HUMBER INDUSTRIAL CLUSTER PLAN

TOGETHER IT IS POSSIBLE

HICP HUMBER INDUSTRIAL CLUSTER PLAN

UK Research and Innovation

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The Humber Industrial Cluster Plan (HICP) is one of six projects receiving funding from UKRI's Industrial Decarbonisation Challenge to create a regional blueprint towards decarbonising the region. In many ways, the HICP has the greatest challenge, as the Humber is the UK's largest carbon emitting industrial cluster; as such it is essential that we decarbonise the Humber to meet our national net zero targets.

Working in partnership over the last two years, the HICP has built on the rich heritage and natural assets of the region to develop an ambitious plan to achieve low carbon status by 2030, and support the UK's ambition of the world's first net zero industrial cluster by 2040. The Cluster Plan highlights key contributions towards skills development, supply chain, inwards investment, workforce planning and socioeconomic impacts for the cluster, alongside technical recommendations supporting the roll out of carbon capture and storage, and low carbon hydrogen deployment. The mandates outlined in this report are an impressive set of recommendations, essential for the region to decarbonise and achieve its future potential for local businesses and people, as we transition to a low carbon economy.

The achievements of the HICP will create a lasting legacy, enabling the cluster to achieve its world scale industrial decarbonisation plans, and the net zero future that will be key to regional and national success.

THE HUMBER REGION IS TURNING THE TIDE IN FAVOUR OF CLEAN, GREEN GROWTH. STEEPED IN INDUSTRIAL HISTORY IT HAS BEEN ON THE FRONT LINE OF INDUSTRIAL REVOLUTIONS SINCE THE 1700's.

Our region has unparalleled natural assets, including unique CO_2 and hydrogen storage solutions, coupled with extensive port facilities, renewable power generation and investment-ready land serviced by extensive supply chains and the engineering skills needed to drive our ambition. We are poised to become a global leader for industrial decarbonisation.

The Humber Industrial Cluster Plan, funded by the UK Research and Innovation Industrial Decarbonisation Challenge Fund, is the result of a two-year collaborative journey of wide-ranging research, in-depth analysis, scenario modelling and extensive consultation. Our Plan demonstrates how the Humber can become the first Industrial Cluster to achieve net zero by 2040, and then go beyond to become strongly carbon negative, removing more carbon from the atmosphere than it produces.

Our industries have already invested significantly in plans and feasibility studies. Through working together – Industry, Government, Stakeholders, and Communities - we will build a Humber region that remains attractive to inward investors and provides freedom, choice and opportunity for employment and economic growth. A region that is sustainable, resilient, and inclusive.

Our comprehensive and dynamic plan sets out the next steps.

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When the iconic Humber Bridge opened in June 1981, it did more than just set records for its size. It connected the region, uniting both communities and industries, and allowing the Humber to become what it is today: a thriving industrial hub that contributes more than £18 billion to the UK economy and supports some 360,000 jobs. Climate change is the defining challenge of our time, compelling us to decarbonise our economy, develop energy resilience and invest in new low carbon technologies.

Decarbonising the Humber, the largest industrial cluster emitting more CO_2 than any other region in the UK, is essential to achieve net zero. The Humber Energy Board (HEB) brings together the public and private sectors in the region on both banks of the estuary to help deliver this ambition.

The HEB is hugely supportive of the Humber Industrial Cluster Plan, which has been central to setting the agenda for the direction and purpose of the Board as well as helping to determine the opportunities created by decarbonisation and challenges the region must overcome. The Cluster Plan has been developed from a vast amount of industry led studies, data and modelling; it has engaged a broad audience and created a single conversation on decarbonisation as well as helping to define the economic and environmental benefits that will deliver a sustainable future in the Humber for generations to come.

Through this decarbonisation journey, the Humber has an unrivalled opportunity to level up the country and can set a world leading example in how to decarbonise an industrial powerhouse. The Cluster Plan highlights a number of nationally critical energy and decarbonisation projects including carbon capture and storage (CCS), low carbon hydrogen production, bio energy with carbon capture and storage (BECCS) as well as the delivery of pipelines to take captured carbon dioxide away for permanent storage under the North Sea and bring hydrogen to existing industry to promote low carbon fuel switching.

The Humber has delivered for the UK before, leading the clean energy transition through its thriving offshore wind sector, stepping up to deliver world-class skills, manufacturing facilities and supply chains. Today, business stands ready to make the Humber the world's leading net zero industrial cluster.

The Cluster Plan creates a 'Greenprint' for a sustainable future; now is the time to deliver.

OUR OPPORTUNITY

The Humber Industrial Cluster has the potential to reduce more industrial emissions than any other region in the UK.

And having pledged significant investment our cluster is uniquely positioned to deploy world-class decarbonisation projects. As the UK's Energy Estuary, the Humber region benefits from access to large scale CO_2 and hydrogen storage sites, along with abundant energy generation such as wind, solar and biomass. Deployment of our internationally recognised projects will put the UK on course to exceed deep decarbonisation targets as early as 2030.

Building on our proud industrial heritage and existing strengths in stakeholder collaboration, the Humber Industrial Cluster is set to become the UK's 'Super Hub' for carbon capture & storage (CCS), low carbon hydrogen production and storage, and greenhouse gas removal (GGR).

The Humber Industrial Cluster is ready to become the world's first net zero industrial cluster by 2040.

Together it is Possible

The Humber is the largest industrial decarbonisation opportunity in the UK

OUR PLAN

The Humber Industrial Cluster Plan has completed over 24 months of detailed analysis, which validates the ambition of the region's decarbonisation projects, cementing our unique position as leaders in the UK's Industrial Decarbonisation Challenge.

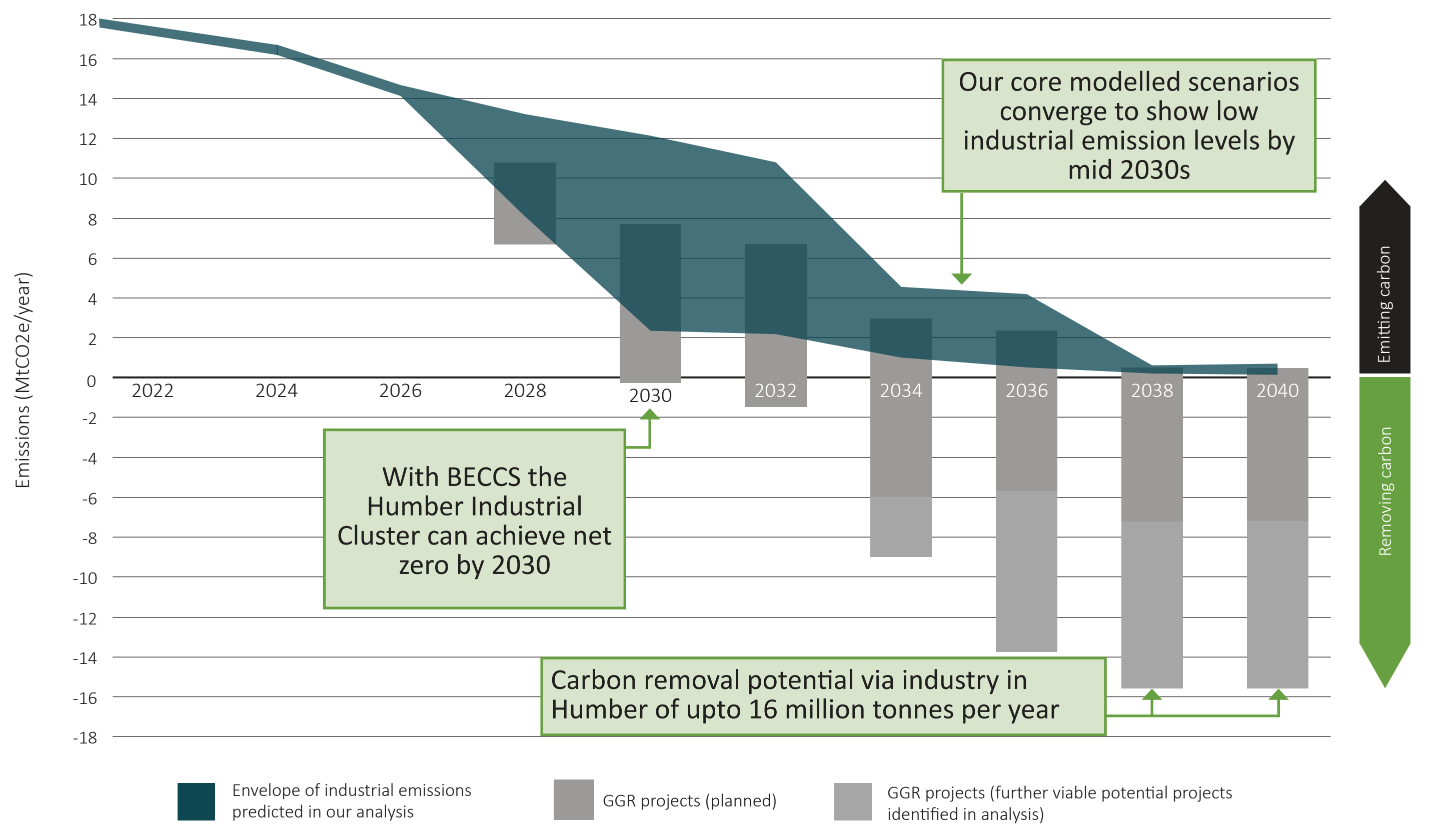
We have modelled different technologies, and uptake rates based on a range of external and legislative drivers. Our findings show that:

- We can significantly decarbonise as early as 2030, reaching net zero by 2040. Our core modelled scenarios fully support the region's decarbonisation projects in addition to providing welcome space to decarbonise other sectors.
- Carbon capture and storage (CCS), and low carbon hydrogen production and storage, provides the backbone to our decarbonisation strategy. In combination with resource efficiency and electrification, we can deeply decarbonise our industrial cluster by 2030.
- Greenhouse gas removal technologies (GGR), will place our region on a pathway to net-negative emissions as early as 2030, and are vital for our cluster to reach net zero emissions by 2040.

Maintaining coordinated action across the cluster is key to harnessing the benefits that our plan will provide for the region. We are strongly positioned, and possess the resources, drive, scale, and capability to deliver.

Download the Humber 2030 Vision Map

Significant emissions reductions and net zero are achievable in the Humber Industrial Cluster



OUR MANDATES FOR ACTION

Mandate 1:
To implement Carbon Capture and Storage and Greenhouse Gas Removal technologies at pace and scale

5-8 $MtCO_2e$/year

Abated by carbon capture and storage by 2040

133%

Proportion of national 2030 CCS target for industrial emissions met by planned Humber projects

160%

Proportion of national 2030 GGR target achieved by planned Drax BECCS

35%-56% by 2040

Cluster emissions abated using CCS

Our modelling shows that carbon capture and storage (CCS) is the most important industrial decarbonisation option for our region, abating to up to 55% of industrial emissions by 2040 which is equivalent to 8 $MtCO_2e$ per year.

CCS is an umbrella term for a suite of technologies, some more advanced than others, which includes separating out CO_2 from a waste gas stream. This technology will play a significant role in the decarbonisation of Ironmaking, Refining, and Combined Heat and Power sectors. As a high capital investment choice, CCS is favoured for heavy industrial processes offering economies of scale. It is also the only viable abatement option for emissions from many industrial processes.

The Humber cluster can significantly deploy CCS before 2030 if favourable policies are in place. The sheer scale of the Humber Cluster makes for a highly attractive CCS proposition. This has been recognised by both the UK Government and industry. Our internationally recognised CCS projects, such as Humber Zero and Zero Carbon Humber, plan to collectively remove at least 8 Mt CO_2e per year by 2030 – exceeding the national CCS target of 6 $MtCO_2e$ from industrial emissions per year by 2030.

CCS is also critical for generating negative emissions through greenhouse gas removal (GGR) technologies such as bio energy with carbon capture and storage (BECCS), without which, attaining net zero is not possible. GGR is currently planned for biogenic emissions at Drax with an annual capture rate of 8 $MtCO_2e$ per year by 2030, exceeding the national target of 5 $MtCO_2e$ per year. By 2030 the Humber will provide a significant contribution to the government's overarching target of capturing 20-30 $MtCO_2e$ per year.

The Humber Industrial Cluster uniquely benefits from being near vast offshore CO_2 stores, with estimated storage equivalent to hundreds of years at 20 $MtCO_2e$ per year, supporting key transport and storage projects that are already in motion: East Coast Cluster (comprising Humber Low Carbon Pipelines Project and the Northern Endurance Partnership), and Viking CSS. To further strengthen Humber's position as the UK's 'CCS Super Hub', the region is capable of future expansion of transport and storage, enabling imports from the wider UK and European markets through our pipelines and ports.

Mandate 2:
To implement low carbon hydrogen at scale

Low carbon hydrogen can be produced in several ways most typically either from methane with CCS abatement or from electrolysis of water. Low carbon hydrogen is one of the decarbonisation options with the highest impact for the cluster, particularly vital for the Chemicals, Combined Heat and Power and Refining sectors.

Hydrogen fuel switching across our region will be the optimal way of abating up to 21% of emissions by 2040, equivalent to 3.0 $MtCO_2e$ per year. These findings support SSE Thermal and Equinor's feasibility planning for the switch of Triton Power to hydrogen, and the potential to switch the 3rd combined cycle gas turbine at VPI Immingham to hydrogen fuel.

Hydrogen fuel switching is a particularly attractive option for smaller point source emissions where carbon capture may be less economically viable.

Our analysis shows that our Cluster's current hydrogen production plans exceed the regional industrial demand, creating an opportunity for surplus hydrogen to be utilised in other sectors such as transport and heating, establishing the Humber as the true 'Hydrogen Super Hub' in the UK. The Humber Cluster is very well suited to making CCS enabled hydrogen from natural gas and electrolytic hydrogen from renewable electricity.

There are well-established plans to produce low carbon hydrogen in the Humber, totalling 5.2 GW by 2030, which represents over half of the national 2030 hydrogen production target of 10GW.

A major new hydrogen pipeline across the region is in the advanced stages of planning, which will connect producers and end users, enabling supply to future hydrogen off-takers. The underground salt caverns at Aldbrough will provide an initial capacity of at least 320 GWh by 2028, while offshore storage would be available via the UK's largest natural gas storage facility at Rough, which will be repurposed to create 10 TWh of hydrogen storage.

11%-21% by 2040

Cluster emissions abated using hydrogen

1.6-3 $MtCO_2e$ /year

Abated by hydrogen fuel switching

52%

Proportion of national 2030 hydrogen production target met by planned Humber projects

50%

The Centrica Rough facility can provide 50% of the UK's hydrogen storage requirements by 2050

Mandate 3:

To adopt all optimal electrification measures

14%-30%
by 2040

Cluster emissions abated through electrification

Electrification is a vital decarbonisation option abating up to 30% of the cluster emissions by 2040, which is equivalent to circa 5 $MtCO_2e$ per year. It is a particularly attractive option for Ironmaking, Refining and Chemicals sectors. The use of electrification in our model is dominated by the early installation of an electric arc furnace (EAF) at British Steel Scunthorpe in the late 2020's. This represents the only site capable of adopting large-scale electrification across all modelled scenarios. This would position the UK as a green Steelmaking economy, protecting jobs, utilising the abundant low carbon electricity produced offshore, and allowing increased reprocessing of steel scrap that is currently exported.

Electrification will play a key role in decarbonising small and remote sites that will not have ready access to CCS infrastructure or hydrogen. A distinct advantage of the electrification option is that industries do not have to wait for the pipeline infrastructure, enabling adoption and emission reduction from 2025 in some sectors.

The viability of electrification is very sensitive to the price of electricity. Government support, or alternative market incentives will be needed to enable the rapid decarbonisation electrification offers.

Mandate 4:

To prioritise efficiency and circular economy measures

11%-13%
by 2040

Cluster emissions abated through efficiencies

Driving industrial emissions to their lowest possible level will require a continual focus on Resource Efficiency and Energy Efficiency (REEE) across all our industries. Our analysis, based on national trends and the specific industries in our region, predicts that this could lower the cluster's emissions by up to 13%, saving over 1 $MtCO_2e$ per year. By rigorously maximising all opportunities for REEE these measures will be cost effective, able to be implemented quickly and should not require access to region-wide infrastructure.

Whilst REEE measures can be implemented in individual industries and at individual sites, collaboration can enable transformative changes. The industrial partnerships formed in the Humber focussed on net zero will enable this. Together we can find opportunities such as waste heat supplying district heating systems, wastewater being recycled to reduce water stress, and waste streams from our integrated works and chemicals parks becoming feedstocks for neighbours.

AN OPTIMISED AND COSTED PLAN

Our analysis supporting this Plan focussed on finding the lowest cost solutions to decarbonise the energy intensive industrial sectors represented in our cluster. We carefully considered which technologies could be adopted for each process at each site, the regional infrastructure required to enable this, and the associated site and system-wide costs. The capital cost of this transition in our modelled scenarios is forecast to be between £7bn and £10bn.

The total cost to industry is also influenced by the additional fuel costs associated with each abatement option. This could result in total costs to industry between now and 2040 of £20bn to £34bn, and average costs of abatement of between £120 and £210 £/tCO_2. Timely and well-defined business models are needed to unlock the cluster's potential to decarbonise. It is clear that by supporting the Humber industries to lead on industrial decarbonisation, we will provide the best national-scale value and impact. The technologies and knowledge developed through this bold transition can then be applied in the harder to decarbonise industrial clusters through CO_2 import and supply of low carbon hydrogen.

The Humber is very attractive to UK and foreign investors due to its existing infrastructure and the expanding low carbon opportunities Decarbonising our industry will further enhance this- as a track 1 cluster we are already leading. The region's investment in decarbonisation will create up to 70,000 new jobs nationally, and over 20,000 in the Humber. It will support new low carbon enterprise through collaborative innovation opportunities, and growth in supply chain businesses through a clearly mapped programme of works.

Through providing investor confidence and continued investment, the Humber's unique contribution to the national economy will continue to grow.

Securing access to water for green technologies

Our water study highlighted the importance of effective management of water supply and demand to avoid water availability becoming a constraint in the Humber region. Electrolytic hydrogen is likely to develop the highest water demand in the Humber, with increased water use predicted for other low carbon hydrogen production, carbon capture and storage technologies.

The study investigated the risks and found that industries are likely to need to adopt a more circular approach, optimise processes and find synergies within the Humber cluster to promote efficient transfer of water around the region. We are working closely with water suppliers and the Environment Agency to ensure long term strategies for water supply are in place.

Mandate 5:

To generate social value through the industrial transition

Our region benefits from a thriving industrial community, with generations of family members contributing to the manufacturing outputs from some of the UK's largest businesses.

Our region delivers highly skilled and in turn highly paid jobs, including those necessary to enable industrial decarbonisation. Through our consultations with members of the local community and key stakeholders, we identified that people are protective and proud of where they live, and the region's heritage. Alongside a strong sense of identity and place, they told us that they want to be involved with the transition from the start, not only for themselves, but to safeguard their children's futures too.

Our Plan carefully considers and recommends that a strong community input is critical to generating buy-in, and that communication efforts need to be reframed to emphasise long term public participation. Young people need to be educated on future opportunities and considered in future consultations.

As a region we are fortunate that many decarbonisation projects have already begun their public consultations. Our recommendations will enable them to refine their processes to further support visibility of opportunities, strengthen our economy, increase resilience and reduce inequality.

Mandate 6:

To further develop Humber skills and supply chains

£7-10bn

Capital Investment

22,800

Jobs created in the Humber region

With ambitious timelines for the creation of a net zero cluster, the coming decade will see a period of intensive activity and high demand for the goods, services and skills needed to drive decarbonisation.

As the Humber's decarbonisation projects move into their development and construction phases, there will be a large increase in the parts and materials and engineering construction skills needed from the cluster's manufacturing, engineering and contractor supply chains.

Supply Chain & Skills

The Humber's engineering and industrial supply chains have grown to support our vast industrial base and continue to respond to the need for a range of services both on and off-shore. By acting now, we can ensure that local supply chains will be able to further grow their capabilities and capacities to meet future demands.

Through early supply chain engagement activities, we have communicated the breadth of requirements for parts and materials to develop the first phase of decarbonisation projects in the region. We have enhanced workforce planning, recruitment and school engagement activities, alongside expanded action to meet equality, diversity and inclusion targets in our future workforce. Successful, strong supply chains will ensure that regional and national economies maximise the benefits from the anticipated investment, and that our suite of decarbonisation projects can be completed on time and on budget.

Our Plan identifies the steps that need to be taken to ensure local supply chains, skills and education providers play their full role in the creation of the UK's first net zero industrial cluster by 2040. Our region is poised to develop the technologies, skills and experience in the Humber which can be exported to other clusters and regions.

Mandate 7:
To drive investment and collaboration to deliver the net zero Humber of tomorrow

Our Plan sets out how the Humber can rapidly achieve net zero through implementation of our mandates. Our research, analysis, and consultation proves that it is viable, robust, optimised, and can be implemented at speed. Our Deployment Projects, along with additional net zero projects that are being developed in the cluster, align with our Plan. Each will contribute meaningfully to deep decarbonisation of the cluster. These projects urgently require the appropriate policy and economic frameworks to be established, and decarbonisation technologies to continue to be developed, to allow the planned and necessary rapid decarbonisation.

The Humber is uniquely positioned to go beyond net zero, with the potential to enable transformational levels of greenhouse gas removals. Decarbonising the Humber industrial cluster will be catalytic, enabling wider industrial decarbonisation and is core to the UK's overall pathway to net zero. Now is the time to start decarbonising the UK's vital energy intensive industries, through developing and implementing projects where they can be done most efficiently- in the Humber.

Our Mandates for action

1. To implement Carbon Capture and Storage and Greenhouse Gas Removal technologies at pace and scale
2. To implement low carbon hydrogen at scale
3. To adopt all optimal electrification measures
4. To prioritise efficiency and circular economy measures
5. To generate social value through the industrial transition
6. To further develop Humber skills and supply chains
7. To drive investment and collaboration to deliver the net zero Humber of tomorrow

Our Plan to reduce emissions is exemplary, both nationally and globally.

Our region has unique access to renewable energy and CO_2 and hydrogen storage.

Our rich industrial heritage equips the region with the skills and capability to lead.

Our industries are primed and ready to invest in this transformation.

Our Plan builds on this momentum, showing how to accelerate delivery.

We invite you to join us on this journey. Together it is possible.

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Introduction

1. Introduction

1.1 Context and overview of our Plan

The Humber region is steeped in industrial history and has been on the frontline of industrial revolutions since the 1700s. This rich heritage of innovation and ambition has equipped the region with the skills and capability to become the UK's first net-zero industrial cluster. The region also has unparalleled natural assets including significant CO_2 and hydrogen storage potential, abundant low-carbon energy sources, and extensive port facilities. These make the Humber region the optimal location in the country to develop and implement decarbonisation technologies. Coupling the regions natural assets with the ambition, innovation and investment of the region's industries positions the Humber to drive the UK's industrial decarbonisation. Our region plays a strategic role in the industrial story of our country, and this Plan sets out the next chapter of that story.

The industries choosing to base themselves in the Humber provide vital goods and services. These enable, feed, and benefit the UK. But in doing so, their greenhouse gas emissions are greater than from any other industrial cluster. To achieve national decarbonisation targets it is essential that the Humber Industrial Cluster decarbonises. This Plan sets out what needs to happen to rapidly and efficiently achieve this. Decarbonising the Humber Industrial Cluster will be catalytic, enabling wider industrial decarbonisation.

This Humber Industrial Cluster Plan (HICP) is the result of a two-year collaborative journey of wide-ranging research, in-depth analysis, and extensive consultation. It demonstrates how the Humber can achieve net-zero, and then go beyond that to be strongly carbon negative, removing more carbon from the atmosphere than industry discharges to it, addressing our legacy. Our Plan is viable, robust, optimised, and can be implemented at speed. The Deployment Projects in the Humber, and the additional net-zero projects that are being developed in the cluster, align with this Plan. Each will contribute meaningfully to deep decarbonisation necessary.

Our industries have already invested significantly, and building on this momentum, have plans to invest over £15bn more in the technologies and infrastructure required. Through working together – Industry, Government, Stakeholders, and Communities - we will build a Humber region that that remains attractive to investment, provides employment and economic growth, and wide-ranging opportunities for communities. Decarbonising the Humber industries will help make our region more sustainable, resilient, and inclusive.

In this introduction to the Plan, we set out why it is needed, the regional Humber context that this Plan is embedded in, and how it has been developed. This background sets the context for the subsequent chapters which present the outcomes of our research and analysis, and from this build up the fundamental elements of our Plan – the Mandates for action.

1.2 Drivers and enablers of industrial decarbonisation

In June 2019, the government passed legislation that committed the UK to net-zero greenhouse gas (GHG) emissions by 2050. This international leadership is being widely followed, with most countries in the world also committing to reduce greenhouse gas emissions with the aim of limiting global warming to 1.5ºC.

Achieving net-zero nationally will require all sectors, including transport, building heating, construction, industry, power generation, waste management, and land use to significantly reduce their emissions. Industry is one of the most challenging sectors to decarbonise due to the specific needs for very high temperatures, and the emission of greenhouse gases, predominantly carbon dioxide, being intrinsic to the processes. This challenge has been recognised by the UK Government, and they are now investing through UK Research and Innovation (UKRI) to address this big societal challenge facing UK businesses.

The UKRI's Industrial Decarbonisation Challenge Fund is supporting the development of low-carbon technologies and infrastructure to increase industry competitiveness and to increase its contribution to the UK's clean growth (UKRI, 2023). UKRI seek to work with industry to find ways to reduce carbon emissions from energy intensive industries, such as iron and steel, power generation, refining, and chemicals, all of which are present in the Humber Industrial Cluster. To initiate the scale of decarbonisation required, UKRI are currently focussing on working with the UK's largest industrial clusters.

The definition of an industrial cluster varies, but at least eight are recognised across the country although the volume of emissions from each of these varies significantly. These clusters comprise the Black Country, Grangemouth, Humber, North West England, Southampton, South Wales, Teesside, and Thames. These industrial clusters secure 1.5 million jobs and annually export goods and services worth £320 billion. However, this industry also releases around 40 – 50 million tonnes of carbon dioxide per year ($MtCO_2e$/year).

The UKRI Industrial Decarbonisation Challenge (IDC) Fund aims to drive industrial decarbonisation whilst enhancing productivity for the UK's industrial regions and creating new jobs for a low-carbon future. It is currently doing this through investing in:

- Cluster plans. A total of £8m enabling funding has been distributed to support the industrial clusters in the Black Country, Grangemouth, Humber, North West England, South Wales, and Teesside to produce bespoke and region-specific blueprints on how to achieve net-zero emissions.
- Deployment projects. £171m of funding has been provided to deployment projects. These are projects which are developing detailed designs and demonstrating industry-scale technologies and shared infrastructure for the cost-effective deep decarbonisation of industrial clusters. There are seven stage 2 deployment projects, with three in the Humber – Humber Zero, Zero Carbon Humber, and Northern Endurance Partnership.
- The Industrial Decarbonisation Research and Innovation Centre (IDRIC, 2023). £20m of funding has been provided to advance cutting-edge decarbonisation research through a virtual multidisciplinary research and innovation centre. This is allowing collaboration between research organisations, industry, government, policymakers, NGOs, trade organisations and the public, to co-create whole-system, multidisciplinary solutions to accelerate industrial decarbonisation.

The IDC has set the UK's industrial clusters the target of reducing emissions in one cluster to net-zero by 2040, and to drive deep decarbonisation of four clusters by 2030. This will be achieved by putting the low-carbon infrastructure needed to support industrial decarbonisation in place, and this being used to the greatest extent possible by industrial users to reduce their emissions (BEIS, 2021).

The Government's 2021 Net-Zero Strategy: Build Back Greener builds on this and made the following key commitments related to industrial decarbonisation, and what is needed to enable this:

- Develop carbon capture, utilisation, and storage in at least two industrial clusters by the mid-2020s, and four by 2030, capturing 6 $MtCO_2$/year by 2030 and 9 $MtCO_2$/year by 2035. *This industrial target is set within the wider Government target of abatement of 20-30 $MtCO_2e$/year through carbon capture and storage by 2030.*
- Develop 10GW of low carbon hydrogen production capacity by 2030.
- Abate between 5 $MtCO_2e$ and 12 $MtCO_2e$ of industry GHG emissions per year by 2050 via electrification.
- Develop Resource and Energy Efficiency measures with ambition of achieving 11 $MtCO_2e$ worth of savings by 2035.
- Deploy at least 5 $MtCO_2$/year of engineered removals by 2030 and to around 23 $MtCO_2$/year by 2035.
- Support deployment of other decarbonization technologies powered by renewable energy – and offshore wind – and future-proofing industrial sectors and the communities they employ.

This sets the context for the Humber Industrial Cluster Plan. The cluster needs to decarbonise rapidly to align with national targets and plans, and it has an opportunity to lead in doing so. The challenge of industrial decarbonisation is recognised by government. Decarbonising industry will require the application of multiple technologies and approaches.

1.2.1 Precursor studies for the Humber region

This Plan builds on previous studies including:

- The 2018 Study of the Humber Energy Intensive Industries Cluster.
- The 2019 Humber Clean Growth Local White Paper.
- The 2020 Baseline local emissions assessment.
- The 2020 Phase 1 Humber Industrial Decarbonisation Roadmap.

These studies detail the significance of decarbonising industry in the Humber as part of enabling wider decarbonisation of the UK's non-industrial sectors. They also stress the need for urgent action by national and local Government and industries across the region.

This previous work has resulted in clean growth, including achieving net-zero by 2040, being strongly embedded in local strategic plans. In 2021 the four Humber Local Authorities also collaboratively developed The Humber Estuary Plan, which focused on accelerating clean growth, developing the ports and manufacturing clusters, managing the Humber Estuary asset, and attracting new development. This is the context within which the region's decarbonisation will be undertaken.

1.3 The Humber Industrial Cluster

The Humber Industrial Cluster is concentrated along the banks of the Humber Estuary. It includes the UK's main steel production centre, its largest port complex and enterprise zone; a third of national fuel refining capacity; the country's second largest chemical cluster, one of the nation's largest concentrations of food manufacturing and cold storage, along with biofuel, lime, and glass manufacturers. These industries provide critical employment and value to the region, supporting some 360,000 jobs and contributing more than £18bn to the UK economy (Humber LEP and CATCH, 2020). The region benefits from excellent connectivity to Europe and the world via its ports.

The Humber is known as the UK's Energy Estuary, a justified description. A sixth of the UK's electricity is supplied from the Humber region from sources including the UK's largest power station and largest single source of renewable energy (at Drax), and the world's largest offshore windfarm. Biofuels and sustainable aviation fuel are produced. Numerous gas terminals and gas storage facilities feed into national distribution networks.

This wealth of industry means that the Humber Industrial Cluster is the UK's largest industrial emitter of greenhouse gases. In 2019, the industrial emissions were 20 million tonnes – nearly 5% of the national total, and greater than any other cluster. Details of the composition of these emissions are given in Section 1.3.1.

As the Humber has the highest concentration of industrial emissions in the UK, it provides the greatest opportunity lead in achieving the challenging national targets. The Humber Industrial Cluster is nationally significant today and can grow this influence nationally and internationally. Decarbonising the Humber industry presents an ideal vehicle for clean green growth, building the region's competitiveness and resilience.

1.3.1 Current and projected future industrial emissions

The Humber is the UK's largest industrial cluster by emissions and economic activity. Figure 1 shows the 2019 emissions from the Humber industries listed in the National Atmospheric Emissions Inventory (NAEI). This totals 20 $MtCO_2e$/year from fossil fuel use, 20% higher than for any other cluster (BEIS, 2021d; Guidehouse, 2022; Element Energy and Cambridge Econometrics, 2022) and 4.4% of the total national emissions of 454.8 $MtCO_2e$.

The major sectors emitting greenhouse gases are Combined Heat and Power, Iron and Steel, Power Production, and Refining and Fuels. Each of these sectors emit over 3 million tonnes of greenhouse gases per year. The Chemicals and Cement, Glass & Minerals sectors are also significant contributors.

Without intervention, emissions are predicted to remain high through to 2040 and beyond. Reductions in demand and progressive decarbonisation of the UK energy systems would reduce industrial emissions in some sectors, but not significantly.

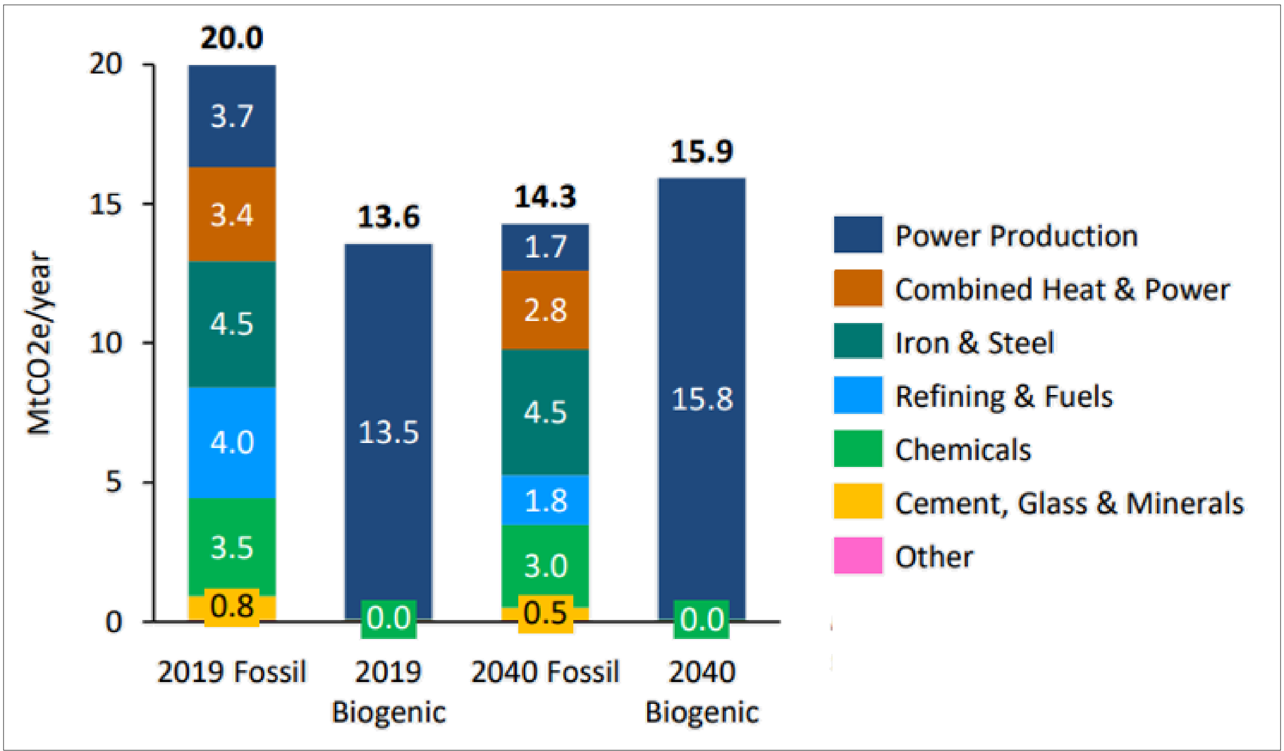

Figure 1 **Breakdown of Humber Cluster emissions by sector for 2019 and projected for 2040. (Systems Model report Chart 2.1)**

Due to geographic proximity and its significant impact on the cluster's infrastructure, Drax power station is included as part of the Humber cluster in this Plan. Drax, and many of the other power generators and Combined Heat and Power (CHP) plants in the region are inextricably linked to the industry, and its decarbonisation. The emissions from Drax's combustion of biomass are biogenic emissions. These are zero rated at the point of combustion in accordance with carbon accounting standards as the carbon released in burning has already been accounted for in the land use sector.

Our Plan details how the Scope 1 fossil fuel emissions from industry can be abated. These are the emissions arising from direct on-site energy use.

1.4 Unique aspects of the Humber region

The Humber region and industrial cluster is unique, with strengths and differentiators that will enable industrial decarbonisation rapidly and efficiently. These are introduced here, with the enabling impact of each of these then being discussed further later in the Plan.

1. Compactness. Although the Humber is a large emitting cluster there is geographical proximity of industry. This:
    a. Allows for shorter and more cost-effective carbon dioxide and hydrogen transport networks.
    b. Reduces investment risk associated with providing infrastructure for carbon transport and storage and hydrogen supply and networks as there will be demands from multiple sites for each.
    c. Makes circularity between industries easier to implement. Feedstocks and waste products from each industry can be more efficiently shared.
2. Large potential for carbon dioxide storage capacities in the saline aquifers and depleted gas fields in the Southern North Sea. This enables:

   a. Carbon capture and storage to be implemented at scale, introducing economies of scale and lower prices per tonne of carbon stored than storage elsewhere in the country.

   b. Carbon capture to be applied to all the industries where this is the optimal decarbonisation technology, as the storage is sufficient for all industrial emissions in the long-term.

   c. Large scale hydrogen production from natural gas via steam reforming, as the captured carbon can be stored locally. Per unit costs will therefore be lower in the Humber than elsewhere in the country.

   d. Future storage of carbon from Direct Air Carbon Capture and Storage (DACCS), allowing this to be implemented in the region cost-effectively.

3. A scalable and integrated hydrogen network. There are multiple planned projects in hydrogen production, transmission, and use to decarbonise industry. Within the region there will be sufficient demand for hydrogen to make the business case for investing in production capacities. This network will then be scalable in the future as demand increases for hydrogen for non-industrial uses, such as transport or domestic use.

4. Drax Power Station results in there being significant electricity generation from biomass in the region, with this ready to adopt carbon capture. In conjunction with point 2 above, this will enable Bioenergy with Carbon Capture and Storage (BECCS) to be deployed rapidly, and negative emissions to be achieved. Any other region would firstly need to transition to or build biomass power stations before carbon capture could be installed to achieve negative greenhouse gas emissions.

5. Nationally important hydrogen storage capacity at Aldbrough and Rough. This will allow:

   a. Short-term (hours) to medium-term (weeks) storage to balance energy supply and demands.

   b. Long-term (inter-seasonal) storage to provide energy system resilience.

   c. Flexible utilisation of electricity to generate hydrogen during periods when it may otherwise be curtailed – hence helping optimise the overall energy system efficiency.

6. Extensive offshore wind farms already installed and being continually expanded. This enables large scale production of hydrogen via electrolysis and provides low carbon sources of electricity to support electrification of industry across the region.

7. Port access via the largest UK port complex. This will facilitate import of energy products such as ammonia and compressed CO_2 for subsequent storage. Additionally, this provides opportunity to green shipping and port operations through supply of low carbon fuels. The ports would also enable export of CO_2 from the Humber on a short-term basis, if necessary, during maintenance windows on the region's CO_2 stores.

8. The Humber industries are actively collaborating on decarbonisation projects. All understand that decarbonisation can only be achieved together. This collaborative approach is leading to:

   a. New ventures and groups being formed, including those successfully funded as deployment projects (Zero Carbon Humber, Humber Zero, Northern Endurance Partnership).

   b. Industry investing in and developing projects to enable their decarbonisation. Some of these are now advanced beyond front end engineering design (FEED) stages to engineering, procurement and construction (EPC). Planning permissions are being granted. These projects are ready to implement as soon as the policy environment and business cases are sufficiently clear to reduce the investment risk to acceptable levels.

   c. Industry committing to invest substantially (£15bn - £30bn) in decarbonisation of their operations over the next 20 years.

1.5 Developing this Plan collaboratively

Our Plan has been developed collaboratively, with input from over twenty organisations. It therefore reflects the diversity of perspectives and needs from stakeholders across the region to the extent possible.

UK Research and Innovation part-funded the development of this Plan via its £8 million Industrial Decarbonisation Challenge Fund and provided steering via quarterly review meetings. UKRI has separately developed a national industrial cluster plan, which the HICP team contributed toward (see Section 4.1).

The HICP team who led the development of this Plan was formed from Hull and East Yorkshire Local Enterprise Partnership (HEY LEP) and the Centre for Assessment of Technical Competence Humber (CATCH). CATCH is an industrial skills development organisation working across the region.

The HICP team was complemented by eight Industrial Partners - British Steel, Centrica Storage Limited, Drax, Equinor, National Grid Ventures, Phillips 66, SSE Thermal and VPI Immingham. These partners provided £0.9m match funding, shared site information and supported sector-specific decarbonisation research projects.

Other organisations were involved with the Plan development as Strategic Observers – EP UK (developers of the South Humber Bank Energy Centre Project), Harbour Energy (leaders of the Viking CCS project), Prax (owners and operators of the Lindsey Oil Refinery), Singleton Birch (owners of the Birch Lime plant in the region), Uniper, Greater Lincolnshire LEP, East Riding of Yorkshire Council, Hull City Council, North Lincolnshire Council, and North East Lincolnshire Council.

The involvement of Industrial Partners and Strategic Observers enabled us to pro-actively identify risks to be mitigated and opportunities to be seized, and ensured this Plan is evidence-based, practicable and implementable.

Members of both the Humber Leadership Board and the Humber Energy Board were key stakeholders throughout the development of the Plan. Their endorsement of the approach taken, and the Mandates developed, has been reinforced through the Humber Energy Board agreeing at its February 2023 Board meeting to take a strategic oversight and guardian role for the Plan going forward (see Section 4.2.1).

Four suppliers, Element Energy, ERM, KPMG and Arup, provided independent research and analysis to supplement the Plan's evidence base. Each of the outputs from this work are available (see Section 6.1). The way that the each of the supporting studies fed into this Plan is illustrated in Figure 2. In developing this Plan, the full range of evidence and recommendations were integrated and honed. This Plan communicates the key principles of how the industrial cluster can be optimally decarbonised, summarised in our Mandates for action, with the supporting evidence providing guidance on how this can best be implemented.

Element Energy:

- Developed and applied an Industrial Decarbonisation Systems Model (termed the *Systems Model* in this Plan) to analyse a range of industrial decarbonisation technology options and timescales for adoption. This model provided a robust and scientific tool to explore options for how industries may decarbonise, and understand the options for achieving greenhouse gas reduction, and their relative impact, costs, and infrastructure requirements.
- Undertook an extensive Markets, Policy, and Regulatory study (the *MPR Study*), providing detailed insight into the risks and barriers around industrial decarbonisation, and recommendations to mitigate them. This study explored fuel switching technologies, carbon capture, use and storage (CCUS), GHG removal technologies, emissions offset export prospects (national and international), and commercial viability of CO_2 import (national and international).
- Conducted an Industrial Decarbonisation Water Demand Study (the *Water Study*) to determine potential constraints arising from projected changes in industrial water demand, and its consequences for decarbonisation plans.

ERM:

- Conducted a Societal and Cultural Challenges and Social Innovation Study (the *Societal Study*), which considered the social and cultural strategies needed to support transformational shifts in the cluster, characterised the enabling environment and quantified the social value and benefits of decarbonisation technologies.

KPMG:

- Prepared an *Inward Investment Study* which assessed the impact of decarbonisation measures and net-zero status on inward investment.
- Conducted a *Supply Chain Study* which mapped the existing capabilities, capacities, gaps and pressure points of the engineering supply chain and contracting services sector to support decarbonisation efforts over the next 20-years.
- Delivered a *Skills Study* into the region's ability to meet key skills requirements needed to support the transition to net-zero, highlighting both strengths and needs.

Arup:

- Compiled and distilled the outputs, insights and deliverables from all contributors, and worked with the HICP team to develop our Plan.

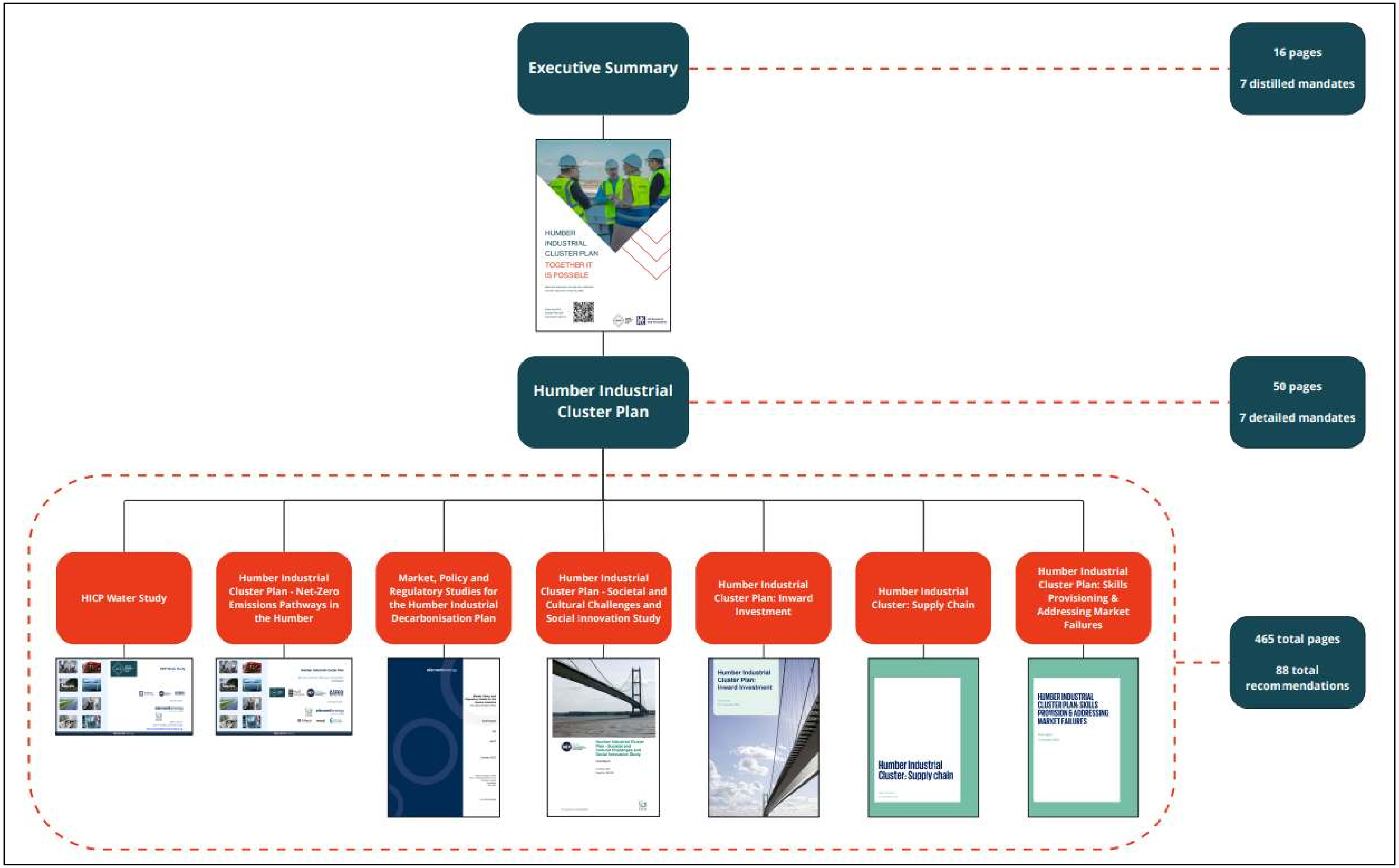

Figure 2 Illustration of how the range of commissioned studies supported the development of our Plan.

Section 2

Developing the evidence underlying our Plan

2. Developing the evidence underlying our Plan

To be able to understand the optimal approach to decarbonising Humber's industry we needed a method to provide representations (i.e., models) of the decarbonised future out to 2040. This needed to be able to cut through the clutter of uncertainty and changing conditions. Developing this representation of the future is a complex task because new carbon dioxide transport pipelines and hydrogen networks will bring new interdependencies between what are, in the main, separate industrial sites. This brings constraints and uncertainties meaning that deploying one decarbonisation technology to one site can affect the options available to other sites.

The methodology we developed needed to be able to identify optimal decarbonisation approaches at each site (at the site level) and then iterate each towards an optimal whole Humber system approach across all sites (at the Humber system level).

In this section we outline how we developed and used a comprehensive Systems Model, and then present the overall headline results.

2.1 The Systems Model

Our Phase 1 feasibility study in 2020 (the Humber Industrial Decarbonisation Roadmap) identified that we needed a scientifically robust and credible energy systems model to provide the necessary evidence to this Plan. Analysing the existing situation and extrapolating forward could provide insight into what may happen in the near future but was not a sufficiently robust approach to analyse the range of possible, complex, long-term scenarios which could emerge between 2022 and 2040. In response, the Systems Model we developed uses optimisation and simulation algorithms which enable it to understand and advance from the data it acquires, adapting responsively, to provide insight on the question of "What is the optimal system-wide solution over time?".

2.1.1 How our model was built and its key features

Our model was developed by Element Energy, with the supporting report (Element Energy, 2023) detailing of its configuration and methodology. The model was based on modelling Element Energy did to support the Climate Change Committee's 6th Carbon Budget, where it was used to assess optimal national industrial decarbonisation approaches. The model was developed and used to provide insight and evidence for this Plan. However, it remains a live and operational tool which we can continue to use to further investigate optimal routes to decarbonising the Humber industrial cluster.

The model is independent of current industry projects and proposals – it does not act to replicate announced projects, recognising that there are uncertainties surrounding planned projects and proposals, which are often dependent on successful receipt of economic support or future final investment decisions. The model instead decides on abatement technologies, timelines, and extent of adoption via a bottom-up approach, aggregating the abatement technologies implemented for each industrial process and optimising these across the entire cluster.

The model focuses on Scope 1 industrial emissions in the region, the technologies that could be adopted to decarbonise them, and their interactions. It is technologically agnostic and identifies the most cost-effective solution. Scope 2 and 3 emissions are also essential to be addressed and may well be reduced because of Scope 1 decarbonisation. These were not the focus of the model but have been taken into account to ensure that the overall optimal emissions reduction is achieved, including Scope 2 and 3 emissions.

The Systems Model included all 53 industrial sites in the Humber which are National Atmospheric Emissions Inventory (NAEI) sources of emissions and split these down further into the different industrial processes producing emissions at each site. It also included:

- Likely future hydrogen production projects.
- Anticipated power production demands based on planned projects.
- Onshore pipeline networks for both hydrogen and carbon dioxide transport (with the rate of the buildout of these pipelines varying between scenarios).

- Limits to the uptake rate for abatement technologies (based on planned development for hydrogen production and subsea CO_2 storage).

The Systems Model used an iterative process to work out the 'optimal' approach to decarbonising each industry in the Humber. This was defined as the overall least cost solution, with the incentive to abate emissions being a 'shadow' carbon value (or price) for all carbon emitted. The model was not set to reduce emissions to any pre-defined level, but it self-determined the level of emissions which would likely be abated for the imposed shadow carbon value. The modelling approach of using a shadow carbon value to represent the incentive to reduce emissions is consistent with Government guidance on valuing GHG emissions when appraising policy options (BEIS, 2021). The shadow carbon value therefore represents all incentives to reduce emissions, which could include both policy and market drivers, such as carbon taxes, product pricing, grants, etc.

2.1.2 Developing and using scenarios to provide insight

The future is uncertain. There are many things which could change which would influence how the Humber Industrial Cluster optimally decarbonises. So, we used the Systems Model to explore four different futures, or scenarios, for the Humber. Each of these could plausibly develop over the next 10-20 years. Each scenario answered the question "what should we do to optimally get to net-zero by 2040" but imposed different constraints and operating conditions. The principal differences between the four scenarios were:

1. How committed, consistent and rapidly mobilised the necessary policy support is to support the full range of necessary decarbonisation approaches.
2. How much of a focus there is on more established abatement technologies, versus investing in innovation and new approaches.

The main attributes of each scenario are outlined below.

The first scenario focused strongly on one of the Humber's natural advantages, the plentiful storage for CO_2 beneath the North Sea. In this scenario – termed CCUS Commitment – there is strong momentum towards widespread use of carbon capture as the preferred abatement technology. In this future there would be:

- Strong early policy and economic support for large scale carbon capture projects and hydrogen generation with carbon capture. Existing planned projects can be implemented without delay and available carbon capture technologies gain widespread early adoption.
- Construction of the necessary region-wide transport and storage (T&S) infrastructure for the captured carbon dioxide, alongside the hydrogen distribution network, removing connectivity barriers for industry.
- Well-developed storage capacity for CO_2 enables the region to accept imports from the UK and abroad, as well as enabling the region to become a hub for GHG removal using CCS.
- An initial focus on CCS-enabled hydrogen production although this would gradually become more balanced between CCS-enabled production and electrolysis. The region could export hydrogen as generation capacity exceeds the regional industry demand.
- Electrification progresses slowly due to the focus on decarbonisation through CCS (reducing focus on lowering electricity prices).

The future we explored in the Innovations and Incentives scenario is initially similar to the CCUS Commitment scenario. There is strong initial policy support and incentives for CCS and hydrogen projects. The necessary shared T&S infrastructure is promptly deployed. But we then considered what may happen in the longer-term if a more diversified approach to industrial decarbonisation was adopted, including:

- Significant increase in renewable energy production by large offshore wind farms reduces electricity costs, incentivising hydrogen production by electrolysis and hydrogen storage.
- Increased focus on electrification and resource and energy efficiency measures reduces the scale of abatement demand.
- Reduced focus on CO_2 storage and hydrogen infrastructure for the wider economy, with a more regional perspective adopted.

The third scenario – termed Barriers with Limited Enablers – explored a future with a focus on established technologies in the long-term (as in the CCUS Commitment scenario), but where initial implementation is delayed. This is due to there not being strong and integrated policy support – regulatory barriers remain, business models are delayed. This scenario assumes:

- A lower price for carbon emissions reduces the incentive for industry to decarbonise.
- Unresolved technical issues prevent region-wide infrastructure being rolled out, preventing delivery of some planned projects.
- Uncertainty around economics and infrastructure mean that some industries delay their emission reduction plans.
- The region loses out on opportunities for CO_2 imports and hydrogen exports.

The fourth scenario explored a future with enhanced national policy support for decarbonisation driven by electrification, where renewable energy from offshore wind becomes an enabling local resource for industry in the cluster and the wider economy. Electricity would become progressively cheaper whilst gas prices increase. This is termed the Alternative Solutions scenario and assumes:

- Carbon capture still plays a role, so the transport and storage deployment of CO_2 in the region proceeds.
- Lower electricity costs incentivise hydrogen production by electrolysis, with less support for CCS enabled hydrogen.
- Several major CHP projects adopt electrification solutions (electric steam boilers) instead of CCS.
- The focus electrification reduces opportunities to support the wider economy via CO_2 storage or hydrogen production.

2.2 Systems Model results

We analysed the results from each scenario through comparing, contrasting and exploring them. We identified where there were common themes, such as industries and sectors adopting the same abatement approaches irrespective of the scenario. We delved into the factors influencing the differences between the scenarios to understand how sensitive each scenario was to the modelling parameters. We identified where there may be tipping points at which the optimal technology for adoption in a sector may change. Through doing this we developed our insights into how the Humber may optimally decarbonise based on the outputs from the Systems Model.

It is important to recognise that none of the scenarios themselves are the optimal, or right, solution for the Humber. Each provide essential insight into how our industries may optimally decarbonise in different futures. But by understanding what is causing the similarities and differences in their results, we can identify what needs to happen to achieve rapid emission reductions.

2.2.1 Emission reduction pathways

Figure 3 shows the calculated emission reduction pathways for each scenario and demonstrates the following key points.

1. Maintaining ‘business as usual’ will only reduce emissions 18% by 2040. This is consistent with previous estimates (Element Energy, 2021). **Radical and transformative changes are needed to drive industrial decarbonisation.**
2. Each scenario achieves deep-decarbonisation by 2040, with all scenarios reaching a 96% abatement compared to 2022 baseline levels. Each scenario provides a viable way for the cluster to achieve the required transition. **It is possible to reduce emissions to very low levels if appropriately planned, supported, and implemented**. There is some flexibility in how the Humber cluster decarbonises as each scenario ultimately achieves similar levels of residual emissions.
3. **To achieve ‘net-zero’ there will need to be greenhouse gas removals, or ‘negative emissions’.** No scenario will reduce industrial emissions to absolute zero - 0 $MtCO_2e$/year and adopting greenhouse gas

removals will be the most cost-effective and practicable solution to reaching net-zero. Reducing emissions to the lowest possible level prior to offsetting is important, as offsetting cannot be used as a panacea to the decarbonisation challenge faced. Developing credible and robust greenhouse gas removals in the region is an essential part of achieving net-zero. See Section 2.2.2 for further discussion on the reasons for none of the modelled scenarios abate emissions to absolutely zero.

4. The rate of emission reduction, and residual emissions by 2030, could vary significantly. Although all the scenarios have initially similar trajectories, they start to diverge beyond 2026 with the Innovations and Incentives scenario having an 80% reduction in emission to 4 $MtCO_2e$/year in 2030 compared to 12 $MtCO_2e$/year under the Barriers with Limited Enablers scenario (a 31% reduction). **The decisions made now, and the current projects supported, will drive how low emissions could be by 2030 and the extent to which the Humber rapidly decarbonises.**

5. Total cumulative emissions between 2022 and 2040 could vary significantly under the different scenarios. Earlier decarbonisation would abate over 50 $MtCO_2e$ more by 2040 compared to slower acting scenarios. **The earlier the Humber cluster starts to reduce emissions, the greater long-term impact this will have.** All early reduction measures should be prioritised.

6. Delays in emission reduction are generally linked to delayed deployment of the regional hydrogen and carbon dioxide transport networks. **The necessary supporting regional infrastructure needs to be in place to allow industry to abate their emissions. Delivery of this is a key enabler.**

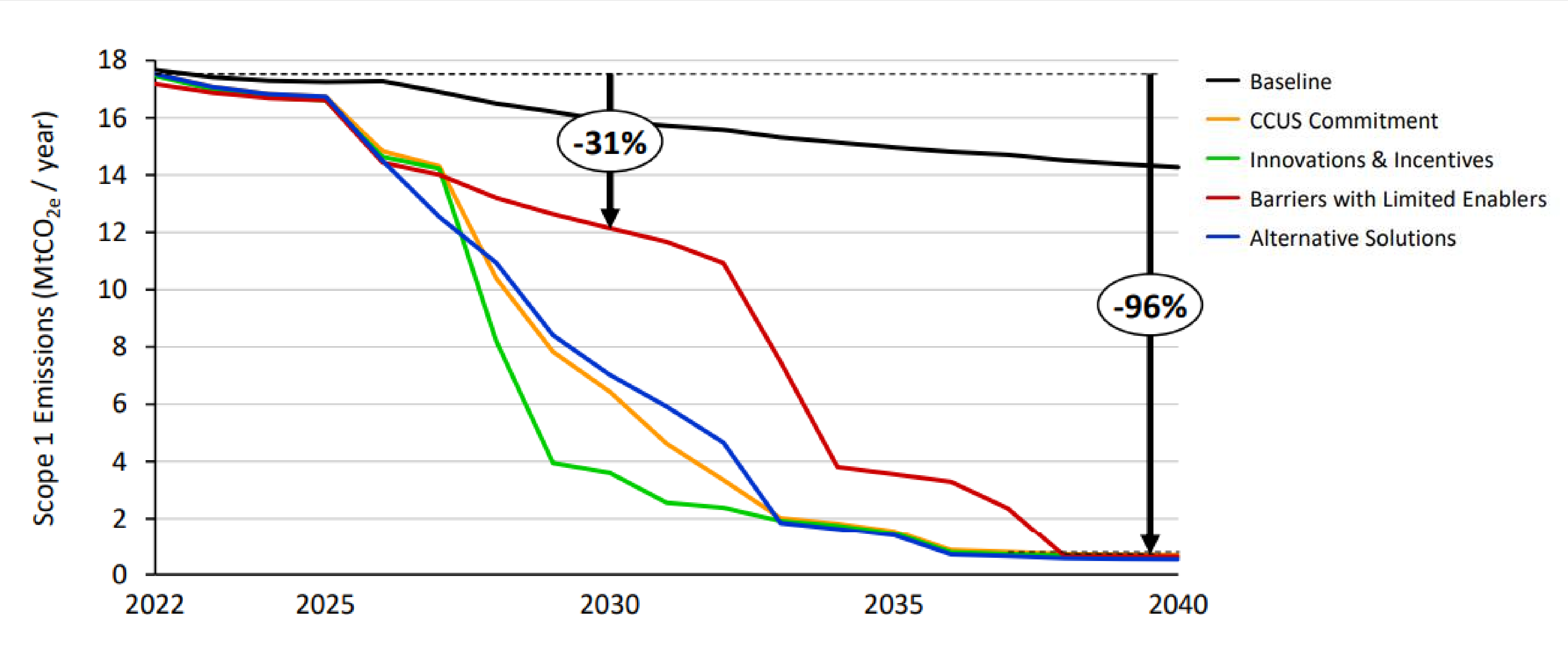

Figure 3 **Total Scope 1 emissions from the Humber Industrial Cluster in the scenarios modelled. (Systems Model report Chart 2.2)**

2.2.2 Residual emissions and achieving net-zero

There are two reasons why none of the modelled scenarios achieve absolute zero emissions by 2040 before removals are considered.

The first is that carbon capture technologies are not 100% efficient leading to residual greenhouse gas emissions to atmosphere from the sites adopting CCS. Capture efficiencies are expected to improve from the current 90-95% up to around 99%.

The second reason is that across the region there are multiple small emission sources which have no cost-effective or technically viable abatement options. These industries, sites and processes continue to emit as although this will result in costs from carbon taxation, that remains cheaper than abating emissions. As the model finds the lowest overall cost solution across the whole cluster (based on the shadow price of carbon used in each scenario) it does not 'force' the residual emissions to any level. Some of these residual emitters will be sites that are remote from the proposed CO_2 and hydrogen networks and so unable to connect to and benefit from these. Further build-out of the networks over time may allow more industries to use these. It is also possible that technology development will result in lower cost abatement options being available, and thus enabling deeper decarbonisation.

In devising any strategy to achieve net zero, it must be acknowledged that there will always be residual, unabated, emissions which have to be dealt with through greenhouse gas removals (GGRs). The residual emissions from the Humber industries are estimated to be between 0.5 and 0.7 $MtCO_2e$/year in 2040. To achieve net-zero within the region these residual emissions would need to be offset and there are at least three mechanisms by which this will happen.

1. Within the cluster there are some industrial processes (such as some industrial dryers, some small-scale power units, and waste incineration facilities) that partially use biomass as fuel. When these capture the carbon dioxide in their biogenic emissions this results in GGR. This is evident in the Systems Model, although as there are not many industrial processes using biomass currently, the impact of this is only small. If further industrial processes transitioned to biomass with carbon capture the volume of emissions removed would also increase.

2. The Humber will likely become the prime location in the country for new Direct Air Carbon Capture and Storage (DACCS) projects, due to the abundance of low-carbon electricity, waste heat from industrial systems, and the carbon dioxide transport and storage infrastructure. Although this technology is in early stage of commercialisation currently, multiple start-up companies are actively developing and piloting ways of doing this, with the aim of gaining first-mover advantage. As these companies transition into full-scale implementation and start to remove carbon dioxide from the atmosphere at scale, this will result in increasing volumes of negative emissions.

3. At the western end of the proposed Zero Carbon Humber pipeline, Drax's existing biomass power station near Selby, uses wood pellets made from otherwise unused forestry materials. Drax aim to become the world's first 'negative emission' BECCS power station once the carbon capture transport pipeline is installed. Drax's current ambition is to deploy carbon capture on two of its combustion units with a target of capturing 4 $MtCO_2e$/year by 2027 and a further 4 $MtCO_2e$/year by 2030. The Systems Model also indicated that deploying carbon capture on the remaining two combustion units would be part of the overall optimal decarbonisation pathway in three of the four scenarios. This would potentially result in capture of up to 15.8 $MtCO_2e$/year from Drax by 2035. However, this conversion of a further two combustion units does not align with any current Drax plans.

The significance of the proposed negative emissions of 4, 8 or potentially 15.8 $MtCO_2e$/year at Drax is evident, being an order of magnitude greater than the region's residual industrial emissions. The potential impact of Drax in enabling national targets to be achieved is also evident. The national target of deploying at least 5 $MtCO_2e$/year of engineered removals by 2030 could be met entirely by Drax.

Figure 4 overlays each scenario's emission reduction pathways with the planned and potential greenhouse gas removals in the region (excluding any future DACCS). This demonstrates that it would be possible to achieve net-zero by 2030, 10 years in advance of the UKRI's Industrial Decarbonisation Challenge target of having one cluster achieving net-zero by 2040. By 2040 the region has the potential to be removing nearly as much greenhouse gas from the atmosphere as is currently being emitted by industry.

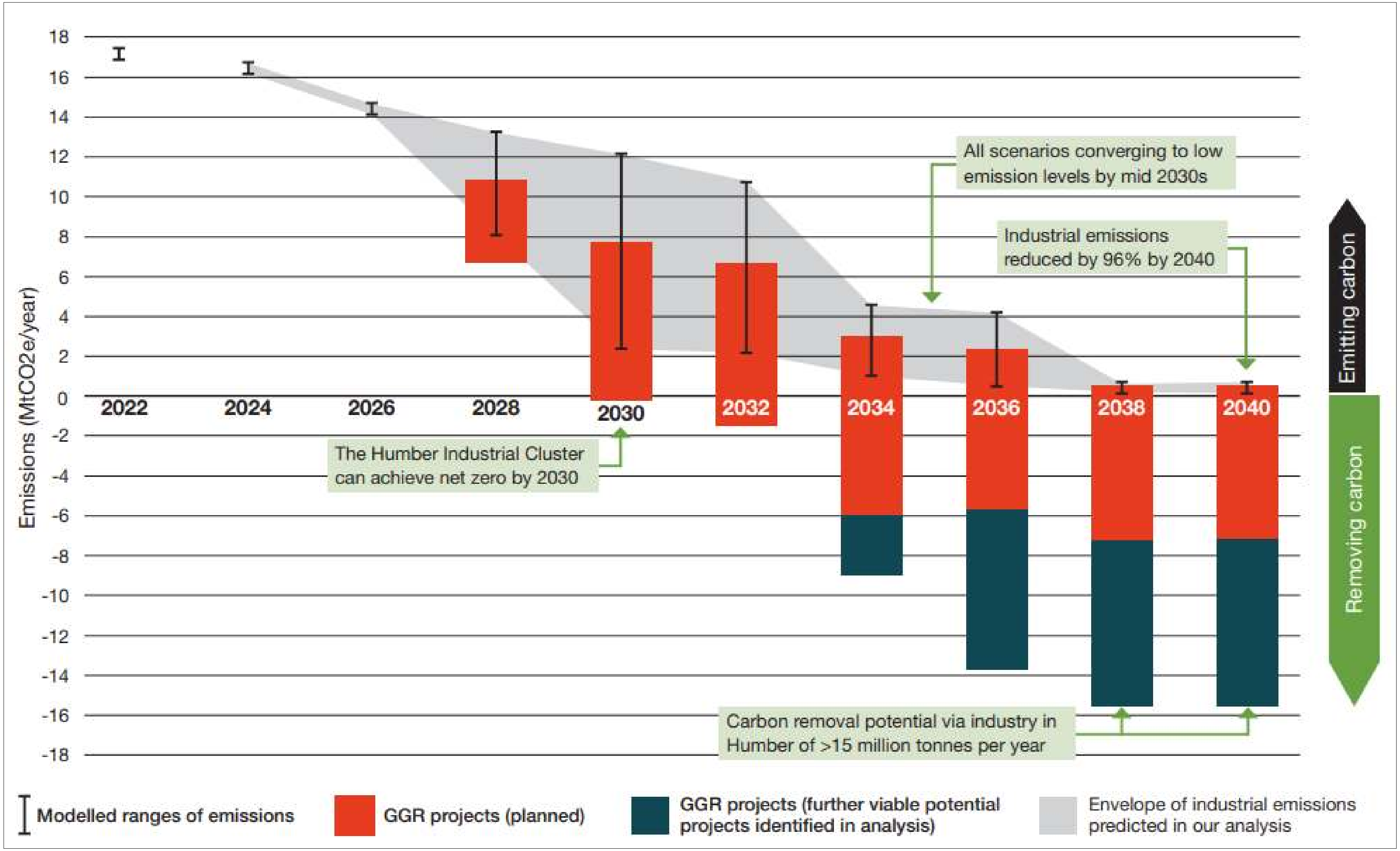

Figure 4 Summary of our Plan, showing industrial emission reductions and greenhouse gas removals resulting in significant negative emissions across the Humber.

2.2.3 Technology adoption

The Systems Model also provided insight on the extent to which each possible decarbonisation technology is adopted in each of the scenarios, with Figure 5 providing a high-level summary of this. The pie charts show this split in 2040 for each scenario, with the plots over time showing how the proportional role of each abatement measure evolves. This graph introduces the critical and co-dependent roles of each of the four main emission abatement measures – carbon capture and storage, hydrogen fuel switching, electrification and resource and energy efficiency. Each of these interventions are described in detail in Section 3.

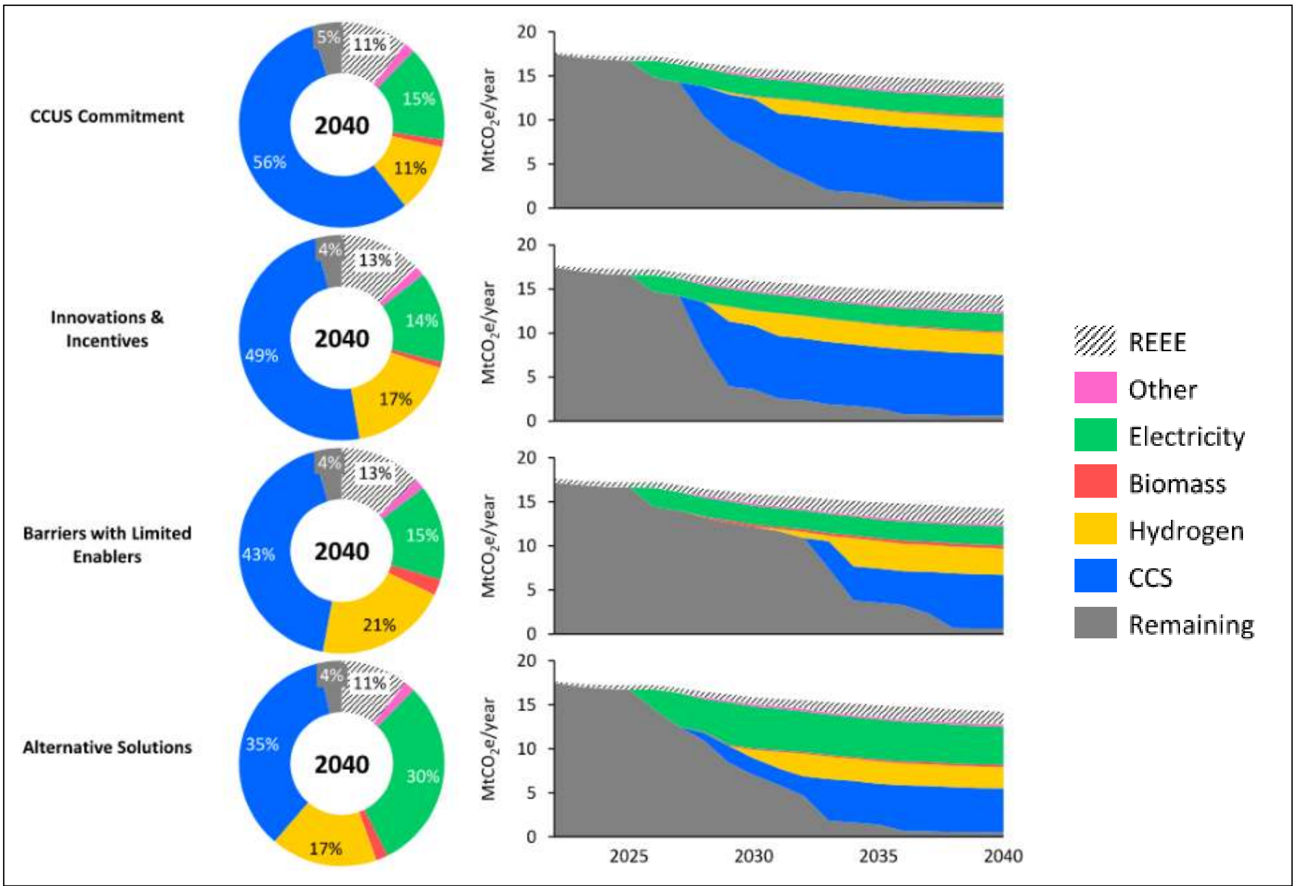

Figure 5 Emissions abatement by each technology in each scenario from 2022 to 2040. (Systems Model report Chart 3.5)

Section 3

The key industrial decarbonisation interventions

3. The key industrial decarbonisation interventions

In this section we explore in more detail each of the key industrial decarbonisation interventions adopted in the Systems Model. We initially focus on carbon capture and storage then hydrogen fuel switching due to their significance in abatement, the unique aspects of the Humber which enable these at scale, and the need for collaboration to enable their deployment. We then discuss electrification and resource and energy efficiency. We explain how each of these key industrial interventions leads to one of our identified Mandates for action.

3.1 Synergies between each key industrial intervention

Figure 6 shows an aggregated summary of the Systems Model results from analysing how much of the region's industrial emissions will be abated by each main abatement technologies across the four scenarios. It collates the information in Figure 5 to show the range of predicted extents of adoption. For some interventions, such as resource and energy efficiency, there is little difference between the scenarios. For others, such as carbon capture and storage, there is a much greater range calculated. The reasons for this are explored in the following sections, but Figure 6 demonstrates the fundamental importance of the four key industrial interventions.

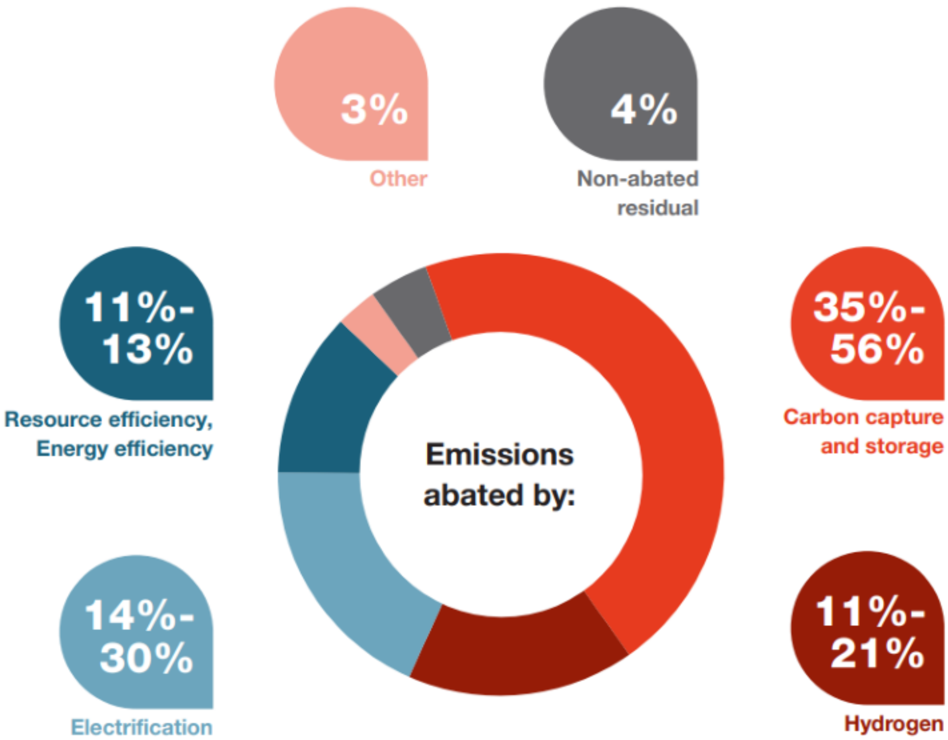

Figure 6 Summary pie chart showing the ranges which each of the key industrial interventions could contribute to abating the industrial Scope 1 emissions in 2040.

The four main industrial interventions lead to the first four of our seven Mandates for action – the priority focus areas needed to bring change at scale and pace across the Humber region. The first four Mandates, ordered by impact on the overall goal of net-zero by 2040 as identified through the modelling, are:

1. To implement carbon capture and storage and greenhouse gas removal technologies at pace and scale.
2. To implement low-carbon hydrogen at scale.
3. To adopt all optimal electrification measures

4. To prioritise efficiency and circular economy measures.

This should not be taken as the order of adoption though. Each process on each site will require careful ongoing analysis to identify the optimal way to reduce emissions, and it is likely that the fastest short-term abatement will be through resource and energy efficiency measures.

Although we discuss each of the Mandates in isolation, it is vital that an integrated approach is taken. We have carefully identified dependencies and synergies between the interventions to ensure a holistic energy systems approach is taken to decarbonisation of the Humber Industrial Cluster. This will need to continue through the planning, implementation and delivery, including:

- CCS enabled hydrogen production requiring carbon capture, transport and storage facilities.
- Sustainably sourced biomass being used to generate electricity or fuel industrial processes, with CCS resulting in negative emissions.
- Surplus energy generation by wind farms being used to generate hydrogen via electrolysis, presenting a viable energy storage alternative to large scale batteries.
- Existing grid electricity generation and transmission assets supplement renewable generation when demand exceeds supply, and to transfer excess to other points of use via the grid.
- Existing gas transfer corridors or pipelines that can be partially or fully repurposed or used for hydrogen or carbon dioxide transport.
- Existing industrial processes may have waste streams or feedstock requirements that could improve the cost effectiveness of another process, e.g., treated wastewater effluent being used for electrolytic hydrogen generation.

3.2 Carbon capture and storage

The Humber, as the UK's greatest carbon emitting cluster, is adjacent to the UK's largest accessible subsea carbon store. The proximity and hence accessibility and cost of subsea storage to the Humber means CCS will likely play a larger role than in other industrial regions. Our first Mandate reflects the vital importance of carbon capture for industrial decarbonisation – a consistent finding from every scenario we analysed. The analysis set out in this Section leads to this Mandate for action.

1. **To implement carbon capture and storage and greenhouse gas removal technologies at pace and scale across the Humber.**
    a. **To capture carbon from each industrial process where this is the optimal decarbonisation option.**
    b. **To implement the necessary region-wide and offshore infrastructure to convey all captured CO_2 to permanent subsea storage.**
    c. **To develop and optimise the offshore storage reservoirs to ensure the necessary short-term injection rates can be achieved, and the long-term capacities maximised.**
    d. **To facilitate engineered greenhouse gas removal projects through connections to the region's carbon capture and storage infrastructure.**

In this Section we present how the region's accessible storage can be used, the role that CCS will play in abating emissions from certain industrial sectors, the current proposed CCS projects, and the wider opportunities to facilitate large-scale engineered greenhouse gas removals.

3.2.1 Carbon dioxide transport and storage

The narrative for CCS in the Humber begins with the opportunity presented by depleted gas reservoirs and saline aquifers in the southern part of the North Sea (Figure 7). The Humber region has ready access to these, and there are two CO_2 Transport and Storage (T&S) projects being developed to use these.

- The proposed Zero Carbon Humber pipeline would run from Drax power station near Selby, along the south bank, across the estuary to Saltend and then to Easington on the north bank, connecting to industries along its length. From here the Northern Endurance Partnership (NEP) offshore pipeline would take the captured CO_2 to the Endurance field. The planned injection rate is 8.25 $MtCO_2$/year in 2030, doubling to 17+ $MtCO_2$/year by 2035. This storage has a capacity of 520 $MtCO_2$, with the potential to add other sites bringing storage capacity up to 1,000 $MtCO_2$.
- The proposed Viking CSS pipeline would transfer CO_2 via the Humber Zero pipeline from Immingham on the Humber's south bank to Theddlethorpe on the east coast, then offshore to the Viking and Victor fields. The planned injection rate into the depleted gas fields is 11 $MtCO_2$/year by 2030, and 12+ $MtCO_2$/year by 2035. The current assessed storage capacity is 328 $MtCO_2$.

Across our scenarios we predicted a demand of 16 - 28 $MtCO_2$/year in 2040 for CCS T&S across the region, from the cluster's biogenic and non-biogenic emissions and from generating CCS enabled hydrogen. This is less than the current planned injection rate of 29 $MtCO_2$/year from existing projects, indicating that the cluster's demands can be accommodated in the planned projects. However, there will likely be further expansion of the storage areas, with subsequent increases in injection rate. In terms of capacity, we predict that under the CCS focussed scenarios there could be 280 $MtCO_2$ stored by 2040, a small proportion of the 850 $MtCO_2$ planned, prior to any further expansion. The full and timely completion of both these T&S projects will be key to enabling CCS and GGR in the region.

Future expansion of storage projects would enable the Humber to capitalise on its potential as a carbon storage hub with the potential to import CO_2 from the wider UK and Europe, as well being an optimal location for future GGR deployments via BECCS and DACCS.

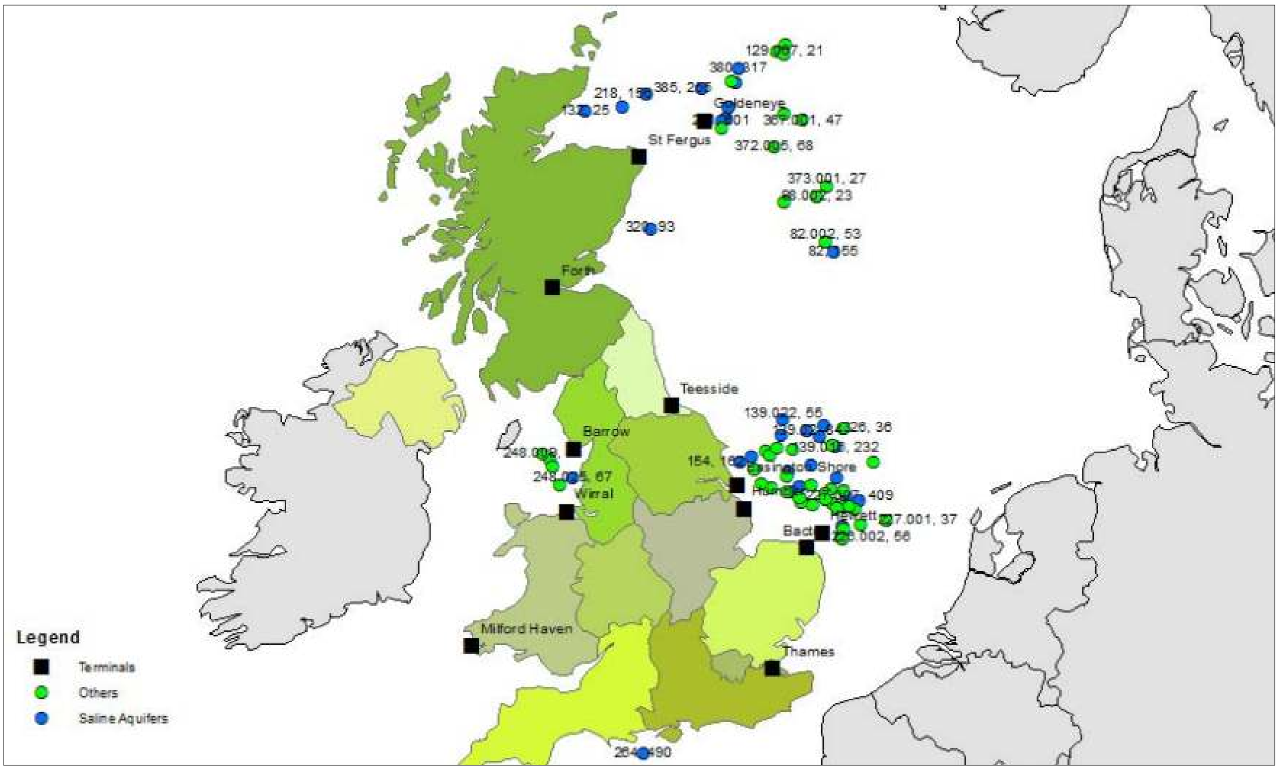

Figure 7 Map of the UK highlighting the proximity of the Humber to carbon storage in the southern part of the North Sea. (Energy Technology Institute, 2013)

3.2.2 Carbon capture from industry

The Systems Model demonstrates that deploying carbon capture on the large emitters which are suitable to adopt this will have a significant impact of the region's total emissions. In the model the Chemicals, CHP, Iron & Steel, Power Generation, and Refining & Fuels sectors were the significant adopters. Across all the modelled scenarios CCS was the abatement technology responsible for the greatest percentage of removals. CCS was predicted in the model to abate 35 - 56% of the cluster's annual Scope 1 emissions in 2040 (5 - 8 $MtCO_2e$/year).

The modelled adoption of CCS across the different sectors is highlighted in Figure 8.

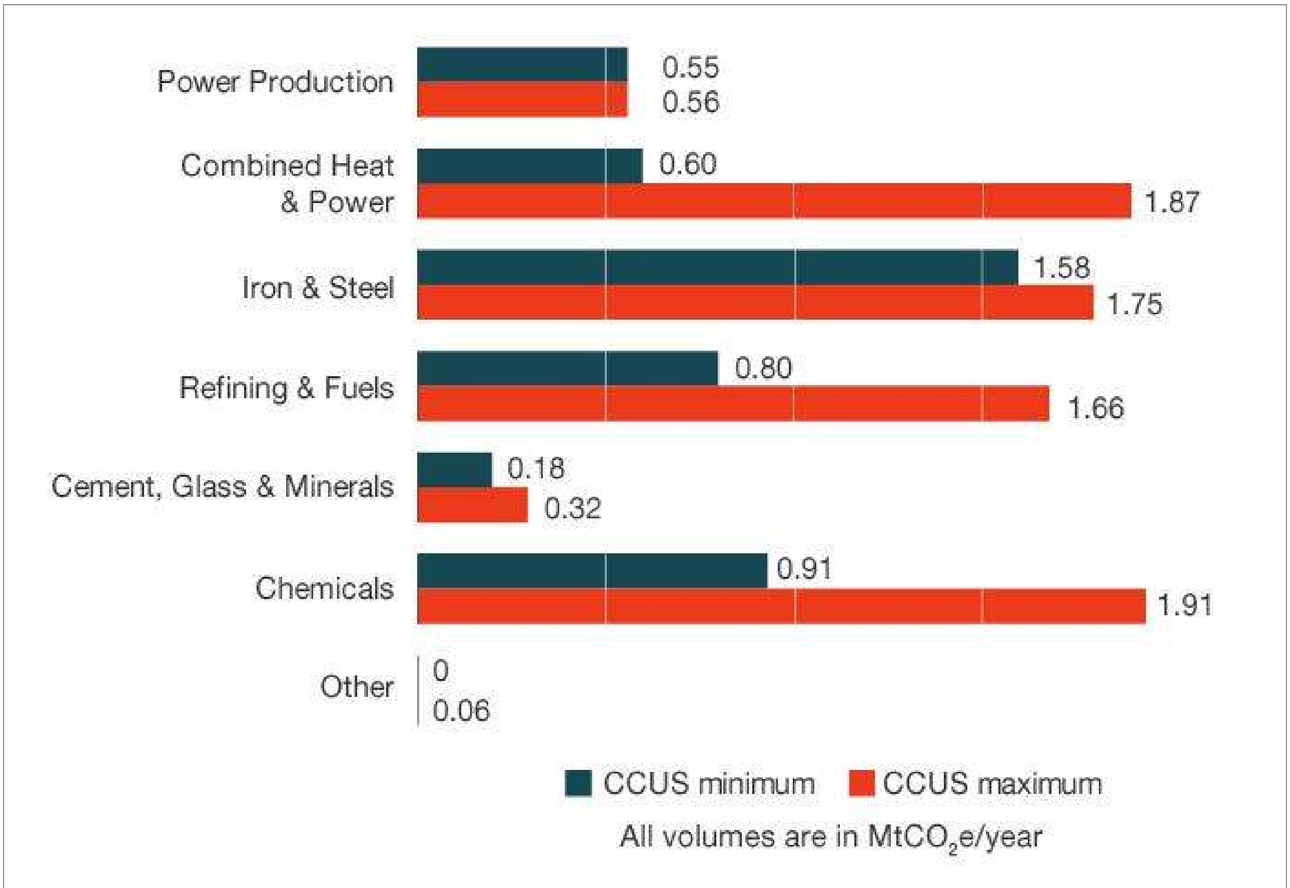

Figure 8 Modelled maximum and minimum emission abatement using CCUS in 2040 in each industrial sector.

For some industries carbon capture will be the only viable and economic decarbonisation pathway. For example, CCS will be the primary way of abating chemical feedstock CO_2 emissions, such as from some of the large-scale processes in the Chemicals sector, or from lime production. Switching feedstocks to biomass would be possible in some instances but is not yet widely implemented at the scale necessary. The dependence of some sectors on CCS is shown in Figure 8 where there is little variation between minimum and maximum levels of adoption. In some sectors though there are more viable options which can be adopted. Our modelling has identified that the following five factors are critical influencers of adoption of CCS across the Humber cluster:

- Volume of emissions. The high capital costs of carbon capture technology mean that it is most viable for large industrial processes. The large emissions results in economies of scale for capital investment (in capture equipment, compressors and pipe networks). In the model, estimated CCS abatement costs for major emitters was £100-£200/ $MtCO_2e$ abated. However, there may be potential for adjacent smaller emitters to share the economies of scale or for third parties to provide CCS as service and hence scale their operation accordingly.

- Processes impacts. Installing CCS requires little modification to the operation of the existing technologies and processes at a site, reducing disruption to pre-existing industrial process. This is particularly important for controlling the grade of metal in Iron and Steel production.
- Technology development. Our modelled scenarios consider how different rates and scale of carbon capture vary between scenarios, according to the availability of technology. The earliest adoption (from 2028) is of the incumbent form of CCS technology (Advanced Amines) which has a high technical readiness and so is ready for early adoption. However, other CCS technology options are expected to emerge in the future, which could reduce costs through improved fuel efficiency, whilst also improving capture efficiencies. Fuel efficiency improvements are essential as the incumbent technology has significant energy demands. Capture efficiency improvements to levels of 99% or greater are essential to reduce residual emissions to the lowest possible level and allow net-zero to be achieved nationally. The model assumes that these cheaper and more efficient 2nd Generation CCS technologies will be available for deployment from the early 2030s. Some emitters may choose to delay their investment until the emergence of 2nd Generation CCS technologies to avoid being locked into less efficient systems, which would result in greater long-term operational expenditure.
- Access to T&S infrastructure. Significant CCS deployment is possible before 2030 if the enabling T&S infrastructure is available. Modelling indicates that T&S utilisation would commence in 2028 if it is available. If this is likely to be delayed it may influence decisions on which abatement measures to adopt.
- Incentives. Carbon pricing is an economic instrument used to incentivise greenhouse gas emission reductions and enable emission offsetting via carbon credits. Modelling revealed that high shadow carbon values incentivise rapid adoption of emission reduction technologies, with CCS being the preferred abatement approach for the cluster. If carbon prices remain low, there will be less incentive to decarbonise, and lower overall levels of CCS will be adopted.

Carbon capture of industrial emissions is being developed at scale in the Humber, enabled by the two planned transport and storage projects. We have several internationally recognised projects which plan to remove 6.75 $MtCO_2e$/year by 2030 using CCS (excluding CCS at Drax, CCS at British Steel, or from CCS enabled hydrogen generation in the region). This exceeds the national CCS target of 6 $MtCO_2e$/year from industrial clusters by 2030, solely through projects in the Humber Cluster.

Table 1 summarises the current proposed CCS projects, with further projects likely to emerge.

Table 1 Current proposed CCS projects in the Humber region.

Sector	Location	Details
Power production	Drax	This 3.9GW (including coal units) / 2.6GW (excluding coal units) power station near Selby processes biomass to generate electricity. It aims to be the world's first 'negative emission' BECCS power station once the CCS pipeline is installed in or around 2027. This would be supported by the power-BECCS business model. Current plans (subject to a £2bn investment decision in 2024) would deploy CCS on two of the combustion units with a target of capturing 4 $MtCO_2e$/year by 2027, doubling to **8 $MtCO_2$/year by 2030**.
	Keadby 3	Keadby 3 is a 901 MW power station which could become one of the UK's first power stations equipped with carbon capture capability. It would use natural gas as its fuel and be fitted with a carbon capture plant to remove the CO_2 from its emissions. When complete, Keadby 3 is expected to capture at least **1.5 $MtCO_2e$/year**. This project was given planning permission in December 2022 and could be operational as early as 2027 (Laister, D., 2022).
Iron and steel production	British Steel, Scunthorpe	The Scunthorpe plant is planning to utilise CCS on the 2nd blast furnace, after an electric arc furnace has been utilised for decarbonising the other production line (British Steel, 2021). Research ongoing currently into technologies for application to the existing site power station. Abatement would likely be in the order of **1.9 $MtCO_2e$/year** based on the planned adoption of the electric arc furnace also abating 1.9 $MtCO_2e$/year.

Sector	Location	Details
Refining and fuels	Prax Lindsey Oil Refinery	Prax Group plans to deploy carbon capture to capture over 85% of the site's CO_2 emissions. The Prax Lindsey Oil Refinery Carbon Capture Project would direct processes flue gases to a dedicated amine-based carbon capture unit which could capture **1.2 $MtCO_2$/year.**
	Philips 66 Humber Refinery	A consortium of Phillips 66 Limited and VPI Immingham aims to remove up to **3.8 $MtCO_2e$/year** by around 2027, capturing emissions from processes at the VPI Immingham CHP Plant and Phillips 66 Limited Humber Refinery. Carbon capture will be retrofitted to two of the three gas-fired power generators at the power plant.
CHP	VPI Immingham	
Lime production	Singleton Birch	The Origen-Singleton Birch ZerCaL250 project would use Origen's ZerCaL technology to replace and extend the existing lime production facilities. Origen's innovative kiln design can decarbonise the lime industry through carbon capture, while safeguarding a 200-year-old industry and the industrial supply chain it supports (steel, cement, glass production, water treatment etc). The projected plans would reduce emissions by **0.25 $MtCO_2e$/year.**
CCS enabled hydrogen		There are 5 proposed CCS enabled hydrogen projects in the Humber which will capture carbon dioxide for offshore transport and storage.

3.2.3 Greenhouse gas removals

Engineered and natural greenhouse gas removal (GGR) will provide a critical contribution to reaching net-zero by 2050 nationally. These will compensate for residual emissions from hard-to-abate sectors of the economy that cannot be technologically and economically decarbonised. Carbon removals beyond achieving net-zero may also be required to limit global temperature increases.

The MPR Study provides a comprehensive description of the market, policy, and regulatory status of the options to remove and permanently store atmospheric CO_2. The options are commonly split into engineering (or technological) solutions and Natural Climate Solutions. The Humber has a key opportunity to deploy GGR rapidly and at scale.

Natural Climate Solutions opportunities available for the Humber include restoration of saltmarsh, wetland, peatland, forestry areas, and seagrass, all of which increase natural carbon sequestration. However, more research is needed to determine their long-term impact, and how to best optimise carbon storage in these environments. Their scope for adoption onshore in the Humber is likely to be limited, although where possible, should be implemented.

The main technological opportunities for our region are Bioenergy with Carbon Capture and Storage (BECCS), and the less developed Direct Air Carbon Capture and Storage (DACCS). Each would be efficiently enabled by the T&S infrastructure being developed. It will be more cost effective to implement this in the Humber than any other region in the UK over the next 20 years. This is due to the proximity and capacity of the carbon dioxide storage capacities in the Southern North Sea, and the economies of scale arising from the widespread use of CCS in the Humber. Wider research also suggests that adopting BECCS, specifically from Drax, is essential to achieve net-zero nationally in the most cost-effective manner (Baringa, 2021).

The impact of GGR in the Humber region is outlined in Section 2.2.2. Drax's aim to become the world's first 'negative emission' BECCS power station and once the CCS pipeline is installed in or around 2027 (based on current project plans) will play a key role in this. This would be supported by the power-BECCS business model. To achieve the full capture potential, the pipeline network must be sized so that this does not become a limiting factor in the medium-term. The scale of Drax's captured carbon and its geographic location at the west end of the cluster, means it would be an anchor CO_2 contributor, building the case for early deployment of CCS projects in the Humber.

The MPR Study provides nine recommendations to implement sustainable BECCS, DACCS and GGRs in general in the Humber.

3.2.4 CO_2 imports

There is likely to be rapid demand growth for CO_2 storage, both in the UK and Europe as CCS projects come online. The Humber is well positioned to be a catalyst for industrial decarbonisation for regions where there is little or no proximity to significant, long-term stores.

Figure 9 shows low and high uptake scenarios for CO_2 importation to the region between 2030 and 2040, with this arriving from UK pipelines and shipping from UK and European sources. The rate of likely ramp-up will be influenced by the rate at which European countries begin to drive industrial decarbonisation and start seeking storage options. A nearby example of CO_2 shipping, albeit to the 'Northern Lights' CO_2 store (Equinor, 2022), is the '3D' pilot project by a French consortium at Dunkirk.

Import of CO_2 will only become commercially viable once enabling infrastructure becomes available. This will include features such as unloading jetties with articulated loading arms or flexible cryogenic hoses, temporary storage, CO_2 conditioning and transfer pipelines.

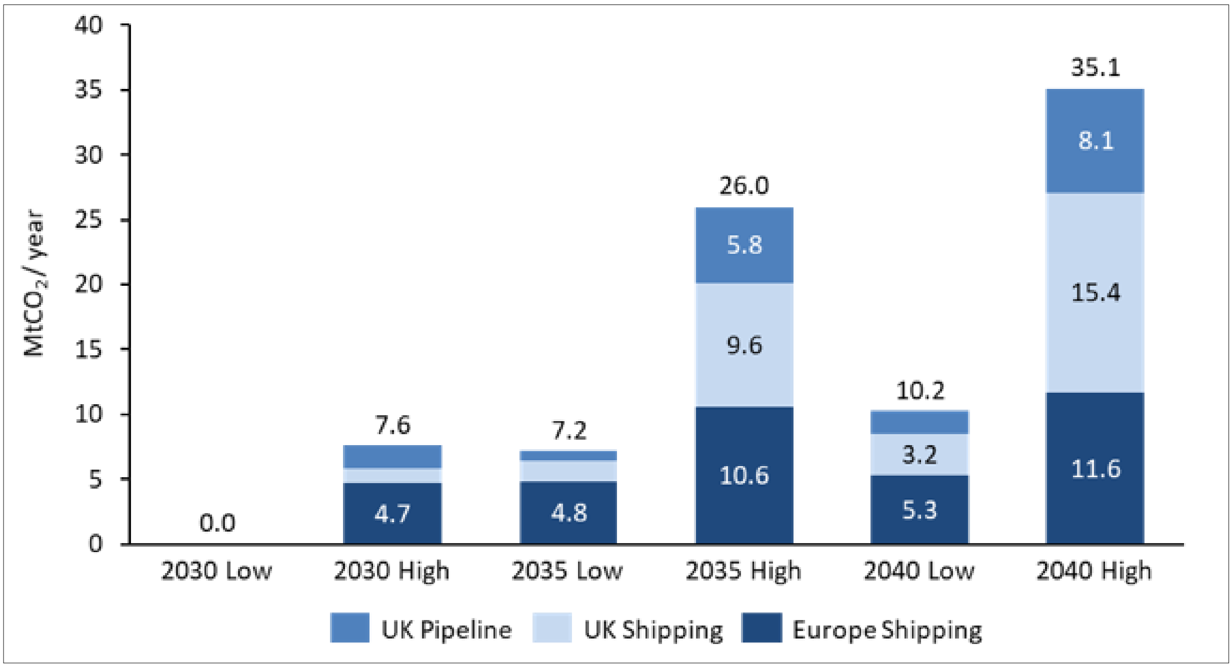

Figure 9 Potential CO_2 imports into the Humber via pipelines and shipping. (Market, Policy, and Regulatory Study Figure 20)

Although the T&S infrastructure in our Systems Model is based on the two current planned projects in the region, further expansion of these, or additional projects, could enable industrial sites from the surrounding areas to decarbonise via carbon capture. The potential adopters of this within 100km of the cluster are shown in Figure 10. This progressive build-out would maintain jobs and skills in the Humber region whilst enabling decarbonisation of more challenging regions and industries.

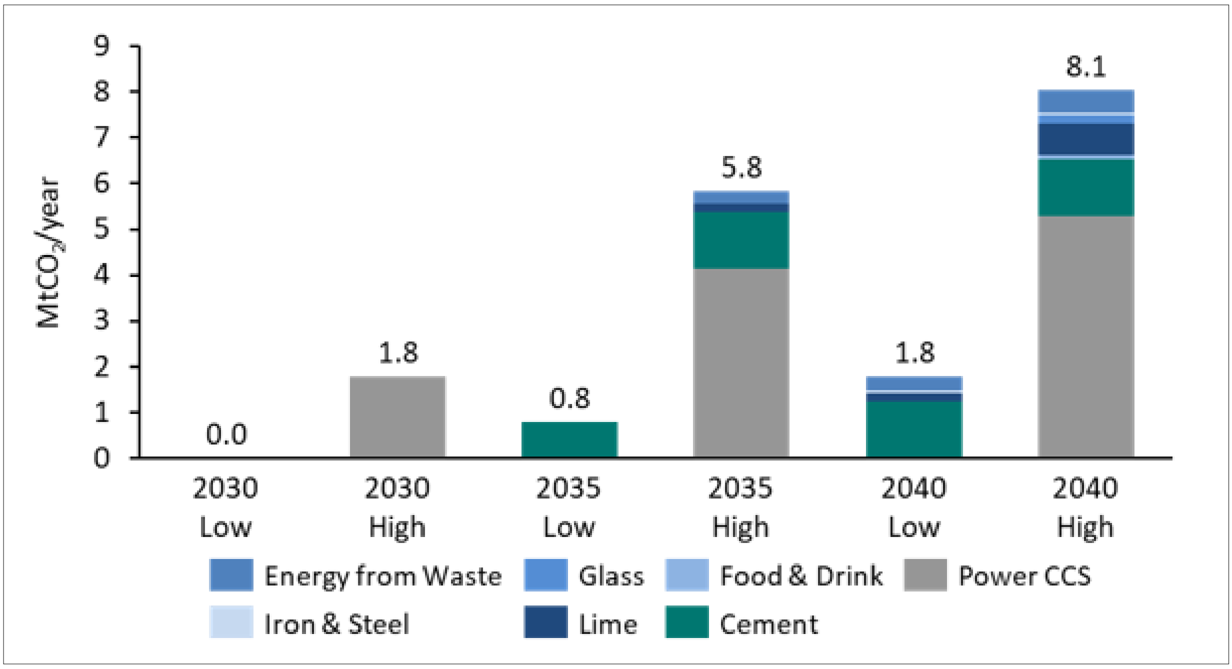

Figure 10 Potential UK import demands via land.
(Market, Policy, and Regulatory Study Figure 22)

3.3 Low carbon hydrogen

Low carbon hydrogen will be a critical part of the Humber's drive to decarbonise. It is both a fuel to replace natural gas and an energy store to address the energy resilience and the intermittency of renewables. The ready availability of low carbon hydrogen will be central to the Humber's industrial decarbonisation and has the potential to be a major contributor to national decarbonisation efforts. To deploy hydrogen in the Humber and beyond, requires all elements of the hydrogen system to be developed simultaneously: hydrogen production, hydrogen storage, hydrogen distribution and hydrogen end use.

Over 50% of the UK's 2030 target of 10GW hydrogen capacity is planned to be delivered from the Humber region alone, highlighting the national significance of the region's hydrogen transition, anchored on industrial decarbonisation through fuel switching. This is enabled by both the access to carbon storage and low-carbon electricity from offshore wind, two factors which differentiate the Humber.

The analysis set out in this Section leads to our second Mandate for action.

2. To implement low-carbon hydrogen at scale across the Humber.

   a. To use hydrogen for each industrial process where this is the optimal decarbonisation option.

   b. To produce low carbon hydrogen, supported by renewable energy generation, at scale.

   c. To implement the necessary region-wide infrastructure to distribute hydrogen.

   d. To store hydrogen at scale for operational resilience, seasonal needs, and to optimise energy use in generating hydrogen.

   e. To explore opportunities for the Humber hydrogen network to enable decarbonisation in other sectors of the economy, where appropriate.

3.3.1 Hydrogen production

There are well-established plans for hydrogen production throughout the Humber, with projects representing a total energy production of 5.2GW. Most of the more developed proposals are CCUS enabled (through natural gas reformation), however, it is anticipated that further electrolytic hydrogen projects will emerge in response to significant growth in electricity generation from offshore wind farms. The hydrogen production projects currently underway in the Humber region are summarised in Table 2.

Table 2 Current proposed hydrogen production projects in the Humber region.

Location	Details
H_2H Saltend	Equinor's flagship **600 MW** low carbon hydrogen production facility with carbon capture. Six local operators could use the hydrogen produced to lower their carbon footprint, initially reducing Saltend Chemicals Park's carbon emissions by 0.9 $MtCO_2$ (30%).
H_2H 2	This is Equinor's second **1.2 GW** low carbon hydrogen production facility with carbon capture, contributing to Equinor's aim for 1.8 GW of hydrogen production in the Humber by 2028 and the government's aim for 10 GW UK hydrogen production by 2030. Hydrogen produced will be transported via the common infrastructure created through the Zero Carbon Humber and East Coast Cluster network.
Gigastack	A partnership of Ørsted, Phillips 66 and ITM power, the offshore windfarm Hornsea 2 will power a **100 MW** scale electrolyser system to generate hydrogen, which will then be supplied to Phillips 66 Limited's Humber refinery. Hydrogen will replace gas currently used in their industrial-scale heaters (by 2025). BEIS has awarded £7.5 million to Gigastack to provide a blueprint for scalable electrolyser technology in the UK.
Humber H_2ub	Shell and Uniper plan to produce low carbon hydrogen at Uniper's Killingholme site, representing an annual carbon capture of approximately 1.6 $MtCO_2$/year. This CCUS enabled hydrogen facility will use gas reformation technology with carbon capture and storage and will have a capacity of **720 MW**. Air Liquide Engineering & Construction, Shell Catalysts & Technologies, and Technip Energies were awarded contracts for the process design phase in 2022.
Humber Hydrogen Hub (H3)	VPI Immingham and Air Products propose an **800 MW** low carbon hydrogen production facility in Immingham. The decarbonisation potential of the site is 2 $MtCO_2$.and most of the hydrogen produced will be used in the decarbonisation of VPI Immingham's existing power production, with the remainder available for other industrial users.
DelpHYnus	Neptune Energy has proposed production facilities for CCUS enabled hydrogen alongside a CO_2 Transport and Storage solution at the former Theddlethorpe Gas Terminal site. The **1.8 GW** hydrogen production facility could meet 36% of the UK's target of 5 GW of hydrogen production by 2030.

The in-flight hydrogen production plans would meet and exceed the demand from industrial decarbonisation. This is therefore not likely to form a constraint on industrial fuel switching. Any excess hydrogen generated which did not have a direct use could be blended with natural gas as a transitional measure until there are other direct demands for it.

3.3.2 Hydrogen distribution and storage

Hydrogen must be transported or distributed from production to storage to end use. It can be distributed by road, rail, ship or pipeline as a gas, liquid or in the form of a hydrogen carrier such as ammonia. On land, road and rail distribution is less efficient than pipeline, but may be a transitionary measure before pipelines are built or even as a long-term distribution means for areas that will never be served via pipelines. Here the focus is on gaseous distribution and storage via pipeline which will be the means by which the vast majority of hydrogen is distributed within the Humber region.

Small-scale hydrogen storage will be required at both production and end use to cope with supply and demand fluctuation. But more importantly, large-scale storage is required to manage seasonal demand and enhance energy security. The Humber is uniquely positioned to develop and provide nationally significant hydrogen storage, as summarised in Table 3.

Table 3 Current hydrogen transport and storage proposals the Humber region.

Project		Details
Hydrogen transport (distribution)	Zero Carbon Humber Pipelines	National Grid's proposed network comprises two underground pipelines – one for CO_2 and the other for hydrogen. The pipelines are intended to connect to major industrial emitters and power stations to support decarbonisation projects across the Humber region, effectively connecting decarbonisation projects. The CO_2 pipeline leads offshore to the Endurance store, while the hydrogen pipeline will connect at the western end to the East Coast Hydrogen project.
	East Coast Hydrogen	Northern Gas Networks, Cadent and National Grid Gas Transmission are collaborating on a programme to connect 7GW of hydrogen production by 2030. This project alone would exceed the Government's target of 5GW by 2030 and will connect the Teesside and Humber regions, converting pipelines to 100% hydrogen. This project is currently at pre-FEED stage and includes the investigation for the location of the government's hydrogen town. It is a precursor to Project Union, which aims to connect all the UK's industrial clusters.
Hydrogen storage	Aldbrough Hydrogen Storage	Equinor and SSE are preparing to build a hydrogen storage facility within or adjacent to the current Aldbrough Gas Storage facility north of the Humber Estuary. The existing 11 underground salt caverns will be expanded and converted for hydrogen storage. The storage facility will be operational by 2028, with an initial capacity of 320 GWh. This is enough hydrogen to power 860 hydrogen buses for a year.
	Rough Hydrogen Storage	Centrica currently uses the Rough offshore depleted gas reservoir for natural gas storage, to increase the UK's energy resilience. It plans to repurpose the gas reservoir for both hydrogen and natural gas (as hydrogen is lighter than natural gas, both can be stored in the same reservoir). The Rough is the UK's largest proven natural gas storage facility and could provide 10 TWh of hydrogen storage capacity, which represents the UK's most cost-effective option for long-term hydrogen storage, 50% of the UK's hydrogen storage requirements by 2050, and would be the world's largest hydrogen store.
Hydrogen Import	Immingham Green Energy Terminal	Air Products and ABP are working together on a new green energy terminal in the Port of Immingham. New infrastructure will be designed to service the handling of liquid bulk goods, primarily green ammonia, with scope to import and export others, including CO_2, in the future. The green ammonia would then be stored and processed to create hydrogen for onward transport to other parts of the UK.

3.3.3 Hydrogen end use in industry

The Systems Model demonstrates that hydrogen will play an important part in decarbonising industry, with fuel switching (from existing sources to hydrogen) accounting for **11 - 21%** of the cluster's in-year Scope 1 emission reductions by 2040 (equivalent to 1.6 – 3.0 $MtCO_2e$/year). Fuel switching to hydrogen would be relatively straightforward for large industrial users such as power stations. However, fuel switching options can be more challenging to deploy for other industrial users, as they must be tailored to specific industrial processes, requiring bespoke design approaches.

The Chemicals, CHP and Refining & fuels sectors were identified in the Systems Model as likely significant adopters of hydrogen to replace natural gas.

The modelled adoption of hydrogen fuel switching across the different sectors is highlighted in Figure 11.

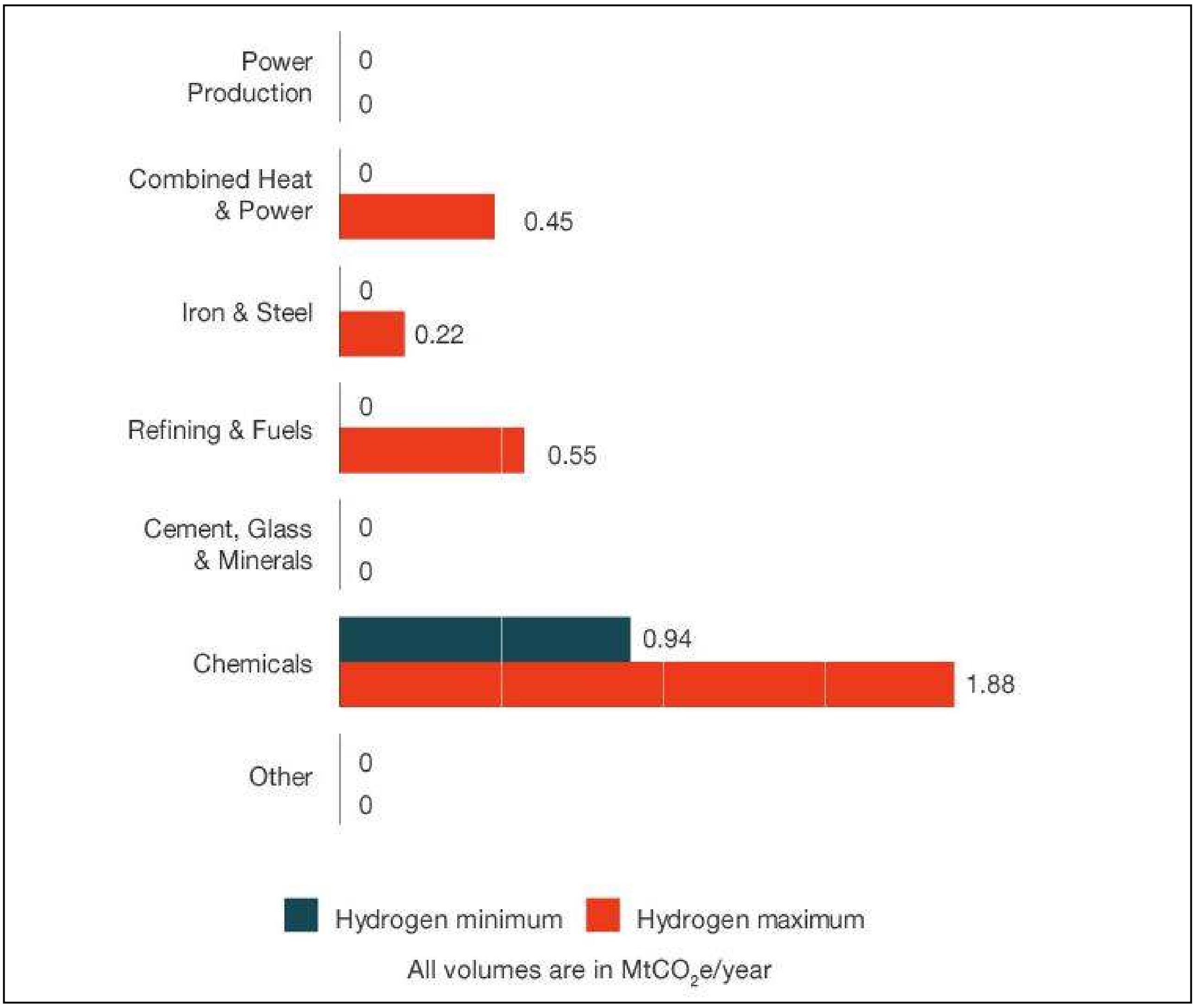

Figure 11 Modelled maximum and minimum emission abatement using hydrogen in 2040 in each industrial sector.

The modelled uptake from the Chemicals sector aligns with the plans of Equinor and SSE Thermal to transition the Triton Power CHP plant to hydrogen to provide heat and power for the Saltend Chemicals Park. As this is enabling decarbonisation of the chemicals park this is classified as Chemicals rather than CHP. The CHP data in Figure 11 relate to VPI Immingham which may fuel-switch its 3rd combined cycle gas turbine train.

A number of large industrial sites have substantial decarbonisation projects underway that are based on fuel switching from natural gas to hydrogen, as summarised in Table 4.

Table 4 Current hydrogen end use proposals in the Humber region.

Project	Details
Keadby Hydrogen Power Station	Keadby is an 893 MW gas-fired power station in North Lincolnshire, which could be converted into the world's first 100% hydrogen-fuelled power station. It would have a peak demand of 1.8 GW and would produce zero emissions at the point of combustion.

Project	Details
Triton Power Station	The Triton natural gas power station provides power to Saltend Chemicals Park. A planned fuel switch to a low carbon hydrogen blend would reduce emissions at the site by almost 1 MT p.a. This will initially be a volume of 30% hydrogen with the aim to increase to 100% as technology develops.
Phillips 66	Phillips 66 is the industrial offtaker for the 100MW Gigastack electrolytic hydrogen project. By 2025 they will switch a portion of their natural gas supply to hydrogen in their industrial heaters.
Brigg Power Station	Centrica and HiiROC plan to inject hydrogen at Brigg power station in 2023. This will be the first time that hydrogen is used within a grid connected gas fired power station in the UK. A 12-month trial, part funded by NZTC, aims to develop the required technology. The initial fuel blend would be no more than 3% hydrogen, increasing to 20% if the pilot project is successful.
Hydrogen Town	Cadent is developing the concept of a 'hydrogen town' on the South bank of the Humber linked to the Zero Carbon Humber pipeline. A UK wide government policy decision on hydrogen in the gas networks is awaited (including a 2023 decision on blending into the gas network, and a 2026 decision on hydrogen for heating).
Immingham port	A trial of hydrogen trucks was commenced at Immingham port to manoeuvre shipping containers with a view to wider expansion.

The cost of hydrogen options relative to natural gas has a major influence on decision making for those considering fuel switching. In summer 2021, BEIS estimated levelised production costs of 5.6-6.2 p/kWh for CCS-enabled hydrogen and 13.3-14.8 p/kWh for electrolytic hydrogen (BEIS, 2021a), at a time when the natural gas price for industrial users averaged 1.83 p/kWh. It is generally expected that hydrogen cost will reduce as the scale of production increases. The Hydrogen Council estimates that the production cost could drop below 2 p/kWh by 2050, for a natural gas price of 0.7 - 1.8 p/kWh. Further discussion on costs of hydrogen generation is contained in the MPR Study.

The Systems Model confirmed that hydrogen abatement costs were relatively high (ranging from £200 per $MtCO_2$ to over £300 per $MtCO_2$ depending on the scenario, where CCS was £100-200 $MtCO_2$). This cost differential constrains the potential for hydrogen fuel switching – the scenarios with lower hydrogen costs enabled more widespread adoption. However, industries which have smaller units, or that operate with more intermittent generation, were indicated to likely favour hydrogen over CCS as this reduces the significant initial capital costs required for CCS. Sensitivity analysis confirms that if the unit cost of hydrogen is reduced, more large processes would consider fuel switching to hydrogen instead of deploying CCS.

3.4 Electrification

Electricity is zero emission at the point of use and is increasingly zero emission at the point of production, not least offshore from the Humber where the largest offshore wind farms in the world are being developed.

In the Humber the largest electrification opportunity is associated with one site, where it will enable the renewal and modernising of the steel industry in the region. Much smaller scale electrification also plays a critical role in enabling emission abatement across multiple disperse sites in the region. This leads to our third Mandate for action, which we explore further in this section.

3. **To electrify industrial processes at each site where this is determined to be the optimal decarbonisation technology.**

In most of our modelled scenarios, electrification had a similar decarbonisation impact to hydrogen fuel switching. Electrification abated 14-15% of the cluster's Scope 1 in-year emissions by 2040 in three of the scenarios, and 30% in the Alternative Solutions scenario. Electrification technologies do not have to wait for pipeline infrastructure, and so where viable can be deployed earlier than either CCS or hydrogen fuel switching alternatives. All modelled scenarios showed electrification of some industrial processes from 2025.

The modelling revealed the uptake of electrification would be predominantly by small industrial processes where it would abate emissions from small piece of equipment (totalling around 0.3 $MtCO_2e$/year). This type of small-scale transition has a relatively low capital cost, making electrification more economical than CCS or hydrogen fuel switching, in these applications.

In contrast the model also indicated that it would be an optimal decarbonisation approach for British Steel Scunthorpe to partially switch to an electric arc furnace (EAF), with this abating 1.9 $MtCO_2e$/year, from the late 2020s. This abatement potential would be dependent on the extent of the switch to EAF steel making and could be greater than 1.9 $MtCO_2e$/year if suitable policy support is provided. This switch to EAF steelmaking removes the requirements for additional process operations, inherent in an integrated Blast Furnace steelworks, with a reduction in their associated emissions. The significance of this adoption in the Iron and Steel Sector is shown in Figure 12.

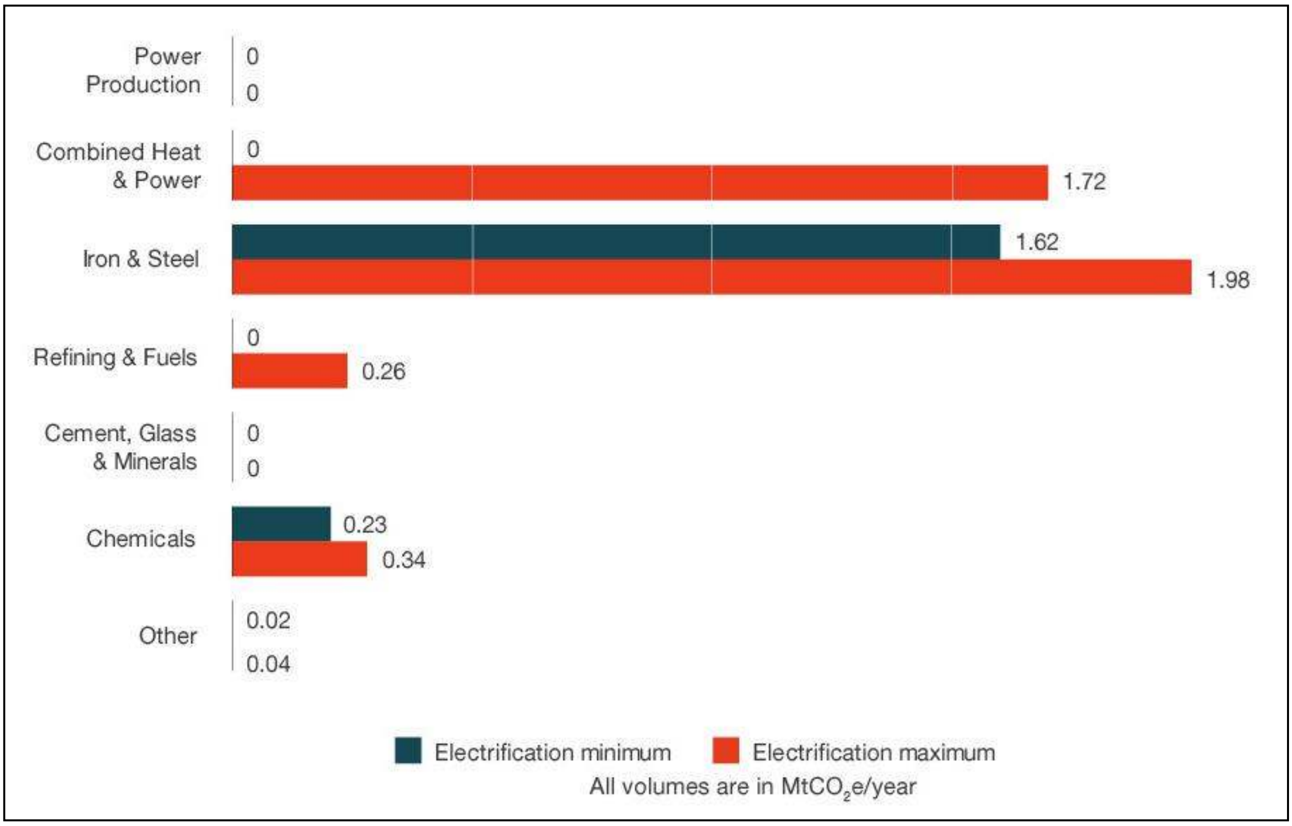

Figure 12 Modelled maximum and minimum emission abatement through electrification in 2040 in each industrial sector.

In scenarios with lower electricity prices, electricity generated by gas at CHP sites may be replaced by grid imported electricity. An electric steam boiler would then provide the steam previously produced by the CHP plant. This sensitivity to electricity prices illustrates one of the uncertainties that large industrial emitters in the region will need to plan around. Electrification of on-site emissions and can be highly efficient compared to combustion, however, the UK's energy intensive industries already face some of the highest industrial electricity prices in the world and are likely to do so for the foreseeable future.

BEIS does not currently have a business model to support the electrification of industrial processes. The UK Climate Change Commission's 6th Carbon Budget (December 2020) noted that industrial electricity prices in the UK were well in excess of the cost of supplying low carbon electricity from renewable sources such as offshore wind. Electrification can contribute toward decarbonisation, but it may not be economically viable to do so. Industrial electricity pricing may need to be reformed to reflect the much lower costs of supplying low-carbon electricity in the future, hence incentivising fuel switching via electrification.

The MPR Study reviews a range of electrification technologies that can be deployed at industrial sites, including electric boilers, oven, kilns, electric arc furnaces, electric dryers and heat pumps. It notes that electrification could be seriously constrained by current capacity limitations of the electricity network, which may not meet anticipated demand increase. It concludes that major upgrades to the grid infrastructure may be required to enable electrification of large industrial heat-raising processes.

Just offshore from the Humber is the Humber Gateway and the Westermost Rough offshore wind farms. The world's largest offshore windfarm, Hornsea 2, became fully operational in 2022. Hornsea 1 is operational with Hornsea 3 and 4 under development. Proposed offshore wind at Dogger Bank, which will be further offshore, aims to eclipse these projects in scale. Developed by a range of companies in various partnerships including Equinor, Ørsted, RWE, SSE Renewables, and Vårgrønn, these facilities will provide national benefit to the decarbonisation of the UK's grid and contribute both to electrification of industry and the deployment of electrolytic hydrogen for the decarbonisation of Humber's industries.

3.5 Resource and energy efficiency

The Humber industries have continually implemented resource efficiency and energy efficiency (REEE) measures in response to economic and environmental drivers. Approaches such as demand reduction, waste minimisation, recycling, process redesign, material substitution, heat recovery and the improvement of inefficient plant and processes all enable continual improvement. This is driven by energy prices, commodity prices, market forces, the national emissions trading scheme and the UK Industrial Decarbonisation Strategy, as well as individual company sustainability commitments. The importance of REEE measures are reflected in our fourth Mandate for action.

4. **To prioritise Resource Efficiency and Energy Efficiency measures in individual businesses and across industrial sectors to reduce baseline emissions to the maximum extent viable, adopting circular economy principles, prior to the adoption of other abatement technologies.**

Changing circumstances such as net-zero commitments, the introduction of full carbon accounting and energy price volatility mean that efficiency options that were previously marginal or uneconomic may be viable now or in the future. Further efficiency gains are particularly important as energy distribution networks approach capacity, significantly increasing the marginal cost of increased supply. Implementing REEE measures can be more cost effective and quicker to implement than fuel switching and CCS alternatives, as they are typically site-based and so less dependent on the development of region-wide infrastructure. The MPR Study highlights four circular economy principles that can support REEE initiatives for heavy industry (based on World Economic Forum, 2018). These are summarised in Table 5.

Table 5 Circular economy principles in industry.

(Market, Policy, and Regulatory Study Table 34)

Circular economy levers in heavy industries	Description	Industry Practice
Increase product utilization	Maximising the use cycles and intensity of use of products, reducing the need for new products.	• Extend product lifecycle • Recover and reuse product components • Design for end of use
Replace material / product with circular alternative	Utilise circular material alternatives, either creating the same product or a substitute.	• Substitute products with improved circularity • Circular (or renewable) feedstocks
Reduce material per product	Reduce material required per product and prevent over supply.	• Optimise product design • Efficient / lean product production
Recycle material for new products	Replace virgin material with recycled material where possible.	• Use recycled material • Maximise reuse value of products

Where different industries are present in a cluster, this presents an opportunity for resource sharing. This could be in the form of collective models for energy generation and transfer (such as private power generation and local distribution networks for water or steam), or for waste utilisation where the waste from one industry can be used as a feedstock by another (such as waste heat recovery from cooling water for district heat schemes, or industrial wastewater being used for metal recovery via electrolysis). Effective resource sharing requires a combination of knowledge exchange, good communication, common standards, risk sharing and trust amongst participants – all things which the Humber industries are currently doing and will continue to do for mutual benefit.

The role of REEE may appear comparatively small to abatement measures such as CSS, but it can and must make a material and ongoing contribution to regional decarbonisation. The Systems Model revealed substantial opportunity to extract further efficiencies in the Humber region, with REEE consistently accounting for 11-13% of the annual emissions abatement by 2040, equivalent to over 1 $MtCO_2e$/year. REEE measures are already being continually implemented across the Humber industries, but this will be accelerated through enhanced knowledge sharing, innovation, and collaboration.

Section 4

Delivering the Humber of Tomorrow

4. Delivering the Humber of tomorrow

This Section of our Plan touches on some important themes related to how we will deliver it. The necessary technical aspects of the Plan were covered previously, and we recognise the critical risks and opportunities around implementing each of these. This section of our Plan leads to our final three Mandates for action, which focus on generating social value, further developing skills and supply chains, accelerating investment, and collaborating to deliver the Humber of tomorrow.

4.1 Alignment with national industrial cluster planning

UKRI has commenced a program to co-create a framework for a UK-wide industrial cluster plan. An outcome from this work is a model of cluster and national decarbonisation, as shown in Figure 13. This illustrates four identified components of delivery:

- **Implementation** of the Plan including strong leadership, monitoring and adaptive planning.
- **Investment,** a priority given the scale of the finance needing to be mobilised nationally.
- **Community engagement** to mitigate consequences and generate social value.
- **Cluster collaboration** to operationalise industrial decarbonisation and to unlock the skills and supply chains to ensure an effective and just transition.

Figure 13 UKRI national cluster plan framework.
(Used with permission from Guidehouse)

We have structured this Section of our Plan on these delivery components but note that we have adopted some slightly different attribution of the sub-components to better align with our research and outcomes.

4.2 Implementation in the Humber

4.2.1 Leadership and ownership of delivery

Our research and analysis proves that the Humber Industrial Cluster can achieve net-zero by 2040. This Plan now needs to be enabled, led, and delivered for it to have impact. The geography and size of the Humber region has historically inevitably led to some divisions at political, institutional and industry levels. The creation of local enterprise partnerships (LEPs) including Hull and East Yorkshire LEP and Greater Lincolnshire LEP has helped enable collaboration across the region. The Humber Leadership Board and Humber Energy Board are also key pan-regional bodies providing leadership and oversight.

The Societal Study identified a desired outcome of enabling 'the Humber to become a global leader and exemplar for industrial decarbonisation'. The first recommendation on how to achieve this was to *'Ensure that there is clear responsibility for delivery of HICP activities across the Humber once the initial plan has been finalised.'*

We recognise the importance of this.

Clear leadership and accountability for the delivery of our Plan is necessary to further the momentum for industrial decarbonisation that has been building over the past five years and that needs to continue for the next twenty. So, it has been agreed that the Humber Energy Board will take responsibility for leading the strategic and governance aspects of the next phase of the Plan. Options for the delivery body are still being considered at the point of publication.

We recognise the value brought by the approach taken in developing the cluster plan. Close working between the Industrial Partners, the Strategic Observers, the HICP team, and wider consulted stakeholders ensured the Plan was evidence-based, practicable and implementable by all affected parties in the region. A key role of the body responsible for leading the implementation of the Plan will be to work alongside all stakeholders in the region and support their plans. The Plan can only be implemented through wide-ranging participation across many of the organisations operating in the Humber.

4.2.2 Monitoring and adaptive planning

While the Systems Model considered four future operating scenarios, models can only approximate reality based on a series of assumptions, due to the infinite complexity of reality. Our modelling provides essential insight into how the industrial cluster must decarbonise, but we recognise that none of the individual scenarios we considered will represent what will actually happen in the future. Irrespective of which scenario the region's decarbonisation most closely follows, there will inevitably be positive or negative factors which will change the operational conditions for industry in the region. For example, these could be policy changes, international events influencing energy prices or material availability, or significant changes in public willingness to pay for lower carbon products. Each change could happen quickly, or develop progressively over a longer time-period, building to a crux point where its impact is felt.

When there are changes in the operational environment a stocktake will be required to review what the optimum future decarbonisation pathway may be. Identifying when there has been sufficient change to necessitate such a review, and then leading the review, will be an important role for the Plan's leadership body. The Systems Model is an ongoing tool which can be used to facilitate these reviews through assessment of alternative approaches going forward.

This Plan outlines what we know now, where there is uncertainty, and some of the future decisions which the industries in the Humber will make. It is adaptable, but that will need to be done in a planned and coordinated way, under the leadership body established. The criticality of this monitoring and adaptive planning is reflected in Mandate 7, where we summarise the need to:

'…regularly monitor this Plan's progress through the leadership delivery structure implemented, adapting to change as necessary, to ensure an effective delivery of net-zero before 2040.'

4.3 Costs and investment

4.3.1 Costs of decarbonising the Humber industries

Our Systems Model provides insight into the significant investment required to abate the Humber Industrial Cluster's emissions. The model calculates that between £15.3 and £33.8bn will be required from 2022 to 2040, with each scenario having different costs. Figure 14 summarises the output from the Systems Model cost analysis. The costs are split into their primary component parts - capital expenditure (CAPEX), operational expenditure (OPEX), fuel costs (including that of hydrogen generation and transmission), and the cost of transporting and storing captured CO_2.

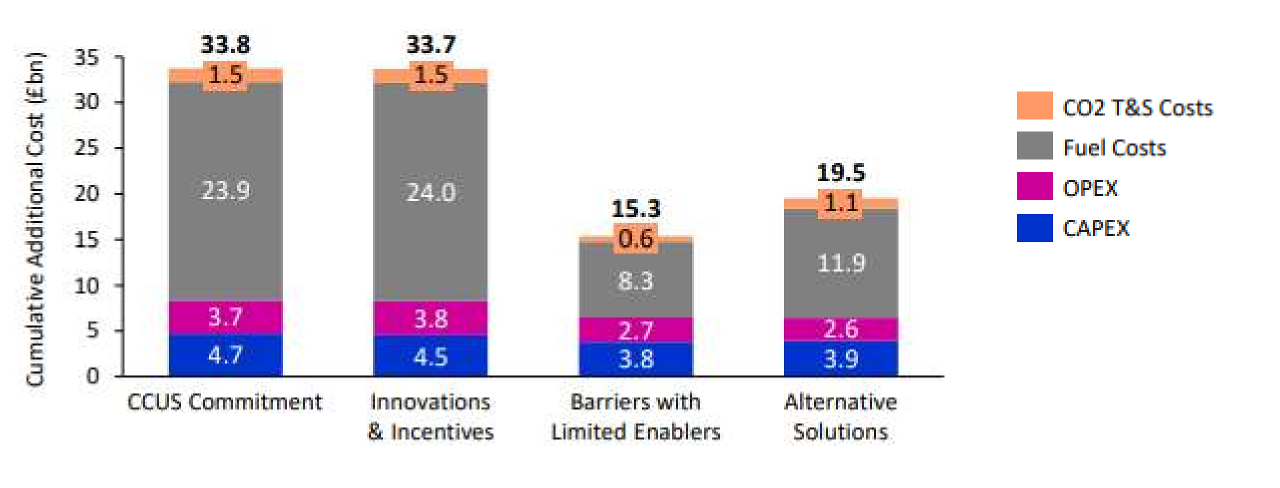

Figure 14 Cost of each scenario (cumulative to 2040).

(Systems Model report Chart 6.2)

Figure 14 demonstrates that:

1. The capital and operational costs are similar in each scenario – there are no scenarios which provide substantially cheaper ways to decarbonise the cluster. Whilst some of the scenarios result in investment being deferred to after 2030, this does not substantially change the overall investment required to install and operate the abatement technologies. This cost is predominantly driven by the installation of CCS, which will be needed for many of the industries in the cluster to substantially reduce emissions.
2. There is a large variation in fuel costs across the scenarios. The scenarios that implement abatement technologies earlier, and achieve a more rapid emission reduction, result in a greater overall cost. This is as the installed technologies then operate for longer compared to the slower initiating scenarios, incurring more fuel costs over time. Additionally, in the scenarios which deploy CCS from the early 2030s, industries can adopt 2nd generation CCS technology. As these should be more fuel efficient the fuel costs will be lower.
3. Over time, the increased fuel costs become the predominant additional cost. Implementing CCS requires additional thermal energy from a fuel source, resulting in additional expenditure when compared to existing operation. Hydrogen, where used, will be more expensive than the natural gas it displaces due to the additional costs incurred in its production. Ongoing optimisation and operational cost reduction of the decarbonisation technologies will be important.

Clear policy incentives on carbon pricing and support mechanisms will be essential to drive rapid and deep cluster decarbonisation. As outlined in Section 2.1.1, the Systems Model used a shadow carbon price as the incentive for decarbonisation. Lower shadow carbon prices reduce the incentive to invest in abatement as it will be cheaper to emit carbon and pay for necessary carbon credits. Our sensitivity assessments indicated that a low shadow carbon price would result in unabated emissions of 14.1 $MtCO_2e$/year in 2030 compared to the 7.3 $MtCO_2e$ predicted with central shadow carbon values used in the scenarios. By 2040 the impact is less significant, but a low shadow carbon price would result in 3.0 $MtCO_2e$/year unabated emissions compared to the 0.7 $MtCO_2e$ with central shadow carbon values.

The Systems Model also provided insight into the average cost of abatement – see Figure 15. Most decarbonisation options deployed in the cluster cost below £200/tCO_2. Hydrogen is the most expensive abatement method across all four scenarios although the cost of hydrogen is expected to reduce between now and 2040 as new production comes online. Electrification is generally the cheapest abatement measure where applied at a small scale. The electric arc furnace at British Steel has a modelled cost of abatement of £100 - £200 / tCO_2e, broadly comparable with CCS. CCS costs per tonne CO_2 abated are lower in the scenarios where 2nd generation CCS technology is available for adoption due to the lower fuel costs incurred. This modelling provides an insight into likely comparative costs of abating emissions in the different scenarios, but it is dependent on the underlying assumptions on the costs of fuels and energy. As the business models are developed for largescale industrial decarbonisation, careful consideration needs to be given to the sensitivity that CCS, hydrogen and electrification each have on fuel and energy costs.

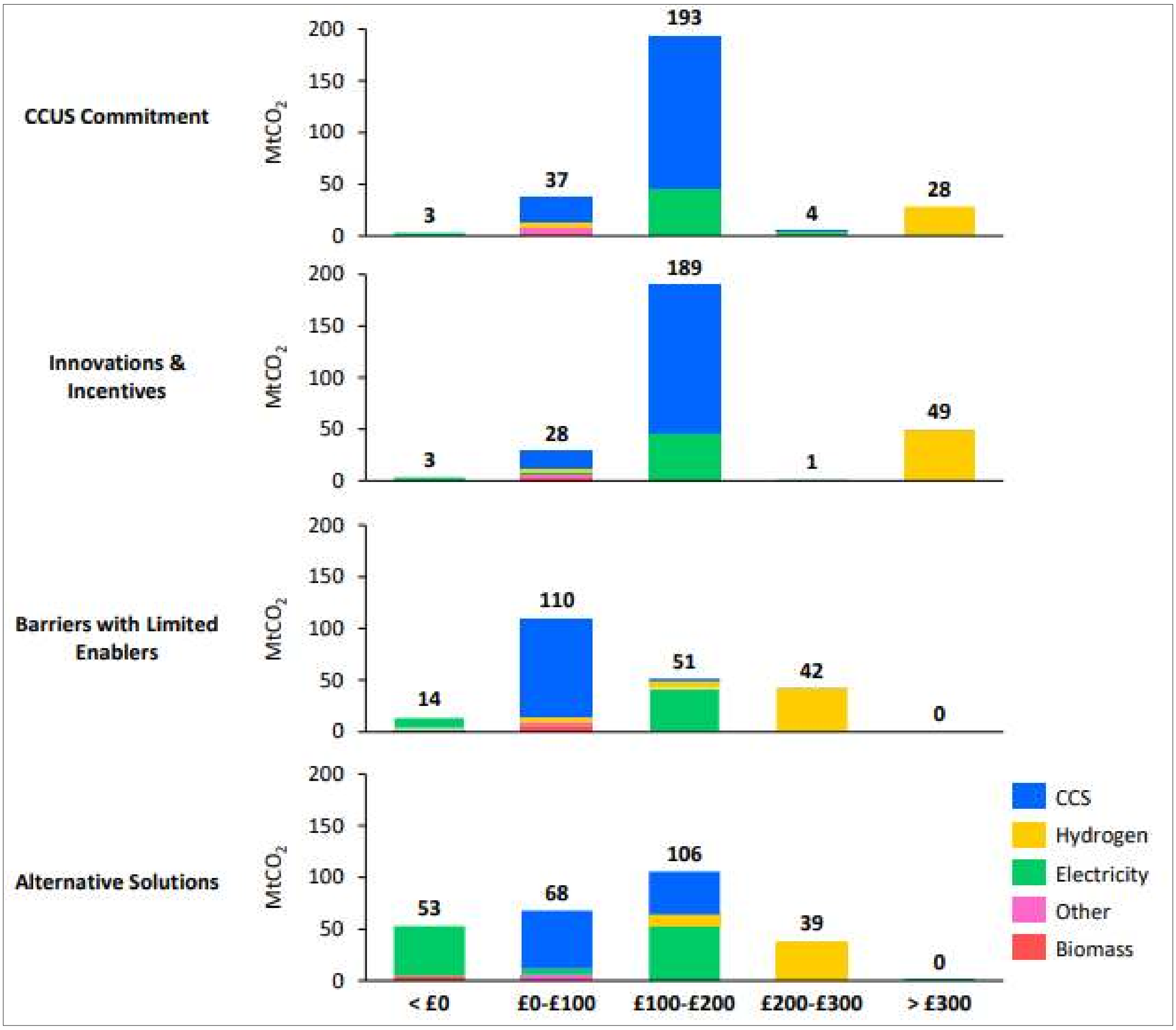

Figure 15 Average cost of each method of abatement across the scenarios (£/tCO_2 on the x-axis).
(Systems Model report Chart 6.7)

Humber industries are poised to invest significantly in decarbonisation, and are taking a long-term transformational view, but this needs support in the form of appropriate policy settings. National policy drivers that could help bridge the gap between the carbon price and abatement cost of interventions include the Emission Trading System, hydrogen and CCUS Business models, and Contract for Difference mechanisms. Project-specific policies and financial support are also important, given the investment risk inherent in the 'first of a kind' deployments currently proposed. There is a critical need for the right funding, at the right time, with clear signals from government, investors and others needed to support delivery.

Our research has proved that investment in industrial decarbonisation across the cluster to achieve net-zero by 2040 will have substantial economic benefits at regional and national level, including £3 - 5 billion/year added to National Gross Value Added (with ~20% of this increase retained in the Humber region) and creation of up to 20,000 direct jobs between now and 2040. Scenarios with a stronger focus on CCS and hydrogen adoption result in the greatest benefit for Gross Value Added and employment, due to the complex supply chains associated with these abatement technologies.

4.3.2 The economics driving industrial decarbonisation

In the Systems Model a shadow carbon value is used to represent the incentive to reduce emissions. If the cost of an abatement measure is less than the shadow carbon value (£/tCO_2) multiplied by the emissions abated, then the model assumes the abatement measure is preferable to adopt. As outlined in Section 2.1.1, the shadow carbon value is a policy neutral representation of all drivers influencing decarbonisation.

To enable and drive industrial decarbonisation the drivers and incentives will need to include a carefully designed set of policies and other interventions (e.g., project grants, carbon tax, product pricing, mandates). The CCUS and hydrogen business models, clarity on which was provided in December 2022, provide a basis for planning for early movers. The Humber's position within the East Coast Cluster and its 'Track 1' status puts it on track for an accelerated deployment, however further clarity on the supporting policies and emerging business models is required. The Emission Trading Scheme is both an opportunity and a threat to industries within the Humber Industrial Cluster, depending on their speed of adoption. The Emerging Voluntary Carbon Market will provide a means for industries to offset the final emissions that they are unable to abate.

4.3.3 Inward investment

The United Kingdom has a good reputation for attracting inward investment and providing the enabling infrastructure that is required. The high level of decarbonisation activity and established infrastructure in the Humber region make it particularly attractive to those investing in decarbonisation, such as:

- Trade and industry investors (SSE, BP) who are seeking 'green' investments.
- Development investors (Octopus, Apax) who finance early-stage projects and sell shares as those projects approach maturity.
- Pension and infrastructure funds (including international funds such as IFM and Allianz) which consider infrastructure a relatively 'safe' investment and are beginning to invest in low-carbon infrastructure due to its perceived longer-term stability.
- Oil and gas companies (Shell, Exxon) who are decarbonising their existing asset base and see this sector as a more viable long-term option than their traditional hydrocarbon-focused business.
- Sovereign wealth funds (Norway, Kuwait) seeking to diversify and green their investment portfolio, secure long-term investments and help development understanding for other projects.

The Humber Industrial Cluster enjoys several advantages over prospective competitors for inward investment, due to its scale (of industry and emissions) and proximity to offshore wind farms and subsea storage, track record on decarbonisation and established Government support through the Track 1 CCUS process.

Prospective investors have many decarbonisation investment opportunities in the Humber, particularly in CCS and hydrogen production. They also consider land prices to be relatively inexpensive, although most of the land available is privately owned which can complicate its acquisition. Access to the 45km^2 Humber Freeport is also likely to attract investors, as it offers both tax zones (proposed for the Humber include Hull East, Goole, and the Able Marine Energy Park) and customs zones at the four main ports (Goole, Grimsby, Hull, and Immingham).

Each Local Authority and both Local Enterprise Partnerships in the Humber is already actively marketing the region and supporting inward investment. We recognise the importance of this to continually bring new companies and expertise into the region for the benefit of the existing industries. The Humber already has frequent delegations coming to view progress, methods, and technologies. We have recognised that there is more we can be doing to efficiently direct inward investment opportunities to the latest and most relevant information. This will be a focus as a we implement this Plan.

The importance of this is reflected in Mandate 7, where we summarise the need to:

'…To seize the unique opportunity the Humber Cluster offers to drive inward investment to provide wider regional, national, and international benefit.'

4.4 Community engagement

Decarbonising the Humber offers economic, social, and cultural opportunities, but also potential challenges. Delivering our ambition of net-zero by 2040 will require public support, and we have engaged with communities who live and work in region. This involved a Societal Study to help us understand public perceptions, values, questions, and aspirations regarding industrial decarbonisation.

4.4.1 The Humber socio-economic context

The demographic profile of the Humber region differs from that of the wider UK. The population and workforce tend to be older, and many areas suffer significant deprivation, while educational achievement lags the national average. However, there are also marked differences within the region, with some areas north and west of Kingston upon Hull classified as amongst the least deprived nationally (see Figure 16).

Industrial activity can help improve this situation by providing high-quality jobs that develop skills and encourage education, while also bringing revenue into the region. In 2020, the average wage of workers in the steel industry was £34,000, 45% higher than the average in the Yorkshire and Humber regions (HM Government, 2021).

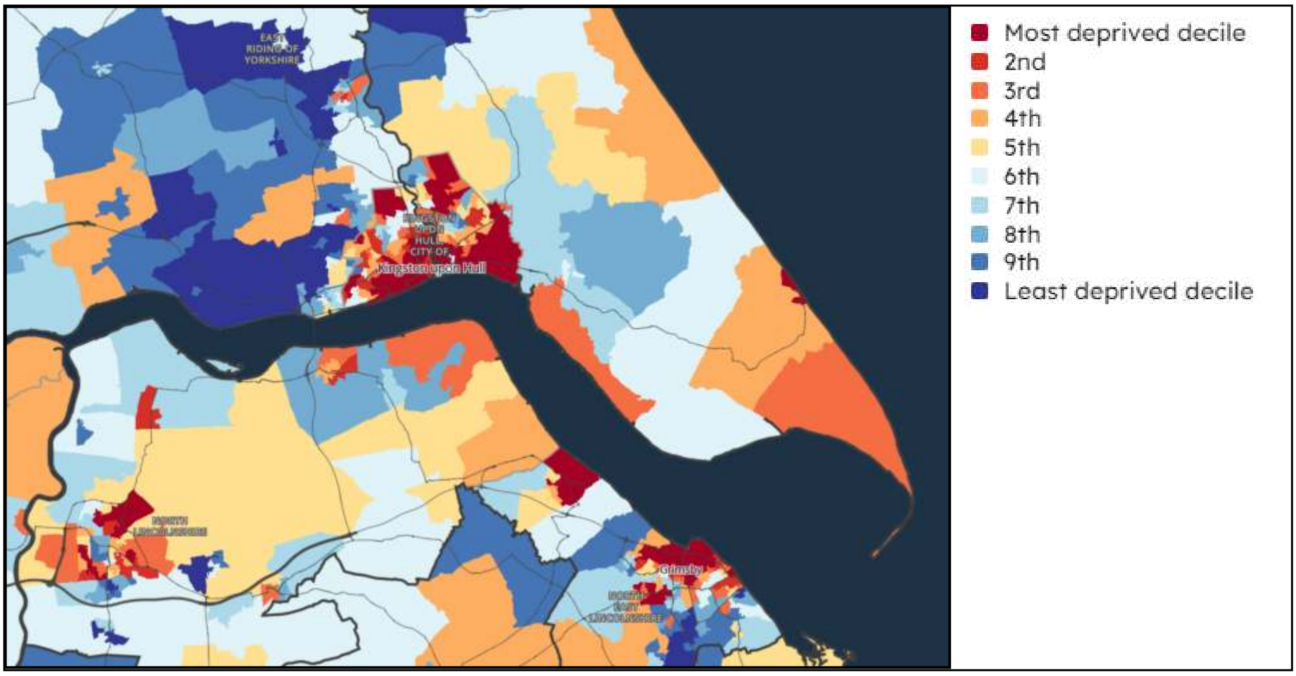

Figure 16 2019 indices of multiple deprivation map for the Humber.

(Original data source: Ministry of Housing, Communities & Local Government (2019))

4.4.2 Societal Study approach

The Societal Study began with a review of over 150 documents to understand the social and industrial context and their interaction. Then our stakeholder mapping exercise enabled us to identify 41 'Key Informant' stakeholders who represented communities (15), public sector organisations (5), businesses (19) and academia (2), who contributed input through interviews and workshops, leading to clarification of their perceptions and attitudes and a shared understanding of the past, present, and potential future of the region. We then convened a series of community focus groups to refine our understanding of their vision for the region, and opportunities and challenges associated with industrial decarbonisation. Figure 17 shows one of the outputs from the workshops.

4.4.3 Outcomes from the study

The study found that the Humber has a unique sense of place and a strong regional identity as the UK's Energy Estuary (CATCH, 2021), but that this is not always acknowledged outside the region. While industrial heritage is an important aspect of the region's culture, there is a sense that in some cases the benefits of industrialisation do not always outweigh the costs. A key aspiration was for fair distribution of the benefits of industrialisation, while key concerns raised included economic sustainability, employment opportunities and the need for improved public sharing of relevant information about development proposals.

While there was strong support for decarbonisation, a limited public understanding of carbon reduction and abatement technologies risks undermining public trust, while there were also reservations about how industrial transformation may compromise cultural identity.

The stakeholder vision for **what** the region could be was:

- The Humber becomes a global leader and exemplar for Industrial Decarbonisation.
- Planning and placemaking across the Humber delivers community benefits from industrial decarbonisation and enhances industrial heritage.

- The Humber has thriving businesses and supports many highly skilled, highly paid jobs, including those necessary to enable industrial decarbonisation.
- Industrial decarbonisation is 'nature positive'.

The study also provided insight into **how** this vision could be delivered:

- Public participation in decision making.
- Provision of information and signposting.
- Visible benefits to communities and individuals.
- Perceiving a fair distribution of impacts and benefits.

The Societal Study resulted in 34 recommendations which focused on the need for a long-term vision aligned with local plans and effective delivery, a collaborative approach with effective coordination, honest communication and fair distribution of opportunities, efforts to prepare and retrain employees, and environmental enhancement by regeneration of disused industrial sites and a fund for wider biodiversity net gain.

4.4.4 Our Mandate to generate social value through the industrial transition

The Societal Study leads to our fifth Mandate for action. There is a large opportunity for the region's industrial transition to bring widespread benefit to the communities who live and work here. Our Mandate is:

4. **To plan, implement, and manage the integrated programme of decarbonisation activities in this Plan to generate social value and bring benefit to all through place making.**
    a. **To meaningfully engage with communities throughout each project to mitigate negative consequences and maximise local benefit.**
    b. **To deliver each project in a way which enhances the environment across the region.**

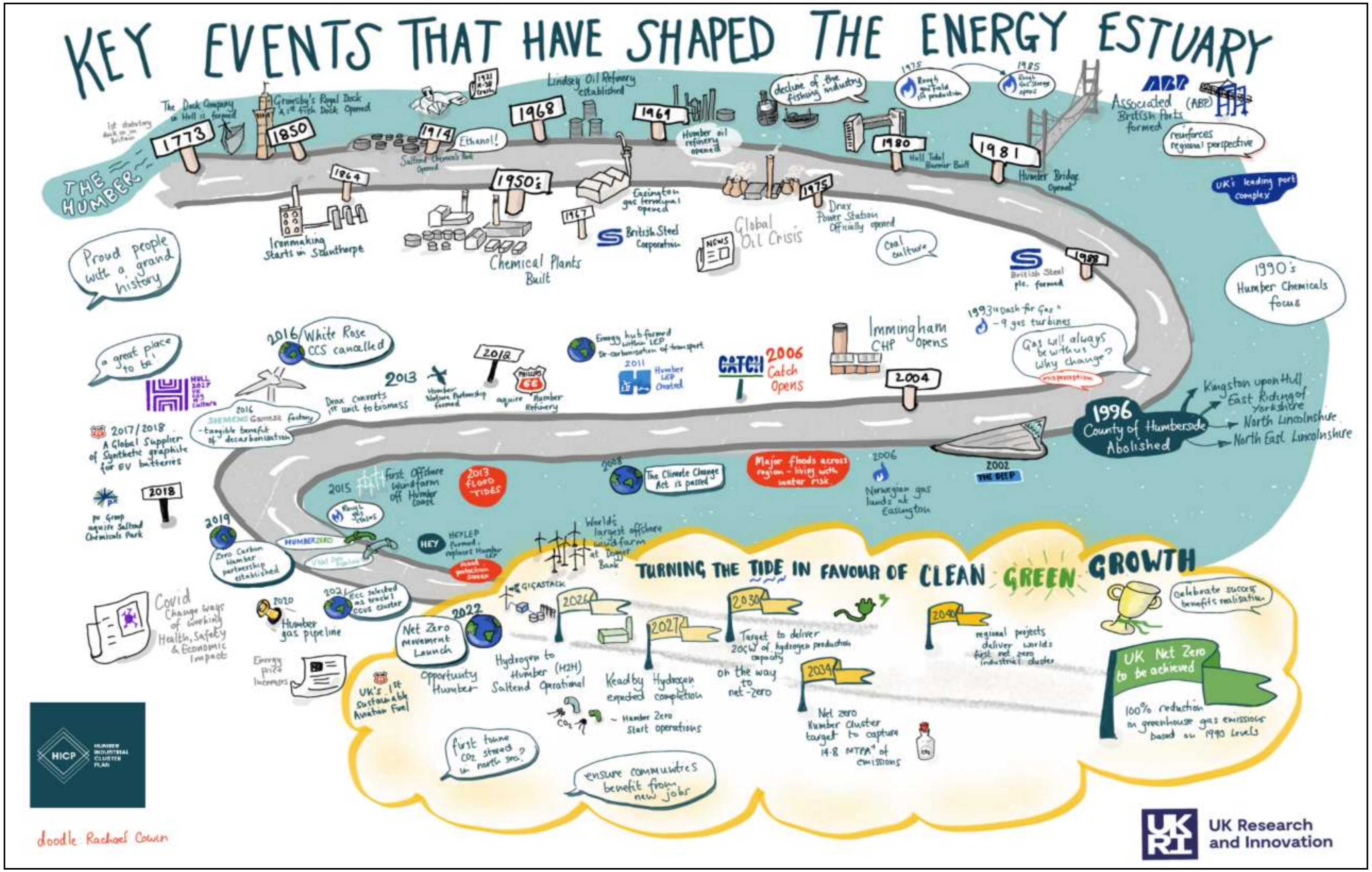

Figure 17 Output from one of the stakeholder workshops showing what local communities identified to be of relevance in the history and future of the Humber.

4.5 Cluster collaboration

This section of our Plan looks beyond the boundary of individual industries to key enabling issues where there must be a collaborative focus to unlock an effective and just transition. The two main issues of focus are skills and the associated need to work with educational providers to develop these, and supply chain capabilities and the need to collaborate to unlock potential bottlenecks. We then also consider how our Humber cluster interfaces with the other industrial clusters and with the national Government.

4.5.1 Collaboration on Skills

The Humber region has a rich industrial heritage which is apparent in the existing skills make up, as well as in the existing providers, institutes and collaborations who are focused on skills. However, a significant surge in demand for specific skills is predicted across the Humber cluster, which needs to be coordinated across the wider UK, as multiple industrial decarbonisation projects commence construction before the middle of this decade. The projects anticipated to go ahead in the Humber are estimated by 2040 to have required up to 22,800 direct new jobs as shown in the Skills Study report. This estimate is based on the planned capital investment across the region. The Systems Model shows CAPEX spending to peak in 2027, with spending beginning in 2024, and the demand for skills will follow this profile. A key imperative is to work in partnership across the region to ensure local people gain the skills, qualifications and opportunities needed to not just deliver but to thrive in the Humber of tomorrow.

Meeting this demand will require a significant, rapid upscaling of current skills in the Humber. Even before the wave of net-zero investment has begun in earnest, cluster stakeholders are already experiencing significant challenges staffing existing operations, retaining their current workforce, and recruiting experienced individuals. Stakeholders interviewed in the Skills Study had unanimous agreement that without action there will be a critical skills shortage that could make it hard to achieve net-zero ambitions. Contractors find it hard to maintain a steady workforce, with many employed on short-term contracts and a significant proportion reaching retirement age. There are shortages in some areas noted by stakeholders including electrical and mechanical engineers, welders, project managers and specialist plant operators, some who have left the region.

To address the UK-wide industrial skills challenge, IDRIC’s November 2022 report ‘Enabling Skills for the Industrial Decarbonisation Supply Chain’ highlighted how skills gaps need to be addressed nationally, including the sequencing of cluster deployment so demand can be met. Figure 18 shows the current indicative sequencing of industrial clusters around first and second tracks, with the North West, East Coast Humber and East Coast Teesside deploying earlier than others. Given the close relationship between CAPEX and skills, this sequencing is likely to lead to significant initial skills demand in the Humber, although this then gives an opportunity to redeploy these skills in the other clusters over time as they subsequently transition.

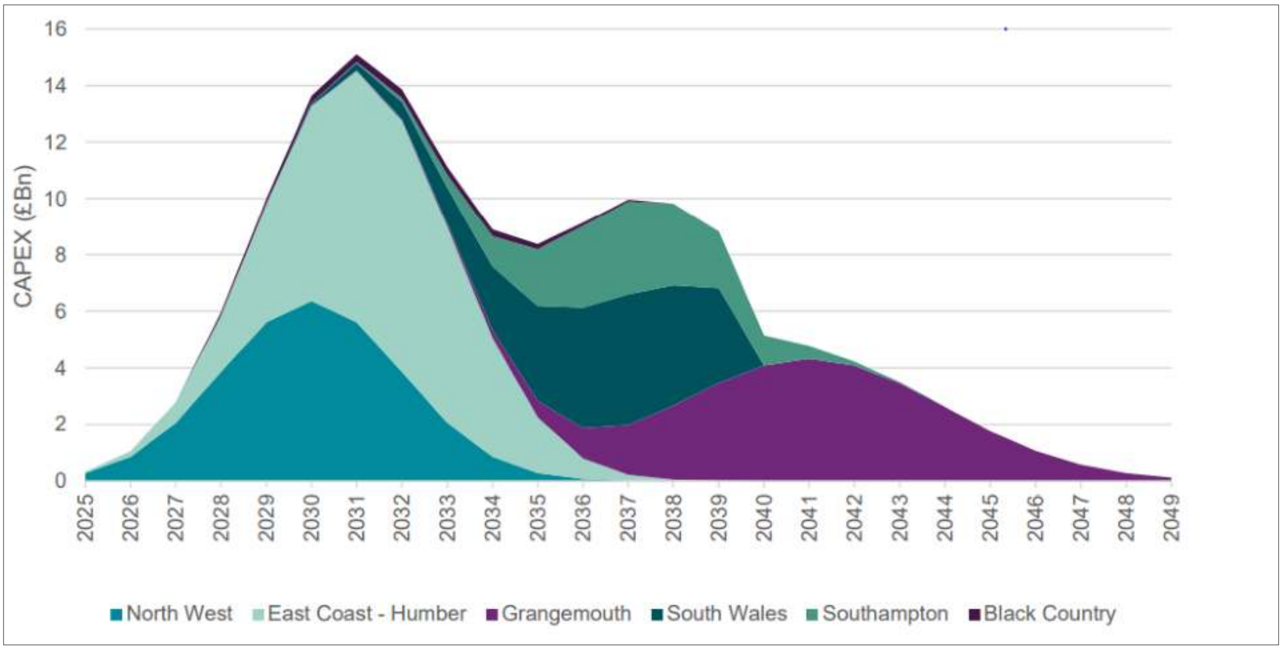

Figure 18 UK industrial cluster capex profile to 2050 (IDRIC, Nov 2022)

Many of these challenges are already being addressed at a wider level as can be seen in the Hull & East Yorkshire Local Skills Report (HEY LEP, 2022). The report was led by the HEY LEP Employment and Skills Board and covered skills for Low Carbon Technologies in the context of all the other key skill sectors: Health & Social Care, Construction, Digital & Technology, Haulage & Logistics, Manufacturing Tourism & the Visitor Economy, Medicare, Agri-Tech and Food. The report built on the Green Jobs and Skills Analysis December 2021 and is fundamentally about creating the skills necessary for a sustainable future of the Humber. The report was written following the aftermath of the COVID 19 pandemic and the urgent need to get the economy working again. It includes nine objectives and an action plan, an assessment of progress and positive stories of success to date. This report provides a solid framework for skills provision across the region and the Energy and Skills Board are actively taking forward this work.

The Humber has strong platform of organisations and initiatives which to build on its skills provision which include:

- University Technical Colleges in Scunthorpe and in Hull, providing a STEM focused education for Key Stage 4 and Key Stage 5 students.
- A broad range of further education opportunities and sixth form colleges.
- Careers Education, Information, Advice and Guidance hubs within both Hull and East Yorkshire LEP and Greater Lincolnshire LEP.
- Multiple private sector training providers.
- Initiatives within individual industries who are investing in developing the skills of their own workforce and reskilling or upskilling. Over 100 organisations are HEY LEP Skills Network members.
- The Humber Digital Skills Partnership which brings together public, private and education organisations to help increase the digital capability of individuals and organisations in the Humber.
- The Hull & East Yorkshire Local Skills Improvement Plan (funded by the Department for Education). This aims to set out the key priorities and changes needed to make post-16 technical education and training more responsive and closely aligned to local labour market needs.

- Work led by the Local authorities for job seekers through Job Centre Plus to ensure appropriate opportunities are presented to those receiving benefits.

Our Skills Study report presents further specific recommendations to address the anticipated skills shortfall in the context of UK wide decarbonisation. Recommendations include focused collaboration between stakeholders (including central government, industries, business, education and training) to accelerate the existing momentum on skills development. In our Plan, as worded in Mandate 6 below, we highlight the link between skills provision and supply chain provision to ensure local people and products made by local people are prioritised in the programme of decarbonisation activities between now and 2040. Our focus is not on quantity alone, but that jobs are meaningful, secure, with pay in line with other parts of the country, ensuring that no one is left behind. Our Plan reflects this approach and will put skills growth at the heart of the transition.

4.5.2 Collaboration on Supply Chains

Significant volumes of industrial 'goods and services' will be required in the Humber region to develop a net-zero industrial cluster. These will be delivered by complex supply chains. A simplified supply chain scheme is presented in Figure 19. The scale and duration of the decarbonisation programme presents a major opportunity for the region to attain a sustainable, future-proof growth path for its industrial base. The coming years will see a sustained period of intensive activity and high demand, and it is essential that potential supply chain bottlenecks are anticipated and mitigated well in advance of them becoming constraints.

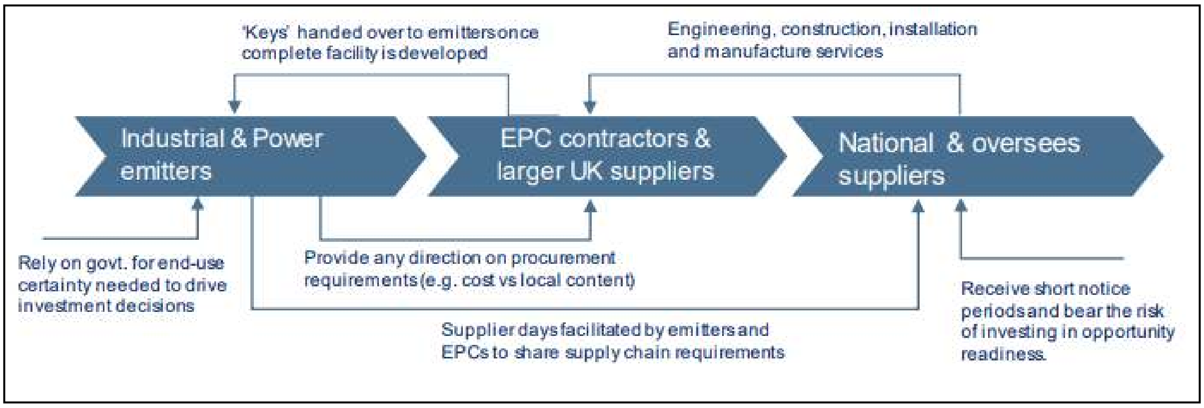

Figure 19 Typical structure of low-carbon supply chains in the Humber.

(Supply Chain Study p18)

Our Supply Chain Study developed parts and materials estimates for the following three components of the cluster Plan in order to start to map the associated supply chains:

- CCS equipment. At VPI alone 3,400 tonnes of steel work and 17,000 m^3 of concrete is required.
- Transportation infrastructure (CO_2 and hydrogen pipelines). For the Zero Carbon Humber pipeline alone, 103 km offshore CO_2 pipeline is required, with 119 km of parallel hydrogen and CO_2 pipeline on land.
- Energy production (power and hydrogen production). Up to 9500 continuous flight auger piles would be required for foundation works.

This study revealed the three key risks to supply chain capacity and resilience were:

- Competing demand from other UK low carbon projects beyond the cluster.
- The disruptive influence of the war in Ukraine and legacy impacts of the Covid-19 pandemic.
- Limited capability and capacity of UK manufacturers to provide and quickly scale-up production of components required for decarbonisation projects.

Key recommendations for responding to these challenges were for greater cross-industry collaboration and the development of modular and standardised components.

4.5.1 Our Mandate to further develop Humber skills and supply chains

The Skills Study and Supply Chain Study support a strong Mandate for action to ensure the region's decarbonisation efforts are not at risk, and that the opportunities for growth have maximum regional impact. Our Mandate is:

6. **To plan, implement, and manage the integrated programme of decarbonisation activities in this Plan to maximise local impact and benefit, and support a Just Transition.**
    a. **To ensure local skills growth, in both quality as well as quantity, matches demand at all levels whilst supporting new skills being brought in where necessary.**
    b. **To ensure local supply chain growth of materials, components and services matches demand and is optimised to drive local benefit.**

4.5.2 Collaboration with other industrial clusters and national Government

As detailed at the start of this section, UKRI is undertaking a program to co-create a framework for a UK wide industrial cluster plan. We recognise that this is essential to the successful long-term implementation of this Plan, and each of the other cluster plans. Each individual cluster will face similar challenges, and are exposed to the same broader, external factors. Decisions made at the national level have implications for all the clusters and the actions they choose to take. Equally the UK does not operate in isolation and there are global factors that influence the Humber, not least with similar ports across the North Sea given the Humber's geographic context.

The Humber is one of six industrial clusters in the UK, the others being the Black Country, Grangemouth, North West England, South Wales, and Teesside as shown in Figure 20.

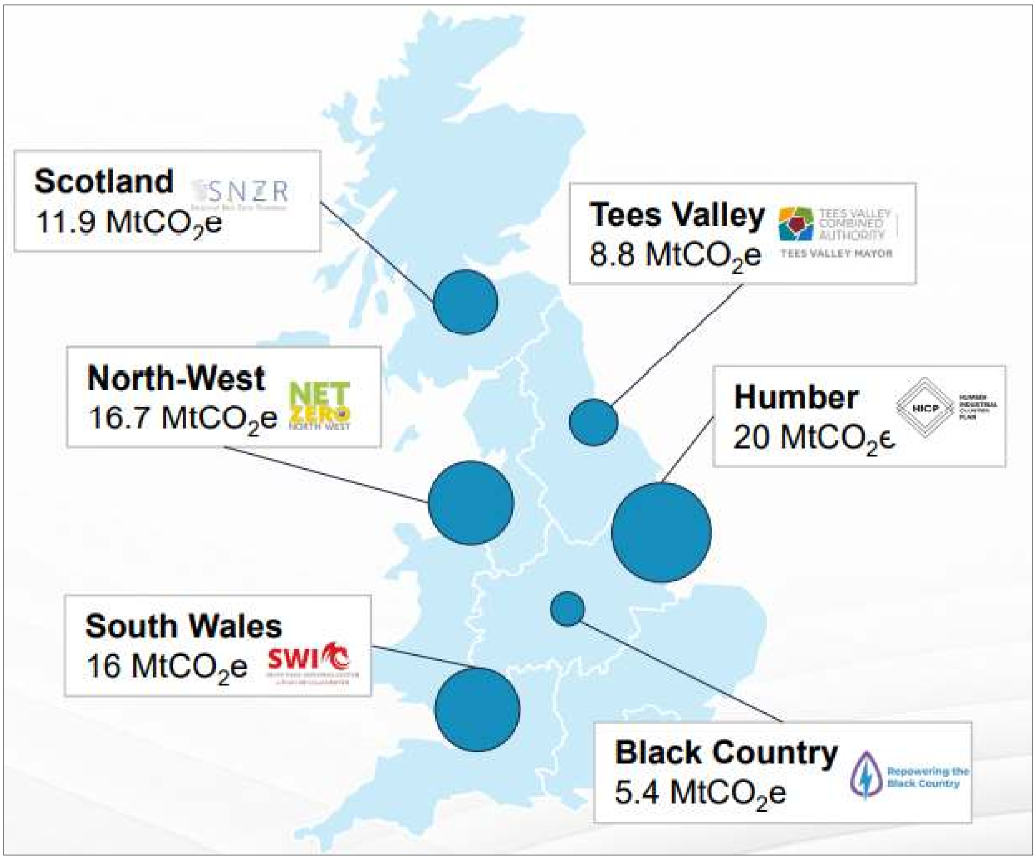

Figure 20 Map to highlight the UK's 6 Industrial Clusters.

(From preliminary IDC workshops where emissions values were provided by the clusters and are indicative only)

Our detailed MPR Study identified a series of Humber and UK wide recommendations necessary to operationalise industrial decarbonisation. A series of action partners or stakeholders have been mapped and the actions categorised as:

- Urgent - now is the time to act.
- Critical - no decarbonisation without it.
- Low hanging fruit - easy way to make some progress.

This table is replicated here, but reference should be made to the full study for the supporting evidence behind each of these recommendations.

Stakeholder	Action Category	Recommendation / Action
Policy Makers		Finalise business models for carbon capture, H_2 production and greenhouse gas removals, specifically providing clarity on the level of financial support that will be made available.
		Develop a business model for electrification.
		Implement carbon border adjustment measures or equivalent instruments to enable carbon pricing to drive decarbonisation whilst not contributing to carbon leakage.
		Devise policies that stimulate and support demand for green products.
		Increase innovation funding for new technologies that will reduce the cost of decarbonisation.
Industry		Pursue opportunities for circularity starting with industrial symbiosis for using waste heat and other physical streams to air, water, or land.
		Identify easy wins for hydrogen fuel switching opportunities.
		Stimulate demand for green products through the development of increased Scope 1-3 emissions traceability across the full product supply chain.
		Focus on reducing energy and water consumption as well as minimising impacts on air quality and the environment.
Regulators		Ofgem should reform industrial electricity prices, decoupling the cost of electricity from fossil generation and the market price of natural gas.
		Environment Agency (EA) should investigate future water availability in the Humber region.
Local Authorities		Work alongside the government to update how planning consent is awarded for projects of national significance.
Local Leadership		Communicate the benefits of low carbon technology deployment to the wider public.
		Identify potential synergies between Humber industrial operators (e.g. to utilise waste streams).
Academia		Focus R&D efforts on reducing the cost of CO_2 capture, hydrogen production and electrification, alongside further analysis of promising alternative pathways.
Utilities and Networks		Identify constraints in the UK electricity grid and opportunities for electrification.
		Identify potential water constraints to industrial operators and project developers in the Humber region.

Figure 21 Priority recommendations and actions. (MPR Study Table 1)

The MPR Study identified critical challenges and key recommendations to overcome them which need to be addressed by action partners in the Humber and across the UK. Our tagline for the Humber cluster is ‘Together it is possible’, and we recognise the need to work widely with the other clusters to collaboratively achieve national industrial decarbonisation. Across the Humber Industrial Cluster we will:

- Work with other industrial clusters to address where specific government policy may not be aligned with the needs to operationalise cluster decarbonisation. This includes CCUS, hydrogen, electrification, circularity and GGR business models, policy, incentives, and subsidies.

- Work with other clusters to coordinate on unlocking skills and supply chain issues to ensure obstacles are overcome by a coordinated, enabling build out of both people and products across the UK required for industrial decarbonisation.
- Accelerate the shared infrastructure projects we have with Teesside, given the geographic proximity, both on offshore CCUS and onshore on hydrogen distribution.
- Work with adjacent non clustered industry to find solutions to their specific decarbonisation challenges.
- Continue to be a catalyst for industrial decarbonisation globally.

4.5.3 Our Mandate to drive investment and collaboration to deliver the net-zero Humber of tomorrow

Major industries across the Humber, including the three deployment projects, are currently accelerating decarbonisation as a 'Track 1' cluster. These include carbon capture, hydrogen production, and greenhouse gas removals, alongside development of shared infrastructure for CO_2 transport and storage and hydrogen storage sites. Around £15bn is currently pledged by industry to deliver these projects and to support the development of innovative training facilities to ensure local people are equipped for the jobs that will be created.

Our Mandate arising from this is:

7. To drive investment and collaboration to deliver the net-zero Humber of tomorrow.

   a. To recognise the existing ambition, strong alignment with the Plan's proven pathways to net-zero, progress, and momentum of the Humber Industrial Cluster towards deep decarbonisation.

   b. To unlock the market, policy, regulation and technical barriers to further implementation of this Plan and allow acceleration of the Humber Cluster's decarbonisation.

   c. To share the lessons and skills developed through decarbonising the Humber Cluster, to then accelerate the decarbonisation of the UK's other industrial clusters in an efficient and planned approach.

   d. To seize the unique opportunity the Humber Cluster offers to drive inward investment to provide wider regional, national, and international benefit.

   e. To regularly monitor this Plan's progress through the leadership delivery structure implemented, adapting to change as necessary, to ensure an effective delivery of net-zero before 2040.

Section 5
Conclusion to our Plan

5. Conclusion to our Plan

5.1 Summary of this Plan

In Section 1 we set out the background on why this Plan is required and gave details on how we have developed it using a collaborative and thorough approach. This has been formed through over 20 organisations across the Humber working together. It reflects a diverse but united voice.

In Section 2 we explained the analysis and evidence supporting this Plan, outlining how we used a comprehensive Systems Model of the region's energy systems to investigate wide-ranging industrial decarbonisation options. We presented the results from this modelling, showing that the Humber Industrial Cluster is uniquely positioned to decarbonise rapidly and deeply, and there are viable, efficient and integrated ways to do this.

In Section 3 we outlined the key industrial interventions of carbon capture and storage, hydrogen, electrification and efficiency in energy and resources and how these led to the first four Mandates for action. We showed how the demonstration projects in-flight align with the modelled optimal routes to decarbonisation of the cluster, and how there are multiple other aligned projects, which will support each industry to decarbonise.

In Section 4 we outlined how the Humber of tomorrow will be delivered, leading to Mandates five, six and seven; how leadership, community engagement and a focus on unlocking skills and supply chains are necessary for an effective, as well as just, transition in the Humber. Decarbonising our cluster poses great opportunities for wider benefit, and we are ready to grasp these opportunities.

This Plan provides a robust approach for achieving net-zero for our Scope 1 industrial emissions. Implementing carbon capture infrastructure across the region facilitates future greenhouse gas removal projects. These, including capturing some of Drax's biogenic emissions, will enable net emissions in the Humber region to be substantially below zero.

Our Plan shows how we must capture the existing momentum of the Humber industries and accelerate this. We can transform the Humber from the UK's largest emitting cluster to a global leader in industrial decarbonisation. The Humber benefits from unique assets and resources. Utilising these to enable our decarbonisation will allow this to be done efficiently, learning the lessons to progressively implement wider national industrial decarbonisation. This will require action from all parties – national and regional government, industry, supply chains, academia, the wider community, regulators and a wide range of other stakeholders. Together, through uniting to decarbonise the Humber industries we will drive economic wins, social wins, and environmental wins, allowing the Humber to be the world's leading industrial cluster and a catalyst for change.

5.2 Our Mandates for action

Our Mandates for action have been introduced throughout this Plan. These Mandates are the distilled principles which will guide our subsequent detailed planning and implementation. In detail, our seven Mandates for action, which we will be taking forward, are:

1. To implement carbon capture and storage and greenhouse gas removal technologies at pace and scale across the Humber.
    a. To capture carbon from each industrial process where this is the optimal decarbonisation option.
    b. To implement the necessary region-wide and offshore infrastructure to convey all captured CO_2 to permanent subsea storage.
    c. To develop and optimise the offshore storage reservoirs to ensure the necessary short-term injection rates can be achieved, and the long-term capacities maximised.
    d. To facilitate engineered greenhouse gas removal projects through connections to the region's carbon capture and storage infrastructure.

2. To implement low-carbon hydrogen at scale across the Humber.
    a. To use hydrogen for each industrial process where this is the optimal decarbonisation option.
    b. To produce low carbon hydrogen, supported by renewable energy generation, at scale.
    c. To implement the necessary region-wide infrastructure to distribute hydrogen.
    d. To store hydrogen at scale for operational resilience, seasonal needs, and to optimise energy use in generating hydrogen.
    e. To explore opportunities for the Humber hydrogen network to enable decarbonisation in other sectors of the economy, where appropriate.

3. To electrify industrial processes at each site where this is determined to be the optimal decarbonisation technology.

4. To prioritise Resource Efficiency and Energy Efficiency measures in individual businesses and across industrial sectors to reduce baseline emissions to the maximum extent viable, adopting circular economy principles, prior to the adoption of other abatement technologies.

5. To plan, implement, and manage the integrated programme of decarbonisation activities in this Plan to generate social value and bring benefit to all through place making.
    a. To meaningfully engage with communities throughout each project to mitigate negative consequences and maximise local benefit.
    b. To deliver each project in a way which enhances the environment across the region.

6. To plan, implement, and manage the integrated programme of decarbonisation activities in this Plan to maximise local impact and benefit, and support a Just Transition.
    a. To ensure local skills growth matches demand at all levels whilst supporting new skills being brought in where necessary.
    b. To ensure local supply chain growth of materials, components and services matches demand and is optimised to drive local benefit.

7. To drive investment and collaboration to deliver the net-zero Humber of tomorrow.
    a. To recognise the existing ambition, strong alignment with the Plan's proven pathways to net-zero, progress, and momentum of the Humber Industrial Cluster towards deep decarbonisation.
    b. To unlock the market, policy, regulation and technical barriers to further implementation of this Plan and allow acceleration of the Humber Cluster's decarbonisation.
    c. To share the lessons and skills developed through decarbonising the Humber Cluster, to then accelerate the decarbonisation of the UK's other industrial clusters in an efficient and planned approach.
    d. To seize the unique opportunity the Humber Cluster offers to drive inward investment to provide wider regional, national, and international benefit.
    e. To regularly monitor this Plan's progress through the leadership delivery structure implemented, adapting to change as necessary, to ensure an effective delivery of net-zero before 2040.

Section 6

References, glossary and abbreviations

6. References, glossary and abbreviations

Our Plan draws on the extensive research and analysis delivered by the HICP team, plus wider supporting sources. In this section we provide links to the principal supporting evidence.

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6.2 Glossary

Our Plan is intended to be read, understood and used by anyone who lives or works in the Humber region, or has an interest in it. We have avoided using technical terms which will not be widely known, apart from where necessary, and these are defined below.

Term	Definition
BECCS	Bioenergy with Carbon Capture and Storage. The process of extracting energy from biomass and capturing and permanently storing the carbon released, thus permanently removing CO_2 from the atmosphere.
CATCH	Centre for Assessment of Technical Competence Humber. Created in 1999 to support the development of the £6 billion Humber chemical and chemistry using sectors, CATCH now comprises members and partners drawn from across the process engineering, energy, engineering and renewable sectors, their associated supply chains, regional and national government agencies and local authorities, including all four Humber local authorities.
CCUS / CCS	Carbon Capture Usage and Storage / Carbon Capture and Storage: The capture of the majority of the carbon dioxide (CO_2) emissions produced from the use of fuels in electricity generation and industrial processes, preventing the carbon dioxide from entering the atmosphere. This is then used (if demand exists for the carbon) or stored in depleted fossil fuel reservoirs.
CCUS enabled hydrogen	Hydrogen produced through natural gas reformation with carbon capture and storage, sometimes referred to as 'blue' hydrogen.
DACCS	Direct Air Carbon Capture and Storage: Systems which use a low carbon energy source, such as waste heat or renewable electricity to remove CO_2 from the atmosphere, and then store this permanently.
Decarbonisation	All measures through which a business sector, or an entity – a government, an organisation – reduces its carbon footprint, primarily its greenhouse gas emissions, carbon dioxide (CO_2) and methane (CH_4).
Electrolytic hydrogen	Hydrogen produced through the electrolysis of water, sometimes referred to as 'green' hydrogen.
GHG	Greenhouse Gases: Any gas in the atmosphere which absorbs and re-emits heat, and thereby keeps the planet's atmosphere warmer than it otherwise would be. These include carbon dioxide and methane. As different GHG have different warming potentials, these are normally converted to being an equivalent volume of carbon dioxide – denoted CO_2e
GGR	Greenhouse Gas Removal: Any means by which greenhouse gases in the atmosphere are removed and permanently stored. This includes engineered solutions such as BECCS and DACCS and natural solutions such as large-scale reforestation or reinstatement of wetlands and seagrass regions.
Net-zero	A target of 100% reduction in greenhouse gas emissions. It is referred to as 'net' as there will be some remaining sources of emissions which would need to be offset by removals of CO_2 from the atmosphere.
Scope 1 emissions	Terminology from the GHG Protocol: Scope 1 emissions include direct emissions from the company's owned or controlled sources, as opposed to Scope 2 from purchased or acquired energy, and Scope 3 which are indirect value chain emissions.
Shadow carbon price	A mechanism used in the energy system modelling to represent all incentives to reduce emissions, which could include both policy and market drivers, such as carbon taxes, product pricing, grants, etc.
Track 1 Cluster	Under the UK Government's Cluster sequencing process, Humber, Teesside and Mersey side were selected as Track 1 clusters.

6.3 Abbreviations

The following abbreviations are used in this Plan.

Abbreviation	Words in full
CHP	Combined Heat and Power
EAF	Electric Arc Furnace
EPC	Engineering, procurement, and construction
FEED	Front end engineering design
HICP	Humber Industrial Cluster Plan
REEE	Resource Efficiency and Energy Efficiency
T&S	Transport and Storage
UKRI	UK Research and Innovation

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