HUMBER INDUSTRIAL DECARBONISATION ROADMAP

BASELINE LOCAL EMISSIONS ASSESSMENT

A report for

Element Energy

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This report has been prepared by Element Energy.

Element Energy is a strategic energy consultancy, specialising in the intelligent analysis of low carbon energy. The team of over 60 specialists provides consultancy services across a wide range of sectors, including the built environment, carbon capture and storage, industrial decarbonisation, smart electricity and gas networks, energy storage, renewable energy systems and low carbon transport. Element Energy provides insights on both technical and strategic issues, believing that the technical and engineering understanding of the real-world challenges support the strategic work.

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1 Executive summary

The UK government recently enshrined in law a UK-wide 'net-zero' emissions target for 2050. Achieving this target will require rapid deployment of decarbonisation technologies like low-carbon hydrogen and carbon capture and storage (CCS) in all sectors, including industry. As the UK government's Industrial Clusters Mission indicates, clusters have a key role to play in triggering the development of large-scale decarbonisation infrastructure, including that for producing and transporting hydrogen and CCS.

The Industrial Strategy Challenge Fund (ISCF) by Innovate UK is one of the schemes launched by the UK government to accelerate deep decarbonisation of industrial clusters and establish "**the world's first net-zero carbon industrial cluster by 2040** and at least one low-carbon cluster by 2030", and the 'Humber Industrial Decarbonisation Roadmap' (HIDR) by Humber Local Enterprise Partnership (LEP) and CATCH was one of the projects awarded support under this scheme. This study is one of five work packages within the HIDR phase 1 project and focuses on the following:

- **Collection and presentation of relevant data about the Humber industrial cluster**, including data on emissions, fuel use, ongoing decarbonisation projects, and other information which may influence the HIDR.
- **Development of three 'business-as-usual' scenarios** that assess how emissions from the cluster may evolve until 2040 if no deep decarbonisation measure is implemented, an eventuality that is thought to be representative of what may happen unless new policies or economic incentives are put forward to stimulate deeper emission cuts. These scenarios also represent baselines for the development of the HIDR.

The geographical focus of this study is on the region around the Humber estuary defined by the four local authorities of the Humber: City of Hull, East Riding, North Lincolnshire, and North East Lincolnshire. This is a region of great strategic significance to the UK industrial and power sectors, since it represents the largest industrial hub in the UK – **a hub contributing 15% of the jobs and 23% of the GVA of the local economy** – and also its powerhouse, hosting **over 20% of the UK's electricity generation**, refineries that process a third of the UK's fuel, and numerous gas terminals and gas storage facilities.

The Humber today

Emissions from the Humber industries were estimated to be 14.8 MtCO_2 in 2017, including:

- 10.6 MtCO_2 emitted by 30 large industrial sites, with most of the emissions arising from the refining and iron and steel sectors.
- 1.3 MtCO_2 emitted by a multitude of smaller sites.
- 3.0 MtCO_2 emitted by combined heat and power (CHP) plants to generate steam used by the Humber industries.

A further 5.0 MtCO_2 was emitted from 13 power generators located within the Humber geography, which brings overall emissions from power generators and industries in the Humber to just under 20 MtCO_2. While this study specifically focuses on the Humber geography, synergies in the decarbonisation pathways of sites in and around the Humber may exist, as indicated by the partnerships established to deliver some of the decarbonisation projects reviewed below. Emissions from sites in the neighbouring regions were estimated to be just over 4 MtCO_2 for industry and 14 MtCO_2 for power generation (including the Drax Power Station).

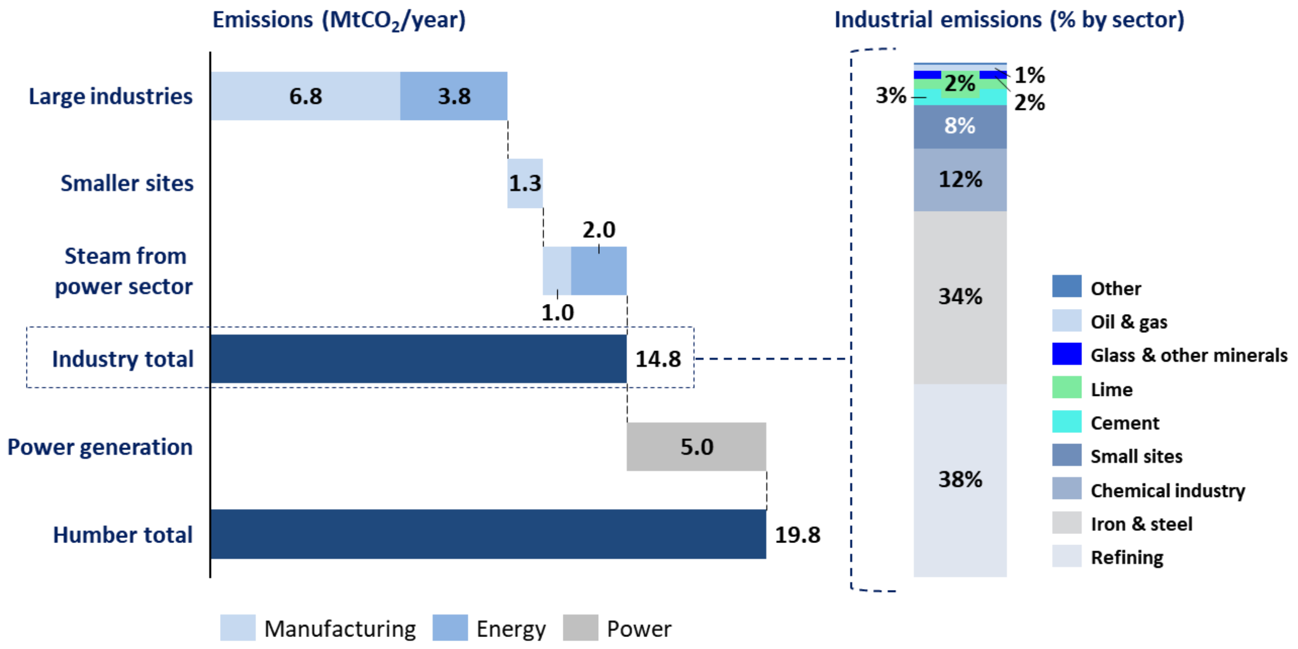

Figure 1: Emissions from the Humber industries and power generators

Two main sources of industrial emission can be defined:

- Fossil fuel combustion to supply energy (often heat) required by the industrial processes, leading to what is known as '**combustion emissions**'. It was estimated that the Humber industries burn just under 50 TWh of fossil fuels every year, which is the source of **93% of all industrial emissions**.
- **Industrial processes** that include chemical processes which emit CO_2, thus leading to 'process emissions'. It was estimated that the remaining **7% of all industrial emissions** arise from processes within the cement and lime, iron and steel, and refining sub-sectors.

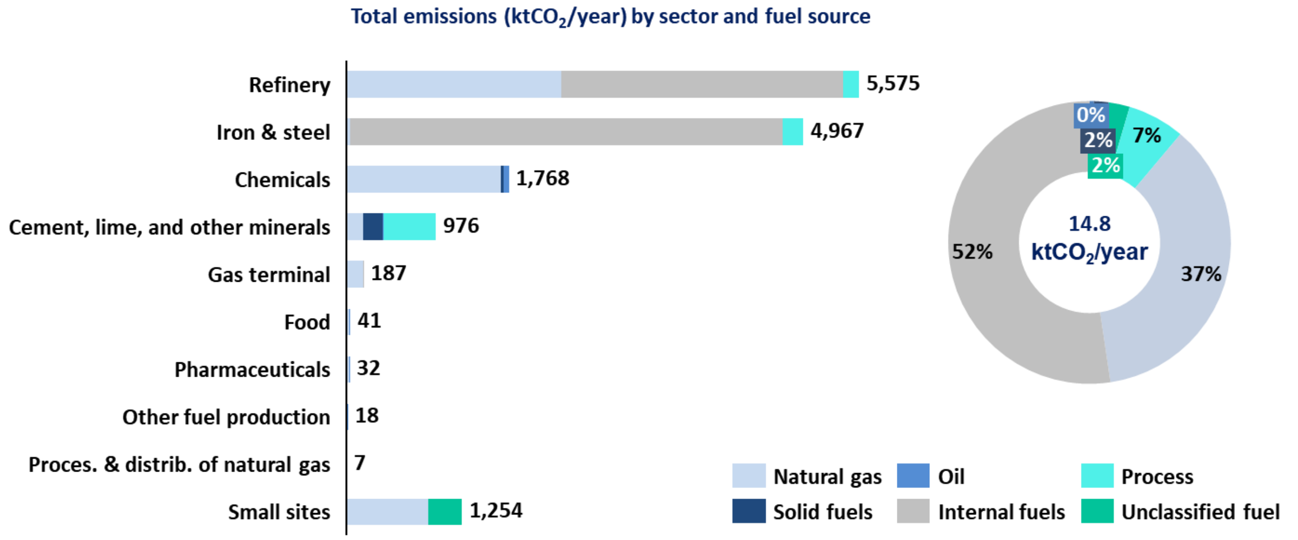

Figure 2: Breakdown of industrial emissions by source

Through more detailed analysis it was also estimated that **56% of the combustion emissions relate to *internal* fuels**, which are unavoidable by-products within some of the steel manufacturing and refining processes. The remaining 44% instead originates from *purchased* fuels, most of which is natural gas. For the purposes of the HIDR, **the distinction between internal and purchased fuels is critical since emissions from internal fuels can only be abated with CCS, by changing industrial processes, or by changing**

products, which are the only options to abate process emissions as well. Instead, purchased fuels can also be replaced with low-carbon alternatives, i.e. via fuel switching.

Emissions could reduce by 2-18% under 'business-as-usual' scenarios

Three 'business-as-usual' scenarios were evaluated in which no deployment of deep decarbonisation technologies occurs: a 'low emissions', a 'high emissions', and a 'central' scenario. Based on different sector-specific growth assumptions by UK Department for Business, Energy, and Industrial Strategy (BEIS), the scenarios are also characterised by different assumptions around the potential opening of new sites and closure of existing sited, as well as by different assumptions around the COVID-19 downturn.

Emission reductions of 2-18% between 2017 and 2040 are estimated to occur under the different 'business-as-usual' scenarios. As illustrated below, **the iron and steel and refining sectors are expected to be the biggest contributors to overall emissions reductions** in most scenarios, which is primarily due to their large relative size compared to other sectors. Differences in growth rates across sectors and between different scenarios have a more limited impact on the overall reduction in emissions. Nonetheless, it is noted that the results are sensitive to the assumptions made around the economic impact of COVID-19. Announced planned openings (e.g. the Altalto waste-to-jet-fuel plant) and closures (e.g. the Cemex cement plan) are also seen to moderately contribute to changes in emissions scenarios other than the 'central' one. Instead, the other sub-sectors give a marginal contribution to the overall change in emissions between 2017 and 2040. **These findings indicate a clear sectoral focus for the HIDR.**

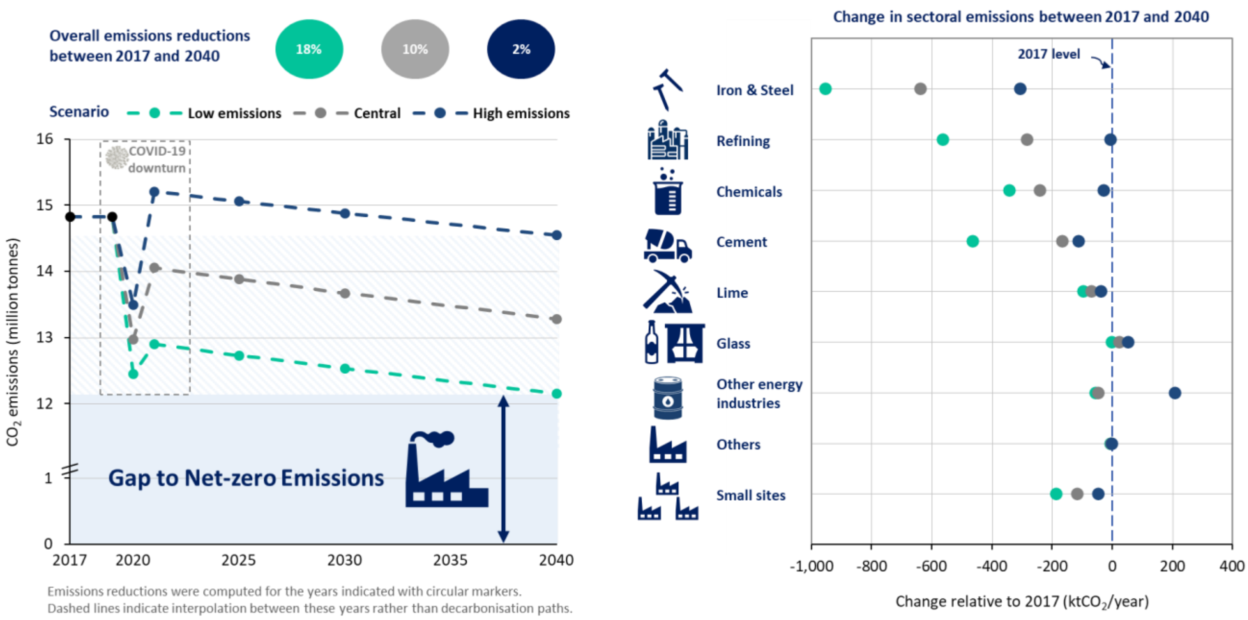

Figure 3: Overall and sector-specific emissions reductions in business-as-usual scenarios

Multiple decarbonisation projects are underway

While the business-as-usual' scenarios presented above assume that no deep decarbonisation occurs, it is noted that **several decarbonisation projects have been announced in recent years which aim to deliver substantial emissions abatement for some of the Humber's largest industries**. Reviewed projects include the two ISCF-supported deployment projects known as 'Humber Industrial Decarbonisation Deployment Project' (Humber-DP) and 'Green Hydrogen for the Humber', as well as the related projects 'Gigastack', 'Humber Zero', and 'Zero Carbon Humber'. These projects investigate multiple ways to deeply decarbonise industry, including:

- Green hydrogen, which could be produced via the electrolysis of water (or 'water splitting') powered with electricity from nearby offshore wind farms. There are currently no announced projects exploring green hydrogen production from biomass is in the region.
- Blue hydrogen, which could be produced in natural gas reformers equipped with carbon capture.
- CCS, also in combination with bioenergy (BECCS) to achieve negative emissions, applied to both industrial processes and to CHP plants.

Although these projects are at an early development stage today, they aim to deploy substantial **decarbonisation infrastructure by the mid-2020s**, which could potentially **generate the necessary momentum to transform the Humber into the first net-zero cluster by 2040**.

Table 1: Major decarbonisation projects in the wider area

	Green hydrogen	Blue hydrogen, CCS, BECCS
Projects	Gigastack Green Hydrogen for the Humber	Humber Industrial Decarbonisation Deployment Project (Humber-DP) Humber Zero Zero Carbon Humber
Infrastructure	Multiple 100 MW electrolysers powered by offshore wind at the Phillips 66 refinery and other sites in Immingham. A 'Gigafactory' near Sheffield to manufacture up to 1 GW/year of electrolysers by 2025.	Large-scale CCS network including BECCS at the Drax Power Station and CCS at the VPI Immingham CHP plant and Humber refinery. Hydrogen production hubs near the Drax site and in Immingham. Aims to develop initial infrastructure by themid-2020s.
Stakeholders	ITM Power; Ørsted; Phillips 66.	Associated British Ports; Centrica Storage; Drax Group; Equinor; National Grid Ventures; Phillips 66; PX Group; SSE Thermal; Saltend Cogeneration Company; VPI-Immingham; Uniper.
Timeline	*Gigastack*: FEED study since Feb '2020 *GHFH*: feasibility study since Apr '2020	*Humber-DP*: feasibility study since Apr '2020 Other projects: unknown.

A decarbonisation roadmap for clean growth

In conclusion, it is noted that the scenarios assessed here appear to fall short of what is required to meet the 2050 net-zero targets, unless industry decarbonises at a much faster pace between 2040 and 2050, or substantial negative-emission technologies are deployed. If all UK industries were to follow the trajectory estimated above for the Humber cluster, **industrial emissions in 2040 would be 57% below 1990 levels at best, or over 75 MtCO_2 when assessed at the UK level**. If emissions reductions continued at the same rate until 2050, emissions would reduce to 68% below 1990 levels by then. This represents a large gap that future decarbonisation projects should aim to bridge.

Considering the major contribution that the Humber cluster makes to both the UK's industrial emissions and the local economy, and in view of the existential risk faced by industries that fail to decarbonise while the world moves towards net-zero, **the development of a Humber Industrial Decarbonisation Roadmap appears necessary**. By creating **a shared vision for decarbonising the Humber**, the HIDR could help to catalyse change among local industries. Beyond this, it could also send a signal to investors who may find the **'net-zero cluster' brand** attractive – especially those looking to develop the industries needed in the future net-zero economy. For these reasons it is envisioned that the development of a deep decarbonisation roadmap for the Humber industries is not only a necessity to meet climate targets, but also an **opportunity to stimulate clean growth**.

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Acronyms

ATR	Autothermal Reformer
BAU	Business as Usual
BECCS	Bioenergy with Carbon Capture and Storage
BEIS	UK Department for Business, Energy, and Industrial Strategy
BFG	Blast Furnace Gas
BOSF	Basic Oxygen Steelmaking Gases
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
COG	Coke Oven Gas
EU	European Union
ETS	Emissions Trading Scheme
FEED	Front-End Engineering Design
GHG	Greenhouse Gas
GVA	Gross Value Added
GW	Gigawatt
ha	Hectares
H_2	Hydrogen
ISCF	Industrial Strategy Challenge Fund
kt	Kilotonne
kW	Kilowatt
Mt	Megatonne
MW	Megawatt
PEM	Polymer Electrolyte Membrane
SMR	Steam Methane reformer

Note on terminology

'**Blue hydrogen**' refers to hydrogen produced from a feedstock of natural gas by steam methane reforming (SMR) or autothermal reforming (ATR) coupled with carbon capture, and storage (CCS) of the resulting carbon dioxide emissions. '**Green hydrogen**' refers to hydrogen produced through water electrolysis using renewable electricity. '**Low-carbon hydrogen**' refers to both blue and green hydrogen.

'**CCS**' is preferred to the more general 'CCUS' (i.e. carbon capture, utilisation, and storage) because of the specific focus of this report on deep decarbonisation, only attained if there is *permanent sequestration* of the captured CO_2. In reading this report, the term CCS should be intended as also referring to forms of CO_2 utilisation that can ensure permanent sequestration.

2 Introduction

2.1 Background

The UK government recently enshrined in law a UK-wide net zero emissions ('net-zero') target for 2050, which requires ambitious reduction of emissions across all sectors of the UK economy, including industry and power. Achieving this target will require rapid deployment of key decarbonisation technologies such as low-carbon hydrogen and carbon capture and storage (CCS). Due to their potentially pivotal role in initiating hydrogen (green or blue)[1] and CCS infrastructure and essential contribution to the UK economy, industrial clusters are seen as a focus area for the decarbonisation efforts. This focus is further justified by the observation that UK industries face an ever more challenging environment due to their exposure to progressively increasing carbon tariffs. Without the right tools to deeply decarbonise, such exposure could threaten millions of UK jobs over the coming decades. This risk was recognised by the UK Government, which in response pledged to support industrials decarbonisation efforts with the stated aim to "establish the world's first net-zero carbon industrial cluster by 2040 and at least one low-carbon cluster by 2030", in line with the UK government's Industrial Clusters Mission and Clean Growth Strategy.[2]

The Industrial Strategy Challenge Fund (ISCF) by Innovate UK is one of the schemes that the UK government established to support the decarbonisation of industry by accelerating the deployment of low-carbon technologies across multiple clusters. A partnership between the Humber Local Enterprise Partnership (LEP) and membership organisation CATCH was among the six winners of the recent 'Roadmap' competition, each of whom secured funding from the ISCF to commence the development of feasible decarbonisation roadmaps able to implement relevant decarbonisation infrastructure by the mid-2020s.

This report summarises the findings from one of five work packages that, combined, make up the first phase of the 'Humber Industrial Decarbonisation Roadmap' (HIDR). Within the context of the HIDR, this study focuses on the collection and presentation of data that is relevant to current and future emissions in the cluster under business-as-usual (BAU) scenarios. In a potential second phase of the project,[3] the HIDR will then progress in formulating one or multiple strategies to "enable the Humber's large industrial emitters, low carbon infrastructure providers and other stakeholders to develop a shared approach to achieving net-zero by 2040".[4]

2.2 Study aims and approach

This study seeks to develop illustrative business-as-usual scenarios for the evolution of emissions in the Humber over the next two decades, and to collect relevant evidence that may be relevant to the development of the HIDR. Since the HIDR may need to consider a broad range of decarbonisation options – including substituting fossil fuels with low-carbon alternatives like hydrogen or electricity ('fuel switching'), CCS, and other measures that can help bring greenhouse gas (GHG) emissions to net-zero[5] – relevant evidence includes data on emissions and fuel use within industry as well as other information about infrastructure and projects under development that may have an impact on local emissions. As outlined below, the analysis was divided into three tasks.

[1] See note on the terminology on the previous page for a definition of 'blue' and 'green' hydrogen.
[2] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/803086/industrial-clusters-mission-infographic-2019.pdf.
[3] Progress to the next phase is dependent on a separate bid to Innovate UK.
[4] https://www.ukri.org/news/ukri-allocates-funding-for-industrial-decarbonisation-deployment-and-roadmap-projects/.
[5] E.g. electrification, energy efficiency, process changes, and bioenergy (potentially in combination with CCS).

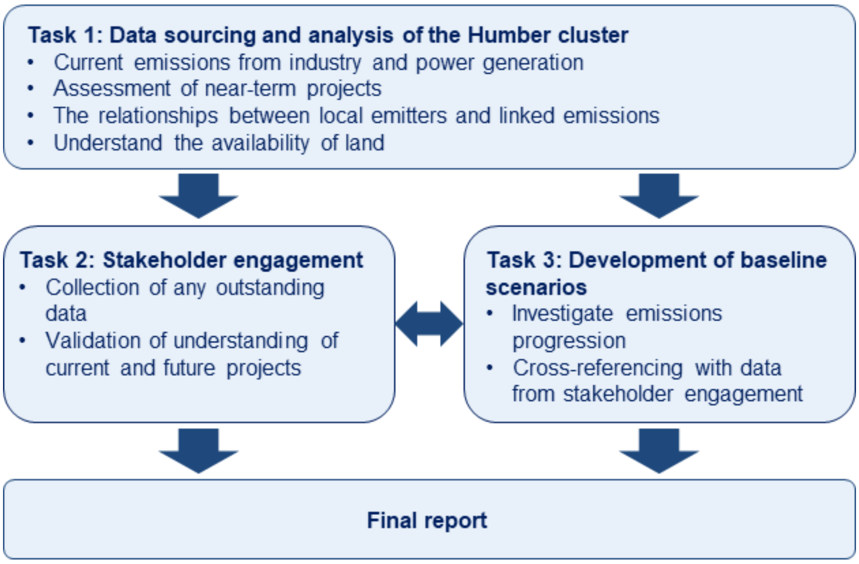


Figure 4: Overview of assessing Humber's emissions

Task 1: Data collection and preliminary analysis of the current emissions and fuel use among Humber industries. Specific steps included:

- Data on site-level (Scope 1)[6] emissions was retrieved from the National Atmospheric Emissions Inventory by BEIS (2017)[7] and validated by comparing it with site-level emissions data from the European Union Emissions Trading Scheme (EU ETS)[8] and with aggregate emissions data reported by each local authority.[9] The latter was also used to estimate cumulative emissions from smaller sites below the reporting threshold. The breakdown of emissions by industrial sub-sector presented in Section 3.1 was thus created.
- Data on energy and fuel use by industry sub-sector was retrieved from Energy consumption in the UK (ECUK) end-use tables,[10] and this was complemented with data on process emissions and internal fuel use from publicly available literature and previous models by Element Energy. This was combined with the NAEI emissions data to obtain the breakdown of emissions by source (i.e. fuel type and process) shown in Section 3.2.
- Additional data that may be relevant to the HIDR was also collected, including data on: current and planned power generation capacity[11] (Section 3.3); announced site openings and closures (Section 4.1); decarbonisation projects in the region (Section 4.2); and available employment land on which these projects may be built (Section 4.3).

Task 2: Stakeholder engagement to validate the analysis. Specific steps included:

- Representatives from ten of the largest sites across all industry sub-sectors were contacted. Seven of them – collectively responsible for 89% of all industrial emissions in the Humber – replied.
- Representatives from VPI Immingham and PX Group were also consulted to understand which emissions from the combined heat and power (CHP) plants in Immingham and at the Saltend Chemicals Park should be 'linked' to the industrial sector rather than to the power sector (discussed in Section 3.1).

[6] I.e. those emissions occurring from on-site combustion of fossil fuels or directly arising from industrial processes. Emissions related to the generation of electricity imported from the grid (Scope 2) and arising alongside other parts of the supply and value chains (Scope 3) are beyond the scope of this study. For further detail on the categorisation of scope 1/2/3 emissions see https://www.carbontrust.com/resources/what-are-scope-3-emissions.
[7] NAEI large point source, (dataset of 2017) by the UK Department for Business, Energy, and Industrial Strategy (BEIS). Retrieved at https://naei.beis.gov.uk/data/map-large-source.
[8] https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1.
[9] https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-to-2017.
[10] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk.
[11] From the Renewable Energy Planning Database (REPD) https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract.

- Finally, a representative from Velocys was interviewed to understand the potential level of emissions that could be expected if the Altalto project is successfully developed (discussed in Section 4.1). Representatives of other industrial sites announced or under construction could not be reached.
- All the inputs from the stakeholder consultation were integrated in the analysis above to improve the accuracy of the results presented in the sections below.

Task 3: Design of three illustrative business-as-usual scenarios to evaluate how emissions are likely to evolve until 2040. Specific steps included:

- Baseline emissions for 2017 were defined in Task 1. Starting from these, three business-as-usual scenarios were developed to represent possible futures where no deep decarbonisation measure is implemented across industries in the Humber. The BAU scenarios are described in Section 5.1.
- These illustrative scenarios provide a baseline against which potential deep decarbonisation pathways could be assessed in the next phase of the study.[12] Emissions projections for 2025, 2030, and 2040 are presented in Section 5.2

2.3 Geographical scope

Located around the Humber estuary and spreading from the eastern coast of Yorkshire to the north-eastern part of Lincolnshire, **the Humber cluster is the largest industrial cluster in the UK** by both greenhouse gas emissions and energy consumption. In addition to the great strategic significance of this region to the UK industrial sector, the Humber is also the country's powerhouse: **over 20% of the UK's electricity** is generated here, and a third of its refined fuel as well as a fifth of its natural gas imports are also processed in the Humber, which is why the Humber estuary is also referred to as the 'Energy Estuary'.[13] Last but not least, the Humber industries play a **critical role within the local economy**, to which they contribute about **15% of the jobs** and **23% of the gross value added (GVA)**.[14]

This study focuses on industries located within the boundaries of four local authorities: City of Hull, East Riding of Yorkshire, North Lincolnshire, North East Lincolnshire, which collectively constitute the Humber. Despite the specific geographic focus, it is recognised that there may well be synergies and interdependencies between industries in the Humber and some of their neighbours when it comes to driving down emissions and devising cost-effective ways to deploy the low-carbon infrastructure needed to deeply decarbonise the region. Drax Power Station for instance has already announced plans for developing a CCS network which industrial users in the Humber could utilise.[15] Likewise, a region-wide hydrogen network could connect low-carbon hydrogen supply and use in and around the Humber, one day possibly also across the rest of the UK.[16] For this reason, the wider region mapped in Figure 5 is considered in the review of relevant decarbonisation projects and power generation infrastructure discussed below.

[12] The next phase of the study is pending on the approval of the upcoming proposal which will be submitted to Innovate UK building on the results from this and other studies occurring in parallel.
[13] https://www.humberlep.org/infrastructure/energy/.
[14] Carbon Trust. (2018). Study of the Humber Energy Intensive Industries Cluster. Retrieved from https://www.humberlep.org/wp-content/uploads/2018/03/Background-Paper-Energy-Intensive-Industries-Cluster-Study.pdf.
[15] See the Zero Carbon Humber project discussed in Section 4.2.
[16] For instance, Sheffield City Region has already stated its aspiration to use hydrogen supplied from the Humber, see https://www.arup.com/perspectives/publications/research/section/establishing-a-regional-hydrogen-economy.

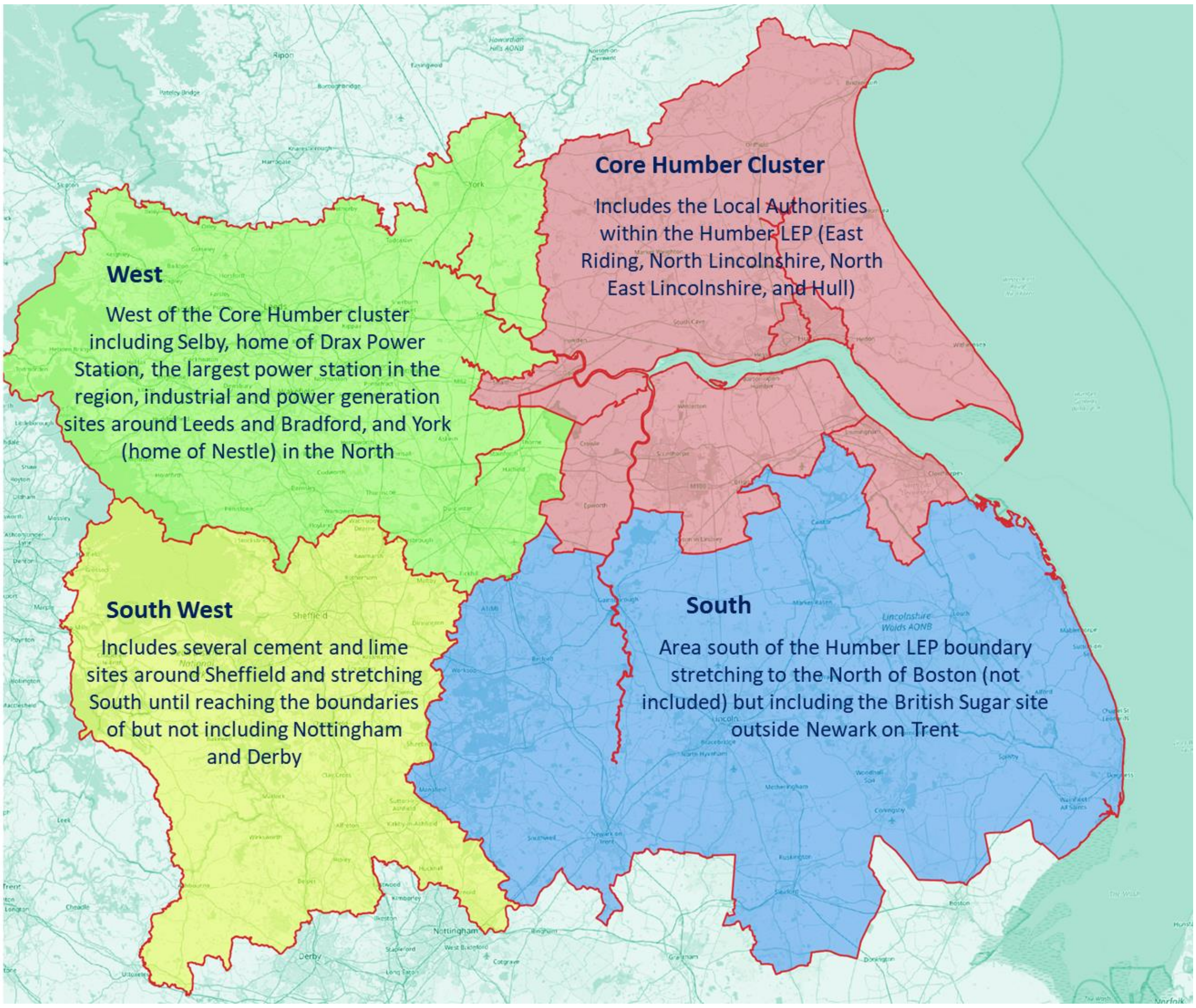


Figure 5: Map of the wider Humber region

The core Humber cluster can be further divided into geographical hotspots or **three sub-clusters**, a conceptualisation that can help better focus on shared pathways for decarbonising neighbouring sites. This approach is purely based on the localisation of direct atmospheric emissions and does not completely describe the political, strategic, and business environment of the region, which is considerably more complex, and features significantly large businesses, key for the local economy, that are not mentioned below.

- The **southern sub-cluster**, which includes the two refineries, the VPI Immingham combined heat and power (CHP) plant which supplies them steam and power, the Uniper power station in Killingholme, as well as various other industries in the local authorities of North Lincolnshire and North East Lincolnshire. This sub-cluster may soon also include the Altalto waste-to-jet-fuel plant, which recently obtained planning approval for its Immingham site. Considering that hydrogen is already used in the refining process, it is no surprise that this sub-cluster is already at the centre of the ‘Gigastack’ and ‘Green Hydrogen for the Humber’ projects discussed in Section 4.2.
- The **northern sub-cluster**, which includes the chemical sites and the Triton Power CHP at the Saltend Chemicals Park, the largest plant in the food sub-sector within the Humber, and a number of gas terminals as well as other sites in East Riding of Yorkshire and Kingston upon Hull. Given the types of industries located in the northern sub-cluster (mainly chemical plants), the interconnection of chemical feedstocks within the sub-cluster leading to linked emissions, and the favourable location to port and pipeline infrastructure, likely decarbonisation of industry could involve hydrogen fuel switching and/or electrification. It must be noted that most of the emissions corresponding to the northern sub-cluster are concentrated

around Hull and to the south of the East Riding of Yorkshire, due to the rural environment in the northern part of the East Riding. However, there are opportunities for the area to leverage current and future businesses, both on-shore and off-shore, all the way north to Teesside.

- The **western sub-cluster**, which includes British Steel in Scunthorpe, the single largest emitter in the Humber, manufacturers of glass and other non-metallic minerals as well as other industrial and power generation sites in North Lincolnshire and the East Riding of Yorkshire. The western sub-cluster also extends west across the boundary with North Yorkshire to include Drax near Selby, which may act as the anchor project for future CCS projects involving this sub-cluster such as the Humber-DP and others discussed in Section 4.2.

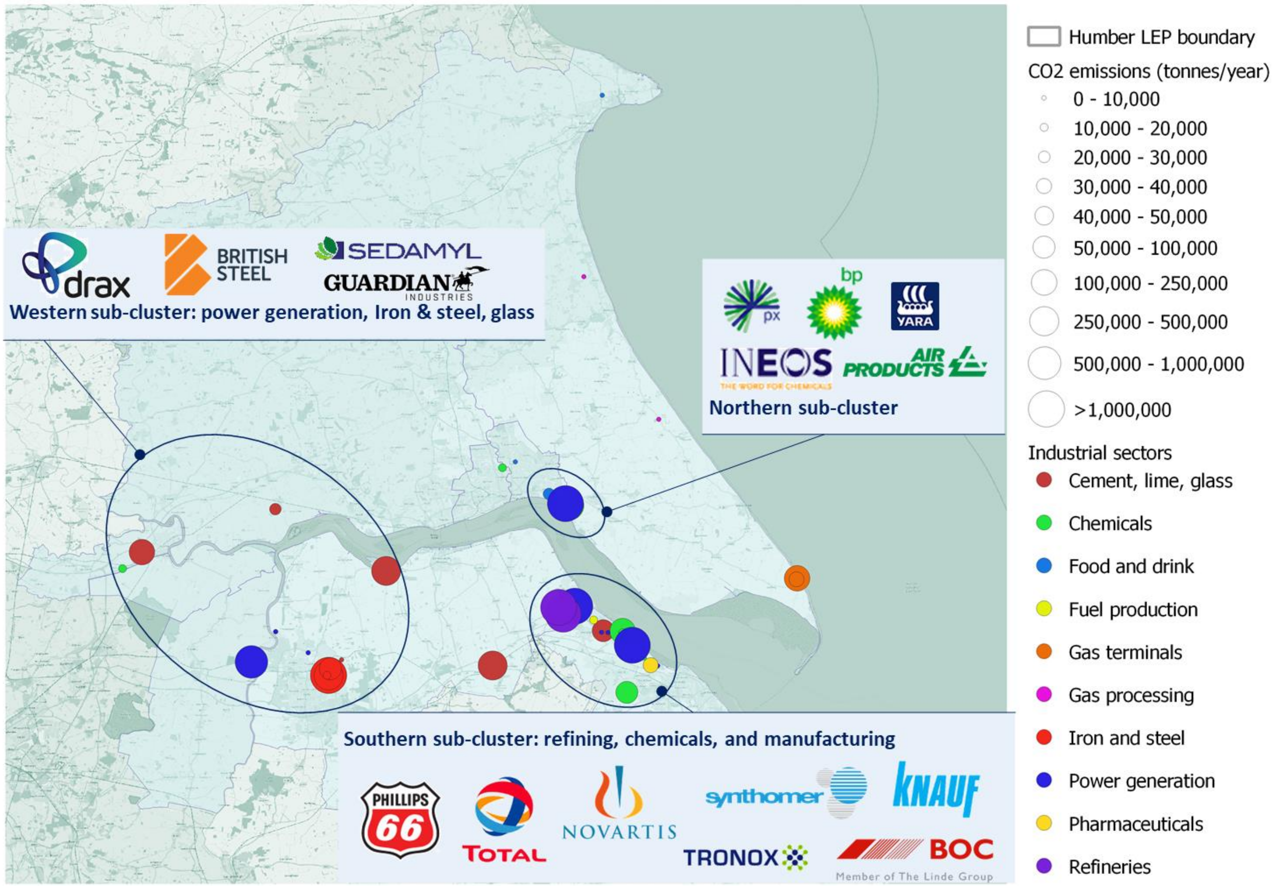


Figure 6: Overview of the main emitters within the Humber and emissions sub-clusters

3 The current industrial landscape

3.1 Emissions from the Humber industries

Emissions in scope

To aid the future development of the Humber Industrial Decarbonisation Roadmap, the first step of the analysis sought to establish a robust baseline for industrial emissions in the Humber. Specifically, the focus is on emissions of carbon dioxide (CO_2) arising from on-site fuel combustion ('combustion emissions') or directly from industrial processes ('process emissions'), collectively defined as 'scope 1' emissions.[17] Three sources of scope 1 emissions have been considered within the analysis presented below:

- Emissions from the large industries included in the National Atmospheric Emissions Inventory (NAEI) by BEIS (2017).[18]
- Emissions from smaller sites estimated from statistics at local authority level.[19]
- 'Linked emissions', i.e. emissions associated with the generation of *steam* at combined heat and power (CHP) plants listed within the power sector but used by industrial sites.[20]

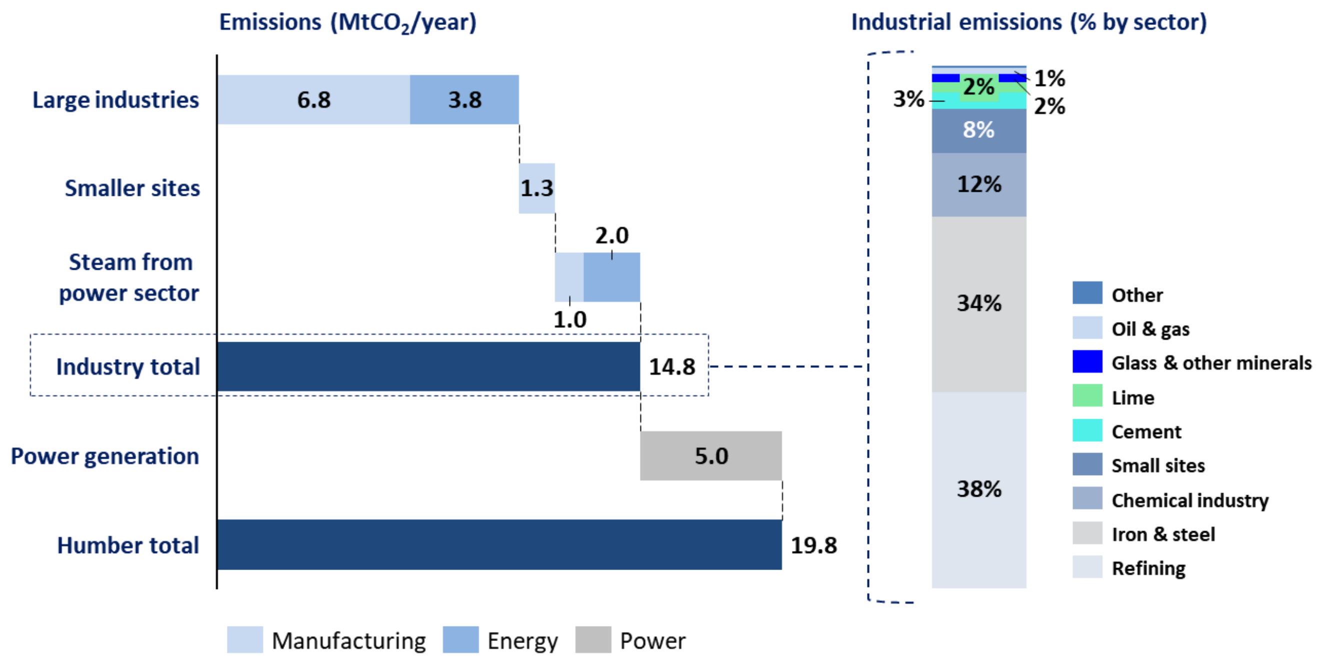


Figure 7: Emissions from the Humber industries and power generators

As shown on the left-hand side of Figure 7, it was determined that **emissions from the Humber industries amounted to 14.8 $MtCO_2$** (million tonnes of CO_2) in 2017. This includes:

- Just under 10.6 $MtCO_2$ from 30 large industrial emitters,[21]
- Just under 1.3 $MtCO_2$ from smaller industrial sites, and

[17] Unless otherwise specified, the emissions discussed below always refer to scope 1. scope 2 and 3 emissions are related to the generation of electricity imported from the grid and to other supply chain emissions, respectively. For further detail see https://www.carbontrust.com/resources/what-are-scope-3-emissions.
[18] NAEI large point source, (dataset of 2017) by the UK Department for Business, Energy, and Industrial Strategy (BEIS). Retrieved at https://naei.beis.gov.uk/data/map-large-source.
[19] See reports from the four local authorities in the Humber at https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-to-2017.
[20] Linked emissions related to electricity generation at the same CHP plants was kept within the 'power generation' subtotal for consistency. Linked emissions are further discussed below.
[21] 6.8 $MtCO_2$ from 23 manufacturing sites, and 3.8 $MtCO_2$ from 7 energy industries (mostly the two refineries).

- 3.0 $MtCO_2$ emitted by sites within the power sector but related to industrial steam use ('linked emissions').

In terms of the sectoral distribution of these emissions, it can be seen from the right-hand side of Figure 7 that there is a high concentration of emissions within just two sub-sectors (and sites). Indeed, seven sites in **the iron and steel and refining sub-sectors contribute just over a third of all industrial emissions each**,[22] with the remaining 23 sites across all other sub-sectors responsible for the remaining 28%. For context and completeness, **a further 5.0 $MtCO_2$ is emitted from 13 power generators across the Humber.**[23]

Estimated emissions from smaller sites

For each of the local authorities of the Humber, the largest contribution to overall emissions is from 'Large Industrial Installations' – i.e. those further broken down in the NAEI[24] and already analysed above.[25] Scope 1 emissions from smaller sites are here estimated on the basis of those emissions reported at local authority level as linked to 'Industry and Commercial Gas' and 'Industrial and Commercial Other Fuels', though these also include an unknown contribution from non-industrial (commercial) sites.[26] Smaller sites are treated as an independent sub-sector since published local authority-level emission data does not provide the level detail require to allocate emissions from small sites to specific sub-sectors.

Linked emissions from industrial steam use

Although this study focuses on industrial sites, a significant amount of the steam used in industry for heating purposes is raised by classified 'power generation', rather than 'industry'. Since the process of generating steam today entails substantial use of fossil fuels[27] and hence causes substantial CO_2 emissions, it is useful for the purposes of this study to also estimate the portion of such emissions that will need to be tackled by the HIDR.

Two large CHP plants are known to supply large amounts of steam to industrial users: the VPI Immingham CHP plant, which supplies the refineries in the Southern sub-cluster, and the Triton Power CHP plant, which supplies a number of chemical industries located in the Saltend Chemicals Park (see Figure 8). Linked emissions from these sites were estimated based on input from representatives of VPI Immingham and PX Group (owner and operator of the Saltend Chemicals Park and responsible for its internal steam network).[28] The main linked emissions uncovered through this analysis are:

- 2.0 $MtCO_2$ associated with steam raised by VPI Immingham and supplied to the two nearby refineries. It should also be noted that the same CHP also uses some of the surplus gas from the Humber Refinery and supplies electricity via direct wire to the Phillips 66.[29]
- 1.0 $MtCO_2$ associated with steam raised by Triton Power and supplied by PX Group to multiple sites within the Saltend Chemicals Park. Figure 8 also shows some of the additional links between these sites, i.e. chemical feedstock, and electrical power.[30]

[22] The seven sites include four operated by British Steel, one by Liberty Steel, and the two refineries.
[23] This already excludes the 3.0 $MtCO_2$ related to industrial steam use.
[24] The equivalence of the 'Large Industrial Installations' to NAEI sites is explicitly mentioned by BEIS (2019), UK local authority carbon dioxide emissions estimates 2017. https://www.gov.uk/government/collections/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics.
[25] Note that a difference of about 0.1 $MtCO_2$ exists between NAEI emissions from manufacturing industries (6.9 $MtCO_2$, when also including Vivergo Fuels, which was excluded from the present analysis due to its recent closure) and those reported by local authorities (7.0 $MtCO_2$). This small discrepancy is assumed to be due to methodological differences.
[26] Other emission categorised as 'Industry and Commercial Electricity' and 'Agriculture' were excluded as not in scope here.
[27] Generally, steam is raised by burning natural gas within the combustion chamber of combined-cycle gas turbines or in steam boilers. In the future, steam could however be raised in alternative, lower-carbon ways.
[28] PX Group manages the entire steam infrastructure at Saltend and are hence best positioned to provide the detailed information required for the HIDR.
[29] Refinery surplus gases account a negligible proportion (<3%) of the fuel used by VPI Immingham, according to representatives from VPI Immingham. Most of the electricity is supplied to the national grid. All information shared here is based on feedback from VPI Immingham, but some of it can also be found on https://www.vitol.com/working-with-us/our-companies/vpi-immingham/.
[30] Of the 7.0 GWh of electricity supplied by Triton Power in 2019, only 0.6 GWh were supplied to users of the Saltend Chemicals Park, with the rest fed to the grid. Source: interview with PX Group.

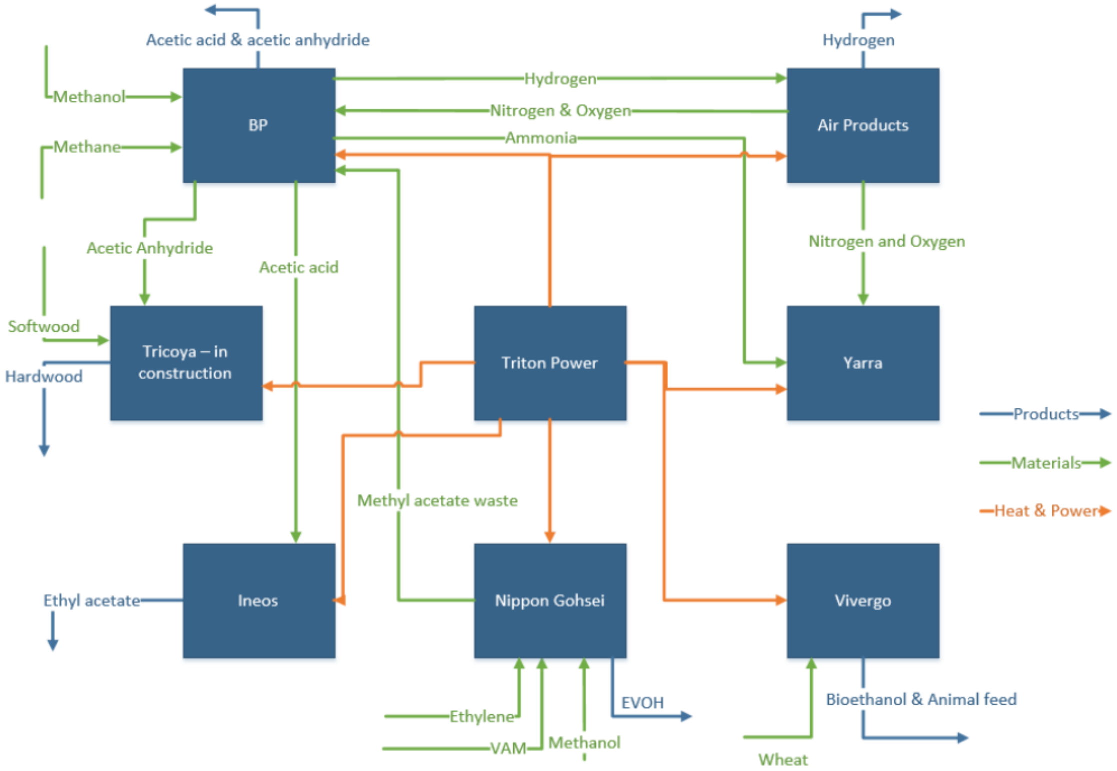


Figure 8: Illustrative links between sites at Saltend Chemicals Park in 2018.[31]
Source: Carbon Trust (2018)[32]

Emissions from the wider region

The decarbonisation of the Humber industries may leverage synergies with or unlock the decarbonisation of other sites located in the neighbouring regions mapped in Figure 5. For this reason, emissions from sites outside the Humber were also analysed and are reported in Table 2. This highlights that the power generation sector (20 power stations) is by far the main source of CO_2 emissions south and west of the Humber, responsible for 77% of the total. Beside this, the main industries in the wider region include multiple cement and lime plants southwest of the Humber, which are responsible for 2.6 $MtCO_2$, and a few glass smelters in the west responsible for 0.6 $MtCO_2$.

[31] It is noted that the diagram may contain inaccuracies, e.g. the finished product from Tricoya is acetylised wood and not hardwood.
[32] Carbon Trust. (2018). Study of the Humber Energy Intensive Industries Cluster. Retrieved from https://www.humberlep.org/wp-content/uploads/2018/03/Background-Paper-Energy-Intensive-Industries-Cluster-Study.pdf.

Table 2: Emissions from industry and power in the wider region (all values in $ktCO_2$)[33]

Region (relative to the Humber)	Power generation	Manufacturing industries	Energy industries	Total
Core	4,978	7,784	5,787	18,549
South	7,672	183	141	7,996
West	6,430	884	7	7,321
Southwest	44	3,051	29	3,123
Total	19,123	11,902	5,964	36,989

3.2 Breakdown of industrial emissions by source

To evaluate the most relevant decarbonisation pathway for each sub-sector it is key to understand the source of emissions further. At the highest level, it is possible to discern between emissions originating from the combustion of fossil fuels to supply energy to a process ('combustion emissions') and those arising directly from industrial processes and the chemical reactions within these ('process emissions').[34] Figure 9 summarises the results from this categorisation, explored in more detail in the sub-sections below.

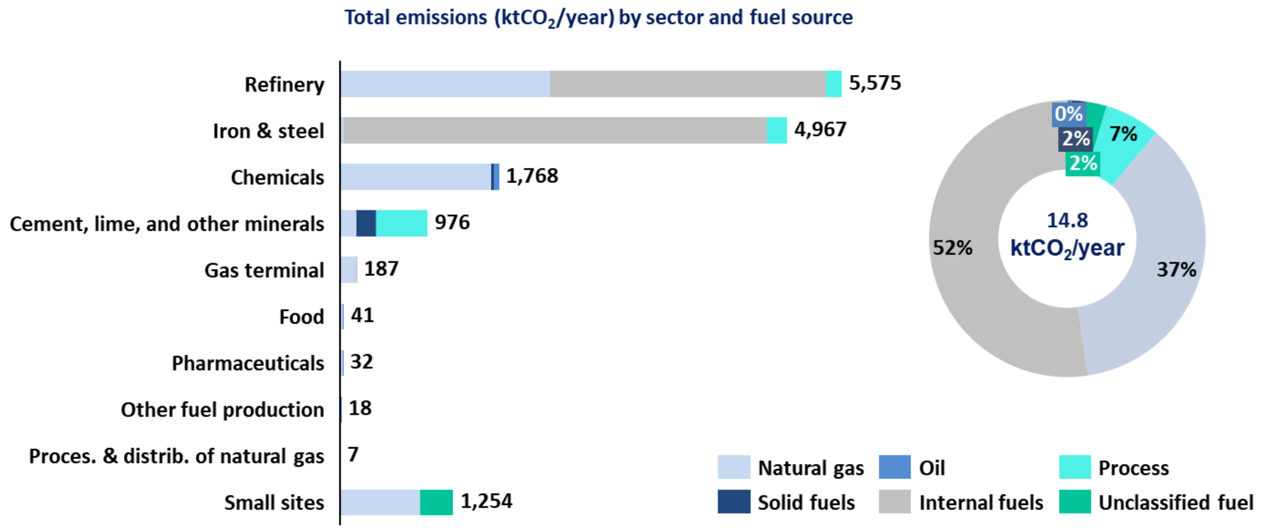


Figure 9: Breakdown of industrial emissions by source

Combustion emissions

Usage of fossil fuels usually involves direct burning or "combustion" to generate heat, alongside carbon dioxide as a by-product. About **46 TWh of fossil fuels** are estimated to have been combusted by industries in the Humber in 2017, which is the source of **93% of all emissions**. For the purpose of the HIDR, **an important distinction must be made between *purchased fuels*** (like natural gas, oil and coal), which represent 41% of total emissions, **and *internal fuels***, which are unavoidable by-products within some of the steel manufacturing and refining processes and are responsible for more than half (52%) of all emissions. This distinction is critical for the purposes of the HIDR because, differently from emissions from purchased fuels, which can be abated through fuel switching**, emissions from internal fuels can only be abated with CCS or process change**. This is because internal fuels are co-produced in fixed proportions to the main output product and must always

[33] Source: NAEI (2017). For the core Humber cluster, the reported emissions include the adjustments for 'linked emissions' discussed above. It is also noted that emissions from power generation in the 'West' region may have changed since 2017 due to the progressive replacement of coal with biomass at the Drax Power Station.
[34] Generally, process emissions arise from a chemical reaction taking process during the manufacturing process (e.g. such as in the production of cement). The only exception is flaring, discussed in footnote 40.

be combusted, hence the corresponding emissions cannot be reduced without changing the process or the product.[35] Emissions linked to internal fuels could instead be abated via post-combustion CO_2 capture (i.e. by capturing the flue gases from their combustion) or by converting internal fuels into blue hydrogen (which also requires CCS) and then combusting hydrogen instead.

The most common internal fuels encountered in the Humber are:

- The blast furnace gases (BFS), coke oven gases (COG), and basic oxygen steelmaking gases (BOSG) arising at various steps of the steelmaking process.[36]
- Surplus gases and the petroleum coke (or 'pet coke') generated within the refineries.[37]

Natural gas is instead the most common among the purchased fossil fuels both in industry and in the power sector, where it accounts for the near totality[38] of fuel use after the recent closure of the last coal power stations.[39] The use of fuel oil and solid fuels is instead far more limited, accounting for only 5% of total emissions (when including the 2% related to unclassified fuels from smaller sites shown in Figure 9).

Process emissions

The remaining **7% of all industrial emissions arises directly from industrial processes**. The main carbon-emitting processes in the Humber are the limestone calcination reaction (cement and lime sub-sectors), steam-methane reforming (SMR) and flaring at the refineries,[40] the iron reduction reaction at Scunthorpe, and the glass smelting process. Due to their independence from fuel combustion, process emissions cannot be abated via fuel switching. Instead, **the abatement of process emissions must rely on CCS or process change**.

3.3 Power generation in the wider region and offshore

As previously mentioned, a high share of the UK electricity is generated in the Humber – the 'Energy Estuary'.[41] This section explores in greater detail the power generation sources, both fossil and renewable.

Fossil generation

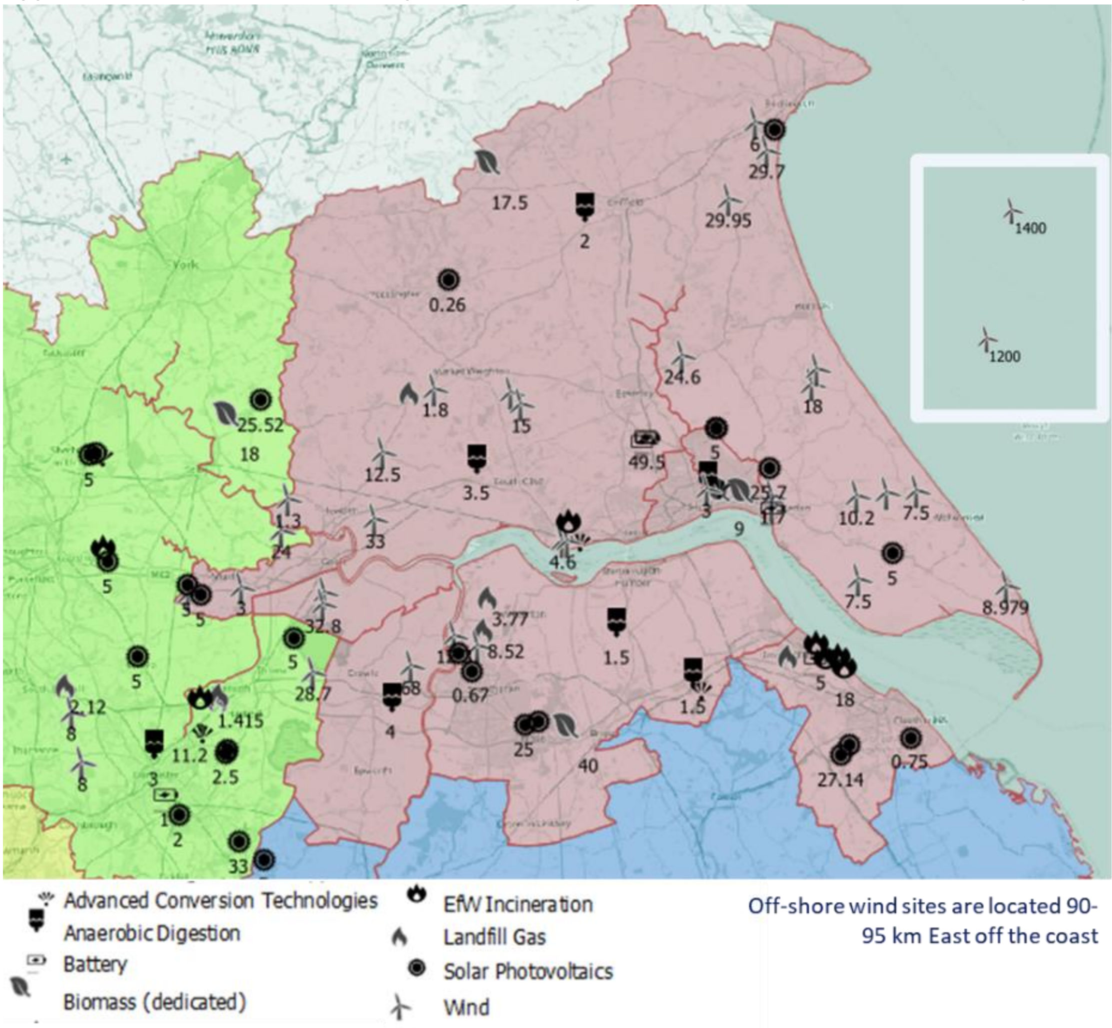
Thirteen fossil power generators operate within the Humber and collectively are responsible for emitting 8.0 $MtCO_2$ every year.[42] Among these, the CHP operated by VPI Immingham and Triton Power are the largest – representing about 75% of total emissions – and also most closely linked with industries as was previously discussed. When looking at the wider region, an additional 14.1 $MtCO_2$ were emitted in 2017 by 20 power plants South and West of the core Humber cluster (see Table 2). Over 40% of these are associated with the Drax Power Station, however it should be noted that this is now likely an overestimate of their *fossil* emissions as Drax has steadily increased the share of biomass as fuel as part of their decarbonisation strategy. Indeed, coal only represented 3% of Drax's power generation in 2019, down from 30% as recently as 2016.[43] Looking ahead, emissions from fossil generation may further reduce as Drax progresses in its announced coal phase-

[35] An additional case could be envisioned where internal fuels are sold to third parties instead of being burnt on site. Since such third parties would also burn these fuels, no *net* emissions abatement could be achieved via this route.
[36] These internal fuels are a product of using solid fuels (coal and coke) in the blast furnace and other processes. However, they are treated as internal fuels rather than purchased solid fuels to reflect the fact that they could not simply be substituted by low-carbon fuels (e.g. hydrogen), since they are also used as feedstock to the core steelmaking reactions and not merely as energy source. Hence, a substantial process re-design would be required for 'fuel-switching' to be possible.
[37] As mentioned in Section 3.1, refinery surplus gases from Phillips 66 are also burnt at VPI Immingham.
[38] Except for the small amount of refinery surplus gas indicated in the previous footnote.
[39] The latest to shut in recent years are the Cottam, Ferrybridge, and Eggborough coal power plants.
[40] The only SMR is at the Lindsey Oil Refinery. Flaring emissions from the refineries are also included as process emissions. This is because flaring is not done to supply energy to a process but is instead done for operational safety reasons and also involves the burning of feedstock gases. Flaring emissions are assumed to be equal to 1.5% of the refineries' total emissions based on feedback from industry stakeholders consulted by Element Energy in previous studies.
[41] https://www.humberlep.org/infrastructure/energy/.
[42] When also considering the steam supplied to industrial sites (see Figure 7).
[43] https://www.bbc.com/news/uk-england-york-north-yorkshire-51659681.

out by 2021[44] and considering implementing the first pilot project for bioenergy with CCS (BECCS), opening a new door to negative emissions generation in the area.[45]

Renewable generation

The progressive transition from coal to biomass also makes Drax the largest renewable power station in the UK. Aside from Drax, the region hosts a broad range of renewable power generation assets shown in Figure 10. Among these, nearly 400 MW of onshore wind farms and another 250 MW of other renewable technologies are in operation today, with a further 500 MW currently under development (Table 5 in the Appendix). Last but not least, and although not strictly within the wider region as defined in Section 2.3, some of the largest offshore wind farm developments in the world are located within 100 km from the Humber coast, and their power is often brought to land within the Humber region.[46] The Humber also supplies the skilled labour force required for the operation and maintenance of these key assets.



[44] Which many see the reconversion of up to two coal units (5 and/or 6) to natural gas https://www.drax.com/press_release/drax-starts-planning-process-battery-storage-gas-options/.
[45] See discussion of the Zero Carbon Humber project in Section 4.2.
[46] The three Ørsted projects *Hornsea Project One, Two,* and *Three* (https://hornseaprojects.co.uk/) and the Triton Knoll Offshore Wind Farm. Only Hornsea Project One is currently (partly) operational. Note that all of these projects are 'offshore' and not within the remit of the four local authorities that make up the Humber.

Figure 10: Renewable power generation in the wider Humber region in 2019, based on BEIS[47]

4 Potential developments in the area

4.1 Announced changes to local industry

As one of the largest industrial clusters in the UK, the Humber is an attractive industry hub thanks to its heritage, access to infrastructure, and local supply chain synergies. A few potential site openings have been announced over the past few years that may affect the level of industrial emissions in the Humber:

- The Tricoya acetylated wood elements plant, currently under construction at Saltend Chemicals Park.[48]
- The Altalto waste-to-jet-fuel plant by Velocys, the potential future emissions from which are shown below.

Altalto waste-to-jet-fuel plant by Velocys

The Altalto project results from a collaboration between Velocys, British Airways and Shell who submitted a planning application for a plant to convert municipal solid waste to liquid fuel.[49] As previously reported, their planning application was recently approved. When fully operational, the plant would process over 500 thousand tonnes of household and office waste every year, converting them into up to 60 million liters of jet fuel and synthetic naphtha. Velocys claims that such fuels could offer 'net greenhouse gas savings of around 70% for each tonne of conventional jet fuel it displaces' and also 'improve air quality, with up to 90% reduction in particulate matter (soot) from aircraft engine exhausts and almost 100% reduction in sulphur oxides'.[50]

Although the products from the Altalto site may help *reduce global* emissions,[51] the opening of a new plant in the Humber would necessarily *increase local emissions*. **The Altalto plant could emit up to 300 ktCO_2 per year** when in full operation, or less if some of the measures currently under evaluation can be implemented. It is noteworthy that the Altalto plant is also partly *carbon capture ready*,[52] since a substantial share of the total emissions occurs as a high purity CO_2 stream that can easily be captured.[53] In addition to CCS, Velocys also sees the use of green hydrogen[54] as feedstock as a promising route to further reduce emissions in the longer term. It is also noted that biomass constitutes a significant proportion of their waste feedstock, which contributes to attaining low lifecycle emissions from Velocys' synthetic fuels. Velocys targets to start construction in 2022 and to have the plant operating from 2025.

Announced site closures

Unfortunately, a few of the industrial sites that were operating in 2017 have closed or announced closing:

- The Vivergo Fuels biofuels plant, which was mothballed in 2018.[55]
- The Novartis pharmaceuticals plant, expected to terminate operations by the end of 2021.[56]
- The Cemex cement plant, which will be mothballed later this year.[57]

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47 Renewable Energy Planning Database (REPD) https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract.
48 https://www.marketinghumber.com/news-events/news/business/breaking-ground-at-the-world-s-first-tricoya-wood-chip-acetylation-plant-at-saltend-chemicals-park-hull/.
49 https://www.velocys.com/2019/08/20/plans-submitted-for-the-first-waste-to-jet-fuel-plant-in-the-uk-and-europe/.
50 https://www.altalto.com/immingham/.
51 If their fuels are produced from waste that would have otherwise been incinerated, and/or if their use decreases the combustion of fossil fuels.
52 https://www.business-live.co.uk/manufacturing/uks-first-green-jet-fuel-17061997.
53 The representative from Velocys indicated that this high-purity stream originating in the syngas clean-up step represents approximately 50% of the plant emissions.
54 The Renewable Transport Fuel Obligation (RTFO) requires that this hydrogen be from renewable electricity specifically, and not for instance blue hydrogen from natural gas reforming with CCS.
55 https://vivergofuels.com/news/vivergo-fuels-bioethanol-plant-proposes-ceasing-production/.
56 https://www.grimsbytelegraph.co.uk/news/business/novartis-make-statement-plans-close-2040546https://www.gi-media.co.uk/2020/05/25/closure-of-grimsby-pharmaceutical-factory-delayed/.
57 https://www.grimsbytelegraph.co.uk/news/grimsby-news/around-100-jobs-go-cemex-4128481.

The emissions from these sites were removed from two of the three business-as-usual scenarios, allowing for the possibility that some of them may reopen (or not close) in the scenario featuring the highest level of emissions ('high emissions' scenario).

Other energy projects in the Humber region

A few other new projects have been announced in the region. Initial assessment of these projects show that they are not likely to have a significant impact on industrial emissions in the region:

- The Yorkshire Energy Park, which would see the establishment of business centre, education campus and research centre in the East Riding of Yorkshire. The planning application also included up to 50 MW of gas-powered generation,[58] although the project developers are now considering alternative lower-carbon generation options like solar photovoltaics and energy storage.
- The North Lincolnshire Green Energy Park, which aims to deploy a 95 MW energy recovery facility to process non-recyclable waste as well as hydrogen storage, battery storage, steam storage, and an ash treatment facility.[59]
- The South Humber Bank Energy Centre Project, which is looking to develop a 95 MW energy-from-waste power station.[60]
- The ABLE Humber Port consisting of the ABLE Marine Energy Park and the ABLE Logistics Park.[61]

4.2 Decarbonisation projects

Multiple industry and power sector stakeholders have been developing plans for deep decarbonisation, and several projects involving some of the largest emitters in the wider region were announced in recent years. These projects broadly support the vision of establishing in Humber the first net-zero industrial cluster by 2040, and seek to deliver substantial emissions abatement via fuel switching to hydrogen (green or blue) and CCS as summarised in Table 3. Such projects could set the foundation of the net-zero transition of the cluster, by installing key infrastructure at selected sites and providing learnings for the wider cluster, as well as the UK.

Three of these projects have already received preliminary funding from the UK Government: the Gigastack project which was one of the winners in the Hydrogen Supply Competition; and two 'deployment projects' that recently won Innovate UK support, i.e. the 'Humber Industrial Decarbonisation Deployment Project' ('Humber-DP'), and ''Green Hydrogen for the Humber'.[62] Other relevant decarbonisation projects reviewed below include Zero Carbon Humber and Humber Zero, which involve many of the same stakeholders who partnered for Humber-DP. Each of these projects is briefly reviewed below. Less developed project concepts such as the H21 project,[63] covering a wide geographic area in the North of England, including sites in the Humber, are not reviewed here as they do not clearly contribute to the HIDR, though they may well contribute to the decarbonisation of the UK industrial and heating sectors. Likewise, the decarbonisation potential of projects such as the anaerobic digesters installed at Singleton Birch's lime plant[64] are not reviewed here as they do not appear to significantly affect scope 1 emissions.[65]

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[58] Up to 9.9MW of on-site generation via fuel cells, and up to 39.9MW of off-site generation via two similarly sized gas turbines). However, lower-carbon generation options like solar photovoltaics and energy storage are now being considered.
[59] https://northlincolnshiregreenenergypark.co.uk/consultation/.
[60] https://www.shbenergycentre.co.uk/.
[61] https://www.ableuk.com/sites/port-sites/humber-port/.
[62] Also known as "Green Hydrogen for the Humber".
[63] https://www.h21.green/.
[64] http://www.planet-biogas.co.uk/singleton-birch/.
[65] The biogas produced does not replace the natural gas fired in the lime kiln, which is the main emission source.

Table 3: Major decarbonisation projects in the wider area

H_2 CO_2	Technology	Green hydrogen	Blue hydrogen,[66] CCS, BECCS
	Projects	Gigastack Green Hydrogen for the Humber	Humber Industrial Decarbonisation Deployment Project (Humber-DP) Humber Zero Zero Carbon Humber
	Infrastructure[67]	Multiple 100 MW electrolysers powered by offshore wind at the Phillips 66 refinery and other sites in Immingham. A ‘Gigafactory’ near Sheffield to manufacture up to 1 GW/year of electrolysers by 2025.	Large-scale CCS network including BECCS at the Drax Power Station and CCS at the VPI Immingham CHP plant and Humber refinery. Hydrogen production hubs near the Drax site and in Immingham. Aims to develop initial infrastructure by themid-2020s.
	Stakeholders	ITM Power; Ørsted; Phillips 66.	Associated British Ports; Centrica Storage; Drax Group; Equinor; National Grid Ventures; Phillips 66; PX Group; SSE Thermal; Saltend Cogeneration Company; VPI-Immingham; Uniper.
	Timeline	*Gigastack*: FEED study since Feb ‘2020 *GHFH*: feasibility study since Apr ‘2020	*Humber-DP*: feasibility study since Apr ‘2020 Other projects: unknown.

Gigastack

The Gigastack project aims to demonstrate low-cost, zero-carbon hydrogen at industrial scale. The project brings together ITM Power’s polymer electrolyte membrane (PEM) electrolysis technology, Ørsted’s offshore wind assets, Phillips 66 as industrial hydrogen off-taker, and with support from Element Energy to undertake a market analysis and explore potential business models for the first industrial-scale electrolysers in the UK.

The project recently completed the phase 1 feasibility study funded by BEIS via the ‘Hydrogen Supply Competition’. In this first phase the project focused on the:

- Design of a low-cost modular electrolyser ‘stack’ with 5MW capacity.
- Optimisation of the layout for ITM Power’s ‘Gigafactory’ currently under construction near Sheffield.
- Evaluation of alternative scenarios for producing hydrogen from wind power.

Having recently received £7.5m in funding support from BEIS the project is **now progressing to the phase 2 Front-End Engineering Design (FEED) study**,[68] through which it aims to:

- Design a hydrogen production system connected to a wind farm and industrial off-taker.
- Install and trial the next-generation electrolyser stack and semi-automated manufacturing machines.
- Validate the production system for manufacturing hundreds of megawatts of electrolysers per year.

[66] Humber Zero is also contemplating green hydrogen production in Immingham, as discussed below.
[67] This represents the *declared ambitions* – assuming that the current and following phases are successfully completed – rather than infrastructure which has already been implemented.
[68] https://www.itm-power.com/news/industrial-scale-renewable-hydrogen-project-advances-to-next-phase.

Through this work, the project ultimately aims to **reduce the electrolyser cost to less than £400/kW** and ramp up operations to a **manufacturing capacity of 1GW/year** possibly as early as 2025. The project generated important learnings during the phase 1, as described in a recent public report by Element Energy.[69]

Green Hydrogen for The Humber

The Green Hydrogen for the Humber project seeks to establish the feasibility of switching to renewable hydrogen for multiple industrial users in Immingham, and thus justify the rollout of a number of 100MW electrolyser deployments which will be manufactured at the Gigafactory being developed by ITM Power.[70]

The project is led by ITM Power with support from Element Energy and involves several undisclosed potential hydrogen users in the Humber. The project has been awarded financial support by the UK Government's Industrial Strategy Challenge Fund (ISCF) competition 'Decarbonisation of Industrial Clusters' managed by Innovate UK. The project could be eligible for a share of the £131 million funding support available to phase 2 projects that will proceed with the implementation of significant decarbonisation measures.[71]

Humber Industrial Decarbonisation Deployment Project (Humber-DP)

The Humber Industrial Decarbonisation Deployment Project ('Humber-DP') aims to "identify and develop potential anchor projects to maximise emission reductions in the most appropriate, timely, cost effective and efficient manner and develop world leading **industrial CO_2 transport and storage system**".[72]

Like the Green Hydrogen for the Humber project, the Humber-DP was also recently awarded financial support by Innovate UK to pursue the phase 1 feasibility study, and likewise aims to access the support available to progress phase 2.

The Humber-DP project brings together multiple stakeholders from industry and the power generation sector: Associated British Ports; Centrica Storage; Drax Group; Equinor; National Grid Ventures; Phillips 66; PX Group; SSE Thermal; Saltend Cogeneration Company (Triton Power); VPI Immingham; Uniper. Prior to the project winning Innovate UK support, subsets of the same stakeholders had already entered partnerships to develop deep decarbonisation projects 'Zero Carbon Humber' and 'Humber Zero', reviewed next.

Zero Carbon Humber

Zero Carbon Humber is a strategic partnership announced in May 2019 by Drax Group, Equinor, and National Grid Ventures that seeks to "build the world's first zero carbon industrial cluster and decarbonise the North of England".[73] The project is exploring ways to develop a large-scale CCS network and hydrogen production.

The project envisions that Drax Power Station could be the first site to deploy CCS – including a pilot bioenergy CCS (BECCS) plant, which could lead to the creation of the **world's first carbon-negative power station with the potential to deliver up to 16 $MtCO_2$ of negative emissions yearly**.[74] At a later stage, other industrial and power generation sites in and around the Humber could use the CCS infrastructure developed for this anchor project. The captured CO_2 would then be stored deep under the seabed in the Southern North Sea.

The availability of CCS infrastructure would also make it possible to start **blue hydrogen production near the Drax Power Station** via the conversion of natural gas in an autothermal reformer (ATR) with annexed carbon capture. A previous study by Element Energy[75] estimates that, by 2030, this could lead to the production of **up to 13 TWh/years of blue hydrogen for industrial use and up to 165 TWh/year for power generation**.

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[69] http://www.element-energy.co.uk/wordpress/wp-content/uploads/2020/02/Gigastack-Phase-1-Public-Summary.pdf.
[70] https://www.itm-power.com/news/green-hydrogen-for-humberside-project-deployment-study.
[71] https://apply-for-innovation-funding.service.gov.uk/competition/498/overview.
[72] https://www.ukri.org/news/ukri-allocates-funding-for-industrial-decarbonisation-deployment-and-roadmap-projects/.
[73] https://www.zerocarbonhumber.co.uk/.
[74] Element Energy. (2019). Zero Carbon Humber: The Impacts of decarbonising Yorkshire and the Humber.
[75] Element Energy. (2019). Hy-Impact Series Hydrogen in the UK, from technical to economic. http://www.element-energy.co.uk/wordpress/wp-content/uploads/2019/11/Element-Energy-Hy-Impact-Series-Summary-Document.pdf.

The same study finds that approximately 1.6 GW of ATR capacity would be required to meet the industrial hydrogen demand alone.

Humber Zero

The Humber Zero project brings together Phillips 66, Uniper and VPI Immingham in the co-development of a large-scale decarbonisation project that is "fully aligned" with Humber-DP[76] and which considers the following decarbonisation options:[77]

- CCS at VPI Immingham CHP plant and selected processing units at the Humber refinery.
- The development of **1.5 GW of blue and green hydrogen production capacity**, the hydrogen from which would be used as fuel for the CHP and by refineries.

By doing this, Humber Zero aims to decarbonise up to up to 2.75 $MtCO_2$ per year from the partner sites, or up 5 $MtCO_2$ when considering other sites that would be using the low-carbon hydrogen generated by the project.

[76] https://www.vitol.com/phillips-66-uniper-and-vitols-vpi-immingham-enter-mou-to-develop-decarbonisation-project-humber-zero/.
[77] Information sourced from the link in the previous footnote and the project's website https://www.humberzero.co.uk.

4.3 Available employment land

The Humber covers a large non-urban area with significant land available for business and industrial use ('employment land'). Availability of employment land is important in the context of the HIDR because of the likely need to develop new land to host the low-carbon infrastructure required by the decarbonisation projects discussed above. Employment land is also needed for the further deployment of renewable generation assets, and it may also be needed by new industries who choose to locate in the area, perhaps attracted by the potential future 'net-zero cluster'. Figure 11 maps data on available employment land which was obtained from the four local authorities.

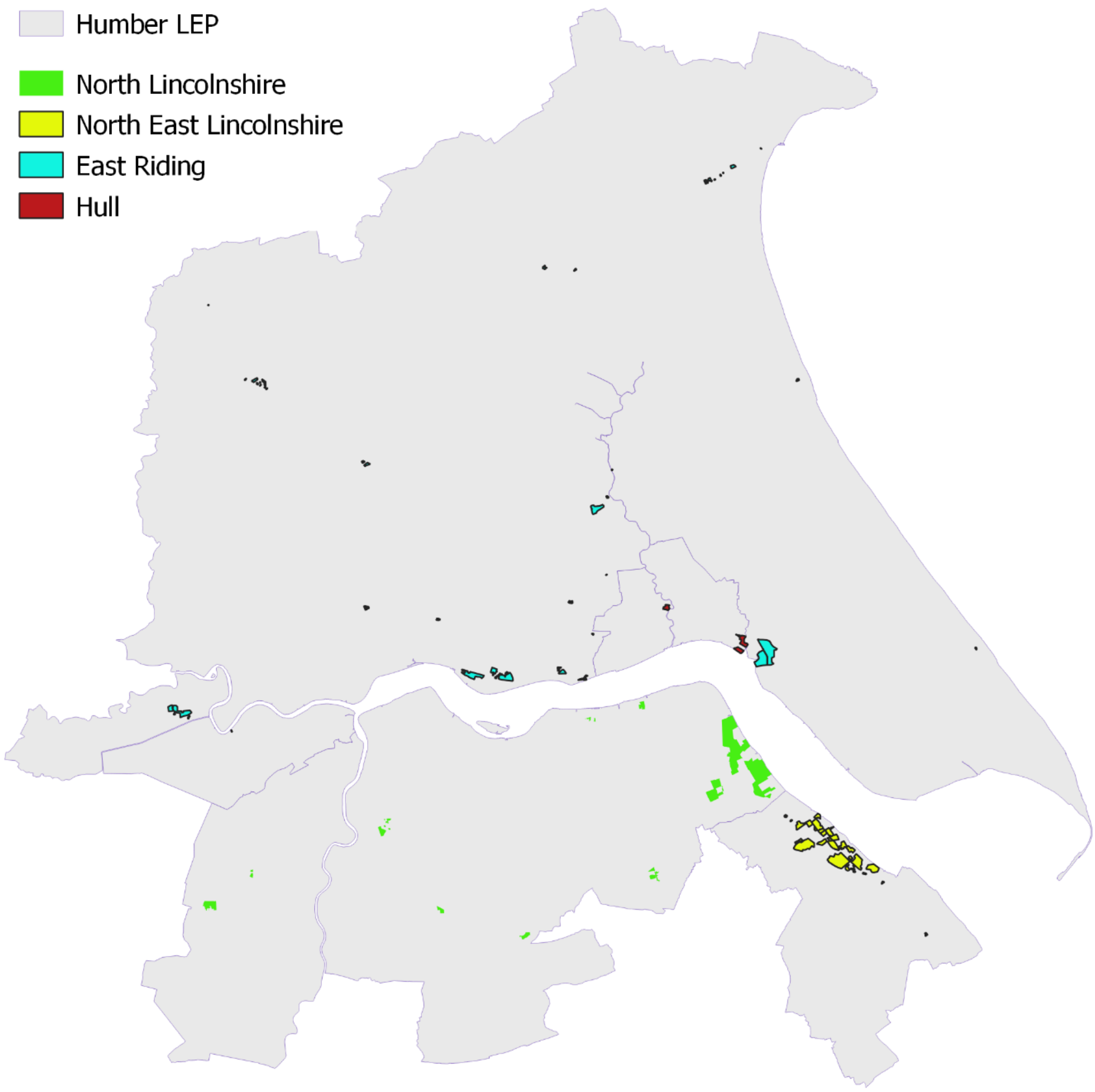

Figure 11: Availability of employment land in the Humber

Three areas with significant land availability and located in the proximity of existing industrial sites were identified:

- Close to the **southern sub-cluster**, there is land available north of the refining sites (left of Figure 12) which could be useful for the low-carbon infrastructure envisioned for the Humber Zero and Humber-DP projects. Additional employment land is also available close to Immingham.

- Close to the **northern sub-cluster**, there is significant employment land available on either side of the Saltend Chemicals Park (top-right of Figure 12) totalling over 250 ha. On the west side, the available employment land is near rail infrastructure and not far from the Triton Power CHP plant, which could provide electricity and steam to nearby users.
- Close to the **western sub-cluster**, there is employment land available west of Goole and not far from the Guardian Glass site (over 600 ha bottom-right of Figure 12). There are other plots of land available across the western sub-cluster, however none of them is closely located to existing industrial sites. Industrial land falling into the East Riding of Yorkshire local authority is present in the Brough – North Ferriby area (site 4 in the figure below), close to the Humber river, which may represent an attractive site for future industry due to the large size of the land (over 100 ha across several sites) and proximity the river front. In addition, it should be noted that potential employment land near the Drax Power Station in Selby was not analysed as this is outside of the boundaries of the Humber. However, the Drax power station holds a considerable area of land within its perimeter. The land currently holds disused infrastructure related to the purification of flue gases from coal combustion, which could be demolished and replaced with decarbonisation assets, such a CO_2 capture plant enabling BECCS. However, Drax may already have plans for the land and it is unclear whether there is additional land outside of the Drax site which could impact directly or indirectly on the Humber's emissions.

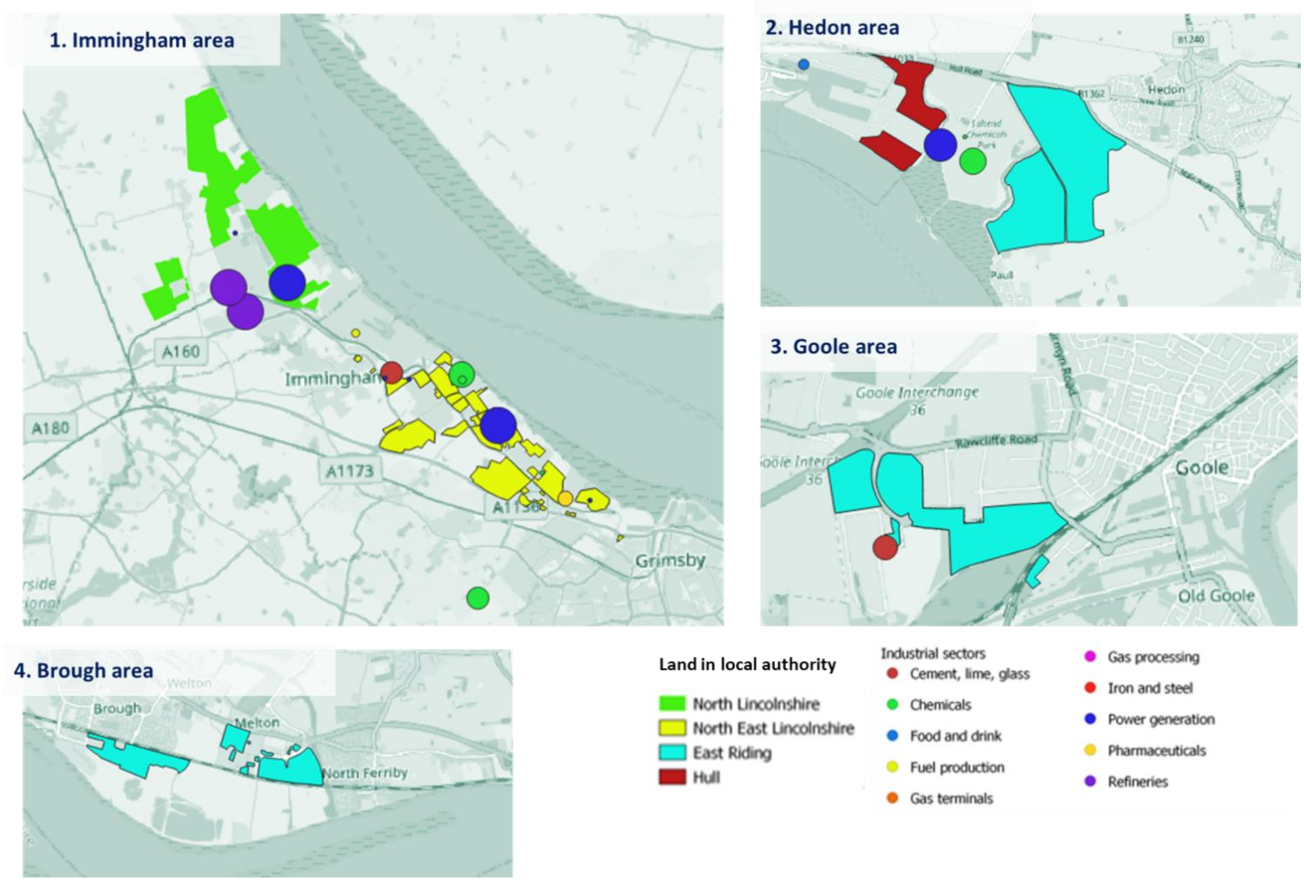

Figure 12: Employment land availability around existing industrial sites

It is also noted that emissions in the Humber are likely to be affected by the use that is made of the available employment land. If the land is used to host the low-carbon infrastructure required to decarbonise local industries – for instance that needed by the decarbonisation projects reviewed above – emissions will reduce. If instead, new industrial sites were to open on part of this land, local emissions will increase. That is the case even though certain industries may contribute to reducing global emissions, like the Altalto waste-to-jet-fuel plant which may open in Immingham.

Finally, it is noted that certain uses of the employment land may also support the achievement of some the objectives set out by Humber LEP's Clean Growth White Paper,[78] including that of establishing a net-zero industrial economy by 2040. In the long term, the region may also participate in decarbonising the supply chains of local industries as well as the wider UK economy. Under the Clean Maritime Plan,[79] for instance, the maritime international shipping industry should reduce its emissions by at least 50% by 2050. And considering the importance of maritime transport to industrial supply chains and the presence of large port infrastructure in the Humber (Hull and Immingham), suitable use of part of the available employment land may help the area to also become a leader in clean maritime technologies (e.g. hydrogen- or ammonia-fuelled ships).

[78] https://www.humberlep.org/strategies-and-deals/industrial-strategy/humber-clean-growth-local-white-paper/.
[79] https://www.gov.uk/government/speeches/clean-maritime-plan.

5 Business-as-usual scenarios for the Humber

5.1 Three scenarios without deep decarbonisation

To inform the development of the Humber Industrial Decarbonisation Roadmap (HIDR), it is necessary to assess how emissions in the Humber would evolve over time assuming no action is taken to deeply decarbonise industrial operations. 'Business-as-usual' scenarios could be the result of lack of deployment of fuel-switching technologies, carbon capture and storage or other significant decarbonisation measures. To cover a wide range of potential future worlds, three illustrative business-as-usual (BAU) scenarios were developed: a 'high emissions', a 'low emissions', and a 'central'. These scenarios represent hypothetical futures and should not be taken as forecasts. They use sub-sector specific growth assumptions aligned with a business-as-usual future. The analysis is based on BEIS's 'High growth', 'Reference', and 'Low growth' scenarios,[80] respectively, all of which include the effect of "all expired, implemented, adopted and planned policies", with different growth assumptions included as discussed in Appendix 7.2.[81]

Table 4: Differences between the three BAU scenarios

BAU scenario	'High emissions'	'Central'	'Low emissions'
Equivalent BEIS scenario	'High growth'	'Reference'	'Low growth'
Site openings	Altalto by Velocys,[82] Vivergo Fuels[83]	None	None
Site closures	None	None	Novartis, Cemex
Emission reductions due to COVID-19 (vs 2017)	9% in 2020 0% in 2021	12.5% in 2020 5% in 2021	16% in 2020 10% in 2021

As outlined in Table 4, the announced site openings and closures reported in Section 4.1 were also assumed to take place in some but not all scenarios. This assumption was made to increase the spread in the emission levels between the different scenarios and should not be taken as a statement around the likelihood that said openings and closures will happen. Last but not least, each scenario includes different assumptions around the impact that the COVID-19 pandemic will have of the Humber industries.

[80] BEIS. (2019). Updated Energy & Emissions Projections, see appendix C at https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2018.
[81] BEIS. (2019). Energy and emissions projections: methodology overview. Retrieved from https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2018.
[82] The upper estimate of 300 ktCO_2 per year disclosed by representatives from Velocys is assumed to apply, and the plant is assumed to open before 2025.
[83] Vivergo Fuels closed in 2018. In the *'High emissions'* scenario it is assumed that the site reopens before 2025 following a hypothetical change in government policy concerning the use of biofuels.

An uncertain recovery post COVID-19

At the time of writing the COVID-19 pandemic is still unfolding and its impact on the UK economy is not yet fully known. Interim estimates by the Bank of England are that the UK GDP could reduce by 14% in 2020 compared to 2019,[84] and PwC estimates a **9-16% reduction in gross value added from the manufacturing sector** in the same period.[85] Should these predictions turn out to be correct, the UK will face in 2020 an unprecedented contraction to the economy which may also have long-term repercussions on the industries in the Humber.

To accurately assess how industry emissions will be affected by COVID-19 over the timeline assessed in this study one would need to know how each industrial sub-sector was affected as well as when and how it will recover. However, there are substantial unknowns:

- The timeline and 'shape' for the recovery is not known. If the sharp economic decline is followed by rapid, complete recovery ('V-shaped')[86] there may be virtually no long-term impact on the scenarios assessed here. If however the recovery is slower (e.g. 'U-' or 'L-shaped') – as was the case with the 2008 downturn, after which it took over a decade to return to pre-crisis levels[87] – it is possible that industrial activity may not return to the previous level for a very long time.
- Policy could affect the long-term viability of certain industries, also depending on whether future business support packages will support -emission-intensive sectors as much as others.

Acknowledging the great uncertainty surrounding future developments as the world recovers from COVID-19 and recognising the impossibility of making accurate predictions about such an uncertain future, **this study assumes that industrial emissions in 2020 and 2021 will be 9-16% and 0-10% lower than in 2017,** respectively, as reported in Table 4.[88]

[84] https://www.bankofengland.co.uk/report/2020/monetary-policy-report-financial-stability-report-may-2020.
[85] PwC. (2019). COVID-19: UK Economic Update on 29 April at https://www.pwc.co.uk/services/economics-policy/insights/uk-economic-update-covid-19.html.
[86] https://en.wikipedia.org/wiki/Recession_shapes.
[87] See *ONS Manufacturing sector performance, UK: 2008 to 2018* at https://www.ons.gov.uk/businessindustryandtrade/manufacturingandproductionindustry/articles/manufacturingsectorperformanceuk/2008to2018.
[88] Assumptions for 2020 based on PwC's projections (see footnote 85).

5.2 Emissions projections

Emissions are envisioned to reduce by 0.3-2.6 MtCO_2 by 2040 compared to 2017 levels – **a 2-18% reduction** in relative terms, depending on the scenario (see Figure 13). These results also highlight the importance developing a roadmap for achieving deeper decarbonisation of the industries in the Humber. In fact, even under the 'low emissions' scenario **emissions from local industries are expected to remain above 12 MtCO_2 per year in 2040**. If all UK industries were to follow a similar trajectory, **industrial emissions in 2040 would still be over 43% of those in 1990**, or over 75 MtCO_2, which might make it challenging for the UK to meet an economy-wide net-zero target only a decade later. Indeed, if emissions reductions continued at the same rate until 2050, emissions would only reduce to 68% below 1990 levels by then.[89]

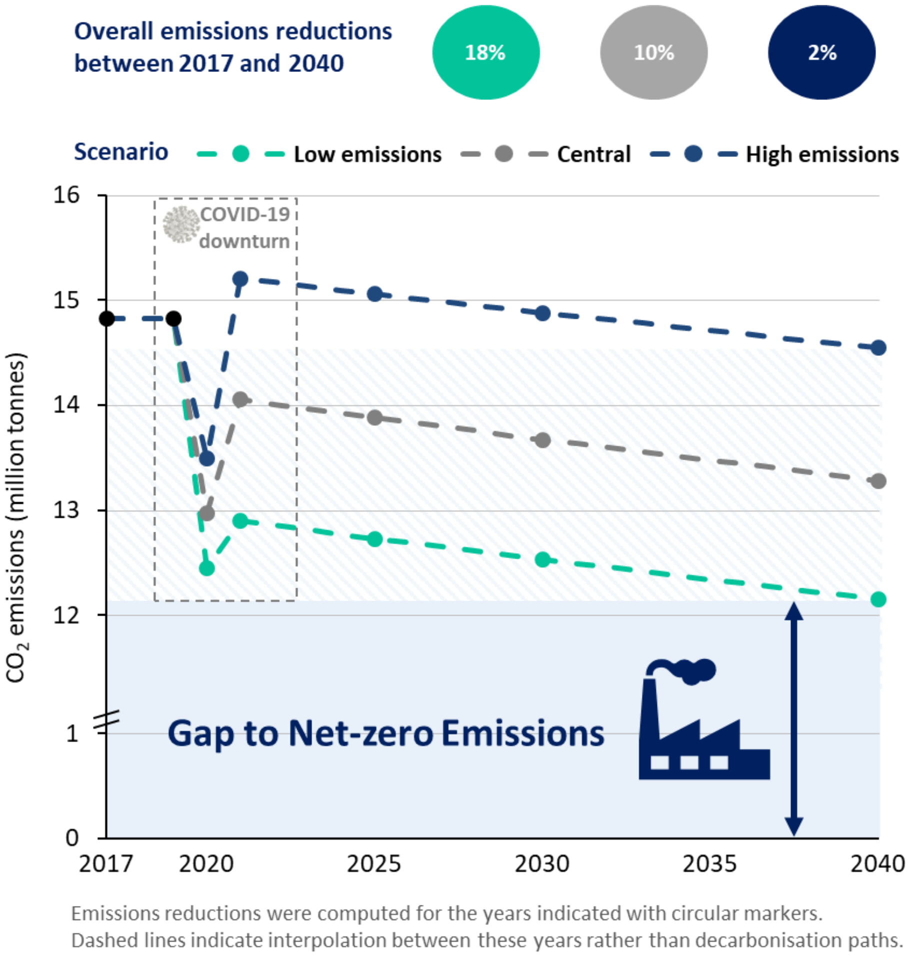

Figure 13: Emissions under all business-as-usual scenarios

There are substantial differences in how the various sub-sectors contribute to the overall change in emissions between 2017 and 2040, as can be noted in Figure 14:

- **The iron and steel sub-sector would experience the largest reduction in emissions in all BAU scenarios** when considering absolute values (308 ktCO_2 and 955 ktCO_2 in the *High* and 'low emissions' scenario respectively). This is explained by the fact that iron and steel is the second largest-emitting sub-sector as well as one of those with the lowest assumed growth rate (see Table 5 in Appendix 7.1).

[89] UK industry emissions were ~175 MtCO_2 in 1990 and ~75 MtCO_2 in 2017. Source: Final UK greenhouse gas emissions national statistics: 1990 to 2018. https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2018.

- **The refining industry is the second-largest contributor to emission reductions, although this reduction is exclusively driven by the assumed impact of COVID-19**. All scenarios by BEIS in fact assume neither growth nor contraction for the refining sector.[90] Regardless, the high baseline level of emissions from the refineries means that a large absolute reduction occur under both the 'central' and the 'low emissions' scenarios (284-563 $ktCO_2$).
- **Announced planned openings and closures** (the mothballing of the cement plant, only assumed to occur in the 'low emissions' scenario, and the opening of the Altalto plant, only occurring in the 'high emissions' scenario) **contribute the third largest change in emissions** (with a 465 $ktCO_2$ reduction and 300 $ktCO_2$ increase respectively). Altalto's opening also explains why emissions increase in the 'high emissions' scenario between 2017 and 2025.
- **Changes in emissions to other sub-sectors instead give a marginal contribution to** the overall change in emissions envisioned to occur between 2017 and 2040. This happens despite the sometimes sometimes-large relative change because of the small absolute size of these sub-sectors.

In conclusion, it is noted that **these results are sensitive to the assumptions made around the economic impact of COVID-19**, which on their own explain approximately two thirds of the difference in emissions between the three scenarios. Hence, the reader is invited to complement the results presented here with additional information which may be available in the future on the sector-specific impacts of the pandemic.

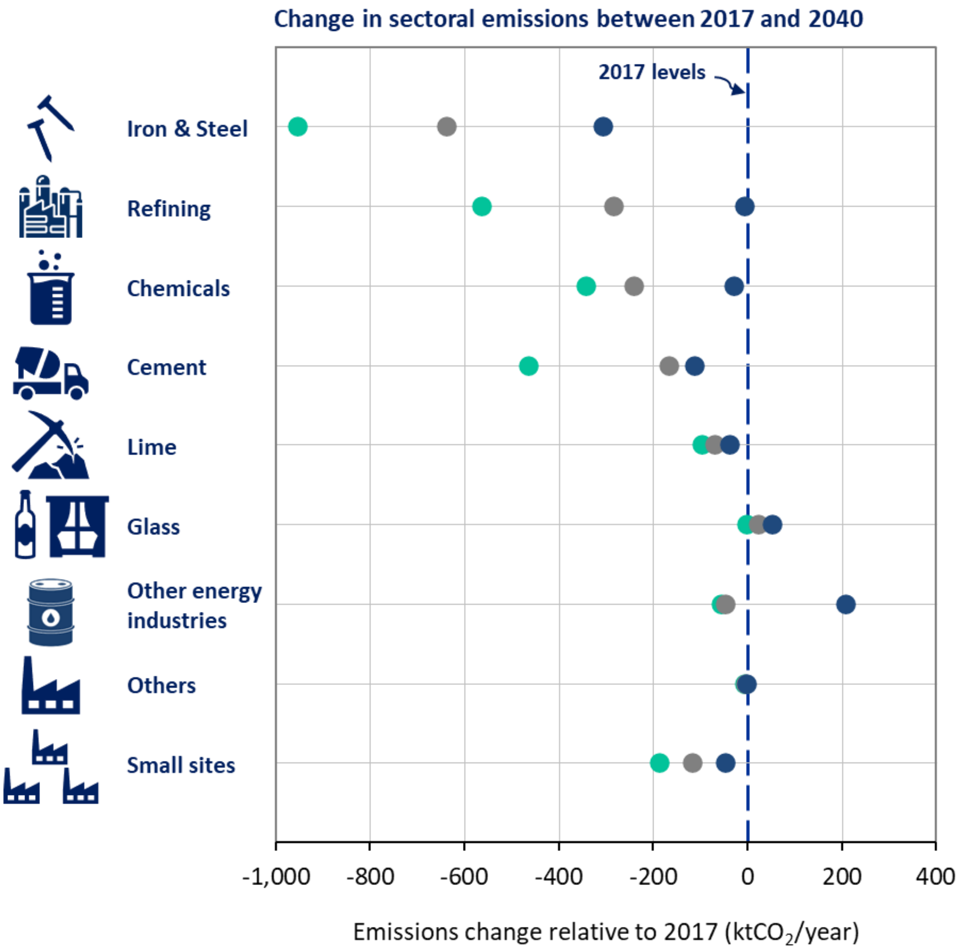

Figure 14: Sectoral changes in emissions between 2017 and 2040

[90] This is aligned with a business-as-usual case, but it is acknowledged that there is uncertainty around the future emissions from certain industrial sectors in a net-zero economy. This uncertainty was not examined further as it is outside of the scope of the analysis.

Deep decarbonisation for clean growth

The development of the Humber Industrial Decarbonisation Roadmap is essential for the local industry. This study estimates that an **emissions gap of 12.2-14.5 MtCO$_2$** per year would persist in **2040** under all business-as-usual scenarios. This is the gap that the HIDR will need to bridge. Whilst this study did not assess the pathways that the region could follow to deeply decarbonise, some of the negative implications that would arise from the failure to achieve decarbonisation in the region can be estimated.

Manufacturing **industries that do not decarbonise may become less competitive** in an economy that aims for net-zero and prioritises low-carbon products. In turn, this can translate into an **increased risk of closure, especially if carbon prices increase**. Even under the moderate carbon price projections by BEIS,[91] it is estimated that local industries would be liable to pay a carbon cost of £500-£600 million per year from 2030 onwards. According to the Carbon Trust,[92] manufacturing industries provide "more than 55,000 jobs (15% of employment) and £4,528 million (23% of the region's GVA)". Thus, substantial **reductions in industrial activity could cause the loss of thousands of jobs and a heavy impact to the local economy**.

Finally, it is noted that while failure to decarbonise may present a threat to the Humber industries, their ability to lead the way in UK and global **decarbonisation** efforts **may represent an opportunity**. The **'net-zero cluster' brand** may indeed attract new industries and hence investment into the region, especially if the by-then-implemented decarbonisation infrastructure can be accessed by future joiners. Hence, it is possible to think of **deep decarbonisation** not just as a way to meet climate targets but also **as a way to stimulate clean growth and enable the Humber to thrive in the net-zero economy of the future**.

[91] Carbon price of £42.7/tCO$_2$ projected for 2035 by BEIS (2018) https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2018.
[92] The Carbon Trust. (2018). Study of the Humber Energy Intensive Industries Cluster. https://www.catchuk.org/wp-content/uploads/2018/04/Humber-EII-Cluster-Study-Summary.pdf.

6 Conclusions and recommendations

This study set out to establish a baseline for industrial emissions in the Humber and to evaluate how these may change over time if no action is taken to decarbonise industry. This information can provide the basis for the evaluation of a future Humber Industrial Decarbonisation Roadmap (HIDR).

A roadmap to deeply decarbonise the Humber is needed

It was found that industrial emissions in 2017 amounted to just under 15 $MtCO_2$, over 70% of which is linked to the refining and iron and steel sub-sectors. An analysis of possible business-as-usual scenarios revealed that, without the implementation of deep decarbonisation measures, emissions in 2040 are likely to be only 2% to 18% lower than in 2017. If this trend were replicated across the UK, industrial emissions in 2040 would still be 43% of what they were in 1990, which would make it challenging to achieve a potential economy-wide net-zero target by 2050. **This clearly points at the need for a roadmap to achieve deep reductions in emissions from the Humber industries.**

Deep decarbonisation can represent an opportunity for clean growth

The importance of energy-intensive industries to the local economy was established as essential, and that the 'first net-zero cluster' positioning of the region may make the Humber an attractive hub for future industrial developments. Thus, not only would **deep decarbonisation** of the Humber industries reduce the risk that local emissions are simply offshored by the relocation of industries to less regulated geographies, but also it **could incentivise investment in the region**. Hence, **it is recommended that the HIDR consider the positive impact that deep decarbonisation might have on local jobs and the economy** as part of the next project phrase. It may be relevant to assess potential synergies between 'deep decarbonisation' and 'clean growth'.

The industrial wealth and diversity of the region suggests that a technology-agnostic analysis of potential decarbonisation pathways is preferable

It is recommended that future work on the HIDR is technology-neutral and considers a broad range of relevant technologies and decarbonisation routes. Whilst this study did not assess decarbonisation pathways that the region could follow, the sheer variety of industries in the area suggests that deep decarbonisation may benefit from combining a broad range of technologies and approaches, including but not limited to CCS, fuel switching to hydrogen, and electrification.[93] For example, nearly 60% of the emissions from the Humber industries relate to sources that cannot be abated through fuel switching and may require CCS deployment, which should be further investigated.

The HIDR could explore synergies across sectors and geographies

It is noteworthy that emerging decarbonisation activities in the area such as the two 'deployment projects' are already investigating a variety of decarbonisation technologies (green and blue hydrogen as well as CCS). Within these, it is encouraging to observe that stakeholders from industry and the power sector are working together to assess synergies in their respective decarbonisation pathways. Moving forward, **the HIDR may also consider cross-sectoral, as well as geographical, synergies**. For instance, these may include the potential of decarbonising industry and the power, heat, and transport sectors outside of the core Humber cluster by leveraging the decarbonisation efforts and infrastructure deployed in the Humber.

[93] E.g. electrification, process change, and demand-side measures like product diversification (possibly in line with the growing demand for low-carbon products and rise of a circular economy) as well as low-carbon hydrogen and CCS.

Further analysis, data, and market observations will be required moving forward

Several emerging projects in the region were also investigated. Whilst these projects could deliver significant emissions reductions, many of them are still at a very early-stage and their plans around low-carbon infrastructure development are today not sufficiently developed, making it difficult to assess their likely contribution to decarbonising the Humber industries. It is recommended that **real data from new industrial developments and decarbonisation projects is considered** wherever possible in the phase of the HIDR. This includes data around emissions, low-carbon fuel production, and infrastructure capacities which may only be obtained by engaging relevant stakeholders.

Further analysis in the second phase of the HIDR should not only focus on the different decarbonisation pathways that the region may see, but it should also carefully consider the interplay between the variety of pathways industrial sites may deploy and the infrastructure building decisions. For example, different scenarios should be examined, considering how the scale of the emissions reductions could affect the size of the infrastructure required (e.g. hydrogen production capacity, pipeline capacities and flow rates, undersea CO_2 storage constraints). Future work could bring together local industrial sites as well as utility providers (e.g. Northern Powergrid) and explore both the technical opportunity for electrification within industrial sites, as well as the availability of high-voltage connections in their vicinity.

Lastly, it is noted that the emissions reductions modelled in this study are sensitive to the growth assumptions employed, including those around the economic impact of the COVID-19 pandemic and the subsequent recovery. **It is recommended that the growth assumptions made for this study be updated when better sector-specific data becomes available.**

7 Appendix

7.1 Current and planned power generation projects

Table 5: Power generation projects in the core Humber by stage of development

	Installed Capacity (MW electric)[94]				
Technology	Application Submitted	Awaiting Construction	Under Construction	Operational	Total
Wind onshore		8		377	385
Battery		148		50	198
Solar photovoltaics	1	72		95	168
Energy-from-waste		139		3	143
Biomass (dedicated)		50	18	49	116
Advanced conversion technologies		35		25	60
Landfill Gas				18	18
Anaerobic digestion		2		14	16
All renewable sources	**1**	**453**	**18**	**632**	**1,103**
Non-renewable (gas turbines)	**>7,000 in the pipeline**			**5,590**	**>12,590**

7.2 Sub-sector growth rates in the BAU scenarios

BEIS scenarios were selected as the source of data since these are the only publicly available dataset that includes projections for industry emissions disaggregated by sub-sector (defined by the IPCC category). Growth rates were calculated as the *compound annual growth rate* (CAGR)[95] for each sub-sector over the 2018-2035 period (a different CAGR for each BEIS scenarios). The start year for the analysis was set as 2018 to avoid the abrupt step changes occurring in the BEIS projections between 2017 and 2018, which are not expected to be relevant to the Humber (for instance, emissions from the IPCC category '*1A2: Iron and Steel*' increased from 6.7 to 12.6 $MtCO_2$ between 2017 and 2018). The year 2035 is the latest included in the BEIS projections, and hence was used as the upper boundary of the analysis to calculate growth rates. The growth rates thus computed and reported in Table 6 are assumed to remain unchanged during the 2021-2040 period.

[94] Please note that some totals may appear slightly incorrect due to rounding errors.
[95] The CAGR is defined as the average yearly growth rate, see https://www.investopedia.com/terms/c/cagr.asp.

Table 6: Compound annual growth rates between 2021 and 2040

Sub-sector	BEIS IPCC Category	'Low emissions'	'Central'	'High emissions'
Refining	1A1b: Petroleum Refining	0.0%	0.0%	0.0%
Other energy industries	1A1c: Manufacture of Solid Fuels and Other Energy Industries	-1.1%	-1.0%	-1.0%
Cement	2A1: Cement Production	-2.7%	-2.1%	-1.4%
Lime	2A2: Lime Production	-1.6%	-1.2%	-0.8%
Glass	2A3: Glass Production	0.5%	0.8%	1.1%
Other	1A2g: Other	-0.3%	-0.2%	-0.2%
Chemicals	2B: Chemical Industry	-0.5%	-0.4%	-0.3%
Iron & steel	1A2a: Iron and Steel	-0.6%	-0.5%	-0.3%
Small sites	1A2g: Other	-0.3%	-0.2%	-0.2%