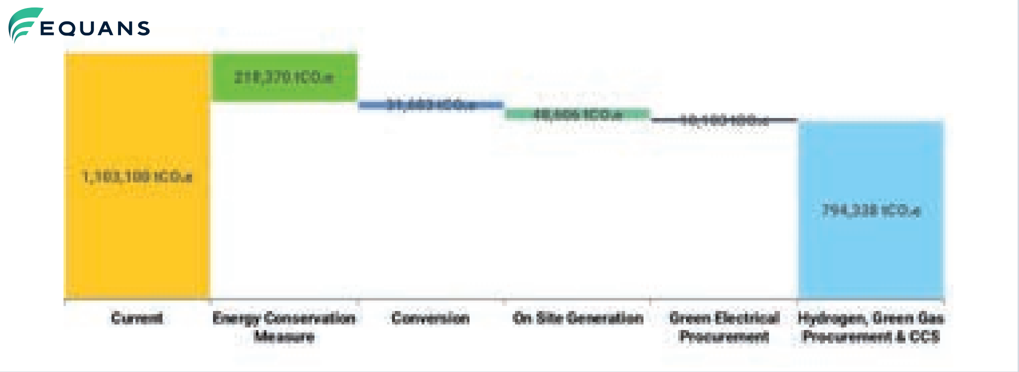

Figure 77 Chemical Sector Carbon Waterfall

For net zero, total CAPEX has been estimated at **£183,683,894** with a financial benefit of **£42,606,095**, giving a simple payback of **4.3 years**. There is no CAPEX and therefore no payback against green electricity procurement and green hydrogen procurement as it is assumed that grid will be decarbonised by 2035 and green hydrogen will cost same as natural gas.

The timeline below is an indication of when these opportunities can be implemented to achieve a carbon neutral position. It is assumed that energy efficiency opportunities will be prioritised and implemented in a 5-year interval. The total implementation of the energy efficiency opportunities will help to define a new energy consumption profile for the site. Therefore, when low carbon technologies and renewable sources are implemented, the site will be already the most efficient that can be.

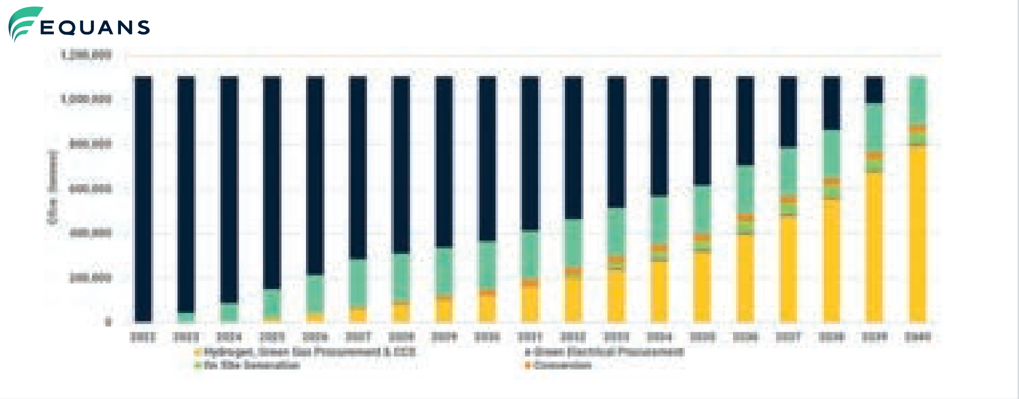

Figure 78 Chemical Sector Carbon Neutral Delivery Plan

6.5.4 ON-SITE GENERATION

6.5.4.1 Wind Energy

Wind energy generation can offer savings to the whole of North West England and North East Wales regardless of sector. The overall savings from wind energy generation in North West England and North East Wales is applied as a ratio to the total emissions from the Chemical sector to estimate sector specific savings.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
1,103,100	2.79%	30,784	2,266,936	14,443,237	6.4

Table 62 Chemical wind energy saving

6.5.4.2 Solar Photovoltaics (PV)

Solar PV energy generation can offer savings to the whole of North West England and North East Wales regardless of sector. The overall savings from solar PV energy generation in North West England and North East Wales is applied as a ratio to the total emissions from Chemical sector to estimate sector specific savings.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
1,103,100	2.23%	24,553	2,972,290	19,142,803	6.4

Table 63 Chemical solar PV savings

6.5.4.3 Anaerobic Digestion

Anaerobic digestion is applicable for sectors that produce organic waste and requires treatment or disposal. Therefore, AD is not applicable for the Chemical sector.

6.5.4.4 Waste Heat reuse

The Chemical sector can utilise heat recovery systems to improve their energy efficiency and save 57,734 tCO_2e every year which amounts to 5.2% of sector emissions. Heat recovery savings are estimated for the whole sector. Further investigation is required to assess the viability of waste heat recovery systems at each site due to various criteria such as site-specific processes, use of heat on site, and existing heat recovery systems. Waste heat utilisation may be appropriate for various applications such as improving the efficiency of a certain process, generating electricity through organic Rankine cycle or recuperating waste heat to be used as a heat source in a heat network.

6.5.3.3 Electrification

In 2015 the government published a decarbonisation and energy efficiency road map for the chemicals sector (91) which was followed by an action plan in 2017 (92). Since these documents were released, the Government has changed its national commitments around greenhouse gas emissions from an 80% reduction by 2050 to net zero. At the time of writing this report the roadmaps are yet to be updated to reflect the change in target however it has been acknowledged that decarbonising heat within the sector is a challenge. The Chemical Industries Association (CIA) has also highlighted the importance of the role of the clusters and hydrogen in decarbonising the chemical sector (87). Electrification can still play a role of the decarbonisation of the chemical industry.

The electrification of the chemical industry could occur in two forms, the electrification of heat or direct electrochemistry. Electrochemistry is still being researched and developed. With current technology the electrification of heat is possible for some of the chemical industries processes. Heat is used within the Chemical sector in many forms, typical processes including, but not limited to, autoclaves, distillation, and cracking. Most of the processes generate heat using fossil fuels, and some require very high temperatures. Due to the wide scope of heat used and temperatures required within the Chemical sector, electrification of heat is likely to play a supplementary role in the decarbonisation of chemical industry. Figure 76 shows a simple heat map for the chemical sector.

With current technology it is possible to electrify some of the low-pressure steam applications such as evaporation and hot water/ washing. Table 61 shows the alternatives that are commercially available. As stated previously, with the currently available technologies electrification will play a small role, if at all, in decarbonising heat. Future technology and RandD appear to be focused on electrochemistry.

Current Technology	Commercially available Electric alternatives
Low pressure process steam	Immersion Steam Boiler, Electrode Steam Boiler, Electric steam generator
Hot water/ Wash water	Electric heater, immersion heater, Electric Process Heater

Table 61 Commercially available electric alternatives

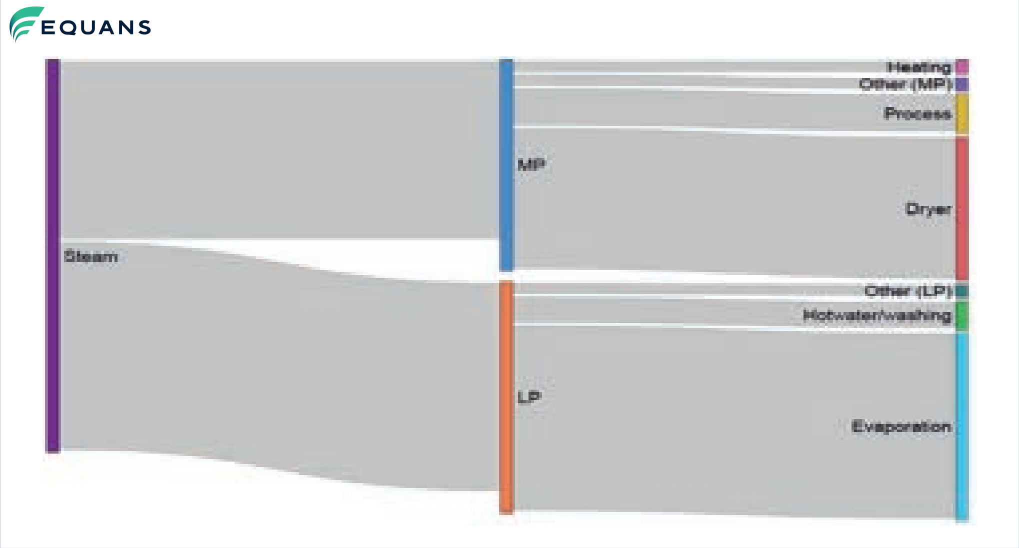

Figure 76 Chemical sector heat map

6.5.3.2 Heat Pumps

Heat pump technology can offer savings to the whole of the region regardless of sector. These savings are shown in the tables and figures below.

High Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
2,349,543	5,550,836	7,401,115	760.15	2.36	763.9	83%	-£78,826

Table 59 Chemical Heat Pump High Temperature Data

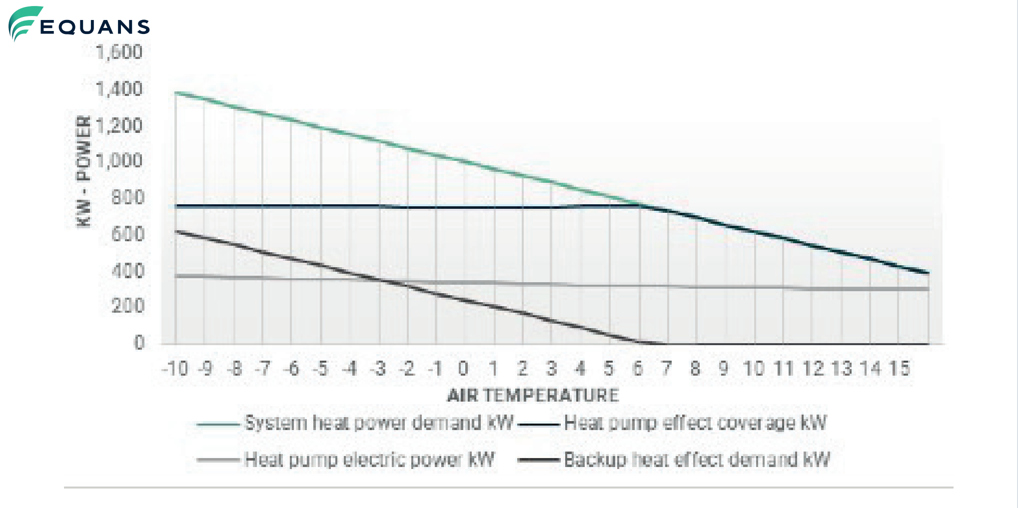

Figure 74 Chemical Heat Pump High Temperature Operation Profile

Low Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
1,724,980	5,491,398	7,321,864	905.22	3.18	926.8	76%	-£14,445

Table 60 Chemical Heat Pump Low Temperature Data

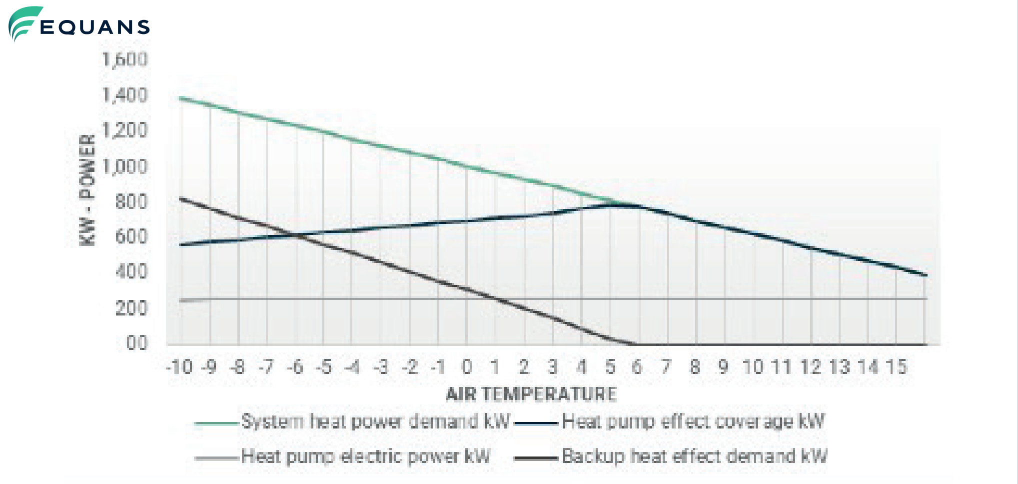

Figure 75 Chemical Heat Pump Low Temperature Operation Profile

6.5.3 Low Carbon Technologies

6.5.3.1 CHP

The chemical sector has been considered for a CHP system due to significant carbon produced from manufacturing, currently being the third highest emitter in North West England and North East Wales. Further to this a third of the sector is recognised to already have CHP generation on site, illustrating its preferred option for onsite generation in this sector. However, for the context of CHP systems within this report, it is understood that CHP plants installed within the sector employ the application of large-scale steam turbines which although utilises the same principles and methodology, does differ in technology. This type of application does offer the use of additional equipment such as carbon capture, which can be used back within the chemical manufacturing process. Analysis of such a system has shown reductions of up to 11% carbon output from the process (89).

The industrial sector recorded consuming 16.5% of the UK's energy in 2012 (91), highlighting the vast amount of energy demand for the sector and hence highlighting a strong advantage in applying the use of CHP technology to centralise energy generation to an onsite application.

Current Emissions for Sector Avg T/Yr	New Emissions with CO_2 Offset T/Yr	Existing Gas Usage for Sector Avg kWh	Gas increase Natural Gas Engine kWh	Carbon Saving (te) p/a	Comparison of gas increase	Gas Engine input
1,103,100	1,102,211	200,436,897	235,929,714	889	18%	1,103,100

Table 57 Chemical CHP data

Indictive CapEx Cost + 1st Yr Service	Electrical cost reduction	Savings per Year	Approx. Payback Years	Electrical Utilisation	Thermal Utilisation
£2,035,715	£1,785,326	£1,289,619.0	1.41	99%	97%

Table 58 Chemical CHP financial data

Considerable energy and cost savings are achievable with an approximate payback period of under 4 years, which is within the payback criteria for most of the chemical factories. Heat recovery, heating systems and combustion are among the top candidates for energy efficiency and carbon savings.

	Electricity		**Natural Gas**		**Total Carbon Savings**	
Technology	**Carbon (te)**	**%**	**Carbon (te)**	**%**	**Carbon (te)**	**%**
Combustion Systems	00	0.0%	30,821	4.0%	30,821	2.8%
Compressed Air	3,224	4.0%	00	0.0%	3,224	0.3%
Energy Supply Optimization	2,418	3.0%	00	0.0%	2,418	0.2%
Heat Recovery	-56	-0.1%	57,790	7.5%	57,734	5.2%
Heating Systems	00	0.0%	30,821	4.0%	30,821	2.8%
HVAC	4,030	5.0%	00	0.0%	4,030	0.4%
Lighting	2,418	3.0%	00	0.0%	2,418	0.2%
Motors and Drives	806	1.0%	00	0.0%	806	0.1%
Process	1,612	2.0%	15,411	2.0%	17,022	1.5%
Pumping Systems	1,390	1.7%	00	0.0%	1,390	0.1%
Refrigeration	2,821	3.5%	00	0.0%	2,821	0.3%
SMT	2,418	3.0%	23,116	3.0%	25,534	2.3%
Steam	00	0.0%	38,526	5.0%	38,526	3.5%
Ventilation	806	1.0%	00	0.0%	806	0.1%
Total Savings	**21,886**	**27.2%**	**196,485**	**25.5%**	**218,370**	**19.8%**

Table 56 Sector Carbon Savings

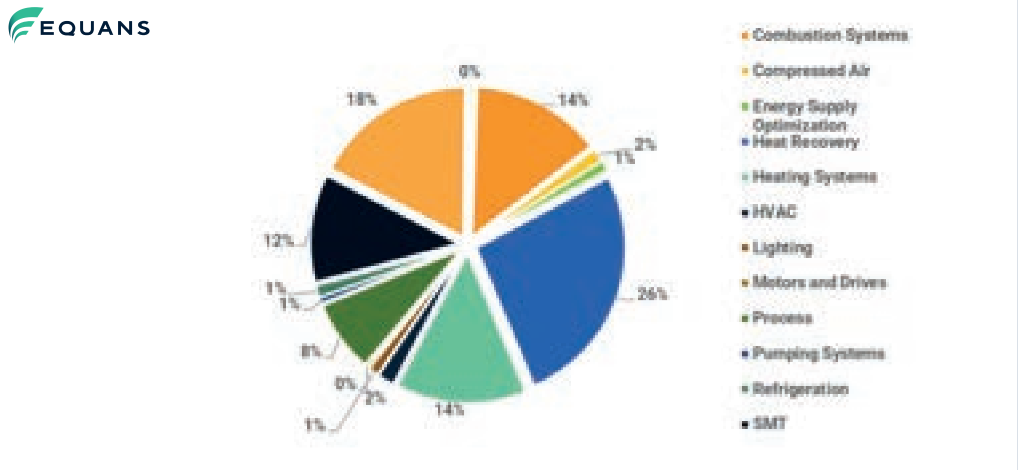

Figure 73 Chemical Sector Carbon Savings (teCO2e)

Like other sectors within North West England and North East Wales, this sector has significant energy saving opportunities with emissions reductions of 20%.

This sector has further decarbonisation opportunities via switching fuel (e.g., green hydrogen, electrification, etc.) considering the fuel combustion within the process, which is discussed in detail in later sections.

6.5.2 Energy Efficiency Opportunities

Driven by the need to minimise energy costs to maintain competitiveness (as a trade exposed energy intensive industry) and by climate regulations like the EU ETS, the sector has already taken significant steps to improve its energy efficiency and reduce its carbon emissions. Despite being a highly energy intensive sector due to the thermodynamics of chemical processes, the sector has reduced its GHG emissions by 70% in the last 20 years. It is the default position within the sector to identify whether there are more environmentally sustainable products and processes it can use, providing they are also commercially viable and cost effective. (90) Several energy efficiency reports including ESOS Phase 2 were analysed for energy efficiency opportunities identified within this sector. Identified savings are extrapolated to estimate the total potential savings for this sector within North West England and North East Wales. The table below depicts the extrapolated savings.

	Electricity		**Natural Gas**				
Technology	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
Combustion Systems	00	00	167,643	3,855,785	3,855,785	15,883,339	4.1
Compressed Air	12,613	1,362,159	00	00	1,362,159	4,620,744	3.4
Energy Supply Optimization	9,459	1,021,619	00	00	1,021,619	4,413,045	4.3
Heat Recovery	-219	-23,649	314,330	7,229,596	7,205,947	28,006,225	3.9
Heating Systems	00	00	167,643	3,855,785	3,855,785	19,665,838	5.1
HVAC	15,766	1,702,699	00	00	1,702,699	3,800,270	2.2
Lighting	9,459	1,021,619	00	00	1,021,619	3,448,979	3.4
Motors and Drives	3,153	340,540	00	00	340,540	1,063,926	3.1
Process	6,306	681,080	83,821	1,927,892	2,608,972	10,327,149	4.0
Pumping Systems	5,438	587,287	00	00	587,287	1,615,302	2.8
Refrigeration	11,036	1,191,889	00	00	1,191,889	4,475,818	3.8
SMT	9,459	1,021,619	125,732	2,891,839	3,913,458	6,842,262	1.7
Steam	00	00	209,554	4,819,731	4,819,731	17,800,078	3.7
Ventilation	3,153	340,540	00	00	340,540	899,923	2.6
Total Savings	**85,624**	**9,247,402**	**1,068,723**	**24,580,628**	**33,828,029**	**122,862,899**	**3.6**

Table 55 Sector Energy savings, Investment & Payback

6.5.1 Energy Consumption

It is estimated that in 2012 the sector emitted 18.4 million tonnes of CO_2, making it the UK's second highest industrial emitter. The sector also consumed 16.5% of all industrial energy used in the UK. 11.2m tonnes of these emissions were direct, primarily from fuel combustion with chemical processes making up the rest, and 7.2m tonnes were from indirect emissions e.g. from grid electricity (90).

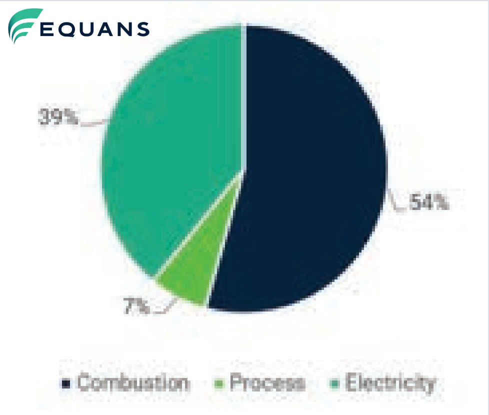

Figure 70 UK Chemical Sector Emissions 2012

Total estimated energy consumption for this sector is 82,561 GWh with the following split between electricity and combustible fuels (in this case it has been assumed to be gas).

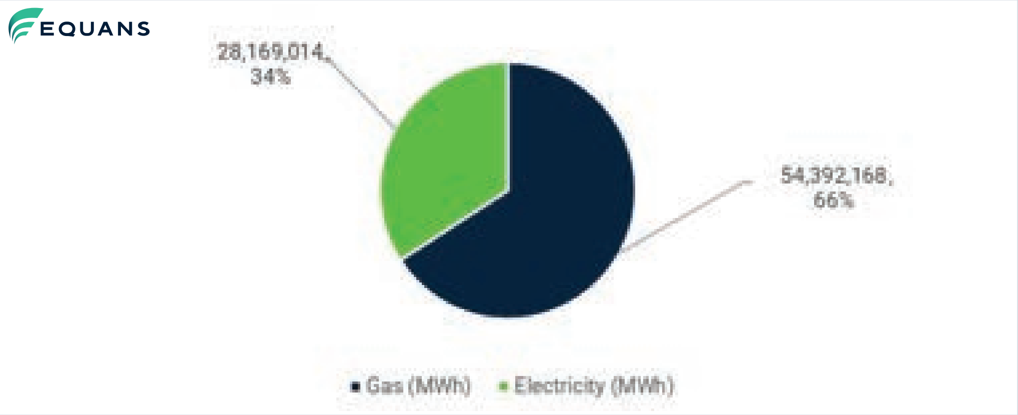

Figure 71 UK Chemical Sector Energy Consumption 2012

There are eight chemical manufacturing factories within the scope of this report. Total energy consumption for the Chemical sector in North West England and North East Wales is shown below.

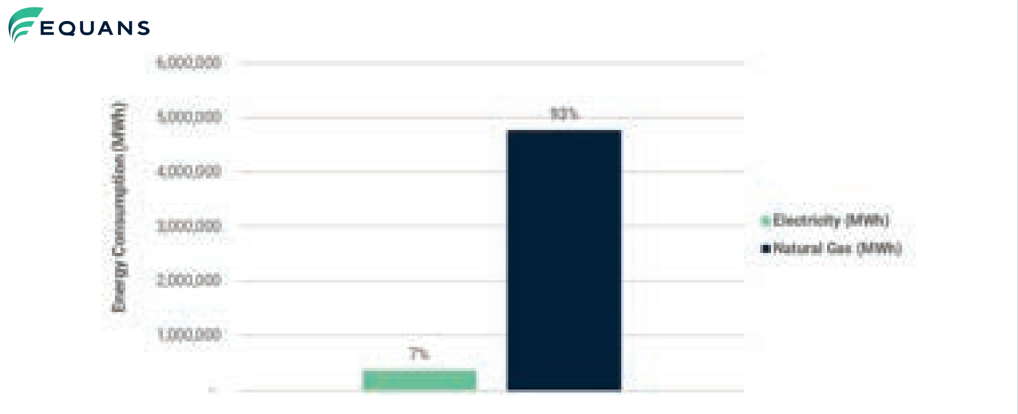

Figure 72 Chemical Sector Energy Consumption

Total energy consumption for the Chemical sector is estimated to be 4,506,385 MWh with total carbon emissions of 851,123 $teCO_2e$.

- This stage produces more carbon dioxide gas which is recycled to join the carbon dioxide stream produced by the burnt limestone. The solution left over after the reaction when the crystals have been filtered is heated to recover the ammonia, which is then recycled to treat the fresh salt solution coming into the process.

- The output of this process is a low-density soda ash (light ash). This is sold to industrial customers for use in a range of applications. Some of the product is also redissolved, recrystallised and dried to form a high-density ash (heavy ash).

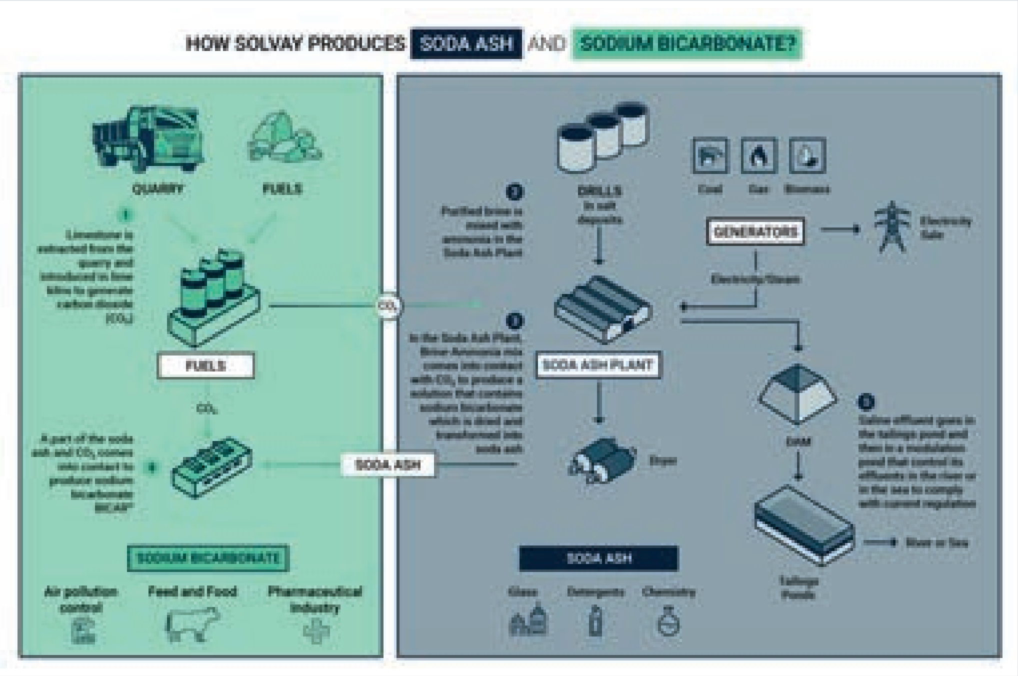

Figure 69 Soda Ash process flow (66)

Therefore, when low carbon technologies and renewable sources are implemented, the site will already be the most efficient it can be. It is assumed that UK electricity grid will be carbon free by 2035 as stated by UK Government.

Figure 68 is a bubble chart for the opportunities identified above. The size of the bubbles coincides with the amount CO_2e saved. This chart demonstrates the relative cost effectiveness of each opportunity to reduce carbon. This chart can help prioritise opportunities with the ones in the bottom right quadrant of the graph with larger bubble size will have the greatest return on investment with the largest CO_2e savings. This shows that the heat recovery and heating systems opportunities would be the most beneficial to implement.

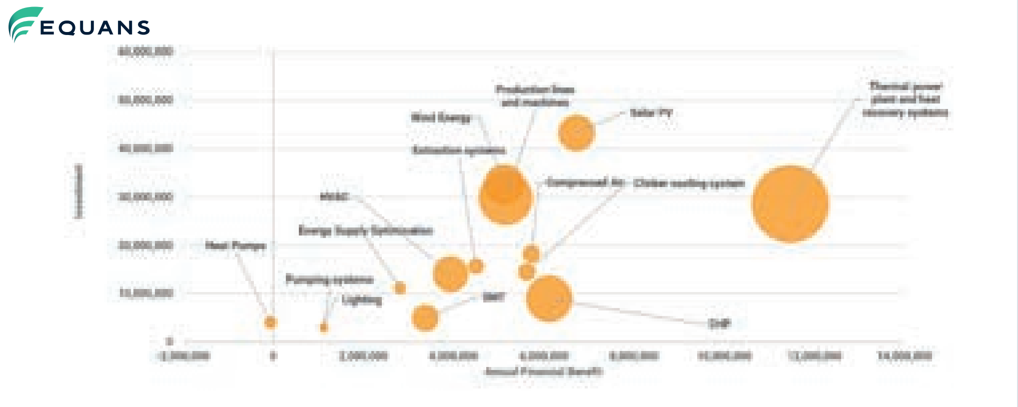

Figure 68 Cement Sector Opportunities Bubble Chart

It should be noted that above bubble chart does not include decarbonisation technologies/opportunities like conversion, procurement of renewable electricity, procurement of hydrogen or green gas and CCS as they have no payback.

6.5 Chemical

The UK's chemical sector is a significant pillar of the economy bringing £18 billion of Gross Value Added (GVA) on a turnover of £55.5 billion. It employs over 150,000 people in regions of the UK targeted for growth, including South Wales, North West England, North East England, Humber Bank and Scotland (86). With some 3,600 businesses across the UK rooted in science and innovation, the sector represents 21% of total UK research and development spend. The industry is the cornerstone of advanced manufacturing (87). The Chemical sector is a foundation industry that is at the heart of UK manufacturing with chemistry and chemicals helping to ensure clean water, sufficient food, clean energy, and many other essentials with 96% of all UK manufactured goods containing chemical industry content (86). The sector has continued operations throughout the pandemic, in many cases repurposing production lines across the UK to help tackle COVID-19 challenges including the production of personal protection equipment (PPE) and hand sanitiser.

The range of chemical outputs is broad, including basic chemicals and materials such as chlorine, fertilisers and plastics, as well as chemical products including agrochemical, personal care, paints and coatings, and catalysts (88).

The Chemical sector expenditure of £5.4 billion on research and development to commercialise sustainable innovations with business investment of £4.6 billion (86). Much of this industry is well placed to deliver decarbonisation technologies such as hydrogen and carbon capture, use and storage, thus making the sector central to decarbonising the industry at large and delivering low carbon benefits to society.

Below is a typical example process for making Synthetic Soda Ash, which is a demonstration of a high energy use process in this sector (89):

- The synthetic soda ash process requires raw materials to produce both light and heavy soda ash. This includes salt, limestone, water, coke, ammonia, heat, and electricity.

- The Solvay Process is a continuous process which is used to turn salt and limestone into sodium carbonate. First, the limestone is burned to produce carbon dioxide which bubbled through a salt solution which has been pre-treated with ammonia. The resulting reaction produces sodium bicarbonate crystals which are filtered from the reacted solution. These are then heated to form sodium carbonate product.

6.4.5 Sector Roadmap

Based on the technologies discussed above, a pathway to net zero for the region's Cement sector has been proposed.

Figure 66 shows the waterfall diagram. Most of the carbon reduction is through energy conservation measures as with all the opportunities stated above the sector can reduce the carbon emissions by 21%.

Figure 66 Cement Sector Carbon Waterfall

For net zero, total CAPEX has been estimated at **£224,186,183** with a financial benefit of **£56,639,715**, giving a simple payback of **4.0** years. There is no CAPEX and therefore no payback against green electricity procurement and green hydrogen procurement as it is assumed that grid will be decarbonised by 2035 and green hydrogen will cost same as natural gas.

Figure 67 is an indication of when these opportunities can be implemented to achieve a carbon neutral position. It is assumed that energy efficiency opportunities will be prioritised and implemented in a 5-year interval. The total implementation of the energy efficiency opportunities will help to define a new energy consumption profile for the site.

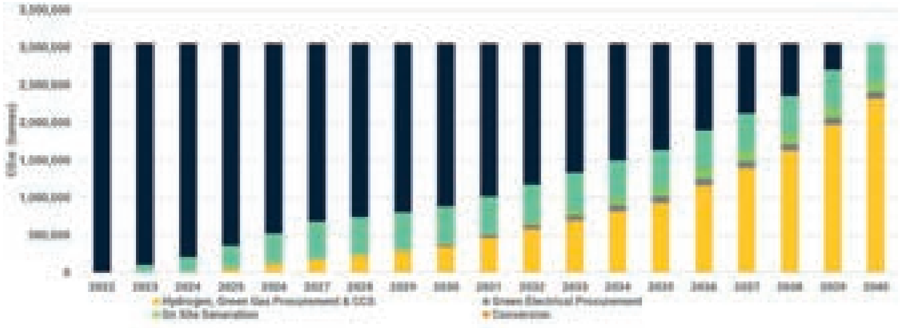

Figure 67 Cement Sector Carbon Neutral Delivery Plan

6.4.4 On-Site Generation

6.4.4.1 Wind Energy

Wind energy generation can offer savings to the whole of the region regardless of sector. The overall savings from wind energy generation in North West England and North East Wales is applied as a ratio to the total emissions from the Cement sector to estimate sector specific savings.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
3,057,649	2.79%	85,330	6,283,649	40,034,763	6.4

Table 53 Cement wind energy saving

6.4.4.2 Solar PV

Solar PV energy generation can offer savings to whole of North West England and North East Wales regardless of sector. The overall savings from solar PV energy generation in the region is applied as a ratio to the total emissions from Cement sector to estimate sector specific savings. Table 54 Cement Solar PV savings

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
3,057,649	2.23%	68,057	8,238,799	53,061,346	6.4

Table 54 Cement Solar PV savings

6.4.4.3 Anaerobic Digestion

Anaerobic digestion is applicable for sectors that produce organic waste and requires treatment or disposal. Therefore, AD is not applicable for the Cement sector.

6.4.4.4 Waste Heat reuse

The cement sector can utilise heat recovery systems to improve their energy efficiency and save 251,624 tCO_2e every year which amounts to just under 10% of sector emissions. Heat recovery savings are estimated for the whole sector. Further investigation is required to assess the viability of waste heat recovery systems at each site due to various criteria such as site-specific processes, use of heat on site, and existing heat recovery systems. Waste heat utilisation may be appropriate for various applications such as improving the efficiency of a certain process, generating electricity through organic Rankine cycle or recuperating waste heat to be used as a heat source in a heat network.

6.4.3.2 Heat Pump

Heat pump technology can offer savings to the whole of the North West England and North East Wales regardless of sector. These savings are shown in the tables and figures below.

High Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/ yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
2,334,543	5,508,497	7,344,663	753.61	2.36	763.9	82%	-£78,534

Table 51 Cement Heat Pump High Temperature Data

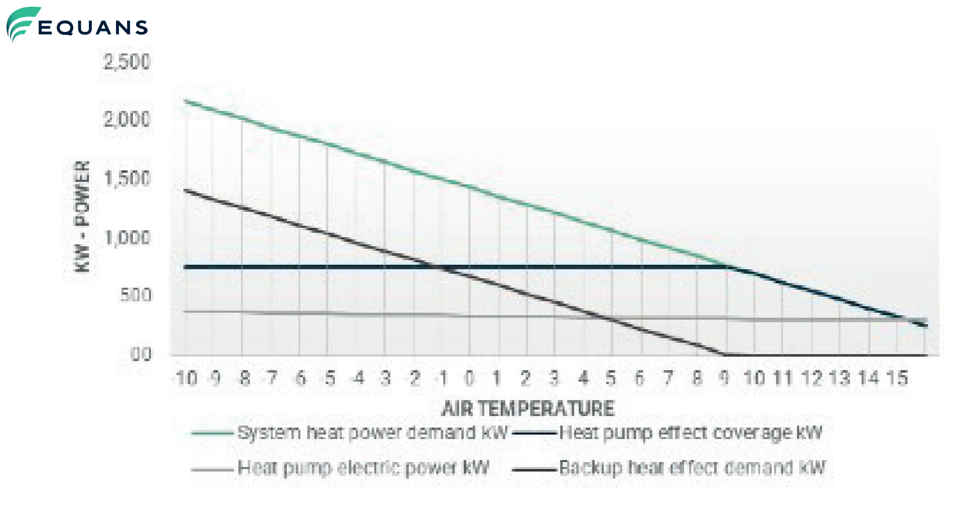

Figure 64 Cement Heat Pump High Temperature Operation Profile

Low Temp							
Electrical Increase Requirement per/yr kWh	**Thermal Output per/ yr - kWh**	**Gas Reduction Per/Year kWh**	**Carbon Saving (te) Per Year**	**SCOP**	**Duty of Uni Selected kW at 12°C**	**100% Operation Percentage for Year**	**Financial Savings per/Yr**
1,919,610	6,320,753	8,427,671	1058.77	3.29	1249.3	67%	-£9,642

Table 52 Cement Heat Pump Low Temperature Data

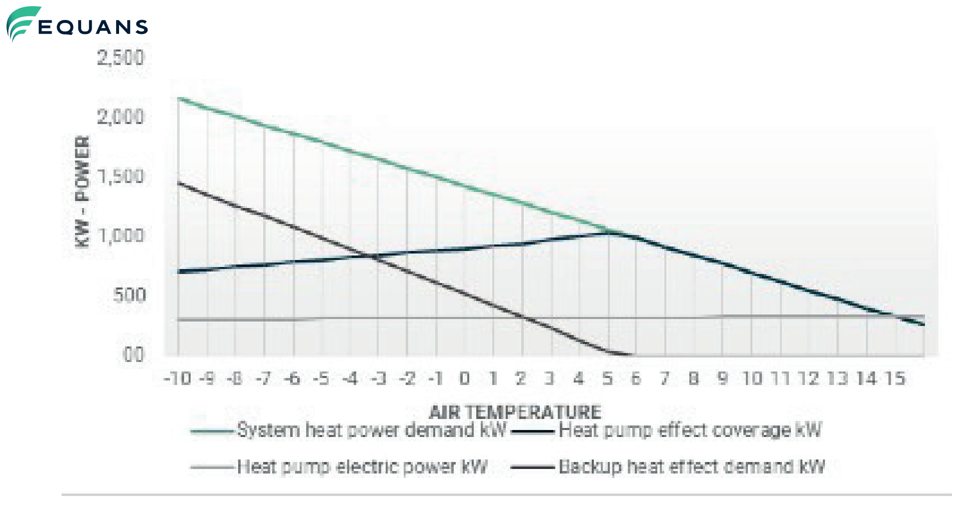

Figure 65 Cement Heat Pump Low Temperature Operation Profile

6.4.3 Low Carbon Technologies

6.4.3.1 CHP

Typical processes within the cement industry require thermal energy for the baking process of clay within kilns. Research has been conducted in electrification to reduce the carbon requirement in this type of high temperature applications. With review of a typical cement process, it is clear the consistency of the system is inadequate to justify the installation of a CHP. This is partly due to intermittent operation of equipment requiring electricity with large swings in demand. This can be seen from the load duration curve in Figure 63.

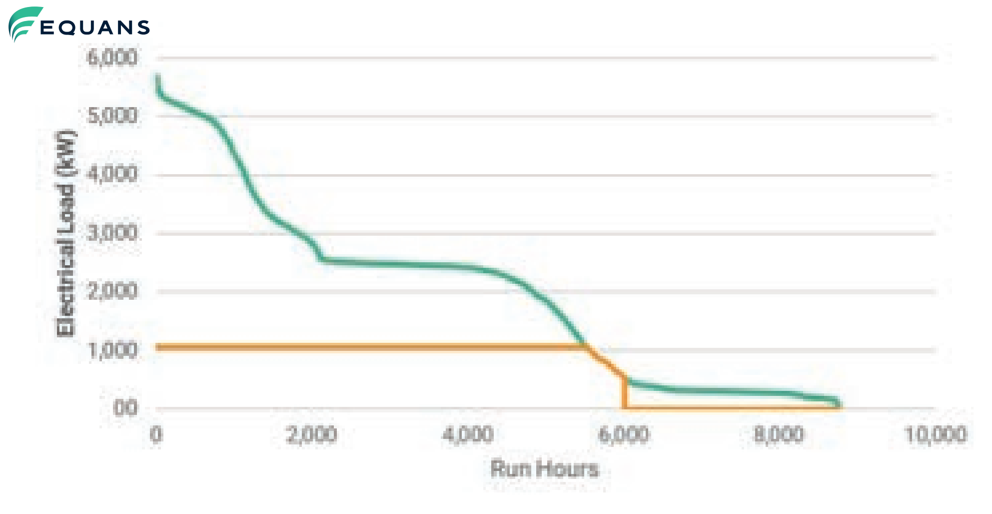

Figure 63 CHP Cement Industry Load Duration Curve

Processes which include MIDAR technology, which is an aqueous process requiring heat <100°C, are now starting to be introduced into the industry. This could introduce the requirement for lower grade heat and pre-heating processes systems, with further opportunities for processes specific systems requiring much lower temperatures.

Current Emissions for Sector Avg T/Yr	New Emissions with CO_2 Offset T/Yr	Existing Gas Usage for Sector Avg kWh	Gas increase Natural Gas Engine kWh	Carbon Saving (te) p/a	Comparison of gas increase	Gas Engine input	Increased OPEX (£)
3,057,649	3,057,296	68,973,565	82,901,554	353	20%	3,057,649	9,211,139

Table 49 Cement CHP data

Indictive CapEx Cost + 1st Yr Service	Electrical cost reduction	Savings per Year	Approx. Payback Years	Electrical Utilisation	Thermal Utilisation
£1,815,000	£633,338	£371,294.3	4.07	99%	98%

Table 50 Cement CHP financial data

	Electricity		Coal		Total Carbon Savings	
Technology	**Carbon (te)**	**%**	**Carbon (te)**	**%**	**Carbon (te)**	**%**
Compressed Air	13,313	4.1%	00	0.0%	13,313	0.4%
Thermal power plant and heat recovery systems	26,625	8.3%	224,999	10.0%	251,624	8.2%
Production lines and machines	11,981	3.7%	112,500	5.0%	124,481	4.1%
Energy Supply Optimisation	6,656	2.1%	00	0.0%	6,656	0.2%
Pumping systems	2,663	0.8%	00	0.0%	2,663	0.1%
Extraction systems	10,650	3.3%	00	0.0%	10,650	0.3%
Clinker cooling system	13,313	4.1%	00	0.0%	13,313	0.4%
Lighting	2,663	0.8%	00	0.0%	2,663	0.1%
HVAC	9,319	2.9%	45,000	2.0%	54,319	1.8%
SMT	7,988	2.5%	22,500	1.0%	30,487	1.0%
Total Savings	**105,169**	**33%**	**404,998**	**18.0%**	**510,167**	**16.7%**

Table 48 Sector Carbon Savings

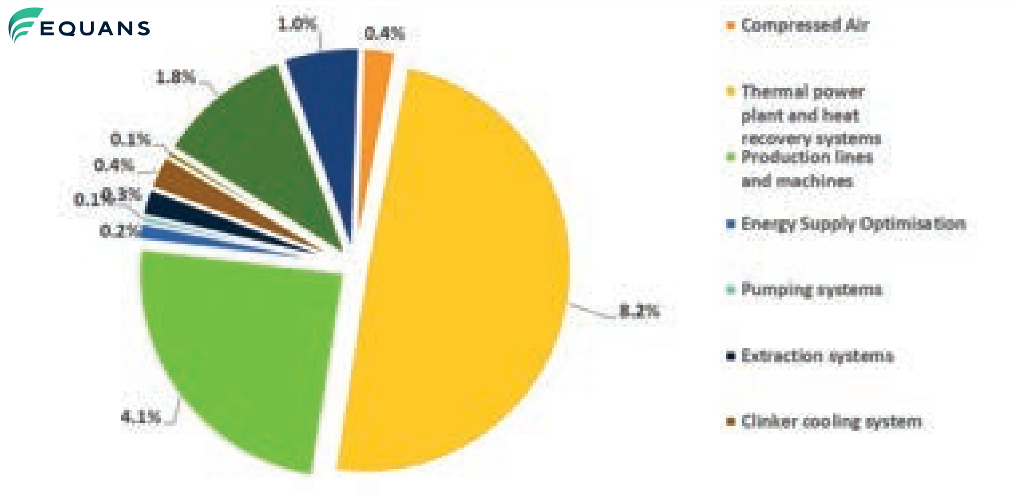

Figure 62 Cement Carbon Savings (teCO2e)

The Cement sector is comparable to other sectors within the North West England and North East Wales region. This sector has significant energy saving opportunities with potential emissions reductions of 17% and further decarbonisation opportunities via switching fuel (e.g. green hydrogen, electrification, etc.) considering the fuel combustion within the process, which is discussed in detail in later sections.

There are six cement factories within the scope of this report. This was used to derive a representative example of the total consumption of cement in North West England and North East Wales, shown below.

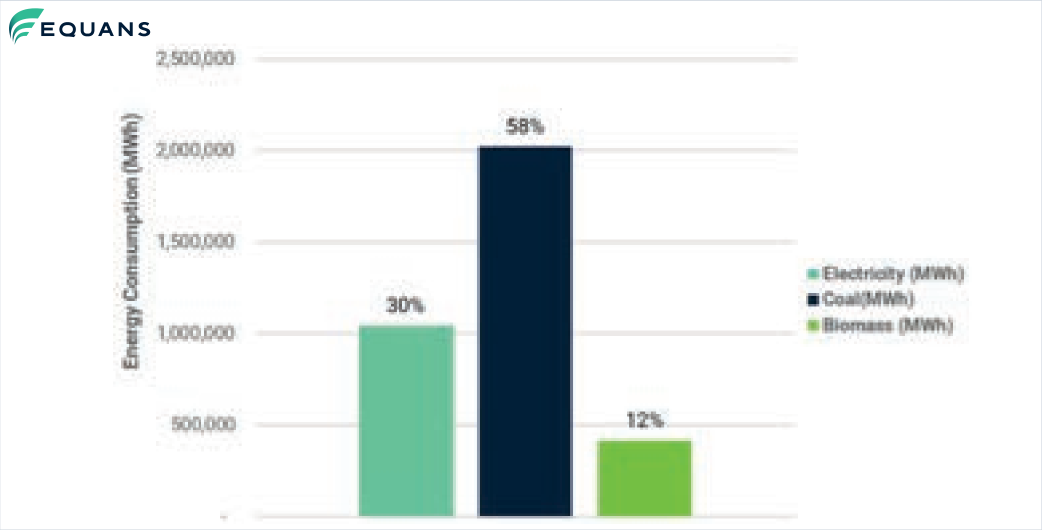

Figure 61 Cement Sector Energy Consumption

Electricity consumption has been estimated from average electricity consumption per site in the UK due to unavailability of data.

6.4.2 Energy Efficiency Opportunities

Like other energy intensive processes, this sector has considerable energy savings opportunities that can help this sector to minimise existing carbon emissions, paving the way for net zero.

The following listed energy savings opportunities have been taken from different published reports, including ESOS, for this sector, therefore, the following is not exhaustive.

	Electricity		Coal				
Technology	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
Compressed Air	52,083	5,729,167	00	00	5,729,167	18,333,333	3.2
Thermal power plant and heat recovery systems	104,167	11,458,333	678,055	00	11,458,333	28,645,833	2.5
Production lines and machines	46,875	5,156,250	339,028	00	5,156,250	29,906,250	5.8
Energy Supply Optimisation	26,042	2,812,500	00	00	2,812,500	11,250,000	4.0
Pumping systems	10,417	1,125,000	00	00	1,125,000	2,925,000	2.6
Extraction systems	41,667	4,500,000	00	00	4,500,000	15,750,000	3.5
Clinker cooling system	52,083	5,625,000	00	00	5,625,000	14,625,000	2.6
Lighting	10,417	1,125,000	00	00	1,125,000	3,375,000	3.0
HVAC	36,458	3,937,500	135,611	00	3,937,500	14,175,000	3.6
SMT	31,250	3,375,000	67,806	00	3,375,000	5,062,500	1.5
Total	**411,458**	**44,843,750**	**1,220,499**	**00**	**44,843,750**	**144,047,917**	**3.2**

Table 47 Sector Energy savings, Investment and Payback

6.4 Cement

Cement is used to bind fine sand and coarse aggregates together in concrete. It is a hydraulic binder, meaning it hardens when water is added which acts as a glue to the concrete mixture (80). Cement is a key ingredient in both concrete and mortar and is always mixed with other materials before use.

A typical cement making process is shown below.

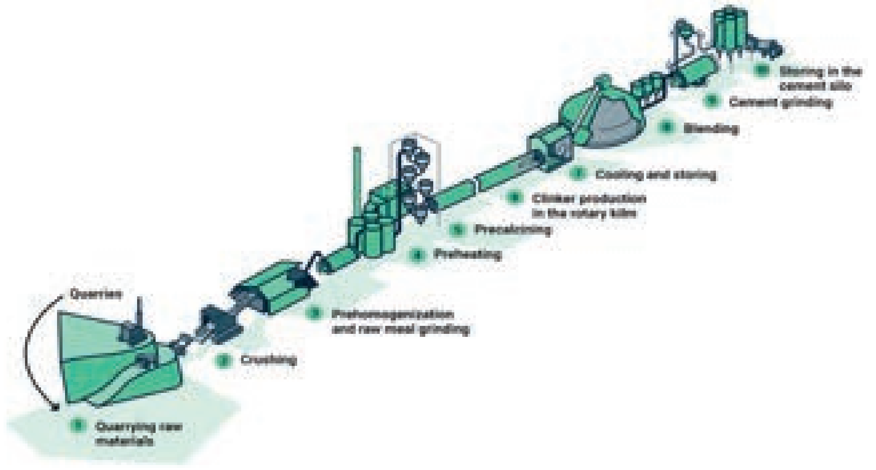

Figure 60 Cement industry process flow (64)

The cement-making process essentially has two main aspects (81):

1. **Steps 1 – 6** above: After the quarrying and processing of the raw materials, clinker (the main constituent of cement) is made in a kiln. The kiln heats raw materials such as limestone (calcium carbonate) with small quantities of other materials (e.g., clay) to 1,450°C. During the process known as calcination, the calcium carbonate (limestone) is transformed into calcium oxide (lime), which then reacts with the other constituents from the raw material to form new minerals, collectively called clinker. This near-molten material is rapidly cooled to a temperature of 100 - 200°C.

2. **Steps 7 – 10** above: Clinker is then ground with gypsum and other materials to produce the grey powder known as cement.

6.4.1 Energy Consupmtion

The average power consumption for cement manufacturing per tonne of cement in 2012 was measured at 110 kWh/t of cement (82).

The cement industry is energy-intensive, mainly because of the fuel requirements of kilns. Wet processes and long dry kilns tend to use more energy, and the phasing out of these processes is a major factor behind the improvements to kiln energy efficiency which have been made since the 1960s. This progress has levelled off since 1990, but the commissioning of new kilns in recent years is expected to restart the improvements in this sector (83).

The predominant fuels used in the UK cement sector are coal and petroleum coke. The UK concrete and cement sector currently account for approximately 1.5% of UK carbon dioxide emissions, five times lower than the global average where cement accounts for around 7% of emissions. Early action by the UK concrete and cement industry has resulted in emissions already being 53% lower than 1990 (84).

'Process emissions' from clinker production make up the largest proportion of UK carbon dioxide emissions from concrete and cement, contributing 4.4. million of a total 7.3 million tonnes of sector carbon dioxide emissions in 2018. Carbon dioxide is a by-product of a chemical conversion process used in the production of clinker, in which limestone ($CaCO_3$) is converted to lime (CaO) (85). In 2018, 2.2 million tonnes were also generated from fuel combustion and the remainder from electricity use and transport (84).

The process emissions for the North West England and North East Wales Cement sector are 2,058,004 $teCO_2e$.

This is an indication of when these opportunities can be implemented to achieve a carbon neutral position. It is assumed that energy efficiency opportunities will be prioritised and implemented in a 5-year interval. The total implementation of the energy efficiency opportunities will help to define a new energy consumption profile for the site. Therefore, when low carbon technologies and renewable sources are implemented, the site will be at optimal efficiency. It is assumed that UK electricity grid will be carbon free by 2035 as stated by UK Government.

Figure 59 shows a bubble chart for the opportunities identified above, the size of the bubbles coincides with the amount CO_2e saved. This chart demonstrates the relative cost effectiveness of each energy reduction opportunity to reduce carbon. This chart can help prioritise opportunities with the ones in the bottom right quadrant of the graph with larger bubble size will have the greatest return on investment with the largest CO_2e savings.

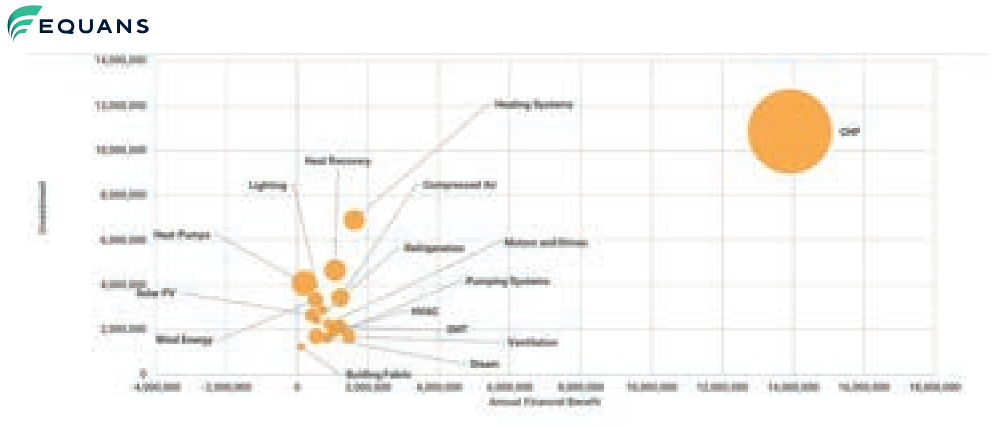

Figure 59 Automotive Sector Opportunities Bubble Chart

It should be noted that the above bubble chart does not include decarbonisation technologies/opportunities like conversion, procurement of renewable electricity, procurement of hydrogen or green gas and CCS, as these opportunities have no payback.

6.3.4.3 Anaerobic Digestion

Anaerobic digestion is applicable for sectors that produce organic waste and requires treatment or disposal. Therefore, AD is not applicable for the automotive sector.

6.3.4.4 Waste Heat reuse

The Automotive sector can utilise heat recovery systems to improve their energy efficiency and save 8,484 tCO_2e every year which amounts to 5.5% of sector emissions. Heat recovery savings are estimated for the whole sector.

Further investigation is required to assess the viability of waste heat recovery systems at each site due to various criteria such as site-specific processes, use of heat on site, and existing heat recovery systems.

Waste heat utilisation may be appropriate for various applications such as improving the efficiency of a certain process, generating electricity through organic Rankine cycle or recuperating waste heat to be used as a heat source in a heat network.

Emission savings for the automotive sector is estimated as an energy efficiency measure excluding energy generation from organic Rankine cycle.

6.3.5 Sector Roadmap

Based on the technologies discussed above, a pathway to net zero for the North West England and North East Wales Automotive sector is proposed below. Most of the carbon reduction is through energy conservation measures as with all the opportunities stated above the sector can reduce the carbon emissions by 29.3%.

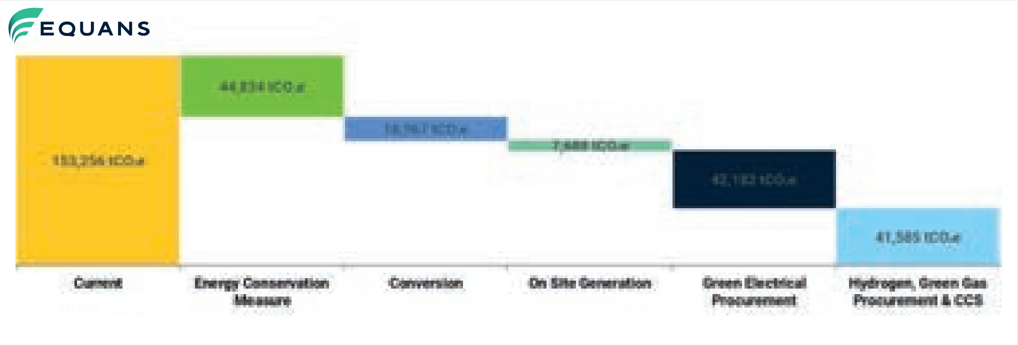

Figure 57 Automotive Sector Carbon Waterfall

For net zero, total CAPEX has been estimated at **£42,986,965** with a financial benefit of **£12,251,487**, giving a simple payback of **3.5 years**. There is no CAPEX and therefore no payback against green electricity procurement and green hydrogen procurement as it is assumed that grid will be decarbonised by 2035 and green hydrogen will cost same as natural gas.

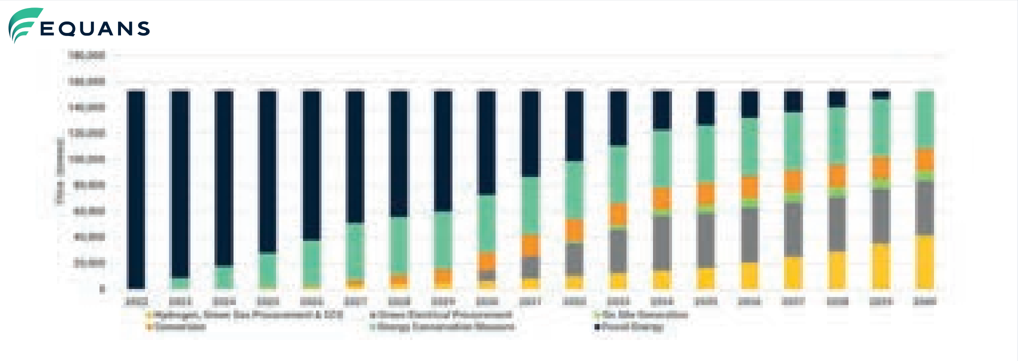

Figure 58 Automotive Sector Carbon Neutral Delivery Plan

Current Technology	Commercially available electric alternatives
Space Heating	Electric Heater, Electric Infra-Red Heaters, Heat pumps
Process Heating	Electric Process Heater, Electric Plasma Gas Heaters Microwave Heaters
Drying Ovens	Electric Infra-Red Ovens Electric ceramic

Table 43 Electrification solutions per heating system

Estimated Electrical Consumption (GWh)	Estimated Gas Consumption (GWh)	Total Emissions (t CO_2e)	Electrical Increase Requirement per/yr (GWh)*	Gas Reduction Per/Year (GWh)	Carbon Saving (te) Per Year**	Estimated CAPEX (£)	Increased OPEX (£)
26,768,388	46,144,139	153,256	7383062	18,457,656	33,934	26,509,661	9,211,139

Table 44 Estimated CAPEX and OPEX for electrification of the automotive industry in North West England and North East Wales

6.3.4 On-Site Generation

6.3.4.1 Wind Energy

Wind generated energy can offer savings to the whole of North West England and North East Wales regardless of sector. The overall savings from wind energy generation in the region is applied as a ratio to the total emissions from the Automotive sector so to estimate sector specific savings. Whilst wind energy often has various barriers to implementation due to planning and spatial requirements a direct wire solution is often a cheaper alternative to offsite Power Purchase Agreements due to network costs. The results are illustrated in Table 45.

6.3.4.2 Solar PV

Solar PV energy generation can also offer savings the whole of North West England and North East Wales regardless of sector. The overall savings from solar PV energy generation in the region is applied as a ratio to the total emissions from the Automotive sector to estimate sector specific savings. The results are illustrated below in Table 46.

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
153,256	2.79%	4,277	314,950	2,006,626	6.4

Table 45 Automotive wind energy saving

Sector Emissions (tCO_2e)	Estimated Sector Emissions Savings (%)	Estimated Sector Emissions Savings (tCO_2e)	Financial Benefit (£)	Estimated capital cost (£)	Estimated Payback (Years)
153,256	2.23	3,411	412,946	2,659,549	6.4

Table 46 Automotive solar PV savings

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* Assumed a 20% increase in efficiency with the new equipment **Assumed the increased electricity is from a renewable source

Due to the consistent thermal and electrical loads based on the data applied it would suggest that the installation of a CHP system would be rewarding for an automotive manufacturer. This is shown within the short payback term for the sector as the thermal and electrical energy can be fully utilised throughout the year. A HP installation would present a strong saving if a low temperature model were to be implemented into an existing process or heating system. Due to the nature of the sector and the temperature of the processes used, the low temperature model would work best if installed as a pre-heat for a boiler.

An additional review of the potential for a site to electrify its thermal process was conducted. This review does not consider the other operational parameters above and only looks to cover 100% of the thermal requirement. This can provide an indictive cost per kg of CO_2 produced by that sector, which can be carried out by the site if the scope 1 emissions are known. Only scope 1 emissions can be calculated as this figure for the industrial site accounts for direct emissions for thermal energy generation.

Scope 1 Industry Avg Emissions Tons/CO_2	Cost per kg CO_2	Percentage of Scope 1 Emissions being Electrified
16,967	£5.0918	24.55%

Table 42 Scope 1 emissions

6.3.3.3 Electrification

For the automotive industry the primary focus in decarbonisation is to decarbonise the fuel not the vehicle, electrification plays a key role in this.

Heat is used in several ways in the automotive industry from curing tyres to annealing steel to heating wash water. The industry requires heat in many forms at different temperatures, therefore as with the other examples it is not a case of electrifying all the processes but evaluating each process and creating a bespoke solution.

As shown in the figure below over half the Natural gas consumption is through a HPHW and the remaining natural gas used is in process. With current technology it is possible to electrify most of the demand. Table 43 shows the alternatives that are commercially available. Although it is possible to electrify the processes it does not necessarily mean it is the best option, as stated above electrification is part of, but not the only, solution. A potential solution could include electrification and heat recovery with heat pumps to satisfy HPHW and another alternative to satisfy the direct fired process gas. In this example electrification would satisfy half of the heat demand and there would be no major change or disruption to the process or production.

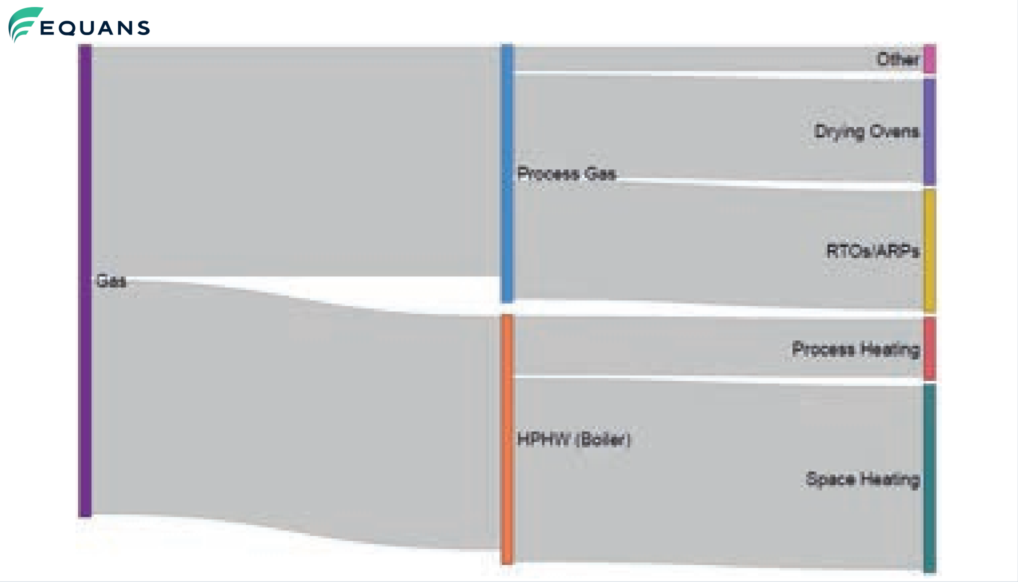

Figure 56 Automotive industry heat breakdown

6.3.3.2 Heat Pumps

The review of HP integration into an automotive site is shown in Table 40 and 41. The analysis included a high and low temperature model, as detailed previously within section 4.3.2 the choice between either of these models is dependent on the site and its processes. Based on the thermal energy data for the automotive sector, it was found that due to the vast difference in load from minimum to maximum the HP selected would only support a small portion of the load.

The figures illustrate where the HP will satisfy the thermal load entirely when the system heat demand line meets the heat pump effect coverage line. When comparing between the two, there is a significant benefit with the lower temperature model with a greater financial and carbon saving (based on the current market). The difference between the financial savings is derived from the large difference between the site demand, presenting the opportunity for a large HP to run at 100% output for nearly 90% of the year.

High Temp

Electrical Increase Requirement per/yr kWh	Thermal Output per/ yr - kWh	Gas Reduction Per/Year kWh	Carbon Saving (te) Per Year	SCOP	Duty of Uni Selected kW at 12°C	100% Operation Percentage for Year	Financial Savings per/ Yr
4,928,472	11,650,256	15,533,675	1596.15	2.36	2 x 763.9	87%	-£175,000

Table 40 Automotive Heat Pump High Temperature Data

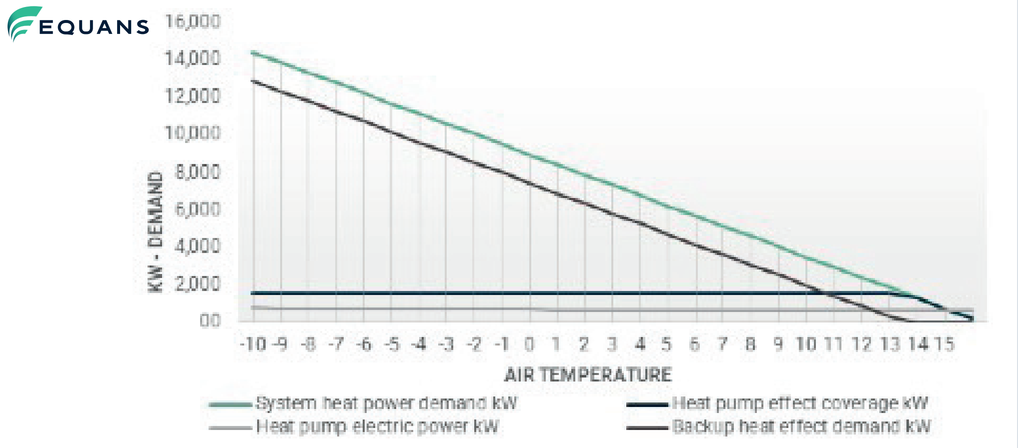

Figure 54 Automotive Heat Pump High Temperature Operation Profile

Low Temp

Electrical Increase Requirement per/yr kWh	Thermal Output per/ yr - kWh	Gas Reduction Per/Year kWh	Carbon Saving (te) Per Year	SCOP	Duty of Uni Selected kW at 12°C	100% Operation Percentage for Year	Financial Savings per/ Yr
3,252,634	12,723,939	16,965,252	2287.69	3.91	1928.4	85%	£38,916

Table 41 Automotive Heat Pump Low Temperature Data

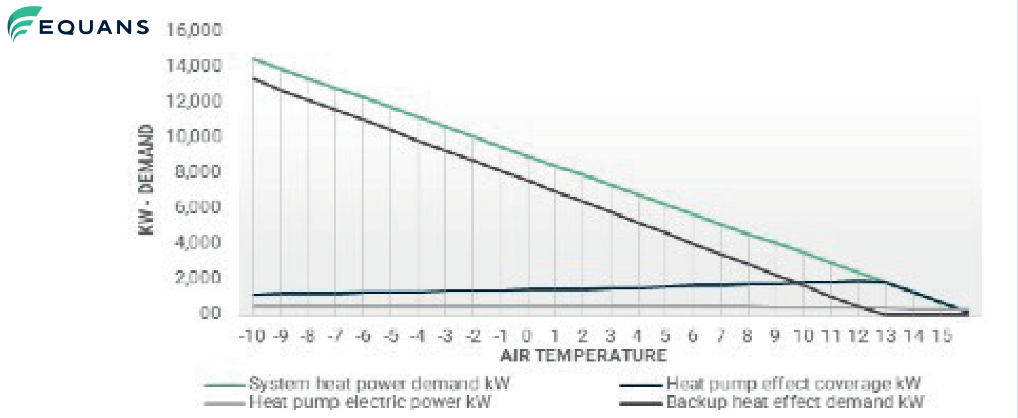

Figure 55 Automotive Heat Pump Low Temperature Operation Profile

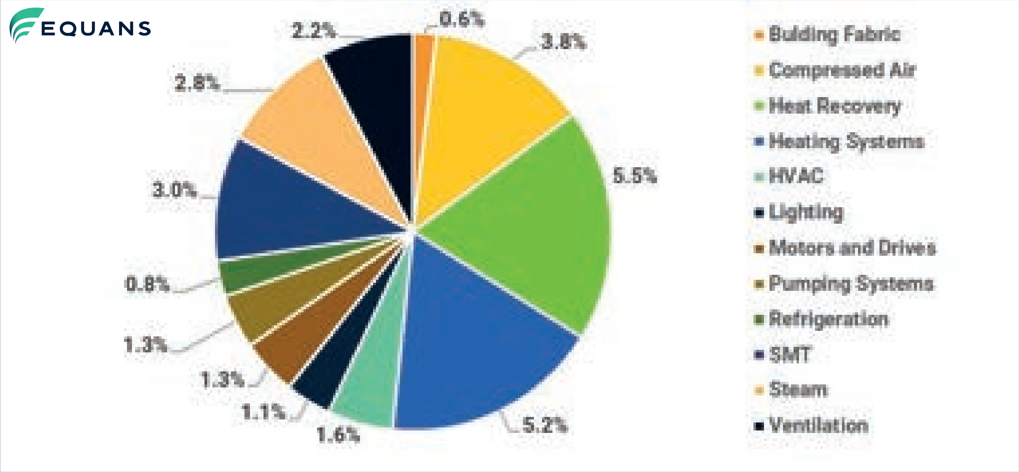

Figure 53 Automotive Carbon Savings (teCO2e)

The above graph shows the energy and carbon savings opportunities identified compared to total energy and carbon for the sector. Heat recovery, heating systems, compressed air system and SMT followed by steam are the large carbon saving projects with slightly higher payback periods than other low-cost energy saving measures. As these systems are energy intensive energy the potential of savings is higher. It would be ideal to start with the SMT opportunity and then depending on the available funding, low or high CAPEX projects can be implemented. SMT would enable confirmation of the savings post implementation and can even provide more accurate data before implementation.

6.3.3 LOW CARBON TECHNOLOGIES

6.3.3.1 CHP

The automotive industry is a significant energy consumer for both electrical and thermal energy. It has been highlighted with this industry the use of certain processes such as high-pressure hot water (HPHW) systems throughout manufacturing, with emphasis made to move away from this type of system due to recent space heating and processing technologies not requiring such high temperatures to achieve the design conditions. Therefore, this makes the automotive industry ideal for the application for a CHP system as this can be used to supplement both space heating and process systems.

The profile applied for the sector shows a flat consistent base load unaffected by seasonal changes. emphasising the requirement for a continuous thermal energy demand for the manufacturing process.

Review of electrical systems for the industry suggest a similar situation for the electrical consumption throughout the manufacturing process. It is commonplace for an automotive manufacturer to make use of machinery and robotics to conduct the bulk of the assembly of vehicles. This creates a higher demand for electrical consumption to the site allowing a CHP to alleviate the requirement of so much electrical energy to be imported from the grid.

Table 38 and Table 39 show a review of CHP technology integration within the automotive industry.

Current Emissions for Sector Avg T/Yr	New Emissions with CO_2 Offset T/Yr	Existing Gas Usage for Sector Avg kWh	Gas increase Natural Gas Engine kWh	Carbon Saving (te) p/a	Comparison of gas increase	Gas Engine input
153,256	152,241	92,288,027	138,939,864	1014.5	51%	46,651,837

Table 38 Automotive CHP data

Indictive CapEx Cost + 1st Yr Service	Electrical cost reduction	Savings per Year	Approx. Payback Years	Electrical Utilisation	Thermal Utilisation
£2,170,792	£2,189,867	£1,696,255.5	1.91	96%	91%

Table 39 Automotive CHP financial data

The table below shows the potential energy and carbon savings for Automotive sector with required investments and associated payback periods, this has been calculated by utilising existing energy efficiency reports such as ESOS.

	Electricity		**Natural Gas**				
Technology	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Energy Savings (MWh)**	**Fiscal Savings (£)**	**Total Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
Building Fabric	00	00	4,614	106,131	106,131	1,245,298	11.7
Compressed Air	6,316	682,116	23,072	530,656	1,212,772	3,431,989	2.8
Heat Recovery	00	00	46,144	1,061,312	1,061,312	4,658,038	4.4
Heating Systems	8,031	867,296	32,216	740,971	1,608,267	6,909,135	4.3
HVAC	9,369	1,011,845	00	00	1,011,845	1,909,992	1.9
Lighting	6,566	709,075	00	00	709,075	2,886,066	4.1
Motors and Drives	8,031	867,296	00	00	867,296	2,259,499	2.6
Pumping Systems	7,763	838,386	00	00	838,386	1,643,355	2.0
Refrigeration	5,086	549,287	00	00	549,287	2,420,958	4.4
SMT	8,031	867,296	13,843	318,394	1,185,690	2,124,927	1.8
Steam	00	00	23,072	530,656	530,656	1,711,014	3.2
Ventilation	13,384	1,445,493	00	00	1,445,493	1,702,200	1.2
Total Savings	**72,575**	**7,838,090**	**142,962**	**3,288,121**	**11,126,211**	**32,902,472**	**3.0**

Table 36 Sector Energy savings, Investment & Payback

With exception to building fabric improvements, the individual project payback periods are between 1 and 4.5 years. The overall payback period for all energy saving measures is 3 years which lies within the criteria of payback periods for most manufacturing industries.

	Electricity Savings		**Gas Savings**		**Total Carbon Savings**	
Technology	**Carbon (te)**	**(%)**	**Carbon (te)**	**%**	**Carbon (te)**	**%**
Building Fabric	0	0.0%	848	1.0%	848	0.6%
Compressed Air	1,614	2.4%	4,242	5.0%	5,856	3.8%
Heat Recovery	0	0.0%	8,484	10.0%	8,484	5.5%
Heating Systems	2,053	3.0%	5,923	7.0%	7,976	5.2%
HVAC	2,395	3.5%	0	0.0%	2,395	1.6%
Lighting	1,678	2.5%	0	0.0%	1,678	1.1%
Motors and Drives	2,053	3.0%	0	0.0%	2,053	1.3%
Pumping Systems	1,984	2.9%	0	0.0%	1,984	1.3%
Refrigeration	1,300	1.9%	0	0.0%	1,300	0.8%
SMT	2,053	3.0%	2,545	3.0%	4,598	3.0%
Steam	0	0.0%	4,242	5.0%	4,242	2.8%
Ventilation	3,421	5.0%	0	0.0%	3,421	2.2%
Total Savings	**18,550**	**27.1%**	**26,284**	**31.0%**	**44,834**	**29.3%**

Table 37 Sector Carbon Savings

6.3.1 Energy Consumption

In automotive manufacturing, energy is typically the second largest variable cost, after labour, and improving energy efficiency is therefore a key focus for the industry at the moment. A great deal has been invested into the implementation of various energy efficiency measures and energy per vehicle produced has decreased by 43.3% over the past 20 years, delivering a 23% reduction in 2017/18 versus 2008 in the Climate Change Agreements (CCA) and a 25% reduction in EU ETS emissions in 2019 versus 2013 (77).

The main energy types used on-site are electricity, steam, gas, and compressed air. Energy is used for many different types of end-uses in vehicle assembly facilities. Fuels are primarily used for space heating, steam applications and in the curing ovens of the painting lines, while some facilities may have casting facilities for engines or other parts onsite. Electricity is used throughout assembling facilities for a range of purposes, e.g., compressed air, metal forming, lighting, ventilation, painting (fans and infrared (IR) curing), materials handling and welding. Estimates of the distribution of energy use in vehicle assembly plants can vary among plants due to different processes being used in different facilities (78). The following graph shows the total energy consumption of this sector within North West England and North East Wales.

Total energy for the Automotive sector is estimated to be 729 GWh with total carbon emissions of 153,256 teCO_2e using EU ETS and NAEI data sets. The gas consumption is approximately two thirds of total energy consumption, indicating the application of combustion and heating for this sector.

The paint shop is by far the most energy intensive process with gas used in combustion for cure ovens and incinerators required as part of overall paint process.

Other gas users include steam boilers, hot water boilers, direct fired heaters for area heating (both for comfort heating and area requirements) and CHP for on-site power and heat generation.

6.3.2 Energy Efficiency Opportunities

In automotive manufacturing, energy consumption can vary depending on various factors such as the size of the cars being manufactured. The total energy assumption of a car manufacturing plant is determined by the operation system, energy efficiency management, HVAC system, etc. Optimisation of energy consumption is likely to reduce this rate. Real-time control of production systems is becoming more critical in improving system efficiency and responsiveness and in reducing breakdown period (79).

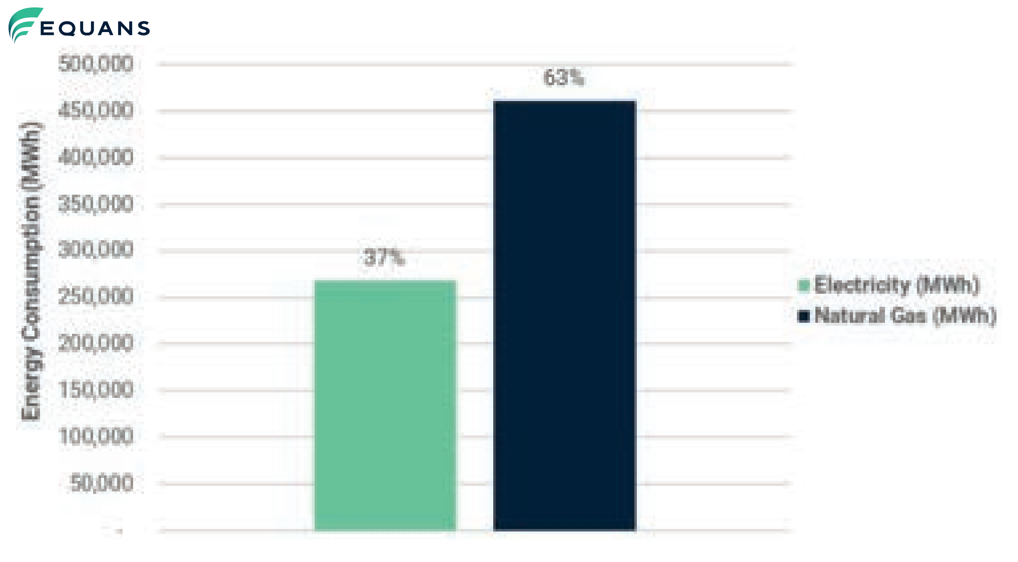

Figure 52 Automotive Sector Energy Consumption

6.2.3 On-Site Generation

On-site generation plays a key role in decarbonisation of industrial facilities as it not only takes away stress from the grid, but it supplies carbon free power with reduced losses due to local application.

We recognise that the installation of wind onsite can lead to several constraints such as planning requirements, however, to provide a view of the potential benefit for wind savings we have assumed that these sites can install on site wind generation.

Wind Savings Summary	
Estimated installed capacity (MW)	96
Estimated electrical savings (MWh/year)	336,000
Estimated CO_2 savings (te)	493,417
Estimated annual financial benefit (£/year)	36,335,040
Estimated budget capital cost (£)	231,500,000
Estimated simple payback period (years)	6.37

Solar Savings summary	
Estimated installed capacity (MW)	301.4
Estimated electrical savings (MWh/year)	259,793
Estimated CO_2 savings (te)	393,540
Estimated annual financial benefit (£)	47,641,214
Estimated budget capital cost (£)	306,825,880
Estimated simple payback period (years)	6.4

Table 35 All sector on-site generation savings

6.2.4 Green Electricity Procurement

As promised by UK government, it is expected that UK grid will be carbon free by 2035, enabling all North West England and North East Wales sectors to decarbonise their Scope 2 emissions with no additional costs.

6.2.5 Green Hydrogen Procurement

With availability of Hydrogen from 2025 via the HyNet project most of the North West sectors will be able to offset their fossil fuel consumption. Once available, Hydrogen can be either used for CHP or direct fired systems such as dryers, furnaces, etc.

6.3 Automotive

The automotive industry plays an essential role in the plan to decarbonise the UK fleet. The sector accounts for around 1% of the emissions in the North West and employs approximately 12% of total sector employment in the UK which will be approximately 21,600 direct employees (75). In North West England and North East Wales, a third of automotive manufacturers produce components, a third manufacture products for the aftermarket and over a quarter produce commercial vehicles (76). The Society of Motor Manufacturers and Traders (SMMT) has supported the UK Government's vision to achieve net zero by 2050, however, there is no published commitment from this sector for achieving net zero during the write up of this report. The automotive manufacturing process largely consists of 4 stages. These are:

a. **Press Shop** – Stamping of sheet metals resulting in moulded parts for the car.

b. **Body Shop** – Welding and assembly of multiple metal parts resulting in the car body

c. **Paint Shop** – Anti corrosion treatments and paint stage

d. **General assembly** – Assembly of all other car components as engines, doors, seats, etc

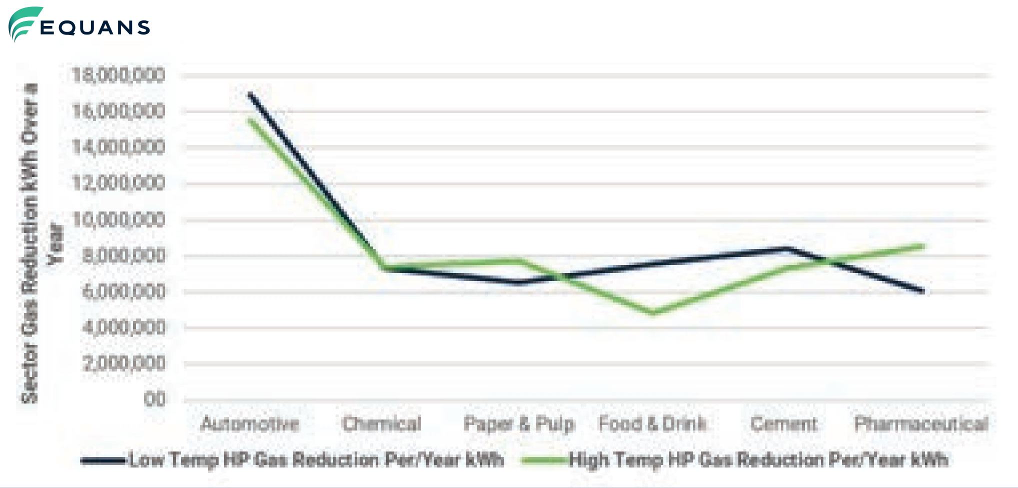

Figure 50 Industrial Sector Gas Reduction High and Low Temp Comparison

Figure 50 Industrial Sector Gas Reduction High and Low Temp Comparison shows the potential gas reduction to an industrial site when integrating a HP. These values are indicative as the reduction is benchmarked against the industry average taken from the ETS 2019 records. As the chart illustrates, there is only a small difference between a high and low temperature unit. This is due to the site demand profile and thermal output of the HP, as these values consider when the HP can offset the use for a boiler to supplement the site demand.

Figure 51 Financial Savings from Heat Pump Installation below shows the potential financial savings for the installation of a HP within each sector. Due to the current gas and electricity prices with the existing Spark spread it is difficult to present a savings and payback. This also does not include any additional RHI scheme which would be offered to the site. If this is introduced, then a further saving would be present making the HP installation more financially attractive. A consideration for the existing market would be to appreciate the carbon savings present when moving away from conventional combustion equipment, as discussed previously discussed within this report.

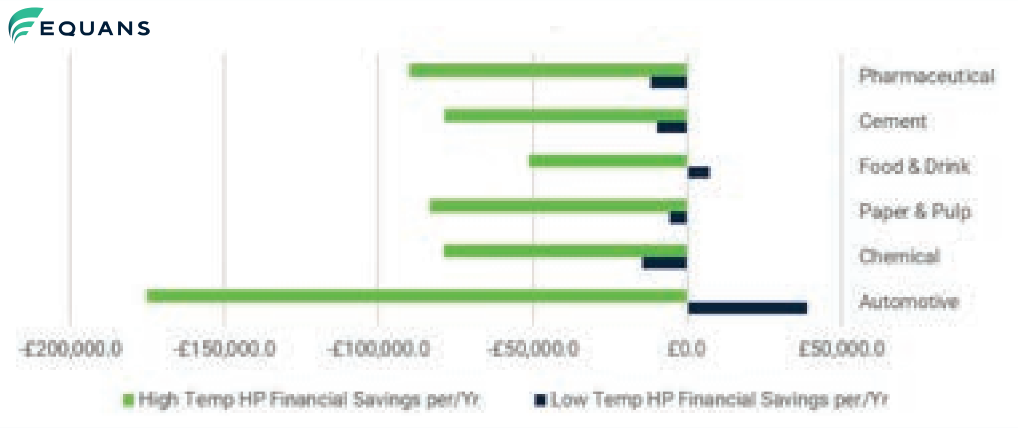

Figure 51 Financial Savings from Heat Pump Installation

6.2.2.2 Heat Pumps Conclusion

The review of each industrial sector illustrates where the specific benefits can be made. The Figure 48 High Temp Heat Pump Electrical Increase Against Thermal Output and Figure 49 Low Temp Heat Pump Electrical Increase Against Thermal Output compare the increase in electrical usage against the thermal output between a higher temperature HP against a low temperature one. As mentioned previously, higher temperature HPs can match an existing system process more closely however at a cost of efficiency when compared with a low temperature model. Figure 50 Industrial Sector Gas Reduction High and Low Temp Comparison and Figure 51 Financial Savings from Heat Pump Installation highlight the ratio between the input against output with low temperature models requiring less electrical input and generating more heat output. This relationship should be explored when reviewing the feasibility of a HP installation into an industrial process.

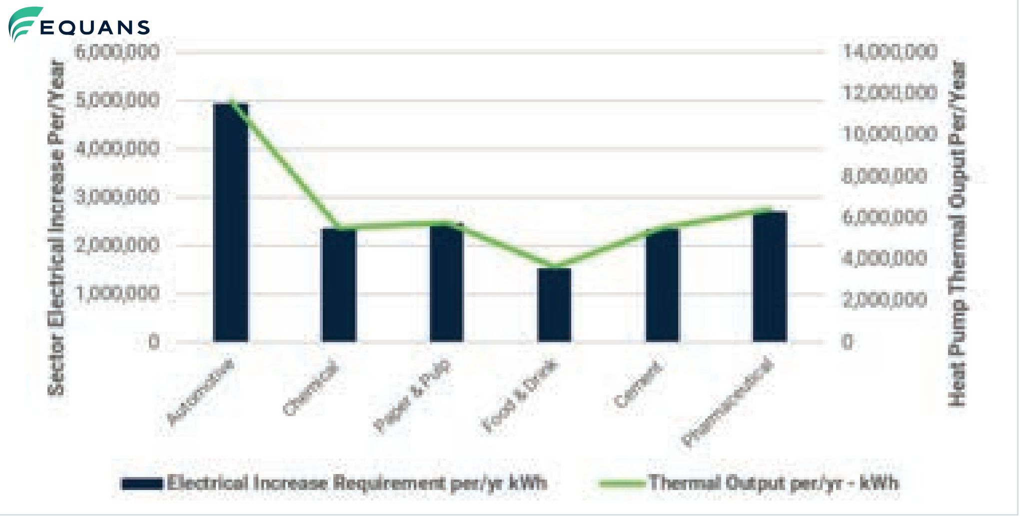

Figure 48 High Temp Heat Pump Electrical Increase Against Thermal Output

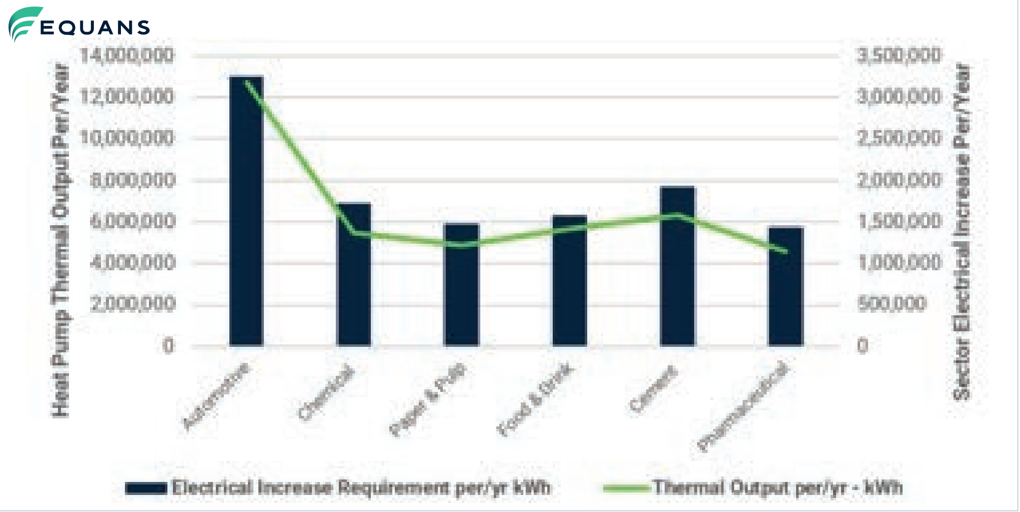

Figure 49 Low Temp Heat Pump Electrical Increase Against Thermal Output

6.2.2 Low Carbon Technologies

6.2.2.1 CHP Conclusions

It can be seen from the individual review of each sector that in some there is a significant potential benefit for the deployment of low carbon technologies such as CHPs. However, the cement industry does not appear to benefit as much due to the processes used for the manufacturing of the product. Both the payback and the carbon savings do not compare to the other industries within this review, as shown by Figure 46.

This illustrates that not every industry will benefit from the installation of a CHP system due to certain site constraints and manufacturing processes.

Figure 47 compares the sector gas input increase from the installation of a CHP system against the savings currently available, all data has been taken from the ETS data for 2019. The gas input is a percentage ratio to normalise the different sectors, allowing for an even comparison. It shows the existing higher users by sector such as chemical, paper and pulp and pharmaceutical against higher electrical users such as food and drink and automotive. Where there is a significant financial saving with the automotive and Food and Drink sectors with a much lower advantage within the cement industry. The remaining sectors do not show as great an increase to gas, as these can be assumed high gas users; however, they illustrate a strong financial saving due to electrical consumption for the sector.

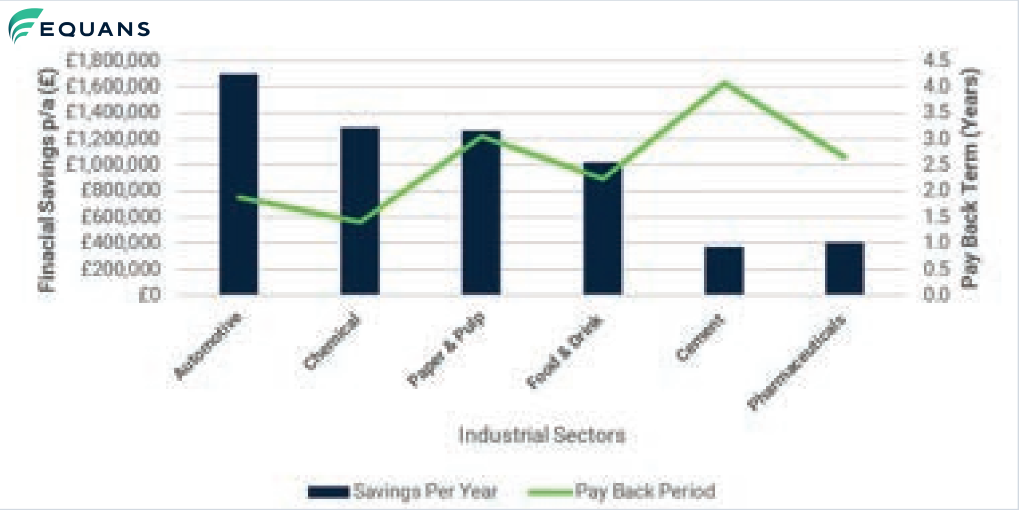

Figure 46 Industrial Sectors CHP System Savings and Payback

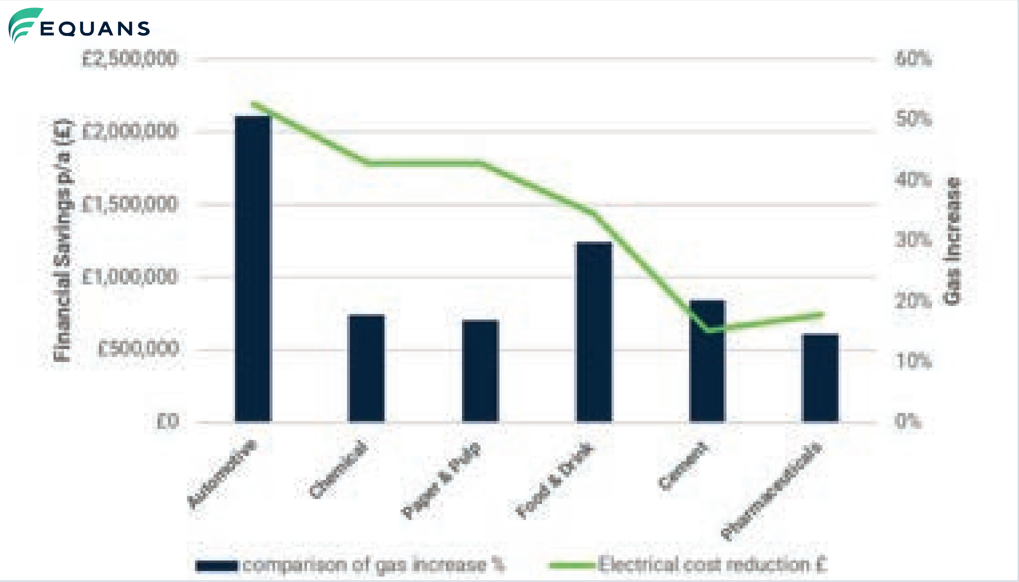

Figure 47 Industrial Sectors Electricity and Gas Comparison

Technology/ Opportunity	Total Savings (tCO_2e)	Fiscal Savings (£)	Capital Investment (£)	Payback (years)
Energy Efficiency	3,463,048	858,021,706	2,792,336,023	3.3
Conversion	194,542	-1,850,667	71,656,926	N/A
On-site Generation	774,143	79,656,383	520,000,526	6.5
Green Electricity Procurement	3,845,847	N/A	N/A	N/A
Hydrogen, Green Gas Procurement & CCS	8,409,717	N/A	N/A	N/A
Totals	**16,687,296**	**£935,827,422**	**£3,383,993,476**	**3.6**

Table 33 Sector indicative carbon and financial savings from each category

The overall payback at the time this report was written is 3.6 years for the energy efficiency and on-site generation measures.

6.2.1 Energy Efficiency Opportunities

Energy efficiency is an important step towards achieving net zero. It not only saves carbon and cost but also enables reduction in size of equipment/utilities and therefore less capital expenditure. Other advantages of energy efficiency include reduced maintenance burden, enhanced equipment life and better reliability/resilience. Therefore, it is suggested that each individual sector and site should start their journey with improved energy efficiency.

Table 34 All sector savings shown below presents the achievable carbon and cost savings with overall payback of 3.3 years, paving the way for Net Zero for North West England and North East Wales.

Sectors	Total Savings (tCO_2e)	Savings (%)	Fiscal Savings (£)	Capital Investment (£)	Payback (years)
Automotive	44,834	29.3%	£11,126,211	£32,902,472	3.0
Cement	510,167	16.7%	£44,843,750	£144,047,917	3.2
Chemical	218,370	19.8%	£33,828,029	£122,862,899	3.6
Glass	94,823	16.9%	£14,439,421	£42,257,599	2.9
Iron & Steel	17,175	26.9%	£2,818,693	£9,558,252	3.4
Food & Drink	250,451	25.8%	£65,288,013	£213,647,099	3.3
Pharmaceuticals	73,927	26.8%	£22,547,120	£71,977,368	3.2
Paper & Pulp	187,810	20.3%	£47,816,493	£172,314,417	3.6
Other Sectors	2,065,491	21.6%	£615,313,976	£1,982,768,001	3.2
Totals	**3,463,048**	**–**	**£858,021,706**	**£2,792,336,023**	**3.3**

Table 34 All sector savings

It would go beyond the scope of this report to ascertain the exact carbon reductions per sector when reviewing the use of all combustion plants. However, with the implementation of CHP technology, when the fuel switch occurs from natural gas to hydrogen, an industrial site can undertake the fluid transient of changing fuels with little change to existing infrastructure.

The UK government announced that the UK grid is expected to be fully decarbonised by 2035 and therefore it has been assumed that procurement of power from 2035 will be carbon free with no additional costs. Following implementation of the energy saving measures, it is also expected that hydrogen will be available to be used to offset fossil fuels such as natural gas at no cost differential.

Figure 45 North West England and North East Wales Overall Carbon Neutral Delivery Plan, shown below, details the action plan to achieve net zero.

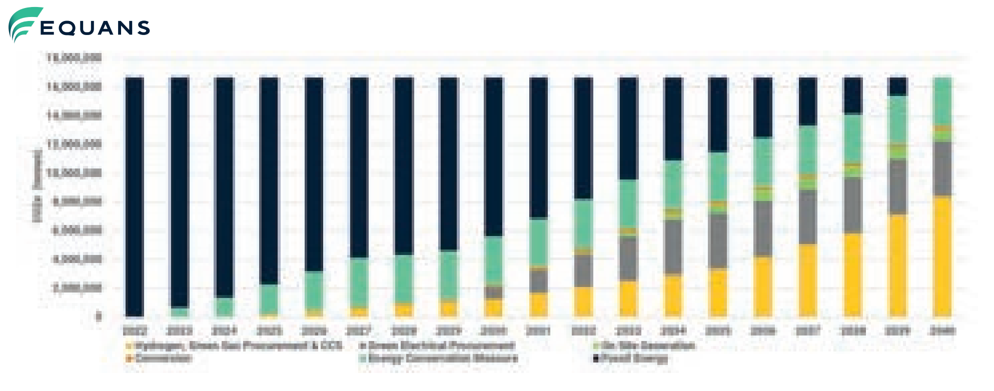

Figure 45 North West England and North East Wales Overall Carbon Neutral Delivery Plan

The above plan has been designed based on the order of priority of implementation and considering the availability of new technology and alternative fuels such as hydrogen.

Sectors	**Total Savings (tCO_2e)**	**Fiscal Savings (£)**	**Capital Investment (£)**	**Payback (years)**
Automotive	153,256	£12,251,487	£42,986,966	3.5
Cement	3,057,649	£56,639,715	£224,186,184	4.0
Chemical	1,133,322	£42,606,095	£183,683,894	4.3
Food & Drink	971,931	£81,366,430	£350,923,191	4.3
Glass	583,313	£20,766,393	£70,392,507	3.4
Iron & Steel	63,952	£3,122,436	£11,505,395	3.7
Paper & Pulp	926,812	£50,170,175	£204,859,096	4.1
Pharmaceuticals	276,272	£23,777,854	£82,809,492	3.5
Other Sectors	9,104,792	£524,629,055	£1,816,997,514	3.5
Totals	**16,271,300**	**£815,329,642**	**£2,988,344,238**	**3.7**

Table 32 Sector indicative carbon and financial savings

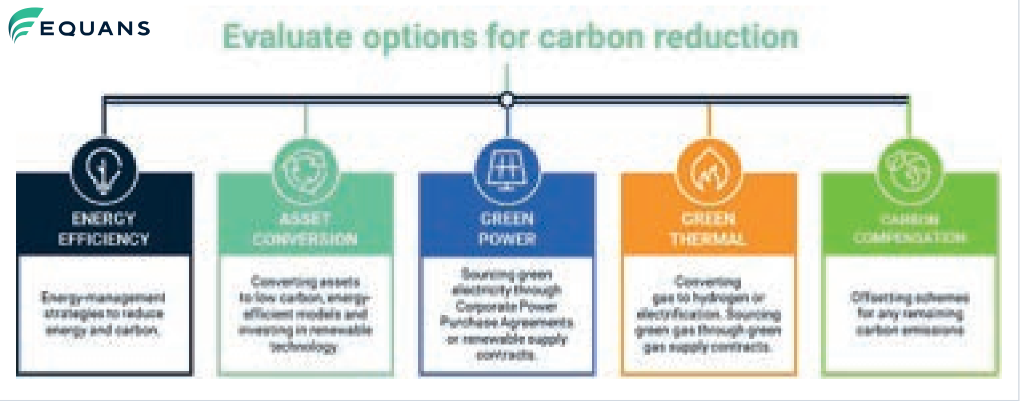

Figure 43 Categorisation of carbon reduction measures

6.2 North West England and North East Wales Overall Roadmap

As discussed previously, the NZNW roadmap includes five categories for emissions reduction. Figure 44 North West England and North East Wales Overall Carbon Waterfall presents grouped emission savings for the entire North West England and North East Wales. As can be seen below; Energy Conservation Measure (ECM), procurement of green power and green hydrogen are the key measures, as they are applicable to each sector in North West England and North East Wales and will deliver substantial carbon savings.

The first key step is decarbonisation through energy efficiency, leading to improved energy performance and cost savings which can be used to fund other capital projects. Following improving energy efficiency, decarbonisation of site processes and heat should be investigated, this includes different technologies such as the use of hydrogen as an alternative fuel. Hydrogen is expected to be available to some parts of the North West England and North East Wales from 2025.

It should be noted that the conversion can be accelerated depending on the availability of hydrogen and the decarbonisation of grid.

On-site generation includes power generation from solar and wind, which can be used to supply carbon free power to all the sectors in the North West England and North East Wales. Table 32 - Sector Carbon and financial savings (shown on next page) presents grouped carbon and financial savings, including indicative paybacks for each sector in the North West England and North East Wales to achieve net zero.

The installation of the system can still contribute to a significant cost reduction to site process from conventional means of electrical and thermal energy production. However, this report details the carbon savings available through hydrogen integration. Natural gas CHP modelling has been applied to highlight the impact of the point from when hydrogen is introduced, as the possible carbon savings shall be vast across each industrial sector. Allowing the reader to understand the existing benchmark for the technology, if they have no prior knowledge of CHP technology and application.

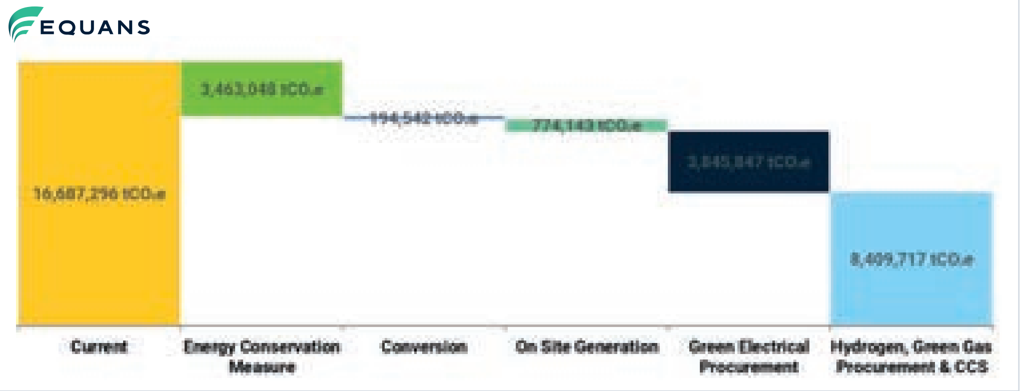

Figure 44 North West England and North East Wales Overall Carbon Waterfall

6. Decarbonisation Opportunities

6.1 Methodology and Approach

The following section examines various energy and carbon enhancements within each sector, derived from the energy savings and opportunities extrapolated from ESOS Phase 2 reports conducted by EQUANS. Further areas of optimisation through energy recovery and efficiency and the integration of renewable technologies are also included for review. As explained throughout the section, the data collected shall be assumed to cover sectors as a whole and not detailing specific sites within each industry. Therefore, typical processes and manufacturing methodologies are assumed, and applications of those assumptions are intended as a guide to the corresponding sites in North West England and North East Wales. A wide range of carbon reduction measures have been considered across the portfolio. The viability of these were assessed through the following methodology:

- For identified sectors, analysis of available data was carried out. The purpose of the analysis was to identify building and asset specific opportunities to decrease energy consumption, increase on-site renewable generation and improve carbon performance. Site audits as part of the data set have followed BS EN 16247 and CIBSE Tm^{2}2 energy audits, and assessments audits, assessment and reporting methodologies. The potential for carbon reduction opportunities covering the following areas was assessed, energy efficiency, low carbon technologies, renewable generation and heat and hydrogen.

- Identified opportunities were explored in further detail following the initial desktop solutioning to determine technical viability, applicability to other sectors within the portfolio, and alignment with the industrial cluster ambitions.

Figure 42 Example Carbon Waterfall and Figure 43 Categorisation of carbon reduction measures show the five categories that are typically used to identify carbon reduction measures. These split carbon reduction measures are generally categories into five categories, reduction in use (efficiency), conversion of traditional fuels to alternative sources of energy, green power and green thermal with any remaining emissions being offset through carbon compensation.

Figure 42 Example Carbon Waterfall

7. Report Conclusion

This report aims to evaluate the characteristics of industrial consumers by sector in the North West. In doing so, it considers current practical decarbonisation strategies and provides an assessment of future technologies when developing sectoral decarbonisation roadmaps. It creates an achievable investment, technology, and infrastructure blueprint for the North West's net zero transition and low carbon recovery post-COVID-19, to transition the North West England and North East Wales to net zero carbon by 2040.

This decarbonisation and clean growth vision will unlock huge opportunities across the supply chain for regional businesses to tap into, including engineering support; construction; parts provision; logistics and distribution; third party maintenance; contracts and many other supporting work streams.

The analysis included in this report is based on desktop analysis and it is therefore recommended that the industrial companies within the North West England and North East Wales produce individual net zero carbon reports and action plans that align with the North West's 2040 ambitions of the world's first net zero industrial cluster.

This can be done by taking a holistic approach to decarbonisation focussing not on individual technologies but integrated energy systems that tackle efficiency first, before considering more complex infrastructure requirements.

Term	Description	Definition
IoT	Internet of Things	Physical objects (or groups of such objects) that are embedded with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks
kWh	kilowatt-hour	A unit of energy equal to 3600 kilojoules (3.6 megajoules) and commonly used as a billing unit for energy delivered.
LGV	Large Goods Vehicles	Vehicle that has a gross vehicle weight of over 3.5 tonnes
LTHW	Low Temperature Hot Water	A low-temperature heating system is defined as one up to 90°C
MW	Megawatt	Unit of power equal to one million watts, especially as a measure of the output of a power station.
MT	Mega tonne	Unit of mass
m3	Cubic metre	Unit of volume.
NAEI	National Atmospheric Emissions Inventory	UK Data for emissions
NZNW	Net Zero North West	North West industrial cluster aiming to be net zero.
PEM	Proton Exchaneg Membrane	Common electrolysis system
PV	Photovoltaics	Renewable energy technology that utilises irradiance from the sun to generate electricity
RHI	Renewable Heat Incentive	Government funding Incentive to promotoe use of renewable heat
RFI	Request for Information	Method of collecting of information
SECR	Streamlined Energy and Carbon Reporting	The UK Government's name for the replacement legislation to a number of existing and some soon to expire programmes covering energy and carbon reporting and taxation. Came into force April 2019.
SCOP	Seasonal Coeffecent of Preformance	Easonal average of the ratio of heat output over the electrical input
SMR	Small Modular Reactors	Low carbon technology using nucleur technology
SMMT	Society of Motor Manufacturers and Traders	Society of Motor Manufacturers and Traders
SMT	Smart Metering and Targeting system	Energy monitoring and targetting systems
VSD	Variable Speed Drive	Devices that can vary the speed of a normally fixed speed motor.
VFD	Variable Frequency Drive	A variable frequency drive controls the speed of an AC motor by varying the frequency supplied to the motor
WSHP	Wate Source Heat Pump	Technology converting heat from the water into useable heat for use in building or processes

Term	Description	Definition
ESOS	Energy Saving Opportunity Scheme	Mandatory energy assessment and energy saving identification scheme typically delivered through an energy survey, introduced by the UK government for large organisations.
EU ETS	European Union Emissions Trading System	The EU ETS operates in all EU countries plus Iceland, Liechtenstein, and Norway (European Economic Area – European Free Trade Association states), limiting emissions from around 10,000 installations in the power sector and manufacturing industry, as well as airlines operating between these countries.
EV	Electrical Vehicle	Vehicles running of electricty rather than fossil fuels
FEED	Front-End Engineering Design	Basic engineering which is conducted after completion of Conceptual Design or Feasibility Study.
FDF	Food and Drink Federation	Food and Drink Federation
GGSS	Green Gas Support Scheme	GGSS will provide financial incentives for new AD biomethane plants to increase the proportion of green gas in the gas grid.
GHG	Greenhouse Gas	A gas that absorbs and emits radiant energy within the thermal infrared range. Greenhouse gases cause the greenhouse effect on planets.
GHI	Global Horizontal Irradiation	Total solar radiation incident on a horizontal surface
GIS	Geographic Informtion System	Computer system that analyses and displays geographically referenced information
GSHP	Ground Source Heat Pump	Technology converting heat from the gournd into useable heat for use in building or processes
GVA	Gross Value Added	Economic productivity metric that measures the contribution of a corporate subsidiary, company, or municipality to an economy
HDS	Hydrodesulphurisation	Catalytic chemical process to remove any sulphur from natural gas or refined petroleum products e.g., petrol, kerosene, and diesel
HGV	Heavy Goods Vehicle	Vehicle that has a gross vehicle weight of over 3.5 tonnes
HP	Heat Pump	Technology converting heat from the renewable sources into useable heat for use in building or processes
HPHW	High Pressure Hot Water	A high-pressure hot water system is defined as one bar above vapour pressure, therefore greater than 10 bar and 120°C
HRC	Hydrofluorocarbons	Environmentally harmful gases
HVAC	Heating Ventilation Air Conditioning	Heating, ventilation, and air conditioning is the use of various technologies to control the temperature, humidity, and purity of the air in an enclosed space.
IETF	Industrial Energy Technology Fund	To help businesses with high energy use to cut their bills and carbon emissions through investing in energy efficiency and low carbon technologies
ICT	Information and communication technology	Extensional term for information technology (IT) that stresses the role of unified communications

8. Glossary of Terms

Term	Description	Definition
AD	Anaerobic Digestion	The process by which organic matter such as animal or food waste is broken down to produce biogas and bio-fertiliser. This process happens in the absence of oxygen in a sealed, oxygen-free tank called an anaerobic digester.
AHU	Air Handling Unit	An AHU is used to re-condition and circulate air as part of a heating, ventilating and air-conditioning system.
ASHP	Air Source Heat Pump	Technology converting heat from the air into useable heat for use in building or processes
BAU	Business as usual	Business as usual is a term that refers to the standard day-to-day business operations in an organisation
BEIS	Business, Energy and Industrial Strategy	Government Department for Business, Energy and Industrial Strategy
BF-BOF	Blast furnace – Basic oxygen furnace	Steel manufacturing method using oxygen
CCA	Climate Change Agreement	Voluntary agreements made between UK industry and the Environment Agency to reduce energy use and carbon dioxide
CCGT	Combined Cycle Gas Turbine	An assembly of heat engines that work in tandem from the same source of heat, converting it into mechanical energy
CCL	Climate Change Levy	Government tax to encourage reduction in gas emissions
CCM	Conservation Measure	The upgrades, retrofits, repairs and replacements that businesses can implement to become more carbon neutral.
CCUS	Carbon Capture Usage & Storage	The process of extracting the greenhouse gas carbon dioxide (CO_2) from the exhaust streams of power stations or industrial processes. The CO_2 is then either used for another purpose or stored.
CFD	Contract for Difference	A contract between two parties stipulating that the buyer will pay to the seller the difference between the current value of an asset and its value at contract time.
CFL	Compact Fluorescent Lamp	A fluorescent lamp
CHP	Combined Heat and Power	Also known as cogeneration, is: the concurrent production of electricity or mechanical power and useful thermal energy (heating and/or cooling) from a single source of energy.
CIA	Chemical Industries Association	Chemical Industries Association
CIP	Cleaning in Place	Refers to the use of a mix of chemicals, heat and water to clean machinery, vessels or pipe work without dismantling plant.
COP	Coefficient of Preformance	The load capacity divided by the electrical load consumed by the equipment.
CO_2	Carbon Dioxide	A Greenhouse Gas (GHG) which is colourless with a density ~53% higher than that of dry air.
CO_2e	Carbon Dioxide Equivalent	A standard unit for measuring carbon footprints
ECM	Energy Conservation Measure	The upgrades, retrofits, repairs and replacements that businesses can implement to become more energy efficient.
EMF	Electromagnetic Force	The rotation of the engine rotates the alternator which in turns produces an electromagnetic force.

According to the 2019 UK Greenhouse Gas Emissions, Final Figures, the report states:

> **"[this sector] is estimated to have been responsible for 21% of UK greenhouse gas emissions in 2019, with carbon dioxide being by far the most prominent gas for this sector (94%)". (23)**

For comparison purposes, it should be noted this categorisation includes emissions from electricity generation and other energy production activities such as mining, refining, and manufacturing fuels.

From our data set we identified 20 power producers based in the North West England and North East Wales, collectively these sites emit 3,502,338 tCO_2e, equivalent to 25% of total cluster emissions – the highest emitting sector.

9.3.13 Textiles And Clothing

The clothing industry is indeed an intricate one when it comes to assessing carbon footprint, as it takes into consideration the lifecycle of singular items from production of components to landfill, as well as consumption of water and the biodiversity and health hazards it is known to create. According to Statista (125), the apparel and footwear market in the UK is projected to grow steadily in the coming years, and that revenues in 2020 were estimated to be around £52m GBP. Total footprint of clothing in use in the UK was 26.2m tCO_2 in 2016 and water footprint was around 8 billion m3. (128)

There is one clothing site operation based at NZNW, that are specialists in the supply of safety, technical, and harnessing equipment for industrial and recreational activities. They account for 11,450 tCO_2e, equivalent to <1% of overall cluster emissions or 0.0004% sector footprint.

9.3.14 Water And Waste

Every day, over 50 million household and non-household consumers in England and Wales receive good quality water, sanitation, and drainage services. These services are provided by 32 privately-owned companies in England and Wales. (129)

The waste management sector consists of emissions from waste disposed of to landfill sites, waste incineration, and the treatment of wastewater. It is estimated to have been responsible for around 4% of greenhouse gas emissions in the UK in 2019. (23) A report from 2008 revealed the water industry contributes 0.8% of annual UK greenhouse gas emissions. However, the emissions that result from heating water in the home increases this figure to 5.5%. (130). Water UK has recently published its Annual Emissions Report for 2021 (131) where they show gross emissions have fallen in the industry by 15%. There are 5 companies operating 8 sites at NZNW relating to water and sewerage services and waste collection, treatment, and disposal. These utility companies collectively emit 572,699 tCO_2e, equivalent to 4.1% of the total cluster emissions (seventh highest).

The Department for Business, Energy and Industrial Strategy (BEIS) have projected that Non-Ferrous Metals industry will reduce emissions from 0.510 $MtCO_2e$ in 2020 to 0.23 3$MtCO_2e$ by 2040. (20)

Two sites operate in this sector at NZNW. together they account for 59,012 tCO_2e, equivalent to 0.4% of total cluster emissions.

9.3.10.8 Panel Board

The panel board industry manufacturers and distributes wood-based panels that are used in a variety of industrial and domestic applications.

Carbon emissions vary for the Wood Panel Industry according to the wood source (Virgin, Recycled, Low Grade), local or import, and with/ without CHP applications (127) .

There are two units at NZNW that produce laminate flooring, wall panels, raw boards for construction, and products for furnishing and interior finishing. These sites emit 136,959 tCO_2e, equivalent to 1% of total cluster emissions.

9.3.10.9 Paper and Pulp

The pulp and paper industry comprises companies that use wood as raw material and produce pulp, paper, paperboard, and other cellulose-based products.

BEIS have projected that the paper, pulp and print industry will reduce emissions from 1.4 $MtCO_2e$ in 2020 to 1.3 $MtCO_2e$ by 2040 (20).

From our data set we identified 21 sites operated by 15 businesses in the North West cluster providing a variety of pulp, paper, and paperboard. Collectively they account for 555,131 tCO_2e, equivalent to 4% of total cluster emissions.

9.3.11 Pharmaceuticals

The pharmaceutical industry plays a pivotal role in the health of all lives. In 2019, the annual turnover of pharmaceutical wholesalers in the UK was over £51 billion. The UK pharmaceutical market is among the global top 10 national markets, holding 2.5% of the global pharmaceutical market (21).

The pharmaceutical industry has its own unique decarbonisation challenges: a new drug can take significant time and resources to develop, test and take to market. In addition, the varying number of chemical components means they have complicated supply chains. There is inconclusive evidence at this time to demonstrate whether the pharmaceutical industry understood its UK impact on climate change in the form of tonnes (t) or Mega tonnes (Mt) CO_2e from any baseline year, as findings indicate emission tools have been developed and rolled out but returned no high-level figure. Results indicate that this industry is greater than that of the automotive industry. The NHS estimates medicines account for 25% of total emissions from the health service, currently equivalent to 4% of England's total carbon footprint (22).

From our data set we identified 5 companies operating across 7 sites in the North West England and North East Wales, collectively they emit 139,120 tCO_2e, equivalent to 1% of total cluster emissions.

9.3.12 Power Producers

There are several operational power stations in the UK categorised by generation type. The following graph is cited from **www.statista.com**: Figure 131 Number of operational power stations in the United Kingdom (UK) as of May 2020, by generation type (21)

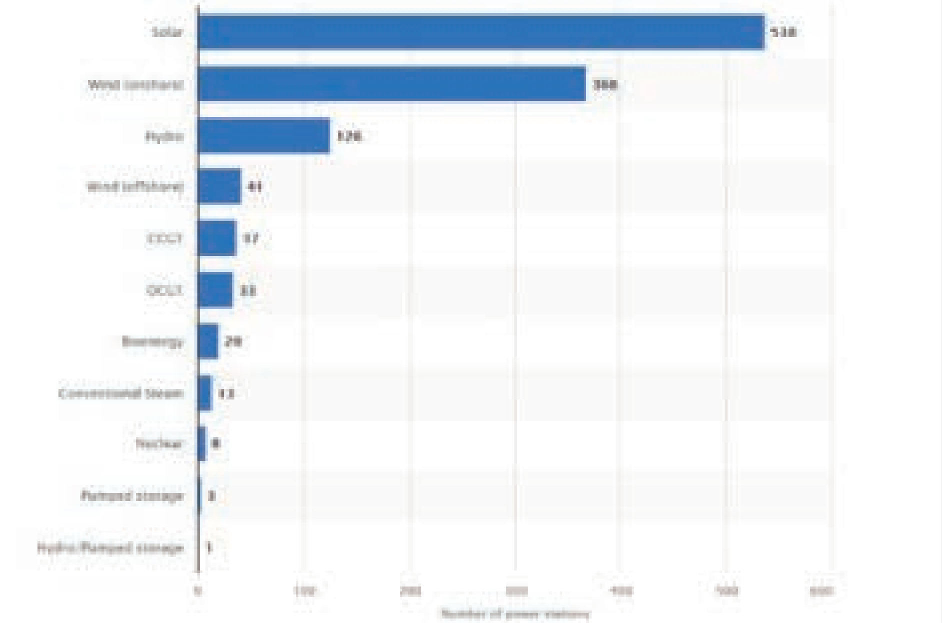

Figure 131 Number of operational power stations in the United Kingdom (UK) as of May 2020, by generation type (21)

- Hindlow
- Hindlow Lime
- Tunstead Lime
- Tunstead Cement

9.3.10.2 Ceramics

Ceramics is the broad term used to describe both natural and synthetic materials with a crystalline structure. Many products are made from clay and similar materials processed at high temperatures. Total UK ceramics sales amount to £2 billion, and 97% of ceramics businesses as SME's. (120)

The industry represents nearly a quarter of all UK emissions. (121)

There are five sites belonging to NZNW cluster, they account for 77,501 tCO_2e, or respectively 0.6% total cluster emissions.

9.3.10.3 Glass

The UK large scale glass manufacturing industry includes 10 companies with 17 sites throughout England, Scotland, and Northern Ireland. The glass industry employs around 6,000 direct staff and indirectly around 150,000 (18) .

The glass industry is split into three categories:

1. **Container** – food and drink and pharmaceutical products.
2. **Flat glass** – used in commercial and residential buildings for glazing.
3. **Fibre** – used in numerous manufacturing applications such as wind turbine blades.

Emissions are reported as 1.5m tCO_2 of Emission Trading Scheme (ETS) (site emissions reported under the ETS). There are eight glass sites based at NZNW collectively they account for 473,258 tCO_2e, equivalent to 3.4% total cluster emissions (ninth highest).

9.3.10.4 Gypsum and Plasterboard

The industry manufacturers gypsum-based plaster products for use in construction. Main activities include:

- Plasterboard manufacturing
- Cornice and coving manufacturing
- Ceiling rose manufacturing
- Acoustic tile and ceiling plaster manufacturing
- Premixed and bagged plaster manufacturing

Market size of this industry is £900m with around 50 businesses. (122) Gypsum plasterboard is commonly used for dry lining building solutions but causes approximately 3.5% of the UK's greenhouse gas emissions. (123)

There is one site at NZNW, home to the long-established plaster and plasterboard plant, and has manufactured Thistle plasters continuously since 1910.

9.3.10.5 Site

This site equates to 38,414 tCO_2e, or 0.3% of total cluster emissions. 9.3.10.5 Iron and Steel

In 2020, the UK steel industry contributed £2 billion to the UK economy in terms of (GVA). This was equivalent to 0.1% of total UK economic output and 1.2% of manufacturing output. There are 1,100 businesses in the UK steel industry and in 2019, produced 7 million tonnes of steel.

The steel industry is a significant contributor and is responsible for 13.5% of GHG emissions from manufacturing and 2% of total UK greenhouse gas emissions (19) .

From our data set we have only identified one site in the North West England and North East Wales which manufactures approximately 500,000 tonnes of metallic coated and pre-finished steel per year. This site emits 54,913 tCO_2e, equivalent to 0.4% of total cluster emissions.

9.3.10.6 Lime

Lime is used in several applications from water purification to iron and steel manufacture, and environmental remediation and emissions clearing from waste plants and incinerators. The past decade has seen this sector significantly reduce its carbon emissions, waste, and the use of fossil fuels. (124) Currently, emissions from lime production average 1.1 $MtCO_2e$ a year (2019) from 1.7 $MtCO_2e$ (1998). (125)

There is one site working in this sector at NZNW, a limestone quarry supplying to Northern Britain. This site accounts for 184,116 tCO_2e, or 1.4% respectively of total cluster emissions.

9.3.10.7 Non-ferrous metal

Non-ferrous metals include aluminium, copper, lead, nickel, tin, titanium, and zinc, as well as copper alloys like brass and bronze. A non-ferrous metal is defined as metal that does not have a significant amount (<1% by weight) of iron in its chemical compound. The UK Metals Industry comprises 11,100 companies, employs around 230,000 people, and directly contributes £10.7bn to UK GDP. (126)

On 6th October 2021, environmental charity WRAP (Waste and Resources Action Programme) stated "Gas emissions must be a key priority for COP26" (117) as industry emissions are equivalent to 35% of the UK total.[iv]

There are twenty-five sites across the NZNW cluster producing a variety of human and pet food and beverages. This sector emits 584,761 tCO_2e, representing 4.2% of total cluster emissions.

9.3.8 Engineering

Engineering is the designing, testing, and building of machines, structures and processes using maths and science. According to The Engineering Council (118), 18% of the UK working population work in engineering roles. This sub-sector integrates with many other industry sectors from Aerospace to Agriculture, Food and Drink to Pharmaceutical, therefore is paramount to the climate change crisis. There are 3 major engineering sites based at the NZNW cluster, at 11,836 tCO_2e, these sites account for a minor (0.1%) proportion of the total cluster emissions.

9.3.9 Oil and Gas

This sector comprises, oil and gas extraction, mining (except oil and gas), and support activities for mining. The term mining is used in the broad sense to include quarrying, well operations, beneficiating (e.g., crushing, screening, washing, and flotation), and other preparation.

According to the 2019 UK Greenhouse Gas Emissions, Final Figures, (23) the report states:

> **"[this sector] is estimated to have been responsible for 21% of UK greenhouse gas emissions in 2019, with carbon dioxide being by far the most prominent gas for this sector (94%)".**

For comparison purposes, it should be noted this categorisation includes emissions from electricity generation and other energy production activities such as mining, refining, and manufacturing fuels.

At NZNW, there are twenty-three sites sub-categorised under this sector. Collectively, the sites account for 2,619,657 tCO_2e, or 18.7% cluster emissions respectively. Site specific detail is further drawn out below.

9.3.9.1 Gas

There are five operating gas terminals/ stations at NZNW they account for 258,793 tCO_2e, or 1.9% of total cluster emissions.

9.3.9.2 Oil Refinery

There are three refineries two at Stanlow, and one located at Nynas. Their combined emissions stand at 2,201,520 tCO_2e which is equivalent to 15.6% of total cluster emissions.

9.3.9.3 Oil and Gas

There is just one oil and gas terminal. Total emissions equate to 0.7% (99,095 tCO_2e) cluster representative.

9.3.9.4 Processing Oil

There is just one processing oil terminal. It has a low representation of cluster emissions (<1%) at 3,390 tCO_2e.

9.3.9.5 Other Mineral Industries

There are ten operators across twelve sites working in a wide range of construction supplies and minerals. Together they account for 56,319 tCO_2e, or 0.4%, of total cluster emissions.

9.3.10 Materials

The UK manufactures and distributes many types of raw and synthetic materials needed to produce products. The UK's material footprint was estimated as 971 million tonnes in 2018, equivalent to 14.6 tonnes per person, and is increasingly a net importer of materials. (119)

9.3.10.1 Cement

Cement is used in construction to bind other materials together. Cement emissions contribute to climate change as approximately 50% of emissions of cement production come from limestone ($CaCO_3$) calcination, which happens at high temperatures in a cement kiln to produce lime (CaO). This leads to a release of waste in the form of CO_2, called process emissions. A further 40% of cement emissions come from burning fossil fuels to heat kilns for the calcination process, and around 10% from fuels needed to mine and transport raw materials. There are twelve manufacturing and two grinding/ blending plants in the UK cement industry contributing £1 billion to the UK economy. There are six cement sites accounting for the second highest sector contributor of CO_2 emissions (2,734,941 tCO_2e; 19.6% representative total emissions) at NZNW:

- Padeswood Works
- Ribblesdale Works

[iv] Emissions from production, consumption, and overseas imported food.

9.3 Sector Description

9.3.1 Aerospace

The UK aerospace industry designs and produces engines, helicopters, wings, structures, and aircraft systems (including landing gear). The UK also designs and manufactures wings for all Airbus aircraft platforms and has a maintenance, repair, and overhaul sector (MRO). The sector had approximately a 16% global market share in 2020 and 97% of domestic aerospace is exported. More than 3,000 aerospace companies operate in the UK (111). NZNW has five aerospace sites as part of the cluster, which represents 0.13% of the UK market and account for 53,968 tCO_2e total emissions, representative of 0.4% cluster total. UK aviation emissions for 2019 have been estimated to be 39.6 $MtCO_2e$. (112)

9.3.2 Airport

There are over 250 register airports (113) in the UK, with circa.58% being used for public aviation. Heathrow, the leading airport in the UK classed as a "small city", emitted 2.09 $MtCO_2e$ (114) across Scopes 1-3 in 2018. The industry sector definition includes businesses operating international, national, or civil airports or public flying fields. It also includes operators that support airports by offering services such as air traffic control and ground service activities, as well as services to military air operations.

NZNW has one airport site as part of the cluster – Manchester Airport – which accounts for 6,648 tCO_2e emissions, which is less than 0.05% of total cluster emissions.

9.3.3 Ammonia

Ammonia, also known as NH3, comes in the form of liquid and gas, and is predominantly used in the following sectors across the globe:

- Agriculture (dominant, ca.80%)

- Textiles
- Mining
- Pharmaceuticals
- Refrigeration

Although ammonia is itself not a greenhouse gas, following deposition to soil it may be converted to nitrous oxide, an important contributor to climate change, of which 272,000 tonnes in 2019 were emitted in the UK. (8)

The ammonia market is estimated to reach 197,216.85 kilo tons by 2026, registering a CAGR of 2.03% during the forecast period (2021-2026). (115) Ammonia production currently accounts for around 1.8% of global carbon emissions. NZNW has two sites producing ammonia, with a total emissions output of 710,047 tCO_2e, representing 5.8% of the cluster .

9.3.4 Asphalt

Asphalt is the surfacing material for over 95% of all UK roads as well as for footpaths, playgrounds, cycle paths and car parks. Over 25 million tonnes of asphalt are produced every year by 275 plants in the UK and is 100% recyclable. The total UK carbon footprint associated with the asphalt industry is estimated at 786,000 tCO_2/ annum which is the equivalent to 5,000 km driven by a million average family cars. (116) NZNW has one site working in the asphalt sector, whose emissions output is 4,824 tCO_2e, representative of 0.03% of the overall cluster emissions.

9.3.5 Automotive

The automotive sector is a vital part of UK industry attributing £15.3 billion value to the economy. More than 30 manufacturers build more than 70 different models in the UK which accounts for 13% of total UK export of goods. (15) With the future of EV vehicles on the increase, the automotive industry is needed more than ever to help meet the UK's net zero targets.

There are six automotive sites at NZNW which makes up 0.61% of total cluster emissions (84,836 tCO_2e):

9.3.6 Chemicals

The chemical industry is one of the largest in the UK and is a top manufacturing exporter. It adds almost £25 billion of value to the economy with 3,700 business providing over 500,000 jobs. It also has the one of the highest labour productivity rates of £123k GVA per employee. (16)

There are thirty-seven sites associated to the chemical sector at NZNW at 1,022,506 tCO_2e, this sector is the fourth highest contributor to the overall cluster emissions (7.3% representative). 9.3.7 FOOD and DRINK

9.3.7 Food and drink

Food and drink accounts for 20% of total UK manufacturing. The Food and Drink Federation (FDF) organisation has stated that in 2018, the sector contributed almost £29 billion to the UK economy, equivalent to 2.3% national GVA. Over 440,000 people are directly employed by the industry across every region and nation, and it has a very complex supply chain. (17)

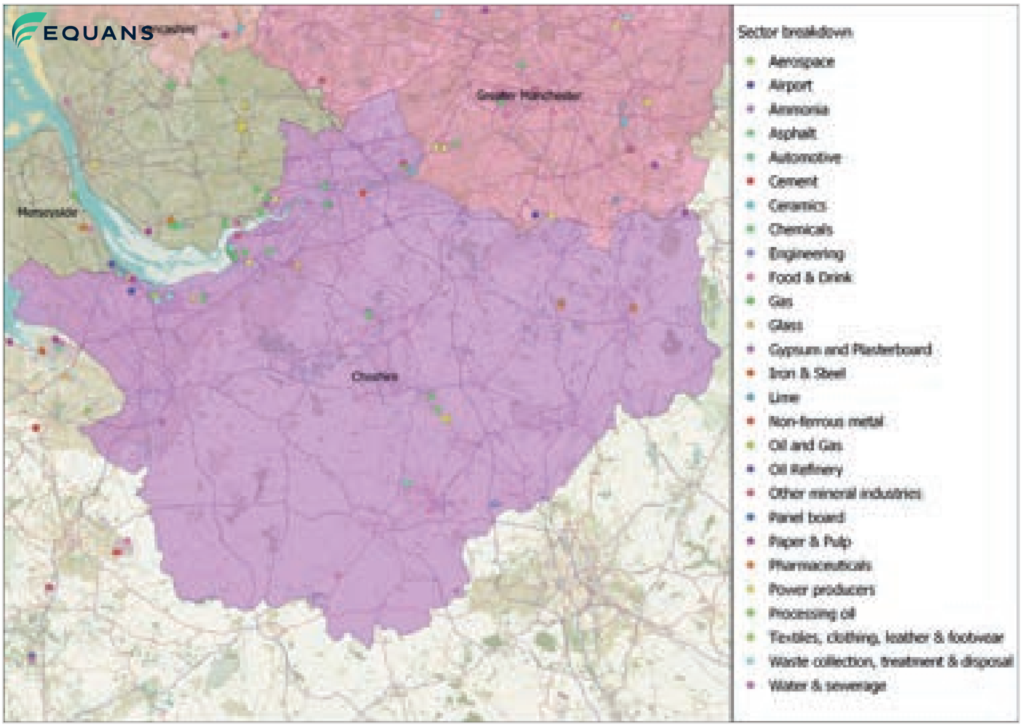

Figure 129 Cheshire sector breakdown of industrial sites

9.2 Local Energy Partnerships

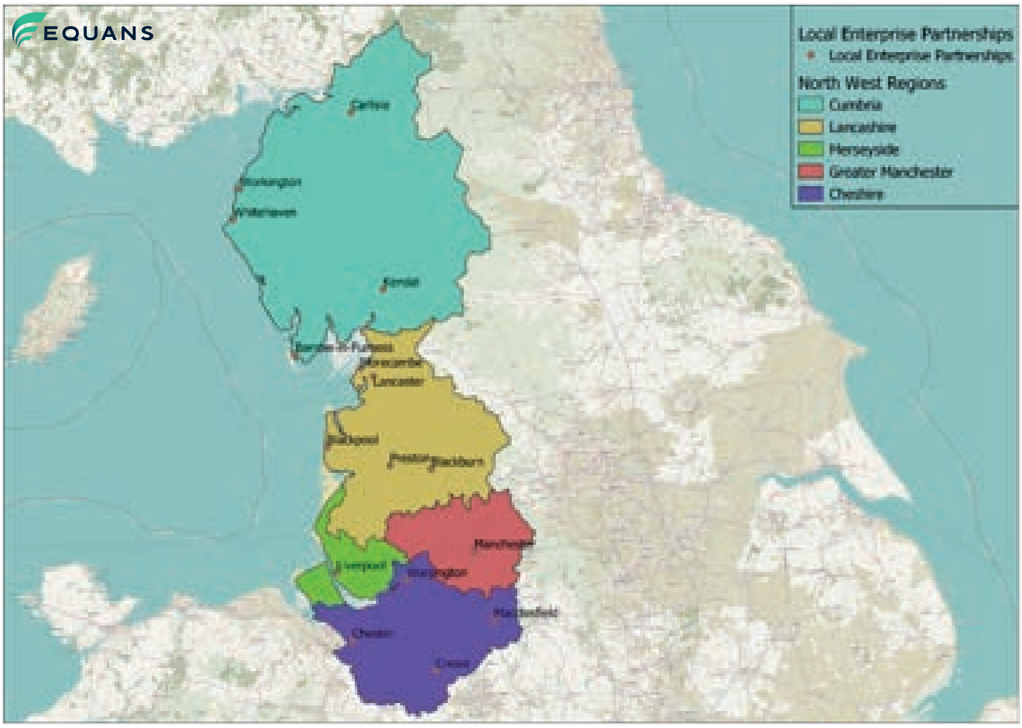

Figure 130 Local Energy Partnerships

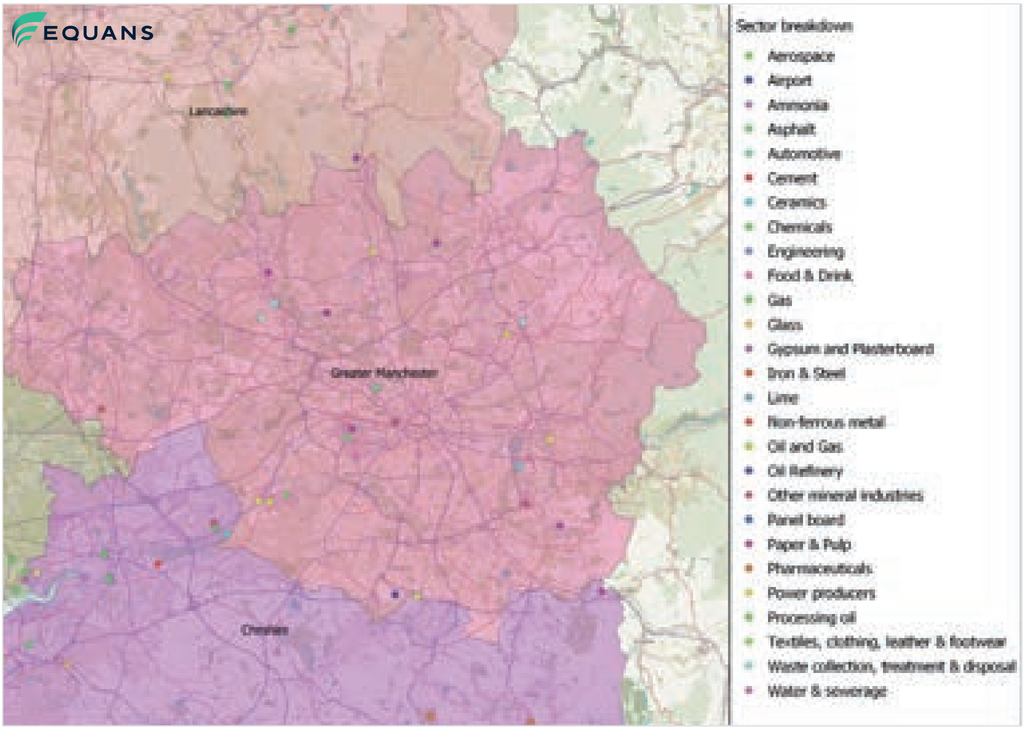

Figure 127 Greater Manchester sector breakdown of industrial sites

Figure 128 Merseyside sector breakdown of industrial sites

9. Appendices

9.1 Region Maps

The below figures illustrate the regional sectoral breakdown in the North West.

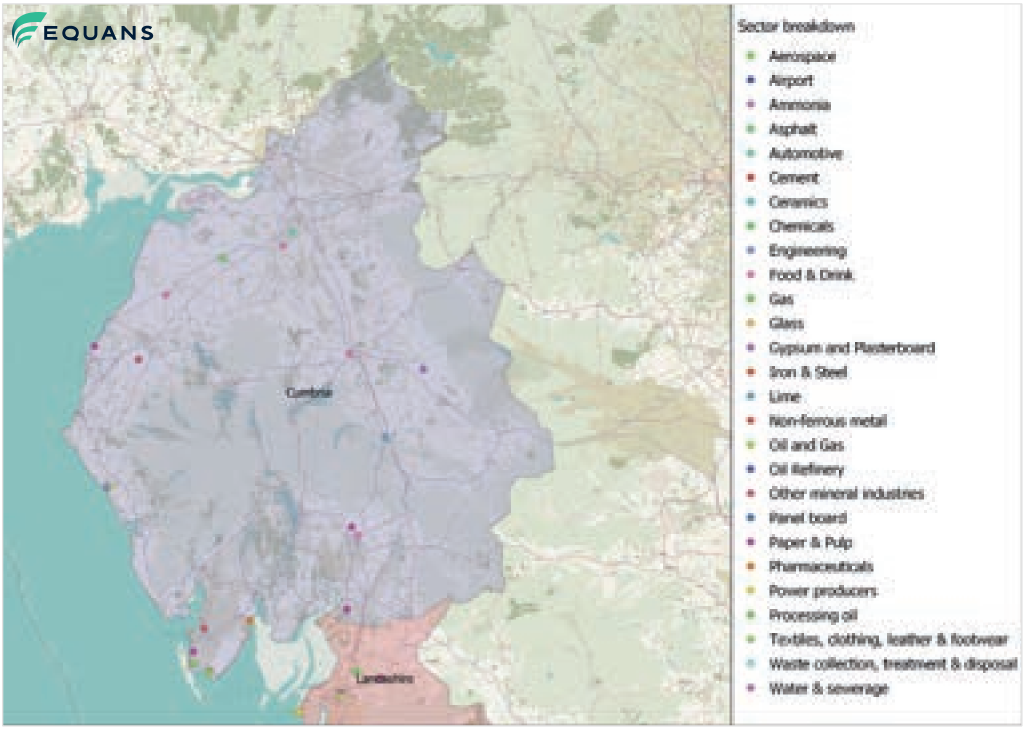

Figure 125 Cumbria sector breakdown of industrial sites

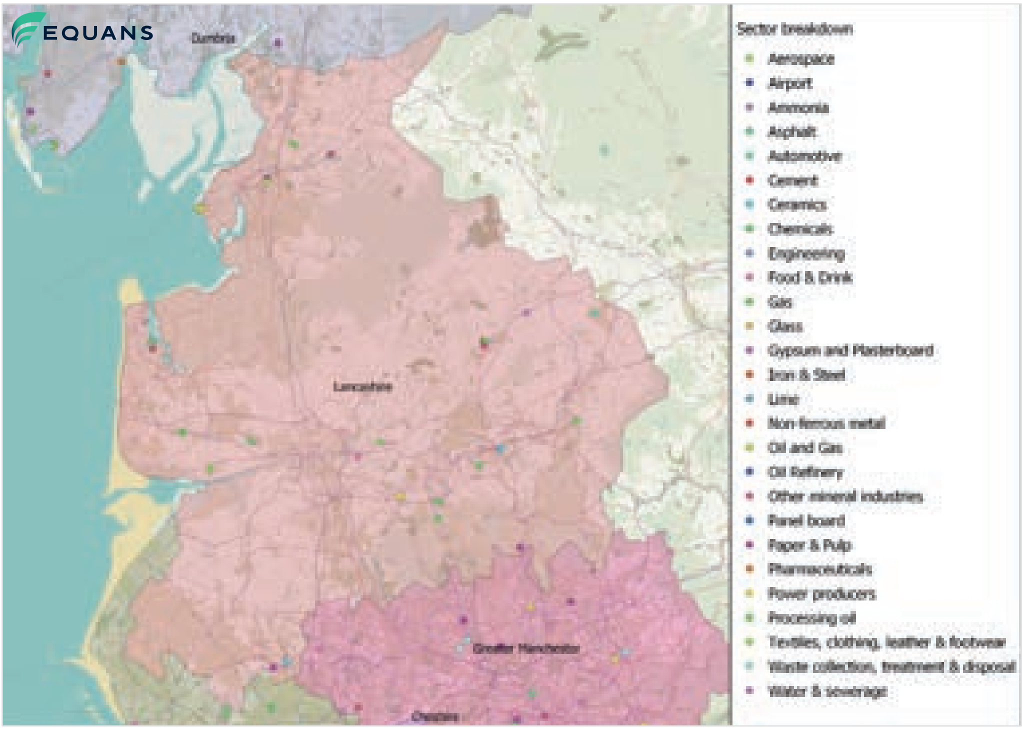

Figure 126 Lancashire sector breakdown of industrial sites

12. Table References

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