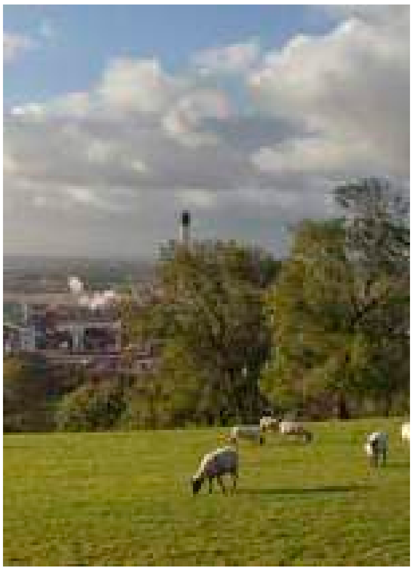
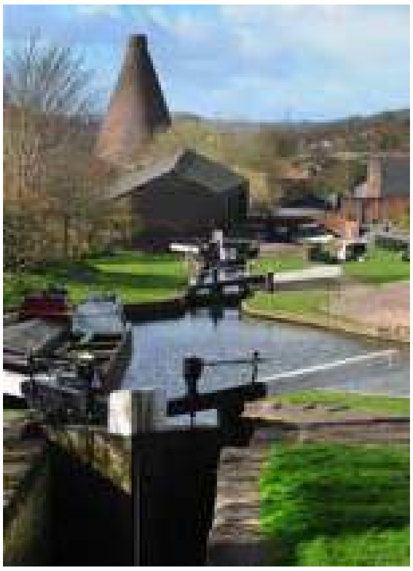
UK Research and Innovation

Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation



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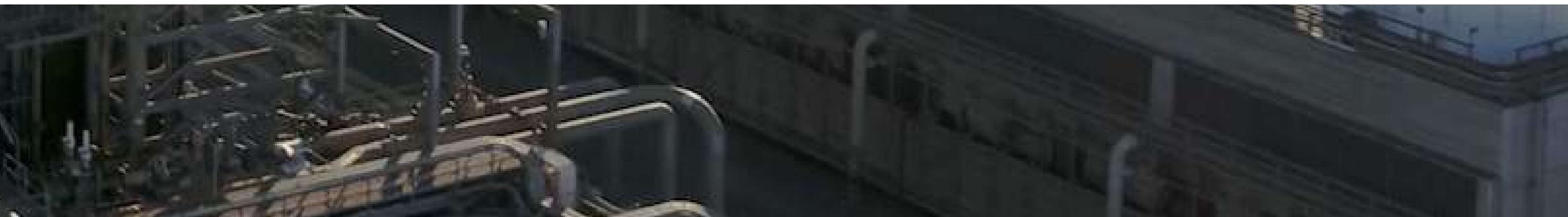


Glossary

Term	Definition
Allam cycle	An Allam Cycle power plant works by combusting natural gas but does so in a closed environment, and all excess CO_2 is captured for utilisation or storage
Anaerobic digestion	The decomposition of sewage or other organic waste material by anaerobic microorganisms, typically used as a means of waste disposal with energy production
Anthropogenic CO_2	CO_2 generated by human activities, including those from power generation, transportation, industrial sources, chemical production, petroleum production, and agricultural practices
Autothermal reformation	A process for producing syngas, composed of hydrogen, carbon monoxide and CO_2 using high concentration oxygen
Bioenergy	Energy produced from recently living organisms and typically referring to electricity and gas that is generated from organic matter, known as biomass
Biomass	Any material of biological origin used as a feedstock for products or as a fuel for bioenergy or biofuels (transport fuels)
Bioenergy with carbon capture and storage (BECCS)	Refers to the process of extracting bioenergy from biomass and capturing and storing the carbon, thereby removing it from the atmosphere
Biohydrogen	Hydrogen produced through biological processes, such as fermentation
Biomass gasification	Refers to a controlled process involving heat, steam, and oxygen to convert biomass to hydrogen and other products, without combustion
Biomethane	Methane gas that is produced by processing biomass. It can be used for the same purposes as natural gas, like producing electricity or heat, and can use the same infrastructure for transmission and end-user equipment
Bio-synthetic natural gas (BioSNG)	A natural gas alternative with similar composition and properties to natural gas. BioSNG is derived from biomass, typically biogenic waste
Blending Hydrogen	A process that introduces hydrogen into existing natural gas pipelines, typically at a low concentration relative to natural gas
Blue hydrogen	Hydrogen produced from natural gas with use of carbon capture and storage
Carbon Abatement	Curbing GHG emissions, particularly CO_2, to reduce the amount of GHGs contaminating the atmosphere
Carbon capture, and storage (CCS)	The process of capturing CO_2 from industrial processes, power generation, and other sources of CO_2. The captured CO_2 is then stored permanently in disused oil and gas fields or naturally occurring geological storage sites
Carbon capture, utilisation, and storage (CCUS)	The process of capturing CO_2 from industrial processes, power generation, and other sources of CO_2. The captured CO_2 is then either used, for example in chemical processes, or stored permanently in disused oil and gas fields or naturally occurring geological storage sites

Term	Definition
Climate Change Committee (CCC)	An independent, statutory body established to advise the UK and devolved governments on emission targets and to report to Parliament on progress made in reducing GHG emissions and preparing for and adapting to the impacts of climate change
Contracts for Difference	A support mechanism for low-carbon energy projects in the UK where developers are paid a flat rate for the electricity they produce over a 15-year period; the difference between the "strike price" (a price for electricity reflecting the cost of investing in a particular low-carbon technology) and the "reference price" (a measure of the average market price for electricity in the GB market)"[1]
CO_2e	Carbon dioxide equivalent is used to represent GHGs' impacts, standardised to an equivalent amount of CO_2 that would have the same impact, based on global warming potential
Combined cycle gas turbine	Refers to a type of combined cycle power plant commonly used for high efficiency, fast responding electricity generators, typically fuelled with natural gas
Commercial Readiness Level (CRL)	An assessment using various indicators which reflects a technology or application's position along the journey to being a bankable asset class[2]
Common infrastructure	Infrastructure whose use and benefits are shared amongst more than one user, and which may, or may not, have shared ownership. This includes pipelines for CO_2 transport, hydrogen networks, and power transmission and distribution infrastructure, among others
Decarbonisation	The process of reducing the amount of GHGs, primarily CO_2, released into the atmosphere by a system, asset, or organisation
Direct air carbon capture and storage (DACCs)	Use of engineered processes to capture CO_2 directly from the atmosphere for permanent storage or use
Direct GHG emissions	As defined by the Greenhouse Gas Protocol, direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity[3]. In an organisational carbon footprinting context, Scope 1 emissions are direct GHG emissions
Dispatchable power	Refers to an electrical power system, such as a power plant, which can adjust its power output to the electrical grid on demand
Dispersed sites	Industrial sites located outside of industrial clusters
Domestic energy production	Refers to any kind of energy production, such as extraction of fossil fuels or production of renewable electricity, within the concerned state, here in the UK
Economies of scale	Economies of scale are cost advantages reaped by companies when production becomes efficient, typically due to large volumes of production
Electrification	Switching from using fuels, such as gas or petroleum, to using electricity
Embodied emissions (or embodied carbon)	The sum of all the GHG emissions produced in the manufacture of a product. This includes emissions from the extraction and transportation of raw materials, repair, replacement and refurbishment of assets, and the manufacturing processes used to create the final product
Emissions Abatement	Emissions abatement means curbing GHG emissions to reduce the amount of GHGs contaminating the atmosphere

Term	Definition
Emissions Trading System (ETS)	Refers to a “cap and trade” scheme where a limit is placed on the right to emit specified pollutants over an area and companies can trade emission rights within that area
Energy from waste	Refers to taking waste and turning it into a useable form of energy, typically electricity
Engineered Greenhouse Gas Removals (GGRs)	Refers to activities that involve the extraction from the atmosphere and long- term storage of GHGs, usually CO_2
Environmental, Social, and Governance (ESG)	A framework that helps stakeholders understand how an organization is managing risks and opportunities related to environmental, social, and governance criteria
Gigawatt (GW)	A gigawatt (GW) is a unit used to measure power representing one billion watts
Greenhouse gas emissions	Addition to the atmosphere of gases that are a cause of global warming, including CO_2, methane, and others as set out in the Kyoto Protocol[4]
Green hydrogen	Hydrogen produced from electrolysis with renewable electricity
Gross value added (GVA)	The value generated by any unit engaged in the production of goods and services
Heat network	A system of insulated pipes that takes heat or cooling generated from a central source and distributes it to several domestic and non-domestic buildings
Indirect GHG emissions	As defined by the Greenhouse Gas Protocol, indirect GHG emissions are emissions that are a consequence of the activities of the reporting entity but occur at sources owned or controlled by another entity. In an organisational carbon footprinting context, indirect emissions are scope 2 and 3 emissions. Scope 2 emissions are indirect GHG emissions from consumption of purchased electricity, cooling, heat, or steam. Scope 3 emissions are indirect GHG emissions cover those produced by customers using an organisation’s products or services or those used by suppliers that are inputs to the organisation’s products and services[5]
Industrial cluster	Places where related industries are co-located. Clustered industrial sectors tend to be those that require energy-intensive manufacturing processes, specifically: chemicals, glass, oil refining, paper and pulp, and iron and steel
Industrial flue gas	The gas resulting from combustion or other processes in an industrial plant, and which contains the reaction products, e.g., CO_2, and residual substances such as particulate matter (dust), sulphur oxides, nitrogen oxides, and carbon monoxide
National Atmospheric Emissions Inventory - UK (NAEI)	The NAEI estimates annual pollution emissions for most pollutants, from 1970 to the most current publication, for the UK[6]

Term	Definition
Net zero	Refers to the balance between the amount of GHG that is produced and the amount that is removed from the atmosphere within a given boundary
Negative emissions	Achieved by removing more GHGs from the atmosphere, for example, through direct air capture or bio-energy production with carbon capture
Paris Agreement	The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21). Its goal is to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels
Pink hydrogen	Hydrogen generated through electrolysis powered by nuclear energy
Post-combustion CCS	A method of collecting CO_2 emissions that are produced from the burning of fossil fuels
Pre-combustion CCS	Refers to removing CO_2 from fossil fuels before combustion is completed
Renewable energy	Energy that is collected from resources which are naturally replaced in human timescales such as sunlight, wind, rain, tides, and waves
Small Modular Reactors	Power generators that use nuclear fission to generate low-carbon electricity. They are modular reactors as the components can be manufactured in factories and then transported to site to be assembled
Steam methane reformation	A process in which methane from natural gas is heated, with steam and a catalyst, to produce hydrogen. CO_2 is a by-product of this process
Syngas	Refers to synthetic gas comprised of mainly carbon monoxide and hydrogen in varying ratios. It may also contain small quantities of other gases
Technology readiness levels (TRL)	A type of measurement system used to assess the maturity level of a particular technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress[7]
Terawatt hour (TWh)	A terawatt hour (TWh) is a unit of energy that is equal to 1 billion watt-hours. Terawatt hours are used to measure quantities of electricity or heat produced
United Nations Framework Convention on Climate Change (UNFCCC)	The United Nations entity tasked with supporting the global response to the threat of climate change[8]
World Economic Forum (WEF)	An international organisation for public-private cooperation. It engages political, business, cultural, and other leaders in society to shape global, regional, and industry agendas

Foreword

Greenhouse gas emission reduction is the defining challenge of our time. Mitigating the worst of climate change is critical to ensuring our planet can sustain us in the future and requires transformation of the economy as we know it. However, achieving decarbonisation, especially of industrial processes, is not straightforward. It is therefore my privilege to present *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation*, a strategy that confronts the difficulties of industrial cluster decarbonisation head on.

Industrial cluster decarbonisation is non-negotiable if the UK is to meet its legally binding emission reduction targets. *Enabling Net Zero* internalises the magnitude and urgency of the challenge to define the actions and conditions needed to establish at least four low-carbon clusters by 2030 and the world's first net zero industrial cluster by 2040. The Plan recognises that true success in industrial cluster decarbonisation will be measured by the future strength of the UK economy, the revitalisation of industrial communities across the country, and the global competitiveness of the UK as a provider of low-carbon products and services.

I am proud to have been a part of the Plan's development over the last three years, along with hundreds of individuals and organisations committed to driving industrial decarbonisation in the UK. I am confident that the Plan's practical insights and recommendations will scale beyond the six clusters selected for the Industrial Decarbonisation Challenge and have cascading impacts worldwide.

So yes, industrial decarbonisation is a challenge, but not an insurmountable one, and one that will reward those who invest now and succeed. My hope is that the collaboration between government, industry, and other stakeholders underpinning this Plan will continue and that the opportunities industrial cluster decarbonisation presents will benefit all.

Dr. Bryony Livesey

IDC Challenge Director

UK Research and Innovation

July 2023

Executive summary

The industrial cluster decarbonisation challenge

The United Kingdom (UK) was the first major economy to legislate for net zero greenhouse gas (GHG) emissions by 2050, an ambitious and necessary target to mitigate climate change. For the country to meet its national goal, however, it needs to reduce industrial emissions by at least 90% by 2050. Half of these industrial emissions (32 $MtCO_2e$) are contained within industrial clusters, locations where a significant number of industrial sites are concentrated[9].

Decarbonising industrial cluster activities requires widespread and concurrent updates across the supply chain, including fuels, infrastructure, machinery, processes, and skills, as well as refinement of relevant legislation and regulation. Success relies on ongoing partnership between government and industry to realise emissions reductions and maximise opportunities for economic growth.

Addressing the challenge

To initiate industrial cluster decarbonisation through partnership between the public and private sectors, Innovate UK, part of UK Research and Innovation (UKRI) launched the Industrial Decarbonisation Challenge (IDC)i in 2019, providing £210 million matched by £261 million from industry, with the aim of creating four low-carbon clusters by 2030 and the world's first zero carbon cluster by 2040[10]. As part of the IDC, clusters representing six distinct industrial regions of the UK, including the Humber, North West, Black Country, Scotland, South Wales, and Tees Valley, developed blueprints for reaching net zero. Throughout the past several years, the cluster plan project partners have worked to understand their emissions, the options to abate them, and the impact this could have on their businesses, local communities, and the UK.

Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation (*Enabling Net Zero* or 'Plan') synthesises the six cluster plans through a national lens. It sets out the next steps for how the UK can harness the power of its industrial clusters and drive the next phase of emissions reductions while contributing to a stronger economy, energy security, greater innovation, and community vitality. In doing so, the Plan creates a platform of shared knowledge and replicable models to support existing and future industrial cluster decarbonisation efforts.

Future-state ambitions

Addressing industrial cluster emissions will support the UK in achieving net zero and its vision of becoming a global leader in industrial decarbonisation and manufacturing of low-carbon industrial products in the coming decades[11]. This Plan identifies how partnership between key stakeholders, including government, industry, local authorities, and research institutions, can support the realisation of not only that vision but also a broader set of outcomes beyond decarbonisation.

Successful industrial cluster decarbonisation should result in industrial clusters that:

- have competitive advantages attracting investment from and trading with the international market,
- enable the decarbonisation of UK supply chains, improving the value of products and services sold,
- are active hubs of cooperation, technology development, knowledge transfer, and learning that support investment and innovation to drive decarbonisation, and
- engage meaningfully with local communities to drive environmental, social, and economic benefits.

Recommendations to further industrial cluster decarbonisation

For the UK to realise these outcomes and harness the full potential of its industrial clusters, *Enabling Net Zero* makes the following recommendations.

Recommendation 1: Provide clear signals to the market to facilitate the transition from interim deployment targets to net zero across all clusters by 2050

The UK has committed to developing at least one net zero industrial cluster by 2040 – which leaves only ten years to address the remaining industrial emissions in line with the UK's 2050 net zero target. While a significant amount of support has been given to the 2040 challenge, attention is still needed for abating all required emissions at a sufficient pace and scale – including what remains even after the delivery of the first cluster and successful interim milestones (i.e., hydrogen produced by 2030, $MtCO_2$ captured by 2030, etc.). Signalling to the market to deliver the collective 2050 goal ensures that the UK is decarbonising industry in a systemic and enduring way.

i. IDC is one of the eight clean growth challenges supported by the 'Industrial Strategy Challenge Fund', which encourages partnership between the public and private sectors to address the biggest societal challenges facing UK businesses today.

Recommendation 2: Rationalise and expedite permitting for common infrastructure

Slow and inefficient permitting of infrastructure has implications for the applicants' abilities to plan with certainty, attract investment, and advance to the deployment phase of projects. Common infrastructure, e.g., pipelines for carbon dioxide (CO_2) transport and hydrogen networks, play a vital role in the six IDC cluster plans. However, common infrastructure projects are amongst those impacted by the UK planning system's limitations for adapting to the complexity and novelty involved with net zero projects. Additional challenges around stakeholder coordination, resourcing, costs, and communication of community benefits also impact permitting timelines. Opportunities should be investigated to rationalise and expedite permitting for common infrastructure projects that are at the core of the industrial clusters' plans while avoiding any unintended consequences, e.g., the dilution of standards around health and safety.

Recommendation 3: Formalise an Industrial Cluster Advocate with strong government connections and develop a mechanism for ongoing coordination and communication with industrial clusters

Industrial cluster decarbonisation requires a significant amount of change from both industry and government across areas such as legislation, regulation, business models, infrastructure provision, industrial processes, and fuel use. The government and industry both recognise the importance of finding the right balance between public sector support and private sector-led development to drive industrial cluster decarbonisation. While a notable amount of collaboration has occurred to date, the implementation of the cluster plans necessitates a mechanism to establish formal, holistic, and enduring engagement between industrial clusters and government. An Industrial Cluster Advocate can serve as that bridge between industry and government to facilitate the two-way exchange of market signals and industry feedback.

Recommendation 4: Develop actionable measures and timings of jobs and skills requirements needed for industrial clusters to decarbonise

With less than two decades until 2040, cluster plans are operating on a compressed timeline for implementation. Many of the proposed projects will take place close to, if not at the same time as, one another to be able to actualise the emissions reductions in line with the 2050 net zero target. Both public and private stakeholders acknowledge concerns around the pressure this timeline places on the supply chain and have begun to identify the gaps. However, measures are needed to take this initial work forward and ensure that a skilled workforce of sufficient capacity is available to deliver on industrial decarbonisation projects, programmes, and initiatives. Doing so will create greater certainty that the plans can be delivered, and the UK's industrial cluster decarbonisation goals can be met.

Recommendation 5: Define and prescribe standardised methodologies for decarbonisation impact estimating

The public sector has funded the IDC, including the development of the cluster plans, to accelerate decarbonisation. To understand the contribution that the cluster plans, and other publicly supported efforts, will collectively make to achieving the national target, it is important that the estimated impacts of the projects can be aggregated. Projects using standardised reporting methods for their impacts, both of GHG emissions and economic benefits, would also enable like-for-like comparison of projects in the pipeline. To facilitate this, common methodologies for decarbonisation estimating need to be identified and adopted to allow decisions to be made based on consistent information, and in doing so, increase the effectiveness of delivering the UK's emissions targets.

Looking ahead

How industrial clusters achieve net zero will be contingent on decisions made at the local and national level. The five recommendations made in the Plan address the high-priority challenges synthesised across the six cluster plans. They provide a clear path forward for the government and industry partnership needed to meet the net zero targets while contributing to a broader set of beneficial outcomes.

The industrial clusters' plans pave the way for themselves and others to position the UK favourably in the global market, serve as a linchpin to economy-wide decarbonisation, generate valuable learnings for industry, and bring co-benefits to communities that revitalise the UK's industrial heartlands and improve outcomes for generations to come. *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation* marks the transition into implementation of industrial cluster decarbonisation and actualisation of ambitions.

Section 1: Introduction

Setting the context and objectives of *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation*

The UK has long been committed to achieving net zero GHG emissions. Beginning in 2008, the UK has set increasingly ambitious targets into legislation and now has the goal of bringing all GHG emissions to net zero by 2050. Delivering on this goal requires coordinated action across all sectors of the economy.

UK industrial emissions stand out as a particular area of significance, accounting for 78 $MtCO_2e$, or approximately 15% of the UK's total GHG emissions[12]. To meet net zero, the UK government has indicated industrial emissions will need to fall by at least 90% by 2050[13]. That is a sizable challenge. Industrial activities, such as steel and cement production, are energy-intensive and often generate CO_2 emissions that are difficult to abate. Industrial sites that are geographically located in proximity will form an industrial cluster, and industrial decarbonisation of clusters in the UK have the potential to cost-effectively provide significant reductions in CO_2 emissions.

The Industrial Decarbonisation Challenge (IDC)

UKRI launched IDC in 2019 to support the decarbonisation of six of the largest industrial clusters in the UK[14]: the Humber, the North West, the Black Country, Scotland, South Wales, and Tees Valley (**Figure 1**)[ii]. Industrial clusters collectively account for about half of the UK's industrial emissions(32 $MtCO_2e$)[15].

Recognising that industrial cluster decarbonisation requires input from both government and industry, the IDC is funded through contributions from both and seeks to research, develop, and scale the partnership and private sector-led models that will deliver against the UK's industrial decarbonisation objectives. Furthermore, the IDC aims to identify and reproduce models that boost the competitiveness of key industrial regions, drive domestic investment, create jobs for a low-carbon economy, and grow the low-carbon export market. To achieve this, the IDC provides up to £210 million, matched by £261 million from industry across three workstreams[16]:

1. **Deployment projects** - The IDC deployment projects focus on identifying the technologies and infrastructure needed to decarbonise industrial clusters in a scalable, efficient, and comprehensive way. These projects have been awarded £171 million from IDC, as well as match funding from industry to support this work.
2. **Industrial Decarbonisation Research and Innovation Centre (IDRIC)** - Funded through a £20 million investment from the IDC, IDRIC works with academia, industry, government, and other stakeholders to deliver the multidisciplinary research and innovation agenda needed to decarbonise the UK's industrial clusters[iii].
3. **Cluster plans** - Using £8 million of IDC funding, the IDC cluster plan projects are intended to develop blueprints, or "cluster plans" to achieve net zero in selected UK industrial clusters. This work and report are aligned with the cluster plan workstream.

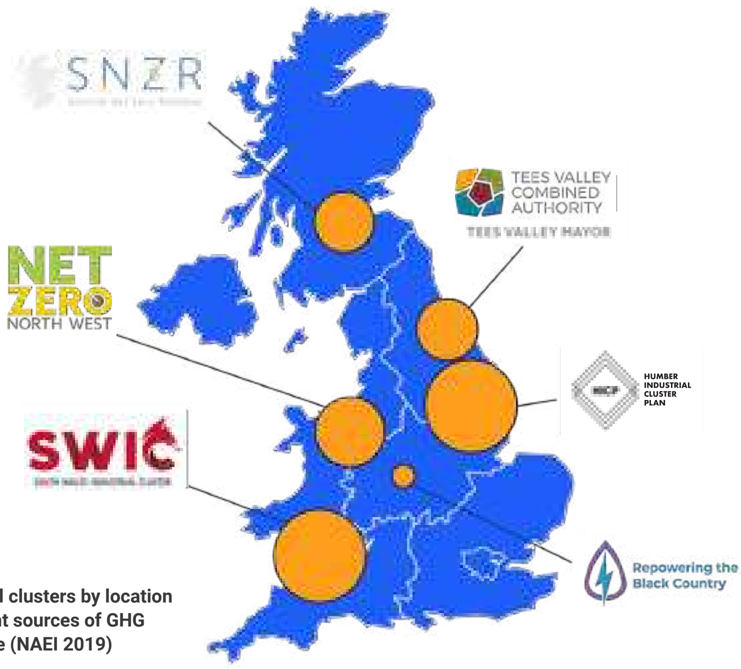


Figure 1: IDC industrial clusters by location and scale of large point sources of GHG emissions addressable (NAEI 2019)

ii. The levels of IDC-provided funding received by these industrial clusters varied. Further details available through the [UKRI gateway to publicly funded research and innovation](#).

iii. See the [IDRIC website](#) for more information.

Collectively, these workstreams lay the foundation for establishing at least four low-carbon clusters by 2030 and the world's first net zero industrial cluster by 2040[17].

About this report

Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation synthesises the six individual cluster plans through a national lens and identifies the next steps needed at the national level for the industrial clusters to achieve their net zero targets. In doing so, it creates a platform of shared knowledge and replicable models that can be used by existing and future industrial cluster decarbonisation efforts within the UK and globally.

Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation provides industry partners and government stakeholders with insights on how to achieve industrial cluster decarbonisation and desired co-benefits. The Plan comprises four sections:

1 Introduction.
The rest of this section situates the Plan in both a global and domestic historical context by outlining international trends in industrial decarbonisation, the role of industrial clusters in achieving net zero, and the status of industrial decarbonisation in the UK.

2 Where the UK is going.
The second section is forward-looking and establishes the vision for industrial cluster decarbonisation in the UK and what the Plan aims to deliver.

3 How the UK will get there.
The third section presents an overview of each IDC-funded cluster plan and highlights how IDC industrial clusters can contribute to realising the UK's vision for industrial decarbonisation. It also describes the Industrial Cluster Decarbonisation Framework, which provides a unifying structure for identifying key learnings across the cluster plans.

4 Achieving the national vision.
In the fourth and concluding section, the Plan presents recommendations for achieving the national vision for industrial cluster decarbonisation and considerations for curbing industrial emissions beyond the clusters.

Industrial clusters are key to economy-wide decarbonisation

Decarbonisation is increasingly urgent and critical

Globally, the industrial sector accounts for around 30% of GHG emissions[18]. Industrial activities are often concentrated – or clustered – in geographically-defined areas, such as those with ample brownfield lands, access to water or infrastructure. Since industrial activities are energy-intensive processes, they account for a substantial proportion (38%) of global final energy consumption[19]. At present, the sector relies heavily on fossil fuels, leading to significant GHG emissions[20], and includes processes with direct GHG emissions. As a result, the global energy transition from fossil fuels to renewable sources will both impact and be impacted by the drive for industrial decarbonisation, and industrial clusters have a crucial role to play.

Global trends are shaping industrial decarbonisation

The International Energy Agency (IEA) has highlighted that the global industrial transition is "not on track" to achieve its net zero emissions by 2050 scenario[iv], which is aligned with the Paris Agreement, and countries globally are accelerating decarbonisation efforts[21]. With an increasing focus on industrial decarbonisation, six trends are influencing industrial cluster efforts worldwide to achieve net zero.

1. **Energy security and resilience as rising priorities:**
   There is increasing emphasis on energy security and resilience, as evidenced by the recent publication of *Powering Up Britain*[22] and associated documents, which include energy security as a central pillar. Recent events such as the war in Ukraine[23] are forcing countries and industry to re-evaluate their energy transition plans[24]; from January 2022 to June 2022, crude petrol and natural gas prices jumped by nearly 65% in the UK[25], eroding their affordability compared to renewable energy sources[26]. While price differentials are beginning to stabilise, the long-term resilience provided by an independent energy system is increasingly acknowledged; emphasis on energy security will directly impact how decarbonisation will be achieved and at what pace, particularly for energy-intensive sectors that are often found in industrial clusters.

2. **Social and environmental responsibility driving corporate behaviour:**
   As climate change awareness grows around the world, there is an increasing expectation for organisations to act responsibly, and investors and consumers are voting in favour of Environmental, Social, and Governance (ESG) principles[27]. The increase in pressure to account for Scope 3 emissions in addition to Scope 1 and 2 reaches back through supply chains to resource extraction and hard to abate industrial processes such as cement production. As a result, more organisations are seeking to take their decarbonisation journeys into their own hands or risk being left behind by competitors[28]. Where formal government programmes do not exist, industry-led clusters are emerging in response to ESG pressure (e.g., the *Australian Energy Transitions Initiative and the Net Zero Basque Industrial Super Cluster initiative* in Spain).

3. **Policies and incentives backing low-carbon technologies:**
   Across the world, there are increasing numbers of policies to support the development and roll out of low-carbon technologies. For example, the European Commission aims to incentivise an increase in the volume of renewable energy with a focus on producing green hydrogen through the *European Union Green Deal*, and in 2022, the United States of America (US) committed $370 billion to climate change and clean energy via the *Inflation Reduction Act*[29,30]. Increasingly supportive policies and incentives at the national level are providing market signals to the private sector to invest, and industrial clusters are primed to benefit from increased access to funds.

4. **Increasing commitments to common infrastructure:**
   Cost-effective decarbonisation is underpinned by common infrastructure. This includes pipelines for CO_2 transport, hydrogen networks, and power transmission and distribution infrastructure, among others. For example, the Energy Transitions Commission, a think tank, has set out an expectation that investment in transportation and storage infrastructure for carbon capture will need to total USD 0.8-1.3 trillion (GBP 0.6-1.0 trillion) globally through to 2050, rising year on year[31]. As discussed in the following section, industrial clusters have geographic advantages such as concentration of industrial energy demand and, in some cases, proximity to storage sites that allow them to benefit from the increasing commitments to common infrastructure that lower cost and investment risks through economies of scale and standardisation.

5. **Emerging competition for skills and supply chains at a global level:**
   Global supply chains are likely to be constrained in the short- to medium-term, with industrial clusters having to compete for skills and equipment by providing incentives and favourable conditions. For example, research by the IEA indicates that many key technologies, including electrolysers and carbon capture and storage (CCS)-enabled

iv. In addition to the Paris Agreement, the IEA net zero emissions by 2050 scenario is aligned with key energy-related United Nations Sustainable Development Goals such as achieving universal energy access by 2030 and improvements in air quality.

hydrogen have an expected supply gap[v] of 50% or more in 2030[32]. This suggests that current production plans for key technologies will be significantly lower than the demand in the market, causing competition. This also illustrates that increased participation on the supply side of industrial decarbonisation technologies is likely to provide significant opportunities for companies developing these technologies, as there is expected demand in the market which is not served by current production plans.

6. **Increasing focus on unlocking economic and social co-benefits:**

   As efforts supporting decarbonisation evolve and mature, there has been a shift from purely emissions-based benefits to inclusion of wider economic and social co-benefits. This can be seen through the rise in alignment of decarbonisation strategies and funding with *Just Transition*[vi] principles to ensure wider economic benefits are achieved by the investment in the energy transition and first-of-a-kind projects[33]. Several initiatives exist to increase engagement with just transition principles, such as the World Economic Forum (WEF)'s *Principles for Financing a Just and Urgent Energy Transition* publication and the *Climate Action for Jobs Initiative*, with 46 countries committing to develop "national plans for a just transition and create decent green jobs"[34]. As major drivers in their local and national economies, industrial clusters have a significant role to play in reskilling or upskilling the workforce, attracting additional businesses to the region, generating more diverse job opportunities, and creating hubs for innovation.

As described in the following section, industrial clusters are well-positioned to be the focal point of policies and commitments backing low-carbon technologies and energy resiliency, benefit from the demand for industrial decarbonisation technologies, and bring co-benefits to their communities.

v. The supply gap is the difference between the required levels of deployment in IEA's Net Zero Emissions Scenario by 2030 and what is currently announced. IEA report: iea.blob.core.windows.net/assets/a86b480e-2b03-4e25-bae1-da1395e0b620/EnergyTechnologyPerspectives2023.pdf

vi. A 'Just Transition' involves maximising the social and economic opportunities of climate action, while minimising and carefully managing any challenges – including through effective social dialogue among all groups impacted, and respect for fundamental labour principles and rights. International Labour Organization: ilo.org/empent/areas/social-finance/WCMS_825124/lang--en/index.htm

Industrial clusters catalyse decarbonisation and economic benefits

Industrial clusters are areas where related and independent industrial activities are co-located, either by design or arising organically due to locational advantages such as availability of land and resources, access to infrastructure, and proximity to workforce or customer centres, among others. Most GHG emissions from industrial activities (60-80% of total industrial GHG emissions) arise from sites within industrial clusters[35]. This presents a unique opportunity for focused initiatives to concentrate on these localities through collaborative decarbonisation, rather than individual sites "going at it alone". It is well recognised by the IEA, WEF, and others that industrial clusters are critical to achieving industrial decarbonisation because of the interdependencies within them[36,37].

There are several ways that industrial clusters can act as catalysts amidst the global industrial decarbonisation trends outlined above.

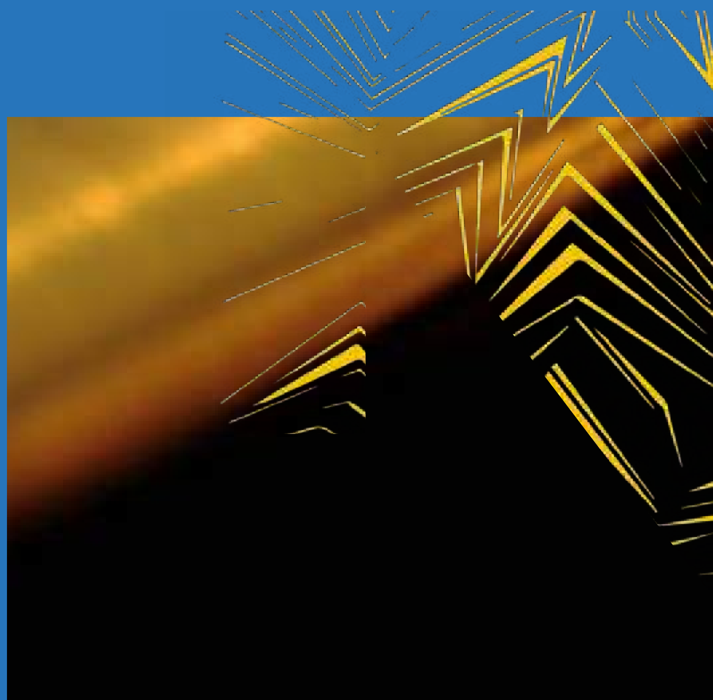
- **Enabling common infrastructure:**
  Pooling of demand and supply of low-carbon solutions, such as low-carbon hydrogen, at clustered sites can help unlock economies of scale and drive efficiency in the delivery of enabling infrastructure. The shared, up-front investment in infrastructure with anticipatory capacity in industrial clusters can cater to future demand and lower the barrier to entry for other sites to connect to solutions such as carbon transport and storage. This is particularly important for clusters that have access to suitable geological storage, as opening these up to shared usage is key to enabling at-scale carbon capture both within the clusters with storage access and to other sites that can export captured carbon dioxide. Developing infrastructure in this shared manner also reduces the cost burden and demand risk for individual sites.

- **Innovation of low-carbon technologies and processes:**
  Although most of the technologies required to decarbonise industry are already commercially available, continued research and technology development will be needed to improve efficiency and reduce costs. The development of next generation technologies will improve energy efficiency and reduce costs, providing benefits to energy intensive industries. Industrial clusters can act as incubators for these innovations. This can lead to the establishment of regional centres of excellence and the creation of high-value technologies and skills. Early movers can secure benefits of upscaling and export for their technologies, skills, and services as industrial decarbonisation accelerates in other regions[38]. In addition, the transfer of technology can open new markets and allow other industrial emitters to achieve decarbonisation at a reduced cost, both through economies of scale and market maturity, thereby scaling up and accelerating the decarbonisation efforts across the economy. Additionally, regulatory and permitting processes may improve as additional experience on project deployment is developed.

- **Low-carbon products for use in other sectors:**
  The "green" products provided by a decarbonised industrial sector will reduce emissions elsewhere in the economy[39]. This could include, but is not limited to, low-carbon building materials, low-carbon or zero-carbon fuels for transportation such as hydrogen, or decarbonised power. Early movers with first-of-a-kind projects will act as industry leaders and promote further development of green products.

- **Promotion of regional social and economic co-benefits:**
  Beyond emissions reduction, industrial clusters drive value by bringing local and regional co-benefits such as economic growth, availability of skilled jobs, and local regeneration[40]. Industrial clusters also bring indirect positive impacts including business growth in a concentrated area, additional investment into the local economy, and the development of relationships between industry and communities[41].

Industrial clusters play a significant role in decarbonising the broader economy while realising economic benefits as well.



The UK has actively supported industrial cluster decarbonisation

The UK recognises that low-carbon industrial clusters are key to achieving its national net zero targets as well as broader political, economic, and social aims. For these reasons, the UK has mobilised clusters around the country to invest and innovate to accelerate the development of replicable models. The IDC is part of a broader suite of interventions from government including legislation, strategy, regulation, and funding to catalyse industrial cluster decarbonisation. These actions support cluster mobilisation by providing direction and confidence to industry that government is committed to industrial cluster decarbonisation as a long-term solution.

A summary of the significant government interventions relating to industrial cluster decarbonisation can be seen in **Figure 2**:

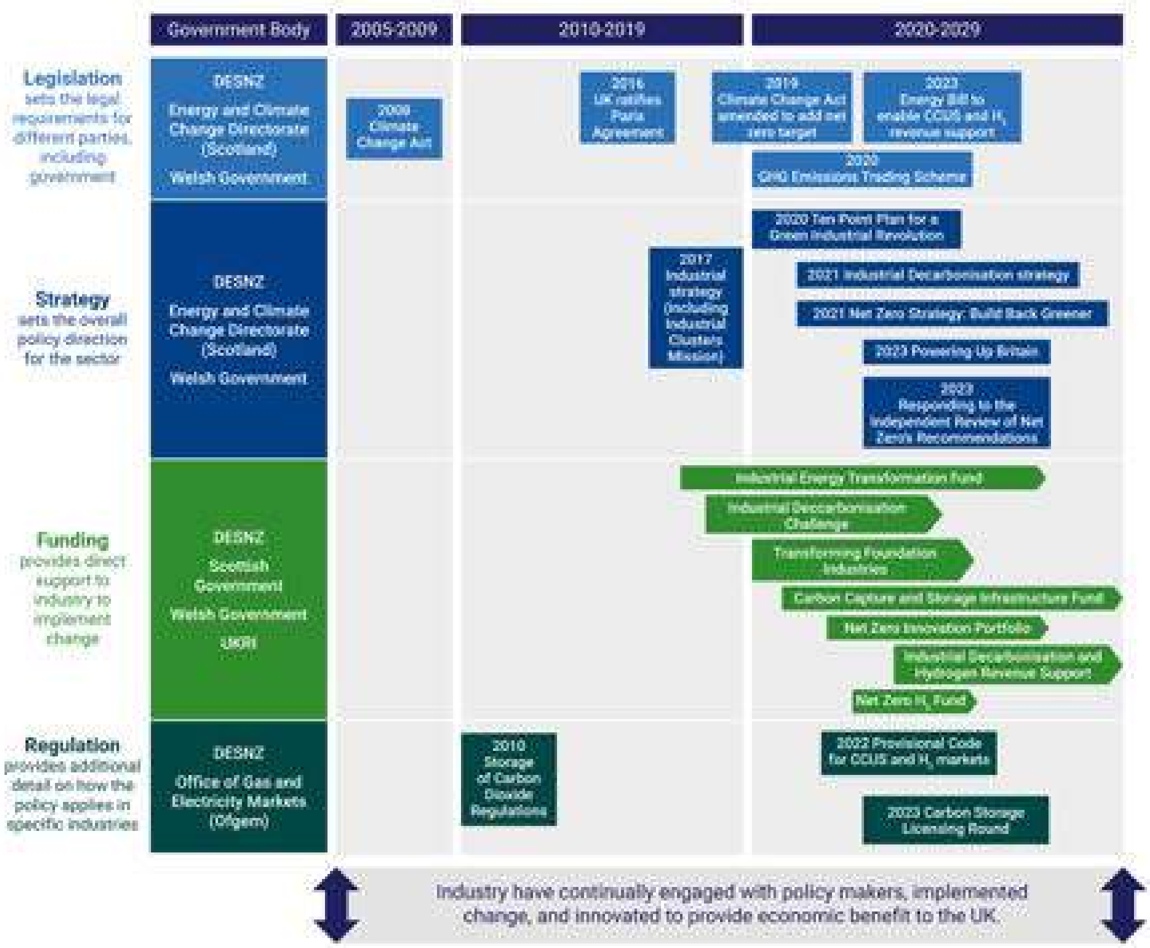


Figure 2: Types of government intervention relating to industrial cluster decarbonisation

Figure 2 highlights the increasing range of support from government aimed at providing clarity and certainty to the private sector to catalyse industrial cluster decarbonisation. Specific funding and market development initiatives are discussed in more detail on the following pages.

Funding opportunities support industrial cluster decarbonisation

Decarbonisation of industrial clusters requires significant financial investment as well as innovation in new infrastructure and technology at scale. To support the implementation of its strategies and policies, government has announced several targeted funds for various aspects of industrial decarbonisation[42]. These range from supporting demonstration projects (e.g., funding for IDC) to the deployment of solutions. Key funding opportunities are summarised in **Figure 3** below and are available, through competitive processes, to industrial clusters and dispersed emitters.

Regulation and contractual support provide more certainty for industry

Part of the transition to net zero involves establishing new industries at scale, such as CCS. With innovation comes uncertainty and risk, particularly around whether and how markets will be regulated, which flows through to the commercial opportunity for the private sector. Therefore, alongside providing strategic direction and funding, the Department of Energy Security and Net Zero (DESNZ) is also proactively developing industry code and business models. Together, these constitute a system of financial standards and regulatory support schemes for the UK carbon capture sector. In addition, government is also providing direct funding for projects through the Carbon Capture Utilisation and Storage (CCUS) Cluster Sequencing Process. Providing clarity around how the government will support the market as it develops is intended to help industrial clusters make low-carbon business decisions and investments well ahead of time, enabling a continued trajectory of emissions reduction in the industrial sector.

Figure 3: Key funding opportunities available to industrial clusters and dispersed emitters

Regulation and contractual support provide more certainty for industry

Part of the transition to net zero involves establishing new industries at scale, such as CCS. With innovation comes uncertainty and risk, particularly around whether and how markets will be regulated, which flows through to the commercial opportunity for the private sector. Therefore, alongside providing strategic direction and funding, the Department of Energy Security and Net Zero (DESNZ) is also proactively developing Heads of Terms for industry code (known as the CCS Network Code) with Ofgem to indicate the direction of future regulatory settings. Additionally, DESNZ is providing increasing levels of detail around business models for these new markets[43, 44]. Together, these constitute a system of financial mechanisms and regulatory support schemes for the UK carbon capture sector. In addition, government is also providing direct funding for projects through the Carbon Capture Utilisation and Storage (CCUS) Cluster Sequencing Process and the Electrolytic Hydrogen Allocation Round[45,46]. Providing clarity around how the government will support the market as it develops is intended to help industrial clusters make low-carbon business decisions and investments well ahead of time, enabling a continued trajectory of emissions reduction in the industrial sector.

Progress to date

The UK has made notable progress over the last 30 years towards its net zero targets: total industry emissions have more than halved from 1990 to 2021[47]. The UK's independent Climate Change Committee (CCC) has attributed this to changes that have been made to the structure of the UK industry and manufacturing sectors, improvements to energy efficiency and fuel switching from coal to natural gas[48]. However, there is still more work to be done (**Figure 4**). To meet net zero, the UK government has indicated industrial emissions will need to fall by at least 90% by 2050, compared to 2021 emissions[49].

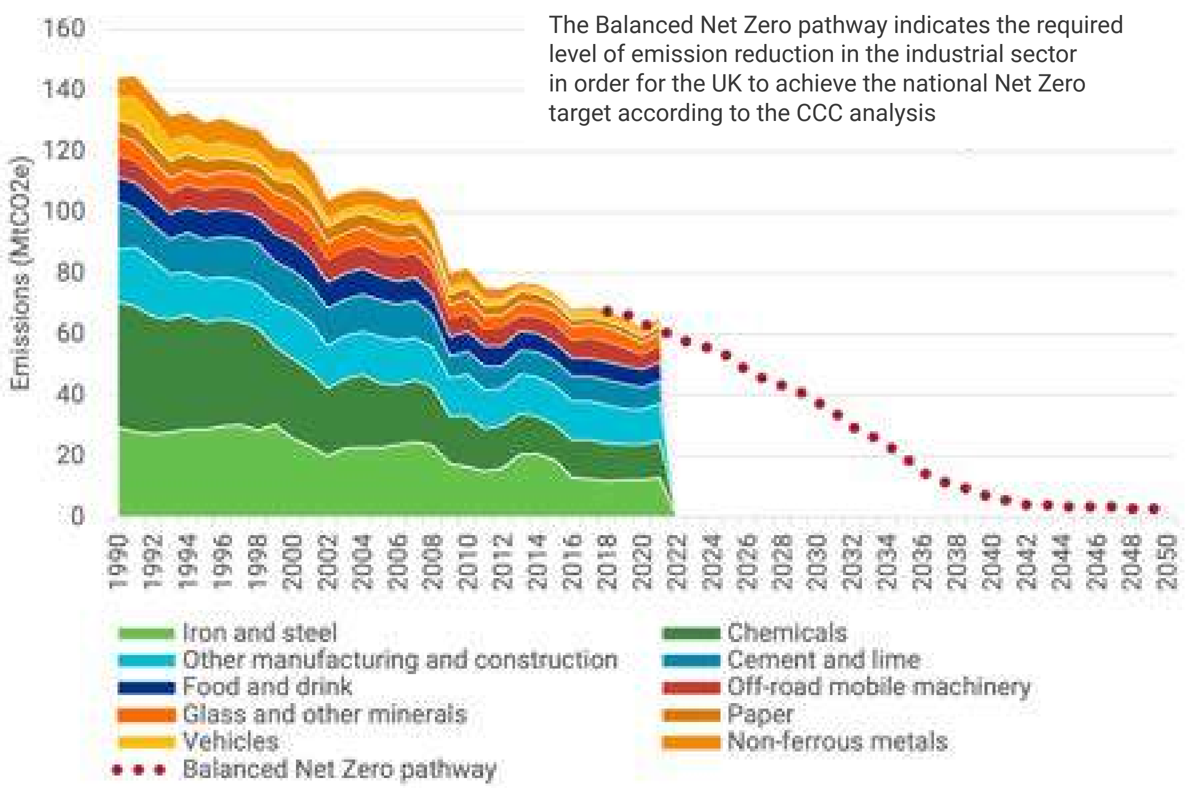


Figure 4: UK industry, manufacturing, and construction emissions 1990-2021, by sub-sector, and Balanced Net Zero Pathway emissions for manufacturing and construction in the UK
Sources: CCC, Progress in reducing emissions: 2022 Report to Parliament (2022) and CCC, Sixth Carbon Budget (2020)

In recent years, additional pressure has been added to the transition. First, COVID-19 has affected all sectors of the UK economy, with some industries and supply chains still recovering from the effects of the pandemic three years after it first began in 2020. In quick succession, Russia's invasion of Ukraine in 2022 has further increased pressure on UK industry. In particular, the conflict in Ukraine has highlighted the importance of domestic energy security. As illustrated in **Figure 5**, oil and gas are currently the largest sources of domestic energy production in the UK, with oil at 37.5% and natural gas at 33.2%. For comparison bioenergy and waste is the next closest at 11.6%[50]. If more domestic energy use is required, CCS may become more pressing as a solution to aid net zero, alongside the acceleration of renewable energy.

However, industrial clusters show some of the most promise for meeting the decarbonisation challenges. In early 2023, former Energy Minister Chris Skidmore published Mission Zero – Independent Review of Net Zero report[51]. In summary, the report suggests that the UK's efforts to tackle climate change has made real difference both at home and on the global stage. Nonetheless, the report suggests more should be done to reap the full rewards available and makes 129 recommendations across several decarbonisation technologies, sectors, and policies. For industrial decarbonisation, the report makes cross-cutting recommendations and, importantly, advocates for industrial cluster-based approaches. For instance, the report advises the government:

- implements a clear CCUS roadmap, showing the plan beyond 2030 and allowing the most advanced clusters to progress more quickly,
- addresses the challenges facing the energy distribution and transmission systems to enable cluster decarbonisation, as well as supply chain and skills gaps associated with this, and
- considers non-pipeline transport for CCS by 2024, targeting dispersed sites and mini clusters.

Emissions reductions in the industrial sector have slowed in recent years[52], but the potential of the UK industrial clusters is only beginning to be realised. This Plan sets out the next steps for how the UK can harness the power of its industrial clusters and drive the next phase of emissions reductions while contributing to a stronger economy, energy security, greater innovation, and community vitality.

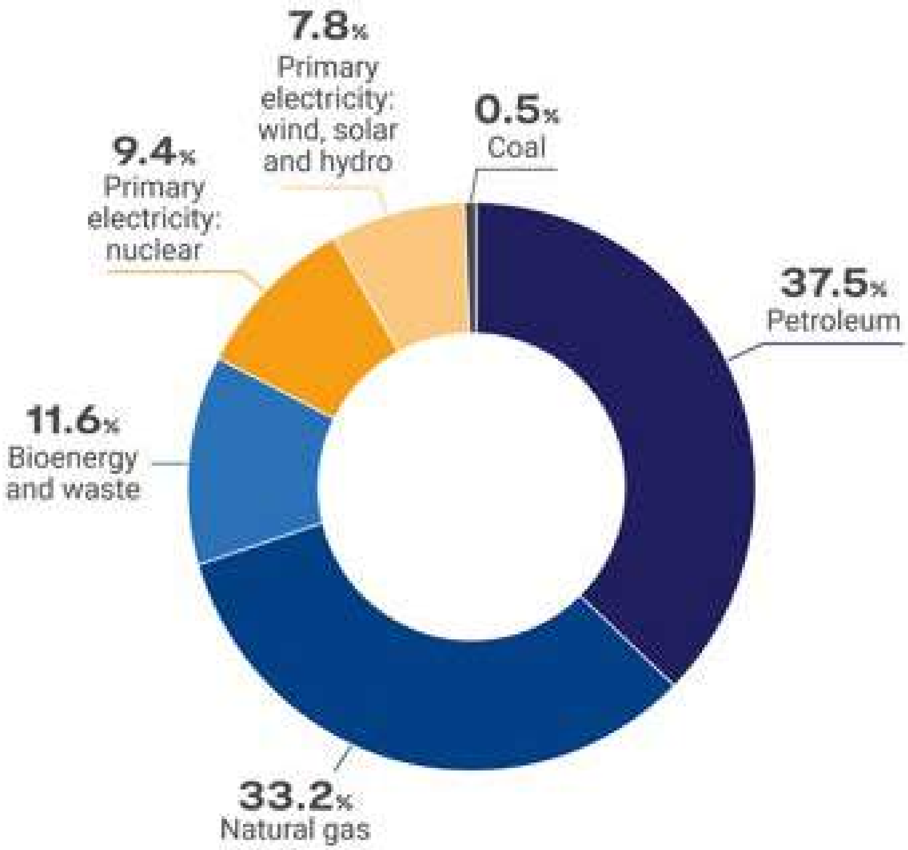


Figure 5: 2022 Indigenous Production of Primary Fuels in the UK
Source: DESNZ, Indigenous production of primary fuels (ET 1.1 - monthly) (2023)

Section 2: Where the UK is going – towards a national strategy for industrial cluster decarbonisation

The UK aspires to be a global leader in industrial cluster decarbonisation

As established in the 2021 *Industrial Decarbonisation Strategy*, the UK's vision is to be a global leader in industrial decarbonisation and the manufacturing of low-carbon industrial products in the coming decades[53]. Given that about half of the UK's industrial emissions are concentrated in industrial clusters, achieving this vision has specific implications: the UK aims to have four low-carbon clusters by 2030 and the world's first zero carbon cluster by 2040[54].

The scale of change required to achieve these goals is significant. It requires concurrent updates across the industrial supply chain, e.g., fuels, infrastructure, machinery, processes, and skills, as well as refinement of relevant legislation and regulation. With such extensive change comes opportunities to improve the status quo and deliver benefits to the clusters themselves, the wider economy, environment, and the local communities in which they operate.

Beginning in the late 18th century, the first industrial revolution led to large-scale economic growth in the UK and had ripple effects, both positive and negative, still evident in society today[55]. Landscapes were forever altered with the construction of transportation networks (e.g., canals, roads), innovation and international trade thrived, and urban populations boomed[56]. Similarly, intentional choices made today and in the coming decade around industrial cluster decarbonisation can set the stage for flourishing in the future.

The UK's industrial clusters can leverage decarbonisation investments to deliver broader economic, societal, and environmental benefits

The UK's vision of being a global leader encompasses more than just the accomplishment of reducing emissions. From its conception, the IDC has recognised the widespread impact of the investments being made to develop the green economy and the responsibility to guide how the process unfolds. The way the UK decarbonises can meet more than net zero goals; industrial decarbonisation has the potential to support economic growth that revitalises the UK's industrial heartlands, improving outcomes for generations to come.

To that end, this report introduces four key strategic pillars for industrial cluster decarbonisation in support of the UK's broader vision (**Figure 6**). These pillars have been developed based on the broader outcomes raised in the cluster plans themselves, engagement with the IDC clusters throughout the development of their plans, and consultation with experts from industry and government. The pillars represent desired outcomes that should occur through the successful implementation of the cluster plans and the recommendations made here in *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation*. Intentionally aligning on the desired outcomes at the start enables them to be built into the industrial cluster decarbonisation process going forward.

Figure 6: The UK's vision for industrial decarbonisation is supported by four strategic pillars that guide industrial cluster efforts

As the cluster plans have noted, many key questions around decarbonisation are yet to be resolved, such as specifics around how markets for hydrogen and carbon capture will operate, what skills will be required and where, and how and when national infrastructure will be available. As critical decisions are made at the national and cluster-level, these strategic pillars serve as guideposts for assessing choices.

Strategic Pillar 1 — Industrial clusters have competitive advantages attracting investment from and trading with the international market

Competition is at the heart of business. It drives innovation and the provision of varied goods and services. Maintaining and improving competitive advantages relative to the international market will be critical to achieving net zero. It is estimated the global market opportunity associated with the transition to net zero could be worth more than £1 trillion[57] to UK businesses from 2021-2030. Realising the opportunity will require British industry to remain competitive with international players, many of which are launching major investment programmes to accelerate industrial decarbonisation. For example, the US has announced the $370 billion Inflation Reduction Act and multi-billion-dollar programmes for carbon capture demonstration[58,59], regional clean hydrogen and direct air capture hubs, and industrial demonstrations.

Currently, the UK benefits from being specialised in green finance[60] and is a global leader in clean technologies such as tidal, offshore wind, nuclear, and CCUS . These specialised areas help make the UK an attractive investment for international capital looking to finance net zero projects.

The IDC recognises that each of the six IDC industrial clusters also possess competitive advantages of their own, whether that be physical (e.g., local geology conducive to CCUS or existing pipeline infrastructure that can be repurposed for CO_2 or hydrogen transport), regulatory (e.g., UK Emissions Trading System (ETS) free allocation allowances), or some other key strengths. Alignment of government growth priorities and cluster competitive advantages supports the realisation of the UK's overall national economic and industrial strategy. With the appropriate market signals, such as permitted projects and certainty of supportive business models, the clusters can capitalise on these competitive advantages to attract international investment and accelerate implementation of decarbonisation solutions. This early mover advantage, in turn, can secure supply chains (e.g., equipment, deployment expertise, skilled workers) and initiate a positive feedback loop by cementing the UK's competitive advantages in export.

Strategic Pillar 2 — Industrial clusters enable the decarbonisation of UK supply chains, improving the value of products and services sold.

Industrial clusters serve as an important link to decarbonising the carbon footprint of the UK economy. The innovations, products, and services produced by the industries within the clusters are foundational to everything from basic household goods to complex sectors like aerospace. Until recently, the carbon footprint of these inputs was largely ignored. However, stricter regulations and greater ESG scrutiny from stakeholders have increased demand for low carbon goods and services and elevated pressure on supply chains to reduce their GHG emissions.

As the IDC industrial clusters implement their plans, they can influence emissions reduction in the broader economy. Other sectors in the UK will gain access to low-carbon goods, innovative solutions, and services that can accelerate emissions reductions across the broader economy. In the future, for example, the construction sector will have access to low-carbon steel and can build infrastructure with a lower carbon footprint; households will have access to food and other goods produced with and transported by low-carbon energy. Decarbonising industrial clusters is a key step in decarbonising the UK supply chain, improving the value of products and services sold, and contributing to the UK's vision of leading manufacturing of low-carbon products in the coming decades.

Strategic Pillar 3

Industrial clusters are active hubs of cooperation, technology development, knowledge transfer, and learning that support investment and innovation to drive decarbonisation

Achieving net zero relies on collaboration. Each of the clusters has developed their own public-private partnership or private sector-led model to drive decarbonisation. Through the creation of their plans, the IDC industrial clusters have provided a range of key learnings for future clusters (e.g., benefits of legal frameworks, how to work with other clusters, international partners, and communities) and demonstrated the opportunities that can be realised through collectively investing in innovation and infrastructure to drive decarbonisation. Clusters have also collaborated with a range of academics through the IDRIC component of the IDC[62]. In addition, many of the IDC clusters have been selected for Track-1 in the CCUS Cluster Sequencing Process[63,64] and shortlisted in the Electrolytic Hydrogen Allocation Round[65,66] for which learning and innovation were part of one evaluation criterion.

To achieve the UK's broader decarbonisation objectives, working in silos is no longer an option. As the IDC industrial clusters move forward with implementation, innovation and learnings must be shared consistently and more widely so others facing similar challenges can follow. This Plan is one step in bringing point-in-time learnings together, but industrial clusters must continue to become active hubs of cooperation and knowledge transfer to enable the UK's vision of being a global leader in industrial decarbonisation.

Strategic Pillar 4

Industrial clusters engage meaningfully with local communities to drive environmental, social, and economic benefits

UK industrial clusters have formed in their respective locations for reasons often due to the physical and regulatory competitive advantages. People have been drawn to these areas for economic opportunities and built communities over generations with a tangible sense of place and pride in their industrial heritage. Transformation of these regions due to the economic prosperity that comes with industry investment has aided in community building, but overreliance of local economies on a limited number of sectors can lead to destabilisation as well. For example, the *Green Jobs Taskforce* highlights that the impacts of the "unmanaged" transition away from coal in the 1980s can be seen in the 43% of all coal communities that now rank among the most deprived communities in Britain[67].

Clusters can learn from previous transformations and take an active role in partnering with their communities to manage the transition. By taking steps to foster open dialogue and encourage co-solutioning with communities, clusters can deliver co-benefits beyond emissions reduction in job retainment and growth, improvements to local infrastructure, and community centre revitalisation. The strong industrial heritage and sense of identity in these communities is associated with greater acceptance of innovation and industrial infrastructure[68]. This can be a differentiating factor in securing the buy-in and political will needed for the buildout required by cluster plans. Where the clusters can demonstrate their commitment to long term community partnership and 'Levelling Up'[vii] principles, they are likely to benefit from local support and experience less opposition to implementation, accelerating their path to delivery.

As outlined by the strategic pillars, UK industrial clusters have the potential to leverage competitive advantages, serve as a linchpin to economy-wide decarbonisation, generate valuable learnings for other clusters and industry, and bring co-benefits to communities. All of these are key elements required to achieve the UK's net zero targets and national vision of being a global leader in industrial decarbonisation and manufacturing of low-carbon industrial products in the coming decades. The scale of the opportunity is significant, but strategic delivery will be critical.

vii. Levelling Up is a government initiative focused on ending geographical inequality in the UK by boosting productivity, spreading opportunities, restoring a sense of community, and empowering local leaders.

Collectively, the UK's industrial clusters are poised to deliver on many aspects of the UK's Net Zero Strategy for industry

In pursuit of the UK's 2050 net zero target, each of the IDC industrial clusters indicated the emissions reductions they are expecting to deliver in their cluster plans. The clusters are ambitious, with many signalling their intent to be the first cluster to achieve net zero by 2040. In addition, each cluster expects to create, safeguard, or both, up to tens of thousands of jobs by successfully transitioning industry to a net zero regime over the next several decades[viii]. This correlates with a value add of billions of pounds for each cluster as well[ix].

The IDC clusters have taken different approaches to modelling emissions and abatement

IDC clusters took different approaches to modelling emissions, described further in **Appendix 2**. To assess their collective impact, this Plan collated metrics from the cluster plans relating to specific UK ambitions,
as well as other sources where necessary.

One of the key metrics is the amount of emissions addressed within each IDC cluster. Given each cluster plan has determined its own boundaries for the emissions sources that fall within scope, both in terms of the assets and the types of emissions included, this Plan uses government definitions for the potential large point sources that each cluster plan could address[x]. **Figure 7** uses national data to illustrate the relative size of the emissions in 2019 by the six IDC industrial clusters. While this neither shows the total potential of emissions reductions in these areas due to the exclusion of smaller emitters nor an outlook on industrial activity changes over time, **Figure 7** contextualises the size of the challenge that the IDC clusters face today.

Most clusters have focused on direct emissions[xi] for the assets included, but some have gone further to incorporate indirect emissions associated with purchased energy as well. As a result, there have been a variety of methodologies used to calculate the emissions abatement expected to achieve over time. However, the target for each IDC industrial cluster has been the same: net zero GHG emissions. Analysis from the Department for Net Zero and Energy Security highlights that large point source sites encompassed by the six IDC clusters represent around 40% of total UK industrial emissions reported in the *NAEI*[69,70]. Therefore, the cluster plans collectively have the potential to cut industrial emissions in the UK from large industrial sites in half by each achieving net zero.

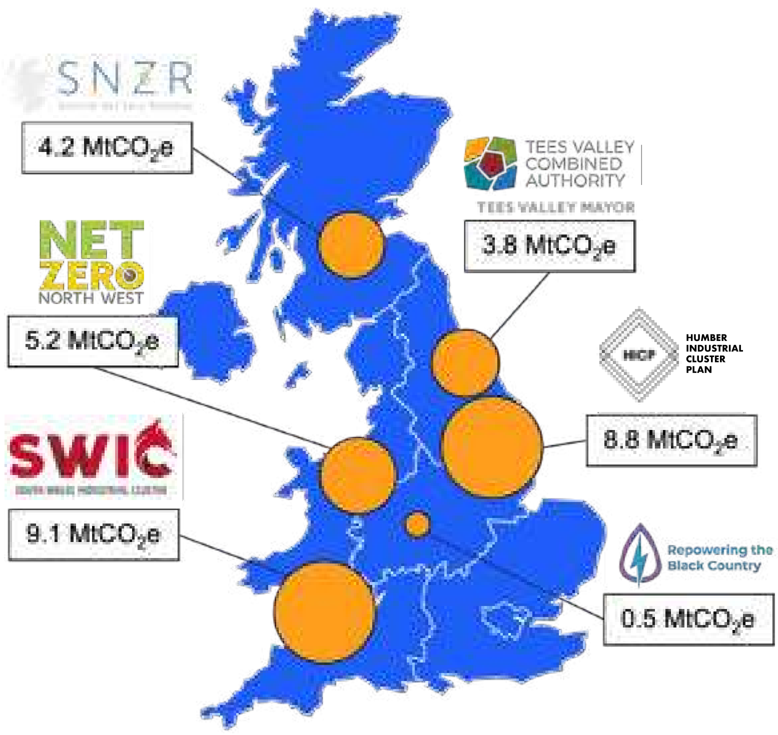


Figure 7: Map of large point sources of GHG emissions addressable by each IDC industrial cluster (NAEI 2019)

viii. See **Section 3** for details.

ix. Ranging between £3-30 billion for each cluster. See **Section 3** for details.

x. The *Industrial Decarbonisation Strategy* sets out the expected coverage of large point sources of GHG emissions for each cluster based on data from the *National Atmospheric Emissions Inventory* (*NAEI*). The NAEI 2019 large point source is compiled using several different data sources and techniques, including but not limited to the UK ETS and data from regulators; emissions reporting is therefore captured in the NAEI where such emissions exceed a certain threshold.

xi. Refers to emissions associated with fuel combustion and fugitive emissions within the project boundary; see Glossary for further details.

Implementation of the cluster plans in and of themselves as published would exceed many of the ambitions set by the UK for industry as a whole

In support of reaching net zero by 2050, government has set specific quantified ambitions in the *Industrial Decarbonisation Strategy* and *Net Zero Strategy* for the key technologies and milestones that are expected to keep the industrial contribution to net zero 2050 on track:

The UK government aims to:

By the mid-2020s

- Deploy two industrial clusters with CCUS
- Deploy one power CCUS project

By 2030

- Capture 20-30 $MtCO_2$ of total emissions per year (including power and industry)
- Capture 6 $MtCO_2$ of industrial emissions per year (excluding power emissions)
- Deploy 10 GW[xii] of low-carbon hydrogen production capacity, with at least half electrolytic generation
- Achieve four CCUS clusters
- Deploy at least 5 $MtCO_2$/year of engineered removals

By 2035

- Achieve 50 TWh of industrial fuel switching to low carbon fuels (including electricity)
- Capture 9 $MtCO_2$ of industrial emissions per year (excluding power emissions)

By 2040

- Achieve one net zero industrial cluster

xii. Updated in the *British Energy Security Strategy* (2022) to 10 GW by 2030, up from 5 GW in the *Net Zero Strategy*

The cluster plans, and their implementation, are an important contributor to achieving these ambitions. Indicative figures taken from the cluster plans, where available, are used in **Figure 8** to show the level of ambition contained within the cluster plans compared to the overall UK ambitions.

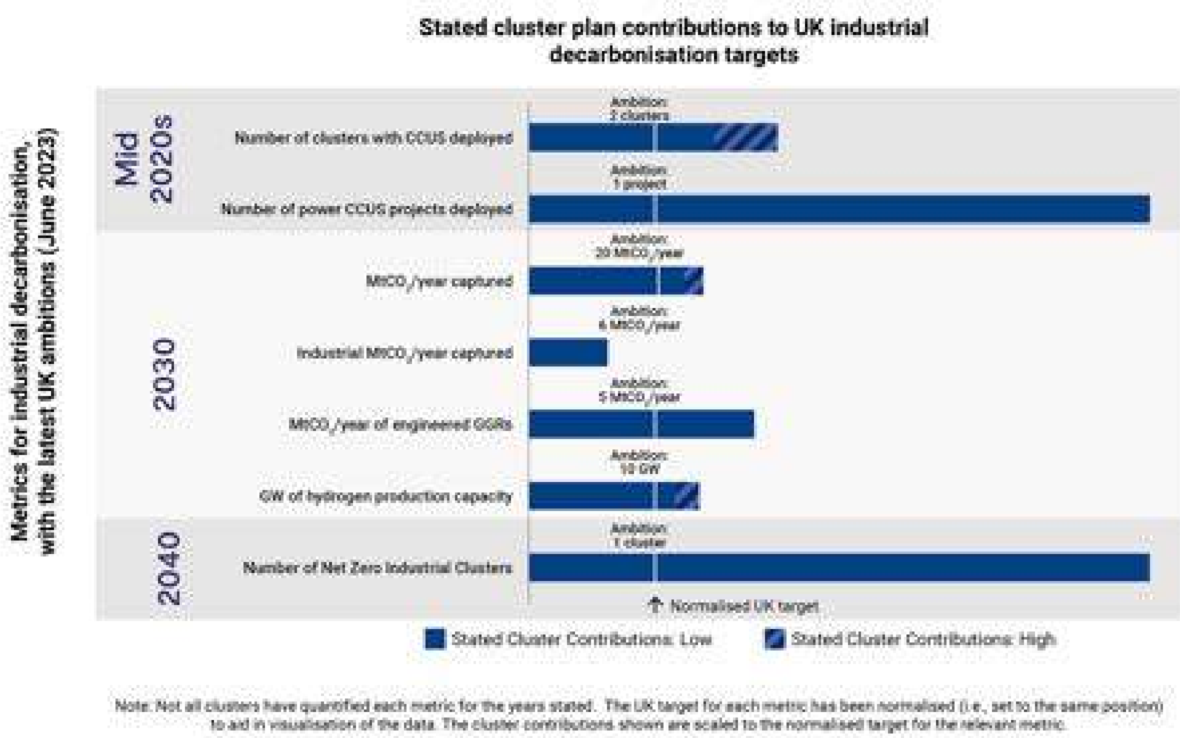
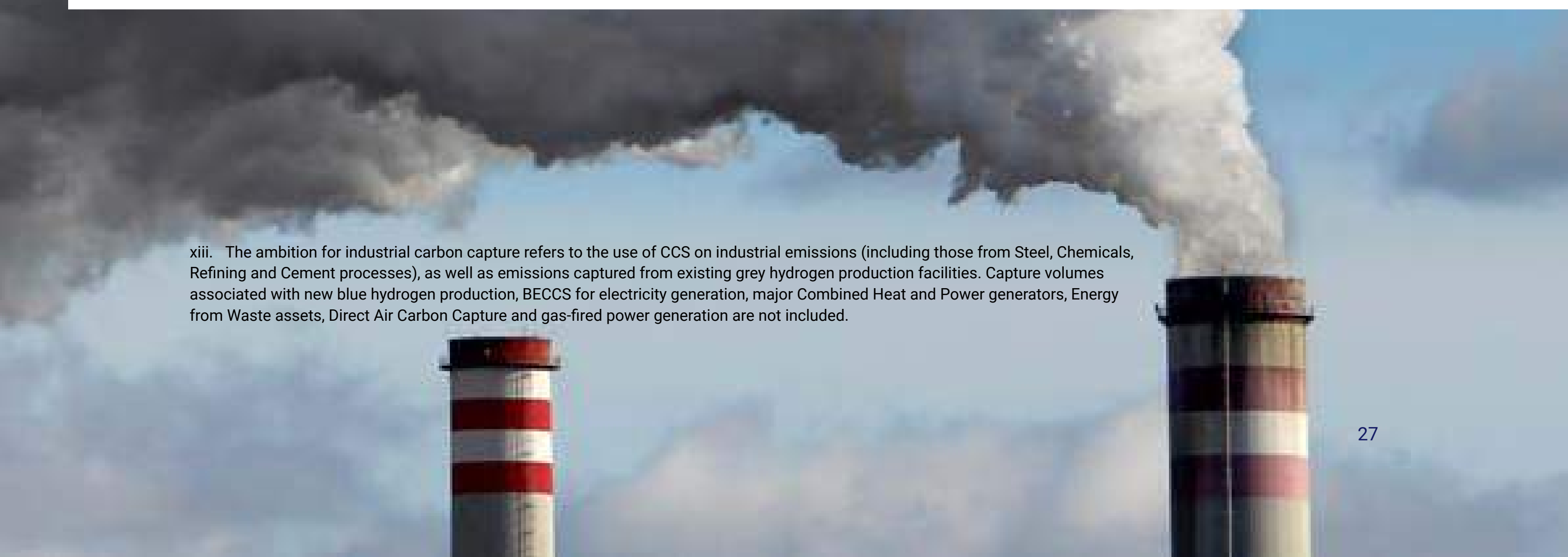


Figure 8: Indicative contribution of quantified statements across the cluster plans towards the latest UK ambitions, as of June 2023[71,72]. Note that this reflects the cluster plans as published and does not account for the results of the CCUS Cluster Sequencing Process Phase 2 decisions.

As shown in **Figure 8**, implementation of the cluster plans as published would exceed many of the industrial decarbonisation ambitions set by the UK government, without any contributions from projects outside the clusters. The exception here is the volume of “industrial” CO2 captured per year in 2030, where the clusters, based on announceable projects, are expected to collectively contribute to about 60% of the ambition. This contribution includes projects beyond the CCUS Cluster Sequencing Process, enabling the government to make significant progress towards the ambition. Some clusters have reported larger “industrial capture,” but following DESNZ guidance[xiii] on the categorisation of projects as industrial carbon capture, the numbers in **Figure 8** represent the projects in the cluster plans that would be counted towards the government ambition. It is worth noting that the UK ambition for Net Zero Industrial Clusters is to achieve one by 2040, whereas implementation of the cluster plans can deliver five net zero clusters by 2040, and six by 2045.

The IDC industrial clusters have demonstrated their plans make a substantial contribution to government’s ambitions set for the whole of UK industry. Decarbonising the clusters provides an opportunity to take a more coordinated approach to building and decarbonising the needed supply chain for the UK, which would in turn enable firms to be internationally competitive. This tremendous potential is encouraging but will require a step up from both industry and government to overcome the challenges identified in the cluster plans to ensure the UK’s net zero ambitions become a reality.



xiii. The ambition for industrial carbon capture refers to the use of CCS on industrial emissions (including those from Steel, Chemicals, Refining and Cement processes), as well as emissions captured from existing grey hydrogen production facilities. Capture volumes associated with new blue hydrogen production, BECCS for electricity generation, major Combined Heat and Power generators, Energy from Waste assets, Direct Air Carbon Capture and gas-fired power generation are not included.

Section 3: How the UK will get there – the IDC cluster plans

Each cluster plan brings unique contributions to net zero

The IDC cluster plans have been produced for six UK regions with notably different industrial, demographic, and geographical characteristics. Though each cluster plan is unique, most set out a roadmap to achieve a common goal: decarbonisation by 2040. The infographic below provides a high-level overview of the different IDC clusters as outlined by their cluster plans.

	Humber Industrial Cluster Plan (HICP)	Net Zero North West (NZNW) Cluster Plan	Repowering the Black Country (RtBC)	Scottish Net Zero Roadmap (SNZR)	South Wales Industrial Cluster (SWIC) Cluster Plan	Tees Valley Net Zero (TVNZ) Cluster Plan
Net zero target date	**2040**	**2040**	**2040**	**2045**	**2040**	**2040**
Current emissions from NAEI large point source sites*	8.8 $MtCO_2e/yr$	5.2 $MtCO_2e/yr$	0.5 $MtCO_2e/yr$	4.2 $MtCO_2e/yr$	9.1 $MtCO_2e/yr$.	3.8 $MtCO_2e/yr$
Industrial Profile	Steel, oil and gas, biofuels, chemicals, glass, lime, and cement	Glass, chemicals, paper and pulp, food and drink,	Aerospace, automotive, minerals, paper, chemicals, and food and drink	Power, oil and gas, and chemicals	Steel, oil and gas, paper, and cement	Process industry and energy
Main decarbonisation approach	CCS Electrification Fuel switching (mostly to hydrogen)	Fuel switching (mostly to hydrogen) CC(U)S Energy and resource efficiency	Energy and resource efficiency CCUS with NPT[xiv]	Levers dependent on scenario[73]	Fuel switching (mostly to hydrogen) CCS with NPT Energy and resource efficiency	CCS Fuel switching (mostly to hydrogen) Electrification
Notable deliverables with transferable learnings	Societal and Cultural Challenges study Water study	Investment prospectus Network capacity and development report	Zero Carbon Hub methodology	Community engagement and messaging study	Policy driver analysis Sustainable development framework alignment	International H_2 development assessment
Investment levels required	£4 billion – £5 billion[74]	£30 billion[75]	£3 billion[76]	£6 billion – £9 billion+[77]	£30 billion[78]	£10 billion[79]
Number of local authority areas in the cluster	**4**	**12**	**4**	**14**	**13**	**5**
Cluster collaborators acknowledged in cluster plans	**24**	**10**	**10**	**19**	**29**	**46**
Future cluster plan owner	Humber Energy Board	Cheshire and Warrington LEP	The Centre for Manufacturing Transition	In discussions with Scottish Government but no plan owner confirmed	Net Zero Industry Wales	Tees Valley Combined Authority

*Based on NAEI 2019 data. Cluster plan boundaries are based on DESNZ geographic boundaries. These emitions do not represent all emissions covered in the cluster plans but are used here to demonstrate relative scale as they are based on a single methodology. Discussion of the IDC cluster plans' own emissions modelling can be found in **Appendix 2**.

xiv. CCUS with NPT: Carbon Capture Utilisation and Storage with Non-Pipeline Transport of CO_2 to storage sites; note that Repowering the Black Country has a 2045 target for emissions from the waste processing sector, which will require networked carbon capture, and a 2040 target for other industry.

These regional characteristics of the IDC clusters have resulted in diverse decarbonisation levers and transferable learnings. The intention is that this diversity, in turn, stimulates a breadth of innovation and knowledge creation across the UK's industrial cluster portfolio. Similarities between IDC industrial clusters, in terms of the industrial sectors in scope or whether they are co-located with other resources, are also important in supporting knowledge sharing and solution scaling. The cluster plans are outlined in more detail in the following pages:

Humber Industrial Cluster Plan (HICP)

The Humber Industrial Cluster is in the region around the large tidal estuary of the same name in North East England. It includes the UK's main steel production centre, its largest port complex and enterprise zone, a third of national fuel refining capacity, the second largest chemical cluster, one of the nation's largest concentrations of food manufacturing and cold storage, along with biofuel, lime, and glass manufacturers. The region also supplies a sixth of the UK's electricity, including from the Drax biomass power station and extensive offshore wind farms[80].

The cluster's plan to reduce emissions focuses on CCS with smaller contributions from resource and energy efficiency measures, electrification, and fuel-switching to hydrogen[81]. Bioenergy with carbon capture and storage (BECCS) applied to the Drax power plant is also a potential lever for carbon removal[82]. To support the implementation of these interventions Humber Industrial Cluster conducted community workshops to understand societal expectations and concerns related to decarbonisation[83].

The cluster benefits from its proximity to CO_2 storage reservoirs and from its compactness, which should allow for more cost-effective networks for transporting CO_2 and hydrogen[84]. If these planned interventions are successful, the cluster plan anticipates that net zero by 2040 in the region could bring £3-5 billion per year in National Gross Value Added (with ~20% of this increase retained in the Humber region) and the creation of up to 20,000 direct jobs[85].

The cluster is also in a prime position to develop a scalable and integrated hydrogen network with plans for multiple new projects covering hydrogen production, transmission, and use to decarbonise industry. It already houses important hydrogen storage capacity at two sites, which helps balance energy supply and demand and improve energy system resilience[86].

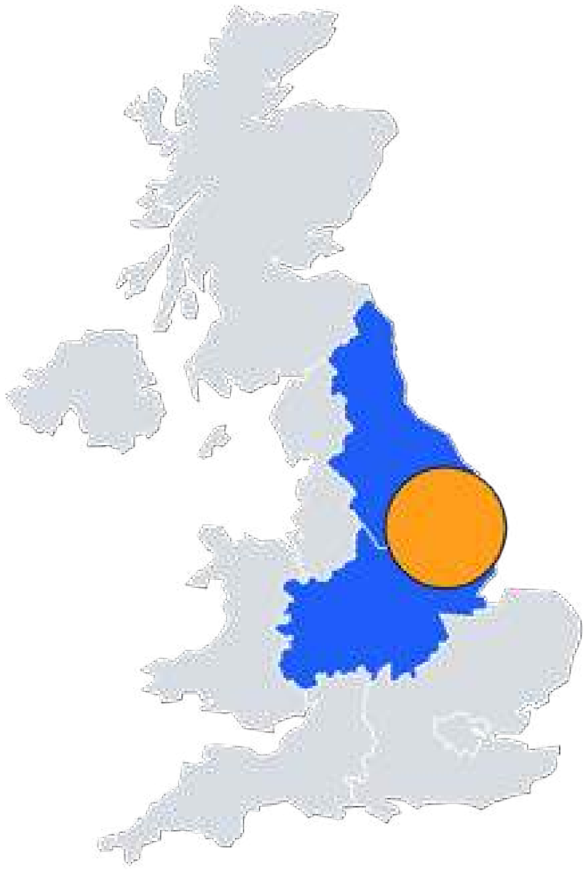
One unique contribution the cluster has made to the knowledge base on industrial decarbonisation is its assessment of the likely impact of water availability on decarbonisation plans[87]. The cluster also took steps to better understand public perception of, and to build public acceptance for, decarbonising the regions' industries[88].

Best practices demonstrated by the Humber Industrial Cluster include:

- Engagement with a broad range of stakeholders, including conducting workshops with local community representatives. The Humber Industrial Cluster used this work to inform how it can best progress with implementing its cluster plan.
- Transparency around how stated impact metrics link to defined project plans, which enables cluster partners to have clarity on how their respective projects contribute to the plan.
- Consideration of local environmental impacts of implementing net zero infrastructure, including specifically how increased hydrogen production would impact water availability. This work enables the Humber Industrial Cluster to proactively plan how it can implement its plan in consideration of these constraints.

Net zero target date **2040**

HICP



Net Zero North West (NZNW) Cluster Plan

The Net Zero North West industrial cluster stretches from Cheshire in the South to Manchester in the East to Cumbria in the North, covering the entirety of North West England and parts of Wales. The region, notably the area around the Dee Estuary, boasts the largest concentration of advanced manufacturing and chemical production in the UK. Significant emitters include major power producers, cement manufacturers, an oil refinery, chemicals and ammonia producers, the food and drink sector, and waste management[89].

The cluster plan sets out a roadmap to a multi-vector energy system, including renewables, hydrogen, CCUS, nuclear and smart grids, to drive clean growth in the region. Approximately half of the cluster's planned emission reductions stem from energy efficiency, on site renewable electricity generation and decarbonising the power sector. The cluster focused on the decarbonisation of dispatchable power (i.e., not wind and solar which are subject to weather conditions) using hydrogen turbines or natural gas turbines with CCUS or more nascent technologies such as the Allam cycle or large-scale fuel cells[90].

Net zero target date **2040**

NZNW

Rolling out green and blue hydrogen production and use is the other main decarbonisation lever in the cluster's plan. The HyNet project is deploying hydrogen infrastructure across North West England and North Wales covering the production, transport, and storage of low-carbon hydrogen. The cluster also explored its options for distributing electrolytic hydrogen: either through connections to the HyNet hydrogen network or supplying industry directly[91].

A focus for Net Zero North West, the industry-led consortium that developed the cluster plan, was accelerating public and private sector investment for industrial decarbonisation. The *Net Zero North West Investment Case* puts the pipeline of investible projects in the region at £30 billion, spread across a strategically diverse mix of net zero intervention types[92]. The cluster plan further indicates that 34,500 jobs and £36.5 billion Gross Value Add (GVA) would be associated with these projects, if realised[93].

Best practices demonstrated by Net Zero North West include:

- Development and promotion of an investment prospectus for a portfolio of projects across the industrial cluster. The prospectus provides potential investors an integrated picture of the investment opportunities in the region.
- Assessment of the capacity of both the electricity system (generation assets and network) to identify how it needs to develop to support the electrification central to implementing the cluster plan.
- Collaboration with the University of Chester bringing together analysis from across the cluster to make recommendations on addressing future workforce needs.

Repowering the Black Country (RtBC)

The Black Country Industrial Cluster covers an inland area in the West Midlands encompassing Dudley, Sandwell, Walsall, and Wolverhampton. The cluster is made up of diverse manufacturing supply chain companies, including small and medium sized enterprises that typically have modest emissions per site but are collectively significant. Manufacturing sectors covered in the cluster include aerospace, automotive, minerals processing, paper, chemicals, and food and drink[94].

The manufacturing focus of this cluster makes it more representative of the majority of UK industry than the high-emitting heavy-industries that dominate the other IDC industrial clusters. 95% of UK's industrial GVA and 98% of industrial employment comes from manufacturing businesses like those in the Black Country Industrial Cluster[95,96].

Although energy from waste plants are the largest point source emitters in the cluster, they are not the focus of the *Black Country Industrial Cluster's Plan*. The cluster plan outlines that decarbonisation of energy from waste plants relies on networked CCS infrastructure[97], which is unlikely to be available in the Black Country region until after 2045. As such, the cluster plan focuses on developing a replicable decarbonisation model for manufacturing companies. In addition, the National Centre for Manufacturing Transition was established as a vehicle to scale decarbonisation solutions for dispersed sites[98].

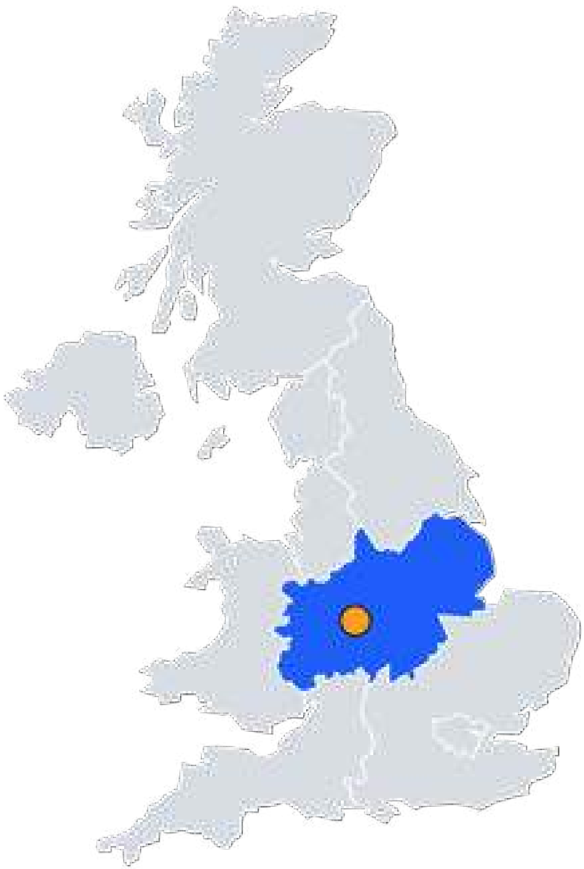
Another feature of this cluster is the dispersed nature of the industrial sites. It is generally more expensive and less efficient to decarbonise dispersed sites through large infrastructure investments such as CCS. As a result, the cluster plan focuses on the development of Zero Carbon Hubs, i.e., collaborations between co-located industries to share energy and material vectors[99]. Zero Carbon Hubs offer manufacturing companies a decarbonisation method which involves a combination of resource and energy efficiency measures, increased electrification, and a modest deployment of hydrogen[100]. The hubs are projected to generate smaller economic benefits individually, with each hub requiring in the tens of millions of pounds in capital expenditure to secure 50-500+ jobs. However, with 60 hubs expected to be required to deliver net zero in the cluster, the corresponding impacts have the potential to scale[101].

Best-practices demonstrated by the Black Country Industrial Cluster include:

- Development and promotion of a replicable methodology (Zero Carbon Hub) that could be used beyond the cluster itself to support broader decarbonisation.
- Collaboration with other clusters on research and innovation to understand how innovations apply in different contexts, e.g., with SWIC, on how the Zero Carbon Hub concept could be applied in their contexts.
- Establishment of the National Centre for Manufacturing Transition to support ongoing collaboration towards implementation of the cluster plan and the scaling of decarbonisation solutions for dispersed sites.

Net zero target date **2040**

RtBC



Scottish Net Zero Roadmap (SNZR)

The *Scottish Net Zero Roadmap* focuses on industrial activity in on the east coast of Scotland[xv], which covers many of the largest industrial sites across a range of sectors and 75% of Scotland's industrial CO_2 emissions. This includes the petrochemical site at Grangemouth, a natural gas terminal handling 30% of the UK's natural gas volumes and a gas-fired power station, the largest whisky and alcohol distillery in the world, as well as glass and cement manufacturing[102].

The *Scottish Net Zero Roadmap* comprises different technology deployment scenarios derived from an analysis of industrial decarbonisation technologies and the policy landscape. Its plan to decarbonise by 2045 (in line with current Scottish Government targets) is dominated by emission reductions in the chemicals, power, and refining sectors. It also accounts for the projected increase in baseline emissions from the waste management and mineral wool manufacturing sectors[103].

Net zero target date **2045**

SNZR

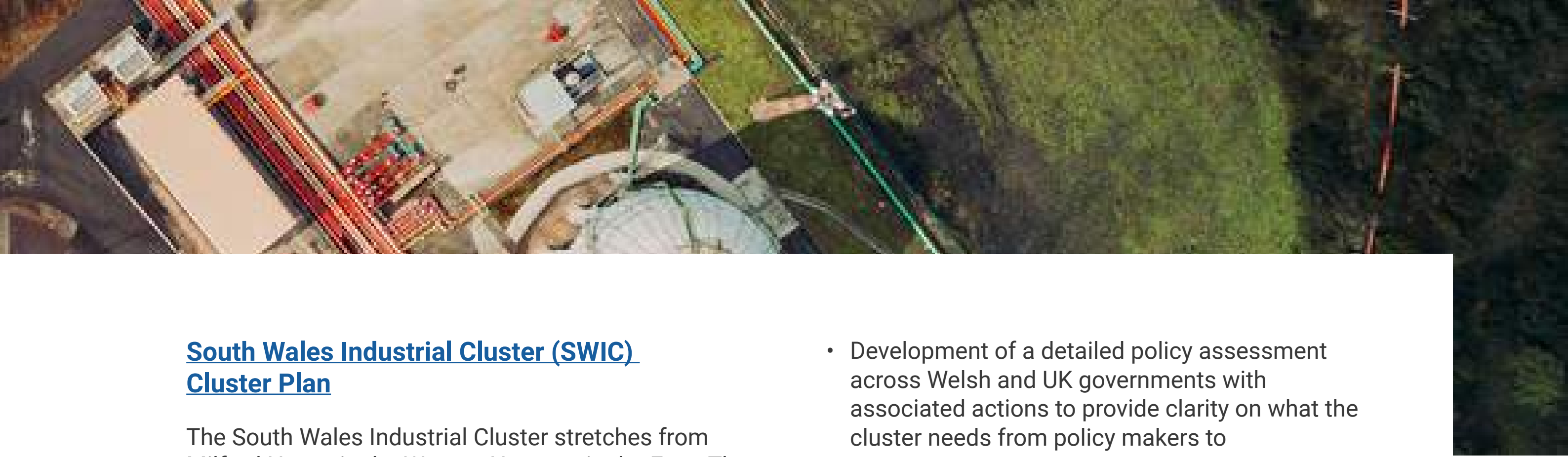
The expectation is that the large Grangemouth emitters will implement CCUS first as they are best positioned to develop common infrastructure at reasonable cost. The development of this infrastructure will drive change in other areas as costs decrease and financing improves. While electrification is an option for sites with small energy consumption, many of the high emitters will require hydrogen to decarbonise. Due to the dispersed nature of the industrial sites (28 within 14 local authority areas), the roadmap proposes that hydrogen plants with carbon capture could form the basis of a regional or national hydrogen network[104]. The benefits associated with these interventions include an average of 5,000 jobs per year between 2023-2045, which translates to an economic impact of £21 billion[105].

The *Scottish Net Zero Roadmap* identified social acceptance as a key component in delivering the challenge of industrial decarbonisation[106] and commissioned research from academics to identify key messages and narratives that would support the development of the decarbonisation plans for CCUS.

Best practices demonstrated by the *Scottish Net Zero Roadmap* include:

- Accommodation of uncertainty in future policy and technology commercialisation into the cluster plan by developing scenarios accompanied by a branching roadmap of actions. This approach enables the cluster to understand how its activities might need to change depending on how policies and technologies develop.
- Assessment of the public messaging required to build support for uptake of new technologies and associated infrastructure (e.g., CCUS). The research conducted enables cluster partners to adopt best practices when engaging with communities during implementation.
- Inclusion of a detailed action plan, with roles and responsibilities assigned, to provide clarity to cluster partners and support the implementation of the cluster plan.

xv. While the focus of the roadmap is on high emitters on the east coast of Scotland, some emitters in the Scottish central belt, i.e., the high-population density region encompassing Glasgow and Edinburgh, are also included.



South Wales Industrial Cluster (SWIC) Cluster Plan

The South Wales Industrial Cluster stretches from Milford Haven in the West to Newport in the East. The cluster is home to high-emitting and economically important businesses across the steel, nickel refining, cement, glass, mineral wool, food, and chemicals sectors. The cluster also includes a large and diverse energy supply sector, including a gas power station, onshore wind generation, and two liquefied natural gas terminals[107].

Fuel switching, including electrification, the use of hydrogen and alternative low-carbon fuels, is the main lever for the cluster's decarbonisation. Because of this, the cluster has explored how the electricity and gas distribution grids must be developed to support the cluster's decarbonisation targets[108].

South Wales Industrial Cluster also envisages using CCS to address a third of its emissions. However, South Wales does not have ready access to geological CO_2 storage and must instead rely on shipping the captured CO_2 to sites elsewhere. As such, the cluster plan includes developing shipping capabilities and exploring technologies and measures to utilise captured CO_2 locally[109].

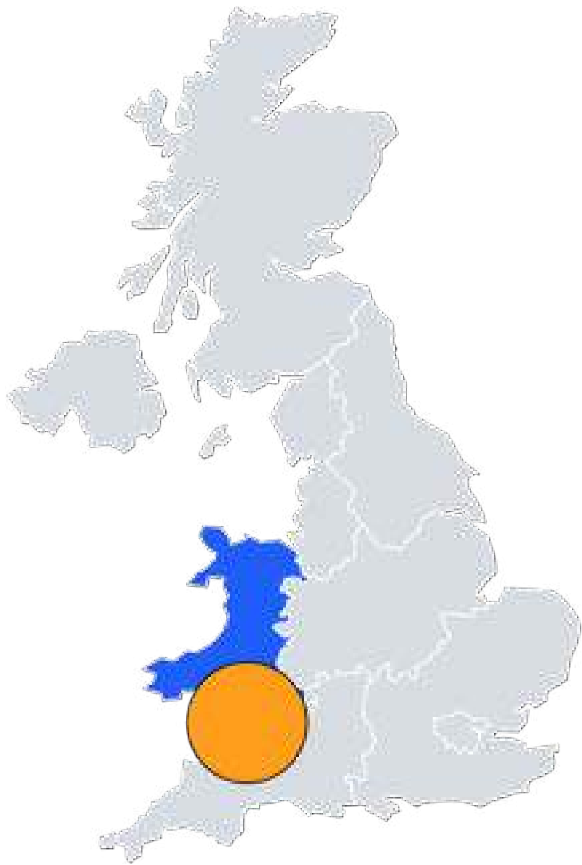
The cluster plan is also aligned with Wales's sustainable development legislation, the *Well-being of Future Generations (Wales) Act 2015*, which sets out how public bodies must have the well-being of future generations at the heart of their policy decisions[110]. Linked to this, the cluster carried out a skills gap study on the Milford Haven Waterway energy sector and has been working with academic institutions to develop a related future skills blueprint[111]. Overall, the *SWIC Cluster Plan* notes that guiding Welsh industry through the net zero transition can help retain 113,000 industrial and manufacturing jobs in the region[112].

Best practices demonstrated by the South Wales Industrial Cluster include:

- Development of a detailed policy assessment across Welsh and UK governments with associated actions to provide clarity on what the cluster needs from policy makers to support decarbonisation.
- Link between the objectives of the Industrial Cluster with the goals in Wales' sustainable development legislation provides clarity on how the cluster will contribute to Wales' strategic objectives.
- Assessment of how industrial carbon accounting methodologies could improve to enhance transparency, simplify reporting, and increase relevance to industry.

Net zero target date **2040**

SWIC



Net zero target date **2040**

TVNZ

Tees Valley Net Zero (TVNZ) Cluster Plan

The *Tees Valley Net Zero Cluster Plan* covers the region covered by the Tees Valley Combined Authority in the North East of England. Tees Valley Industrial Cluster is a concentration of 60 industrial sites within a five-mile radius. It has a deep-water port, access to CO_2 geological storage nearby, and contains the Teesside freeport, a tax and secure customs zone[113].

The Tees Valley Industrial Cluster is made up of a small number of large CO_2 emitters (i.e., chemical works, power and heat (steam) generation, and waste processing and recovery) and many small emitters. Approximately a third of the cluster's planned decarbonisation is directly related to CCS, while up to another third is indirectly reliant on CCS (i.e., capturing the CO_2 associated with the production of blue hydrogen and use of the electricity generated by power stations with pre- and post-combustion CCS)[114].

The cluster plan also outlines how the cluster intends to scale up green and blue hydrogen production to become a net-exporter to other UK regions and European countries[115]. To support this growth area, as well as the broader cluster objectives, the plan highlights the challenge of reversing the decline in "skilled metal, electrical and electronic trades" and "process plant and machine operatives"[116].

The cluster aims to achieve net zero aligned decarbonisation without de-industrialisation, a historic issue in the region. A successful transition to net zero in the region could translate to some £34 billion in cumulative additional GVA by 2040, which is associated with up to 30,000 new jobs[117]. The required investments for the net zero projects are partially being addressed by leveraging funding for the re-development of the old Teesside Integrated Iron and Steel works site[118].

Best practices demonstrated by the Tees Valley Net Zero Industrial Cluster include:

- Investigation and presentation of the business case for international hydrogen market development. This investigation demonstrates opportunities for the cluster to compete in the international market.
- Demonstration of inter-cluster partnership with the Humber Industrial Cluster on the Northern Endurance Partnership, outlining how projects across the two clusters will come together to enable decarbonisation.
- Research into the potential skills and supply chain constraints that could hinder the implementation of the cluster plan, which enables the cluster to proactively address the barriers.

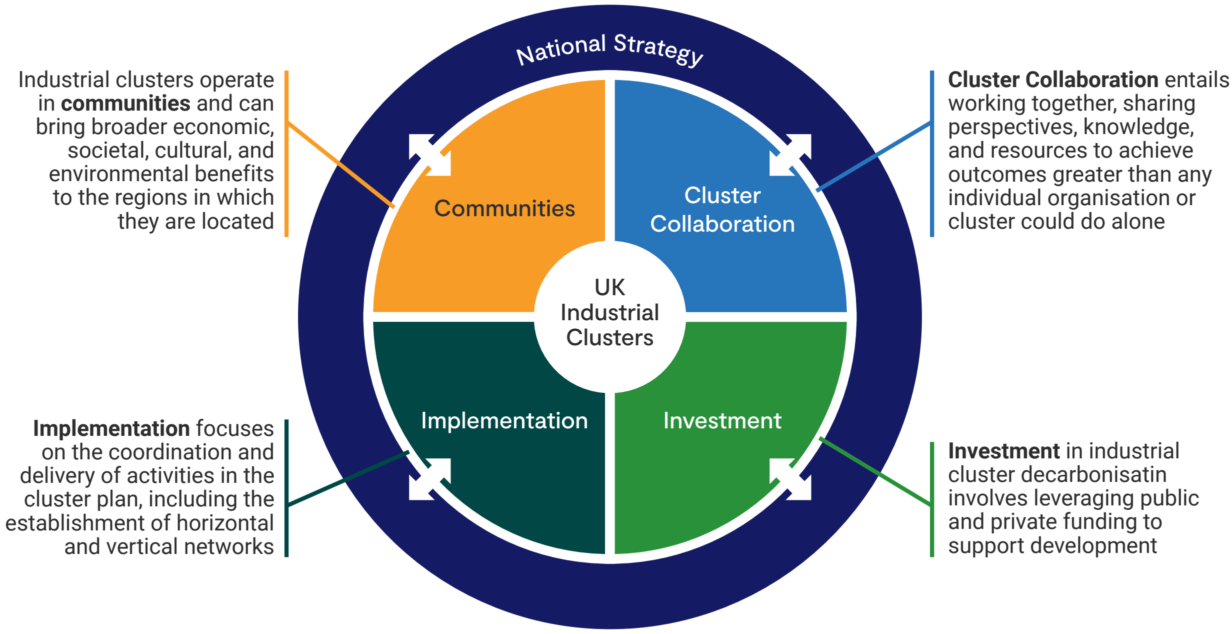
The six IDC cluster plans all contribute to the national vision for industrial decarbonisation

IDC intentionally chose a diverse set of clusters in recognition of the complexity of decarbonising industrial emissions and to maximise the learnings generated by the challenge. From an inland cluster like the Black Country Industrial Cluster, which comprises small and medium sized manufacturing sector emitters, to the *Scottish Net Zero Roadmap* with an industrial site handling 30% of the UK's natural gas volumes, each cluster plan has a separate set of challenges to address. Collectively the cluster plans outline the scale of ambition for industrial decarbonisation in the UK, as well as the technologies, infrastructure, investment, and policy change required to implement them. The IDC clusters are on the path to becoming low carbon by 2030 and net zero by 2040[xvi]. By doing so, they are supporting the strategic pillars outlined in **Section 2** and contributing to government's vision for the UK to be a global leader in industrial decarbonisation and manufacturing of low-carbon industrial products in the coming decades.

The Industrial Cluster Decarbonisation Framework defines the areas of key learning from the cluster plans

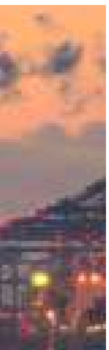
Over the multi-year development process for the six cluster plans, enablers and barriers have emerged. These speak to the opportunities that the cluster plans are actively taking advantage of and the gaps that remain. Taken together, they form a national understanding of what is required to meet the UK's net zero target and provide guidance for other emerging industrial clusters.

Key learnings are synthesised through the application of the Industrial Cluster Decarbonisation Framework (Framework). Developed in collaboration with the IDC cluster plan partners, the Framework encompasses the elements needed for successful industrial cluster decarbonisation and serves as the core organising structure for the cluster plan learnings outlined below. **Figure 9** illustrates how each of the Framework elements fit together:



National Strategy (government policy, regulation, and funding) guides and supports all industrial cluster activity and influences the decisions that the clusters make. This influence is represented by national strategy's placement as the outermost ring with arrows that indicate the dialogue that occurs between this and the other framework components

Figure 9: The Industrial Cluster Decarbonisation Framework used to synthesise the key learnings from the cluster plans



xvi. The *Scottish Net Zero Roadmap* is an exception to this and is targeting net zero by 2045.

The key learnings by framework element are summarised below[xvii]:

National strategy: Government leadership and support is necessary

- Consistent communication and ongoing engagement between industrial clusters and government are needed to address high-priority policy gaps.
- Rationalising and resourcing the consenting process for infrastructure development, in particular common infrastructure, can accelerate the deployment of the clusters' decarbonisation solutions.

Cluster collaboration: Effective industrial cluster decarbonisation requires strong and ongoing collaboration

- Ongoing industrial cluster collaboration requires ownership and dedicated resources.
- Sharing knowledge within and between clusters generates benefits that individual parties and clusters could not achieve alone.
- Clusters are motivated to work together to engage with government and ensure policy settings enable industrial cluster decarbonisation.

Investment: Indication from government on commercial business models reduces uncertainty and sends market signals

- Business model finalisation is an important milestone for final project investment decisions, requiring iteration between the government and project developers.
- Enabling instruments, including business models, will need to align to strategy and policy roadmaps to initiate the transition from delivering the first net zero cluster to delivering net zero by 2050 across UK industry.
- The UK has made major progress in defining business models over the past few years; acceleration of models under development and expansion of the current suite of business models to cover additional solutions could accelerate the investment in and delivery of a wider range of projects, subject to a prioritisation assessment.
- While business models will go a long way to unlocking investment, other instruments such as the UK ETS have potential to reduce barriers for projects and provide the policy landscape to move away from government support.

Implementation: The transition from planning to implementation will raise new challenges and require coordinated effort from many stakeholders

- Clusters are expecting to see a higher proportion of abatement coming from CCUS and hydrogen than previous national modelling anticipated.
- Early deployment of at-scale solutions, such as CCS full-chain major infrastructure projects, are facing issues in the permitting and planning processes due to their novelty.
- Increased certainty and visibility on infrastructure decisions will enable clusters to identify their optimal decarbonisation pathway.
- Constraints of existing infrastructure systems, such as connection capacity in electricity networks and water scarcity, could delay the implementation of plans.
- Competition for constrained supply chains is a risk to deliverability.
- Forecasting the contribution of plans to national targets and tracking progress requires a consistent methodology.
- Continuing research and innovation in technologies and solutions can continue to increase efficiency and improve project bankability.

Communities: Industrial clusters and surrounding communities can mutually benefit from the successful decarbonisation of industry in their region

- The place-based nature of industrial cluster decarbonisation can help ensure that associated benefits are experienced locally.
- The burden of proof is on industrial clusters to make the potential benefits of industrial decarbonisation clear and credible to communities.
- Opposition from local stakeholders can hinder cluster plan progress, but community engagement improves public acceptance of industrial decarbonisation activities.

xvii. The analyses that informed these key learnings are detailed in **Appendix 1**.

National strategy: Government leadership and support is necessary

Meeting the net zero targets relies on factors outside the direct control of the cluster plans. Government policy, regulation, and funding are major contributing factors as to how decarbonisation barriers and enablers are addressed. Industrial clusters are looking to the government for leadership and support in laying the groundwork for the actions needed to implement their cluster plans. This includes establishing market frameworks, setting industry standards, leading on international-facing issues, such as the UK's industrial competitiveness, and long-term considerations, such as the safety and security of legacy CO_2 geological storage sites.

As a result, national strategy is an encompassing element of the Framework (**Figure 9**), meaning that the key learnings across the following sections (cluster collaboration, investment, implementation, and communities) are all discussed through a national strategy lens. However, the two key learnings detailed here relate to the overarching policy setting and the policy challenge most frequently cited by industrial clusters.

Key learnings:

Consistent communication and ongoing engagement between industrial clusters and government are needed to address high-priority policy gaps.

Alignment between industrial clusters and government on their expectations and respective roles is needed to continue progression towards decarbonisation goals. The cluster plans set out the need for a long-term national strategy to support the required commercial and financial planning (e.g., clarity on support for projects beyond those shortlisted in Track-1 of the CCUS Cluster Sequencing Process and for the Electrolytic Hydrogen Allocation Round). There is, however, a balance to achieve between the certainty government strategy can provide and the need to establish market-based mechanisms that deliver value for money in a decarbonised economy. Better communication and engagement will support a consensus on the prerequisites and timing for when the transition to a fully self-sustaining market can and should take place.

The core of the government's signalling on industrial decarbonisation is the 2021 *Industrial Decarbonisation Strategy*[119]. However, clusters indicated in their plans that more detail is required in several critical areas that directly (e.g., business models and workforce development) and indirectly (e.g., planning system and the UK ETS) impact the technical and commercial viability of their plans. As explained further in the **implementation section**, some clusters are planning for multiple eventualities, instead of focusing their efforts on delivering the optimal pathway, because of what they perceive to be a lack of clarity on the overall national strategy[120].

Cluster plans also identified specific priorities for national-level policy interventions. Four or more IDC industrial clusters are seeking:

- improved consenting processes to accelerate infrastructure provision
- clear direction on the national plan for net zero skills
- support for establishing supply and demand for hydrogen
- implementation of the proposed business models for CCUS and hydrogen[xviii]

Various measures, either still in development or published since the IDC cluster plans, at least partly address these high-priority policy gaps. However, adequately prioritised and resourced communication is still important to ensure that industrial clusters and government are, and remain, aligned. This will enable government to provide guidance at the right level of detail to support market-driven investment in decarbonisation measures required by the industrial clusters.

Rationalising and resourcing the consenting process for infrastructure development, in particular common infrastructure, can accelerate the deployment of the clusters' decarbonisation solutions.

National-level interventions related to the consenting process for net zero infrastructure development were the most frequently cited policy gap in the cluster plans. Specific needs mentioned by the cluster plans include:

- extensive coordination in the development of common infrastructure[121]
- insufficient resourcing for planning consent and permitting development[122]
- the incurring of costs due to permitting and regulatory challenges, which could influence technology deployment decisions, e.g., shared or individual site hydrogen production[123]
- the lack of a framework for delivering consistent benefits to communities hosting net zero infrastructure[124]

Other consenting-related policy gaps, associated with the novelty and scale of the types of projects and technologies seeking permitting, are elaborated on further in the **implementation section**.

However, while expediting permitting is a priority for industry, it is the role of regulators to maintain a holistic view of the system to avoid any unintended consequences, e.g., the dilution of standards around health and safety. The government is working on clarifying the regulatory framework for net zero infrastructure consenting through the revision of the *energy National Policy Statements* (NPS)[125]. Also, in the time since the finalisation of the cluster plans, the government published its *Nationally Significant Infrastructure Project* (*NSIP*) *Action Plan* (February 2023) which sets out how the government will reform the consenting process to ensure the planning system can meet the demands of a greater number and complexity of cases[126].

xviii. This list is derived from the policy gap analysis in **Appendix 1**

Consenting for common infrastructure projects is complex, especially when projects occur across different UK planning regimes, e.g., Project Union[127]. The process requires significant stakeholder coordination and management of externalities (i.e., the external factors the project is dependent on and enables). Whether the proposed rationalisation of the planning system, as outlined in the *NSIP Action Plan*, will go far enough in reducing the burden on net zero infrastructure developers is, yet, unknown.

Resourcing in planning roles is a nationwide problem as well, particularly on the side of the regulator[128]. Addressing knowledge gaps that regulators have related to net zero technologies and markets could support the timely and consistent processing of planning applications. Recognising this, the *NSIP Action Plan* focuses a reform area on building a more diverse and resilient resourcing model for the planning system. At a high level, this government commitment aligns with the policy need identified in the cluster plans. However, whether the extra resources will be available at the scale and time needed is unclear.

The consent process is also time and resource intensive, and therefore costly, on the side of the applicant. The likelihood that applications will need significant iteration, both to provide the required assurances to planning authorities, as well as respond to third-party queries and objections, introduces uncertainty for the developers of net zero infrastructure. Without compromising on a full consideration of the local impact of any development, planning authorities could explore all opportunities to control consenting costs through streamlining the planning process, i.e., employing mechanisms to cascade learning from the consenting of first-of-a-kind projects to benefit subsequent projects.

A framework for delivering consistent benefits to communities hosting net zero infrastructure is a resource that could help standardise, and build trust in, the consenting process and encourage communities to host such infrastructure. However, there is a potential conflict between a streamlined national framework and the need for mechanisms at the local level to allow the local communities to engage with the consenting process. As such, these frameworks should be sufficiently flexibility to incorporate input from local stakeholders. While government is developing a community benefits framework for those hosting electricity distribution and transmission infrastructure[129], there is currently no equivalent for other networked infrastructure, such as hydrogen transport or CCUS.

It is critical that the planning system can efficiently and robustly process the applications from common infrastructure projects that are at the core of industrial clusters' decarbonisation plans. The clarification on the regulatory framework provided by the *energy NPS* and the commitment to rationalising and resourcing the planning system set out in the *NSIP Action Plan* will support the processing of such applications. However, the timeliness and extent of the planning reforms will influence their overall impact on accelerating industrial decarbonisation.

Cluster collaboration: Effective industrial cluster decarbonisation requires strong and ongoing collaboration

Reaching net zero by 2040 is a significant, and necessary, task that is bigger than any one organisation. By working together and sharing perspectives, knowledge and resources, industrial clusters can capitalise on the synergy that their co-location offers and pass on learnings to others. Collaboration was critical to the development of the cluster plans and will continue to be so throughout plan implementation.

> "The Cluster Plan Project has resulted in a transformational change in terms of industrial collaboration and vision setting in the region."[130]

In total, the six IDC cluster plans recognised nearly 140 organisations that played a part in their development, from large scale emitters and infrastructure developers, through to academic institutions, local enterprise partnerships (LEPs), councils, and more. These organisations brought together different perspectives and solutions for addressing decarbonisation in some of the most challenging sectors.

With different organisational compositions and challenges, each IDC industrial cluster relied on various approaches to collaboration. For example, an environmental consulting firm led and coordinated the development of the *Scottish Net Zero Roadmap* with industrial emitters and infrastructure providers[131]. South Wales Industrial Cluster took an alternative approach and established a legal framework between industrial cluster organisations to enable knowledge sharing[132]. Knowledge and lessons learned from collaboration will support the next phases of partnership as the IDC clusters implement their plans to reach net zero and new industrial clusters emerge.

Key learnings:

Ongoing industrial cluster collaboration requires ownership and dedicated resources.

Ongoing collaboration is foundational to the successful implementation of the cluster plans and requires ownership to maintain momentum. Implementing the activities outlined in the plans requires continued coordination amongst the organisations within the clusters, as well as with national entities. It also requires specific engagement with local communities, discussed further in the **communities section**. While collaboration and associated governance needs may shift throughout implementation, it will remain an essential part of realising the plans. In recognition of this ongoing need, each of the clusters has identified, and in some cases established, an entity that could take responsibility for collaboration and oversight of cluster plan implementation. These entities include formalised central bodies, where a group is formed to manage the plan, and monitoring organisations, where an interested party monitors progress and updates other members (**Appendix 1**).

- Tees Valley Industrial Cluster established a new industry group, the Net Zero Leadership Group, to "allow [it] to address common themes and provide a unified voice for delivering Net Zero 2040. It will allow [TVNZ] to address infrastructure and resources needs together"[133].
- Similarly, South Wales Industrial Cluster has established a new legal entity – Net Zero Industry Wales – to "provide [a] forum for continued trusted collaboration between industry, governments and academia [and] follow through on the policy driver requirements"[134].

Given the number of organisations involved in cluster plan development, e.g., 40 in the *Tees Valley Net Zero Cluster Plan*[135], clusters recognise the value in formalising the role of a coordinator and plan owner even though securing ongoing funding for this function can be a challenge. For example, the National Centre for Manufacturing Transition established by the Black Country Industrial Cluster secured funding for three months, but after this initial period, its future is uncertain; however, funding options are being investigated via the *West Midlands Trailblazer Deeper Devolution Deal*[136]. The six clusters are exploring various funding sources including lead organisation funding; membership fees from cluster organisations; external funding, such as local public funds; and combinations of these (**Appendix 1**). The consistency and longevity of the funding secured should be monitored moving forward.

Sharing knowledge within and between clusters generates benefits, including the acceleration and coordination of research and innovation efforts, individual parties and clusters could not achieve alone.

Through plan development, the IDC clusters produced a knowledge base identifying industrial cluster decarbonisation needs across the UK and opportunities for meeting those needs. The cluster plans acknowledge the advantages of building strong relationships with partners while also managing the natural tensions that exists between companies in competitive markets.

South Wales Industrial Cluster emphasised the importance of establishing a "safe legal foundation that underpins the ability to collaborate on both the 30 partner and one participant Cluster Plan Project and the 17 partner Deployment Project. The legal arrangements […] allowed initial sharing of ideas, plans and information to kick-start momentum in a multitude of project areas"[137]. The legal framework helped manage tension between knowledge sharing and competition law that would normally present a barrier to collaboration.

In addition to working together within their own membership, the IDC clusters also partnered with one another.

- South Wales Industrial Cluster has adopted the Black Country Industrial Cluster's methodology to decarbonise small and medium sized manufacturing companies, with some adjustments[138].
- Black Country Industrial Cluster has also established The National Centre for Manufacturing Transition with the specific purpose of "maintaining and sharing the necessary knowledge bases and methodologies" from and with existing and future clusters[139].

Knowledge sharing efforts within and across clusters are promising and provide a foundation for industrial cluster decarbonisation, as well as support for emerging clusters. However, there is currently no established, consistent, and systematic way of collecting and distributing the knowledge gained by clusters to inform broader decarbonisation nationally.

Knowledge sharing efforts within and across clusters are promising and provide a foundation for industrial cluster decarbonisation, as well as support for emerging clusters. However, there is currently no established, consistent, and systematic way of collecting and distributing the knowledge gained by clusters to inform broader decarbonisation nationally.

Clusters are trusted and motivated to work together to engage with government and ensure policy settings enable industrial cluster decarbonisation and market development for decarbonised energy, products, and services.

Each of the IDC industrial clusters express interest in engaging with government to ensure the right policy settings are in place to support industrial cluster decarbonisation. For example, Humber Industrial Cluster, Black Country Industrial Cluster, and Tees Valley Industrial Cluster indicate their intent to coordinate and advocate for industrial cluster decarbonisation.

- Humber Industrial Cluster "will [w]ork 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 greenhouse gas removal (GGR) business models, policy, incentives, and subsidies"[140].
- Black Country Industrial Cluster has established the National Centre for Manufacturing Transition with the objective "to work with other industrial clusters and dispersed sites across the UK, and with the UK and regional governments, to develop and implement practical and policy solutions which support UK manufacturing supply chains through the transition to net zero"[141].
- Tees Valley Industrial Cluster intends to "continue to take a lead role in the Multi Cluster Forum … to share experiences and coordinate mutually beneficial activities"[142].

Despite the motivation from the IDC industrial clusters, mechanisms to facilitate this are not well established, presenting a barrier to building on the collaboration momentum from cluster plan development. Coordinated industrial cluster engagement with government would support the right level of specificity and clarity in policy development to enable private sector investment and accelerate industrial cluster decarbonisation.

Investment: Indication from government on commercial business models reduces uncertainty and sends market signals

The cluster plans set out the IDC industrial clusters' expectations for the investment required to achieve their decarbonisation goals. These are not just the necessary costs but encompass broader opportunities for the region and for investors. The UK government views industrial decarbonisation solutions, including low-carbon hydrogen and CCUS, not only as a critical component of reaching legally binding net zero targets, but also as a major economic and investment opportunity, i.e., the "Green Industrial Revolution"[143].

For some decarbonisation solutions, national action is needed to unlock private sector investment. Some innovative, earlier stage decarbonisation solutions carry higher risk premiums or require additional incentives to increase the attractiveness, or even feasibility, of the investment proposition. An example of this national-level facilitation is the suite of business models the UK government is developing for CCUS and low-carbon hydrogen, which offer a defined operational model to projects. The first contracts based on these business models, along with up-front funding, are being awarded to eligible projects via the CCUS Cluster Sequencing Process and Hydrogen Business Model and Net Zero Hydrogen Fund Electrolytic Allocation Round. The business models are commonly cited in cluster plans as representing a major milestone in project investment decisions and planning at the cluster level.

While the cluster plans have modelled the scale of investment required, the actual mobilisation of capital will require a concerted effort. Since all clusters will need to decarbonise by 2050 to support national targets, a challenge will be to facilitate access to the scale of capital required while avoiding heightening competition to the extent that it becomes a barrier to national decarbonisation. Additionally, concerns over enhanced competition from overseas markets, for example competition driven by the *Inflation Reduction Act* in the US[144], is an additional consideration for the UK as it looks to accelerate investment in industrial decarbonisation.

The cluster plans have highlighted where they are facing investment blockers, and where such challenges can be addressed through strong market signals and coordinated efforts.

Key learnings:

Business model finalisation is a requirement for final project investment decisions, requiring iteration between the government and project developers.

UK government business models are a critical enabler of the CCUS and hydrogen projects outlined within cluster plans: for a project to proceed to Final Investment Decision, the business model must first be finalised. For projects being developed now, this impacts the ability to proceed to build out in a timely manner.

Most cluster plans are relying on CCUS and low carbon hydrogen for a substantial portion (in some cases more than half) of their emissions abatement. Both currently require business model support for financial viability. In some cases, the choice of decarbonisation pathway for an industrial cluster depends on the availability of appropriate business models. For example, the *Scottish Net Zero Roadmap* identifies two primary branches for its net zero pathway, a pipeline pathway that relies on "an appropriate financial model for common infrastructure" and a non-pipeline pathway that relies on business models for vehicular movements of CO_2[145].

"This level of deployment, however, is subject to Government putting in place a set of long-term business models for hydrogen and CCUS against which upfront investment from the private sector can be justified"[146].

While clusters are clear that additional certainty on the timeline for business model development would support their project plans, there is an opportunity for a more coordinated approach to outline exactly where key decision points for key projects lie. Cluster plans have indicated that they require more certainty and clarity on what the business models will look like. In many cases, the government has since published more information and updates after the publication of the plans (**Appendix 1**). Full implementation of a business model requires mutual confirmation between projects and government, and there is a limit to the certainty that government can provide without entering the negotiation phase. Many business models are already nearly fully developed (e.g., Industrial Carbon Capture), while others (e.g., BECCS) are less so (see key learnings below).

Enabling instruments, including business models, will need to align with strategy and policy roadmaps to initiate the transition from delivering the first net zero cluster to delivering net zero by 2050 across UK industry.

Business model contracts are initially being awarded to projects that have been successful in the CCUS Cluster Sequencing Process or the Electrolytic Hydrogen Allocation Round. In addition to a business model contract, which provides ongoing revenue support, the CCUS Cluster Sequencing Process and Electrolytic Hydrogen Allocation Round provide capital grants for some project types[xix], and therefore aim to remove first-mover disadvantage (i.e., address risks associated with first-of-a-kind projects). It is not yet clear if the business models will be sufficient on their own to enable commercial investment[xx]. It is important that industry confidence is maintained across the sectors, so that there is confidence that first movers are not the only projects that will go ahead.

- At the time of cluster plan publication, clusters not selected for CCUS Cluster Sequencing Process support felt that the future remained unclear. For example, the Scottish Net Zero Roadmap felt its plans at Peterhead Power Station were uncertain even though it was published prior to the government's announcement of Track-2 cluster eligibility[147].
- South Wales Industrial Cluster highlighted that inclusion within Track-2 of the CCUS Cluster Sequencing Process, and its ability to utilise a business model for CO_2 shipping, is one of its six priority areas[148].

While short-term efforts need to be maintained to get the first contracts in place for deployment projects, it is important the follow-up projects that will launch the scale of deployment across multiple clusters are provisioned.

xix. For example, power projects do not receive upfront capital support.

xx. See **investment analysis in Appendix 1** for more information.

The UK has made major progress in defining business models over the past few years; acceleration of models under development and expansion of the current suite of business models to cover additional solutions could accelerate the investment in and delivery of a wider range of projects, subject to a prioritisation assessment.

The most well-developed UK government business models (i.e., Dispatchable Power Agreement (DPA), Industrial Carbon Capture (ICC) and Hydrogen Production) tend to align with the most relied upon decarbonisation solutions, namely CCS and hydrogen. These decarbonisation solutions will also depend on enabling infrastructure and supporting markets, which additional business models underpin. In addition to CCS and hydrogen, cluster plans also cite additional technologies as needing business model support (**Appendix 1**).

Business models for infrastructure and markets
Carbon capture and hydrogen projects will depend on supporting infrastructure and markets such as hydrogen transportation and storage and non-pipeline transport of CO_2, for which the business models are under development. While non-pipeline transport is particularly important to South Wales Industrial Cluster[149], it may also be relevant for certain branches of the *Scottish Net Zero Roadmap*[150] and for other clusters that may consider importing and storing CO_2 from other regions (e.g., Humber[151]). On hydrogen transport, the *Scottish Net Zero Roadmap's* policy analysis notes that there is "limited policy support" for hydrogen transport and assesses its status as red within its RAG review[152]. Additionally, Net Zero North West states that a hydrogen business model also needs to increase consumer demand and should be compatible with future developments like carbon price changes[153].

Business models for other technologies
While other business models are under development for technologies and solutions like BECCS and GHG removals, there is a reluctance to invest due to the uncertainty. Beyond ICC, Power CCUS and Hydrogen, Tees Valley Industrial Cluster states that organisations are "not willing to invest" in BECCS until the business model is published[154], and the *Scottish Net Zero Roadmap* has noted that policy support for GHG removals is focused on research and development, "not yet commercial deployment"[155] – though this may be to be expected, as development is ongoing and business models targeting large volumes of emissions reductions take priority. Since the publication of the cluster plans, the government has published a response to consultation on GGRs[156], which confirms their intention to proceed with development of a GGR business model based on a contract for difference structure.

Some clusters have indicated that they could be supported by business models that are not currently announced or are under development (i.e., electrification, CCU). For example, Humber Industrial Cluster notes that "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"[157] and lists a business model for electrification as a recommendation for policy makers[158]. South Wales Industrial Cluster has made both CCU and electrification as a priority[159].

Business models have provided a clear indication to industry of what a functioning operational model might look like and are a major milestone to enable plans to move forward. Significant progress has been made over the past few years, with a landmark occurring in March 2023 with the publication of the suite of documents and business model updates alongside *Powering Up Britain*. Business models have been a common theme brought up in the cluster plans as a key enabler. For future business model development, priority should be placed on those technologies and solutions that deliver the most significant carbon reductions.

While business models will go a long way to unlocking investment, other instruments such as the UK ETS also have potential to reduce barriers for projects and provide the policy landscape to move away from government support.

In addition to business models, the clusters also note that wider market support mechanisms or signals may be needed, including carbon border adjustment measures[160,161] and changes to the UK ETS[162,163]. Such changes include measures to address the lack of carbon caps and pricing structure uncertainty in sectors such as hydrogen[164]. South Wales Industrial Cluster noted that, if negative emissions were able to partially offset UK ETS obligations, this would "unleash substantial funding from the private sector without the need for government support"[165].

> "The Emission Trading Scheme is both an opportunity and a threat to industries within the Humber Industrial Cluster, depending on their speed of adoption"[166].

Recent updates from the government in March 2023 outline next steps towards addressing many of these concerns, including the launch of a consultation[167] on addressing carbon leakage risk (e.g., via Carbon Border Adjustment Mechanisms) and a notice in *Powering Up Britain*[168] that government will work with the UK ETS authority to set out a "long-term pathway for the UK ETS" later in 2023. Whether the guidance outlined in the anticipated documents will sufficiently unlock investment cannot yet be determined.

Implementation: The transition from planning to implementation will raise new challenges and require coordinated effort from many stakeholders

With six cluster plans now published, each cluster is looking to move from planning into implementation. Three key considerations underpinning implementation are cluster plan management, technology and infrastructure, and the skills and supply chain required. The short-term focus on these three considerations depends on how advanced the deployment plans are within each industrial cluster. For Net Zero North West, for example, key projects such as HyNet are reasonably mature, so maintaining momentum and lining up the supply chain will be crucial for this cluster. For others, such as South Wales Industrial Cluster, where technical interventions are yet to be detailed, continuing coordination between cluster partners to establish projects will be the short-term focus. Despite the variety of cluster types, sectors and pathways across the published plans, several key learnings are widely applicable at the national level.

Key learnings:

Clusters are expecting to see a higher proportion of abatement coming from CCS and hydrogen than previous national modelling anticipated.

Reliance on carbon capture and hydrogen in cluster plans appears to be higher than expected by early scenario planning at the national level undertaken for the *Industrial Decarbonisation Strategy* in 2021.

If the UK's interim deployment ambitions for CCS and hydrogen are indicative of the amount of support the government plans to provide (e.g., via business models), then there is a potential misalignment between cluster and government expectations. Modelling in the *Industrial Decarbonisation Strategy* shows that in the cluster networks scenario around 14 $MtCO_2$ per year is expected to be captured in the 2035-2050[169] period (including BECCS, excluding power emissions, and assuming hydrogen is primarily blue) in a net zero scenario. However, an aggregation of the cluster plans' modelling results, conducted as part of developing *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation*, suggests that capture of up to 28 $MtCO_2$ per year could be required by 2030[xxi] to deliver the cluster plans. Therefore, if the cluster plans are implemented, the expected capture volumes in the *Industrial Decarbonisation Strategy* analysis would likely be exceeded.

Several clusters, including Humber Industrial Cluster and the *Scottish Net Zero Roadmap*, have modelled several different scenarios to illustrate what other pathways could be taken with reduced volumes of CCS, relying more heavily on other technologies such as electrolytic hydrogen and electrification. Most cluster plans, however, do select scenarios with a high reliance on CCS out of the scenarios modelled, indicating that this is their preferred decarbonisation pathway. Clusters and government need to align on how to reconcile expectations around the scale of CCS deployment required without compromising overarching net zero 2050 targets.

In addition, the high degree of reliance on carbon capture and storage to meet mitigation targets further stresses the reliance and interdependency between decarbonisation projects and common infrastructure.

> "We will work with key infrastructure partners [...] to maximise the benefits of cluster decarbonisation and tackle systemic barriers"[170].

Early deployments of at-scale solutions, such as CCS full-chain major infrastructure projects, are facing issues in the permitting and planning processes due to their novelty.

The clusters are pursuing major projects with technologies that are considered mature individually but, in many cases, have not been used in these applications or at this scale before in the UK. As a result, permitting and planning processes are grappling with the new information, impacts, and risks associated with the projects at the front of the pipeline, causing delays. The current consenting process for infrastructure projects involves multiple stakeholders, including national government, local communities, and local authorities. Humber Industrial Cluster has highlighted that local authorities need

xxi. Aggregated up-side carbon capture projections from cluster plans (HICP, pg. 8, NZNW, pg. ii, SNZR, pg. 28, SWIC, pg. 11 and 36, Tees Valley Net Zero pg. 13) to work alongside government to "update how planning consent is awarded for projects of national significance"[171]. While the National Infrastructure Planning Association gathers lessons learned from Development Consent Orders (i.e., for nationally significant infrastructure), there is no requirement for lessons from all first-of-a-kind projects to be shared across jurisdictions.

To address the issues caused by project novelty, learnings from similar projects will need to be shared. *Powering Up Britain* includes a commitment to speeding up planning and networks, and notes that in areas where risk to investors is greater due to the "novelty or scale" of a project, the government can "co-invest alongside the private sector to ensure good projects happen"[172].

Increased certainty and visibility on infrastructure decisions will enable clusters to identify their optimal decarbonisation pathway.

Related to the above, visibility of national infrastructure priorities and planning decisions is a key enabler, especially for projects that rely on development of infrastructure outside of a project's direct control (e.g., hydrogen and CO_2 pipelines and grid connections). At the project development level, certainty and visibility of national infrastructure priorities impact early-stage feasibility assessments. At a cluster level, it informs the portfolio of solutions a cluster may consider advancing or the pathway it would take to decarbonise.

The *Scottish Net Zero Roadmap,* for example, sets out the different pathways that would result from key decisions on major projects. Based on the uncertainty of these decisions, the range of outcomes of the pathways varies, with hydrogen demand in the cluster being between 0 and 15 TWh per year in 2030, depending on the variety of solutions implemented across the cluster. This is a vivid demonstration of how key decisions could result in hydrogen either being a minor or a major contributor to industrial decarbonisation. The *Scottish Net Zero Roadmap* captures this variability by presenting a branching pathway that will be determined in large part by national signals to prioritise certain technologies, e.g., decisions to prioritise renewables over CCS, and drive for centralised hydrogen production[173]. Without visibility and certainty around these decisions, the clusters will continue to plan for all reasonable eventualities, which may limit their ability to progress with key planning decisions.

Constraints of existing infrastructure systems, such as connection capacity in electricity networks and water scarcity, could delay the implementation of plans.

Industrial clusters will rely on existing networks, such as those providing electricity and water, to implement technologies at individual sites. It is often assumed that these networks will provide whatever is required of them, however, rapid changes in demand can be difficult to accommodate.

Many cluster plans include green hydrogen, for example, which is associated with a high requirement for both water and electricity. Given the scale of deployment, accommodation or rapid provision for new capacity can no longer be assumed. Studies are necessary at early project stages to establish feasibility and timelines for implementation. Several clusters have undertaken work of this type, including Humber Industrial Cluster, Net Zero North West, and Tees Valley Industrial Cluster.

Humber Industrial Cluster identified green hydrogen production as the activity with the highest water demand in the cluster, with additional demand from other technologies such as carbon capture. This will be difficult to accommodate with water scarcity expected in the region. To manage this constraint, the cluster anticipates developing a more circular approach to water usage[174]. The cluster is also expecting a large amount of electrification which, added to the electricity demand from green hydrogen production, could mean that implementation may be "constrained by current capacity limitations of the electricity network"[175].

As implementation begins, the scope and scale of change set out in the cluster plans will necessitate wider efforts to develop core infrastructure in electricity and water networks. Otherwise, implementation could be constrained by the pace at which these can be provided.

Competition for constrained supply chains is a risk to deliverability.

With a substantial number of major projects being delivered over the same period across industrial clusters, and in the context of growing pipelines of similar projects across the European Union (EU) and the US, there is an elevated risk of competition for limited skills and suppliers causing delivery bottlenecks. Tees Valley Industrial Cluster have noted that "until mid-century, the UK is expected to continue building out domestic CCUS facilities and could face supply chain constraints to build out addition CO_2 import infrastructure"[176]. Humber Industrial Cluster also identified supply chain constraints associated with carbon capture and CO_2 import infrastructure.

> "Employment impacts are expected to peak [...] as the investments create jobs across the manufacturing and construction sectors [...]"[177]

A specific concern is the gap between the supply of construction-related labour (e.g., engineering and trades) required for construction periods across the UK cluster plan timelines and what is available in those regions now[178,179]. If the clusters intend to all build their major infrastructure along similar timeframes, which is increasingly likely as 2040 approaches, then these constraints will worsen and result in delays to delivery, and probably increased costs, unless supply-chain capacity building is prioritised. This is likely to also be impacted by similar construction skills being required for other major infrastructure, particularly enabling infrastructure for national net zero targets, such as electricity network upgrades.

Forecasting contribution of plans to national targets and tracking progress requires a consistent methodology.

Clusters have followed various accounting methodologies and approaches to define the impacts of their plans, i.e., inclusion of emissions saved or displaced, emissions abated, and hydrogen produced is inconsistent across the cluster plans. While each model serves the objective of the cluster plan, the differences in their purpose and approach means the outputs are not directly comparable due to variability in baseline emissions, model boundaries, GHG scope inclusions, and underlying assumptions. Comparison across clusters or aggregation to analyse the gap between the impact of the cluster plans and the actions required to achieve net zero 2050 would require the development of a standardised methodology and set of assumptions for quantifying the impacts of the planned interventions.

Consistency in approach is critical. Otherwise, assumptions may not be aligned and will require adjustments (e.g., the CCC's baseline emissions adjustments[180] to enable policy assessment). The South Wales Industrial Cluster recommends that "policymakers…support a more consistent and coherent approach to the monitoring, reporting and verification … and accounting of GHG emissions in industry"[181].

Based on learnings from the breadth of emissions modelling undertaken across the six clusters, the following attributes should be considered when developing a methodology aimed at understanding cumulative GHG emissions impacts of the plans.

- Given current targets to decarbonise the electricity grid and the inclusion of power producers within the scope of many cluster plans, reporting of direct emissions is considered sufficient for understanding cumulative GHG emissions impacts from industrial clusters.
- An emissions model that is site-based, i.e., lists the full range of sources of emissions within the cluster and plans an intervention for each of these, resulting in one-to-one mapping of emissions sources and interventions provides the most robust method and the clearest view of residual emissions.
- Due to the structure of national emissions reporting, it is beneficial to clearly distinguish between emissions from the power sector from other industrial sectors.
- To understand the impact of regional growth on industrial and power emissions, particularly where the cluster is expecting to attract significant new industrials, a time-based baseline or counterfactual for emissions over time is preferable.
- The boundary for the cluster emissions model should mirror the organisations that participate in implementing the cluster plan, i.e., both NAEI sites and others that will address their emissions through implementation of the cluster plans, with scope to expand the remit to include additional cluster members as plans develop.
- When undertaking scenario modelling, which is desirable, the cluster should nominate a preferred or most likely scenario, which represents the path that they are actively pursuing, alongside different scenarios reflecting the influence of key external factors.

While each of the cluster plan modelling efforts were suited to individual objectives and constraints, a consistent methodology for understanding cumulative GHG emissions impacts is needed for the creation of a national picture representative of planned activities.

Continuing research and innovation in technologies and solutions can continue to increase efficiency and improve project bankability.

In addition to established technologies, the scale of the decarbonisation challenge also requires innovative technology solutions that may still be progressing through Technology Readiness Levels (TRL). Many solutions are therefore at a lower Commercial Readiness Level (CRL) than would normally be the case for those whose rapid deployment at scale is being attempted. Continued research and innovation can deliver additional efficiency improvements and cost reductions and improve the bankability of projects through learning from practical implementation. Research and development into establishing and scaling pilot projects can also contribute to the acceleration of technology development and deployment; for example, IDRIC's programmes are jointly led by academia, industry, and government to deliver scientific evidence and recommendations to address commercialisation barriers for decarbonisation technologies[182].

One of the key dependencies identified by the *Scottish Net Zero Roadmap*, which has mapped different potential pathways based on external influences, is the readiness of hydrogen end-use technologies at scale. The path the *Scottish Net Zero Roadmap* pursues depends on timely technology development, and the lower levels of readiness in some technologies pose a risk to "fixed" plans.

Communities: Industrial clusters and surrounding communities can mutually benefit from the successful decarbonisation of industry in their region

Industrial clusters are key contributors to regional economies. However, de-industrialisation of the UK economy over the last several decades has disproportionately impacted the industries in the IDC industrial clusters and the regions in which they reside. In looking to the future, the UK government recognises the value of new industrial cluster decarbonisation projects to preserve, strengthen, and evolve communities across the industrial heartlands and create opportunities for all.

The six cluster plans have acknowledged that successful industrial decarbonisation relies on local stakeholders and that there are important considerations for community engagement going forward.

Key learnings:

The place-based nature of industrial cluster decarbonisation can help ensure that associated benefits are experienced locally.

Cluster plans discuss four types of local benefits: economic, environmental, social, and cultural. Of the four, cluster plans consistently cite economic benefits such as increased local employment opportunity and regional GVA as the primary positive outcome clusters can provide. Several cluster plans have contextualised this at the local level. For instance, Humber Industrial Cluster estimates the effect of decarbonising local industry on the national economy as well as projecting that approximately 20% of GVA impacts may be retained in the Humber region[183]. Clusters also describe other tangible benefits that complement local economic value add. These include:

- opportunities for regional academics to contribute thought leadership on industrial decarbonisation and consult on approaches to decarbonisation[184]
- opportunities for the local education ecosystem to be involved in planning for and training the next generation of workers to support the green economy. An example initiative from the Net Zero North West is the *Low Carbon Academy*, which is a proposed region-wide coordinated syllabus college system[185]
- opportunities to enhance and improve the built and natural environment as decarbonisation related projects break ground[186]

Humber Industrial Cluster commissioned research on the socio-cultural impacts of decarbonising regional industry, which identified intangible benefits applicable to other industrial clusters
as well as:

- successful industrial cluster decarbonisation may enhance a community's sense of pride through the preservation and evolution of a region's industrial heritage[187]
- improved health outcomes may result from more sustainable industrial activity in the region[188]
- opportunities to increase access to built environment amenities (e.g., green space, affordable housing, public leisure facilities) for community members can enhance quality of life[189]

The burden of proof is on industrial clusters to make these potential benefits of industrial decarbonisation clear and credible to communities[xxii].

Cluster plans exercise caution in presuming that local stakeholders will automatically welcome decarbonisation of local industry. Reactions towards industrial decarbonisation in a community can vary based on prior experience[190]. Past negative interactions with similar industry projects may result in adverse sentiment among local stakeholders towards cluster plan activities[191]. Understanding local influence can, at times, make or break projects. Industries within the clusters and their partners emphasise that the onus is on them to proactively engage and foster relationships with the communities in which they are based so that they gain the "social license to operate"[192,xxiii]. This social license to operate is not given when engagement is one-directional- from clusters to communities. Rather, it is granted when clusters provide intentional spaces for local stakeholders to solution together.

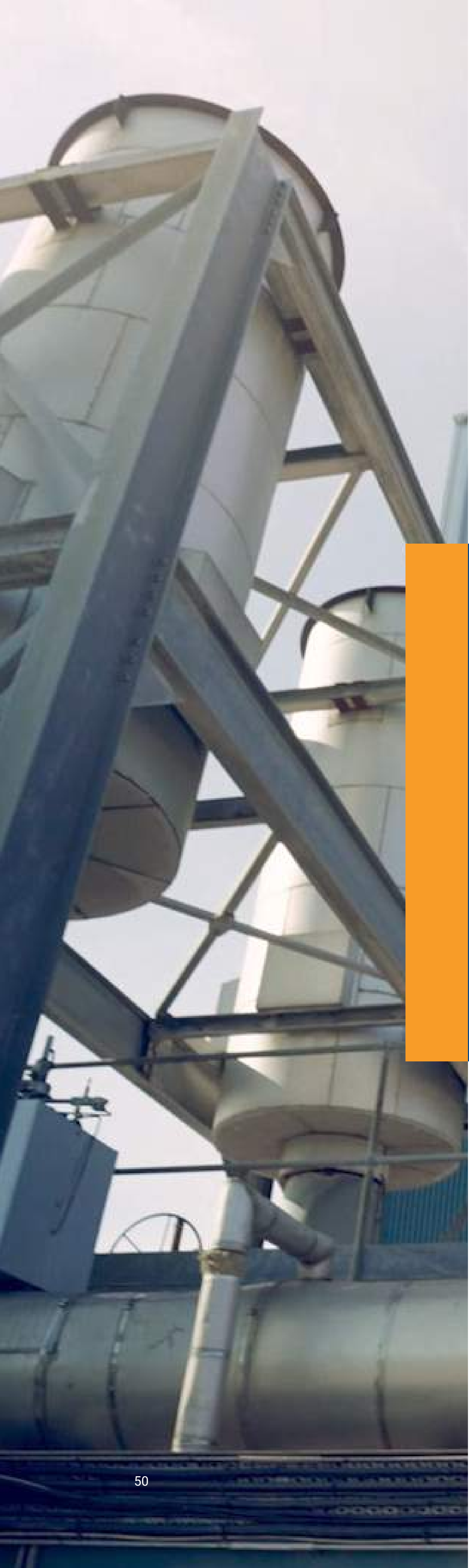
Opposition from local stakeholders can hinder cluster plan progress, but community engagement improves public acceptance of industrial decarbonisation activities.

Cluster plans have identified various channels through which local influence may hinder industrial decarbonisation activities. The importance of engaging local planning authorities early in the planning process has been emphasised so that project owners have adequate time to address regulator concerns and mitigate risk of projects being halted[193]. Cluster plans also acknowledge that resistance from the public can pose permitting obstacles and building public acceptance for low-carbon infrastructure and products to enable the energy transition is important.

xxii. Potential benefits may include skilled, higher-wage employment opportunities.

xxiii. Findings around the importance of industrial clusters' "social license to operate" (SLO) have been identified by other IDC initiatives as well. In particular, IDRIC has released a research series on public perceptions of IDC industrial cluster decarbonisation activity, covering cluster plans such as HICP, NZNW, and SWIC.

To mitigate these potential pitfalls, engagement with local communities can build trust and mutual understanding, which can improve public acceptance and accelerate plan implementation. Humber Industrial Cluster experienced this first-hand through a series of workshops held with local community members. Community members asked for "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"[194]. Humber Industrial Cluster used this collaboration to inform its cluster plan and intends to "plan, implement, and manage the integrated programme of decarbonisation activities […] to generate social value and bring benefit to all through place making"[195]. Humber Industrial Cluster's learning underscores the need for early, transparent, and credible engagement to secure local buy-in for decarbonisation.



Section 4: Achieving the national vision

Decarbonising the UK's industrial clusters requires comprehensive measures and strategies to reduce emissions without compromising economic growth. It is driven by collaboration, innovation, and policy. The cluster plans have provided insights and a greater understanding of the challenges faced, enablers required to accelerate, and benefits that can be realised through industrial decarbonisation.

Based on the analysis of the cluster plans, *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation* presents five key recommendations to enable government and industry to work together in partnership to successfully transition four industrial clusters to low carbon by 2030 and at least one industrial cluster to net zero by 2040. These recommendations include the following.

Recommendations

- **Provide clear signals to the market to facilitate the transition from interim deployment targets to net zero across all clusters by 2050**
- **Rationalise and expedite permitting for common infrastructure**
- **Formalise an Industrial Cluster Advocate with strong government connections and develop a mechanism for ongoing coordination and communication with industrial clusters**
- **Develop actionable measures and timings of jobs and skills requirements needed for industrial clusters to decarbonise**
- **Define and prescribe methodologies for decarbonisation impact estimating**

For each recommendation, a set of possible next steps illustrates how progress can be made. Key stakeholders expected to drive and own these actions are noted as well. Considered together, the recommendations are intended to support industrial clusters through their transition towards a low-carbon future, while ensuring economic prosperity and environmental stewardship for the next generation.

Relevant key learnings by recommendation

Framework element	Key learning	Recommendations				
		1	2	3	4	5
National strategy	Consistent communication and ongoing engagement between industrial clusters and government are needed to address high-priority policy gaps.			X	X	
	Rationalising and resourcing the consenting process for infrastructure development, in particular common infrastructure, can accelerate the deployment of the clusters' decarbonisation solutions.		X	X		
Cluster collaboration	Ongoing industrial cluster collaboration requires ownership and dedicated resources.			X		
	Sharing knowledge within and between clusters generates benefits, including the acceleration and coordination of research and innovation efforts, individual parties and clusters could not achieve alone.	X		X		
	Clusters are trusted and motivated to work together to engage with government and ensure policy settings enable industrial cluster decarbonisation and market development for decarbonised energy, products, and services			X		
Investment	Business model finalisation is an important milestone for final project investment decisions, requiring iteration between the government and project developers.	X		X		
	Enabling instruments, including business models, will need to align to strategy and policy roadmaps to initiate the transition from delivering the first net zero cluster to delivering net zero by 2050 across UK industry.	X		X		
	The UK has made major progress in defining business models over the past few years; acceleration of models under development and expansion of the current suite of business models to cover additional solutions could accelerate the investment in and delivery of a wider range of projects, subject to a prioritisation assessment.	X		X		
	While business models will go a long way to unlocking investment, other instruments such as the UK ETS have potential to reduce barriers for projects and provide the policy landscape to move away from government support.	X				
Implementation	Clusters are expecting to see a higher proportion of abatement coming from CCUS and hydrogen than previous national modelling anticipated.	X		X	X	X
	Early deployment of at-scale solutions, such as CCS full-chain major infrastructure projects, are facing issues in the permitting and planning processes due to their novelty.		X	X		
	Increased certainty and visibility on infrastructure decisions will enable clusters to identify their optimal decarbonisation pathway.	X		X		
	Constraints of existing infrastructure systems, such as connection capacity in electricity networks and water scarcity, could delay the implementation of plans.		X	X		
	Competition for constrained supply chains is a risk to deliverability.			X	X	
	Forecasting the contribution of plans to national targets and tracking progress requires a consistent methodology.	X				X
	Continuing research and innovation in technologies and solutions can continue to increase efficiency and improve project bankability.	X			X	
Communities	The place-based nature of industrial cluster decarbonisation can help ensure that associated benefits are experienced locally.				X	
	The burden of proof is on industrial clusters to make these potential benefits of industrial decarbonisation clear and credible to communities.		X		X	
	Opposition from local stakeholders can hinder cluster plan progress, but community engagement improves public understanding and acceptance of industrial decarbonisation activities.		X			

Recommendation 1: Provide clear signals to the market to facilitate the transition from interim deployment targets to net zero across all clusters by 2050

The UK has committed to developing at least one net zero industrial cluster by 2040 – but this only leaves ten years to bridge the gap between the remaining industrial emissions and net zero by 2050. A significant amount of support is addressing the 2040 challenge from multiple dimensions, including government innovation funding and infrastructure capital funds, business model development, the CCUS Cluster Sequencing Process, Electrolytic Hydrogen Allocation Rounds, and UKRI IDC, to name a few.

While all of these have been critical for building momentum towards the successful delivery of the world's first net zero industrial cluster, attention is still needed for abating all required emissions at a sufficient pace and scale – including what remains even after the delivery of the first cluster and successful interim milestones (i.e., hydrogen produced by 2030, tonnes of CO_2 captured by 2030, etc.). Business models, initially awarded via the CCUS Cluster Sequencing Process, are going a long way towards unlocking commercial investment in decarbonisation solutions. Outlining a clear long-term vision (e.g., beyond the CCUS Cluster Sequencing Process) for enabling instruments, including business models, will help provide more confidence to industry that first movers will not be the only projects that will go ahead.

Many cluster plans have noted ambiguity over the future of business models beyond the CCUS Cluster Sequencing Process and how and when the business model contracts may be extended to additional sites. The *CCSA Delivery Plan 2035* notes that the UK industry (not just within the cluster plans) has published a pipeline of 70 Mt of demand for CCUS by 2035, ~65 Mt of which is by 2030[196]; the UK government ambition, on the other hand, is 20-30 Mt by 2030, and 50 Mt by 2035. If the government deployment ambitions are indicative of the level of support that they anticipate providing (e.g., through business models), then there may be a need to reconcile available support and resources with the scale of abatement that would be required to transition all UK industry to net zero. Clarity on what support will or will not be available, for how long into the future, would help provide clear signals to the market to transition more clusters to net zero, faster.

To take this work further, *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation* recommends the following next steps to provide the market signals needed to ensure all industrial clusters can deliver on the UK's legally binding target by 2050:

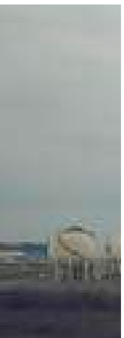
Conduct a gap analysis to signal the scale of ambition and ramp up required between interim targets and 2050 for key metrics including hydrogen production, CO_2 captured and stored, and emissions abated. Such an analysis would consider the volumes of key interventions, including hydrogen produced and CO_2 captured via direct air carbon capture and storage (DACCS) and CCS, that will be required in 2050 based on key pathways (e.g., CCC pathways). It would also compare those volumes to the interim milestones currently in place to determine the rate of scale up for key solutions required, per pathway, to identify common requirements.

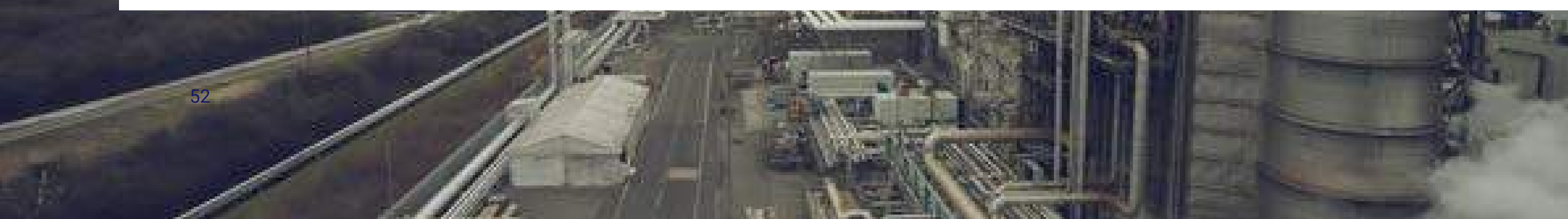
- Ownership of this gap analysis falls under the purview of DESNZ, with the Infrastructure Projects Authority, the CCC, and research institutions as key stakeholders.

Create an action plan for extending cluster decarbonisation learnings and benefits to smaller or dispersed sites within and beyond clusters. Industrial clusters are only half of the industrial emissions challenge – to reach the national net zero target, all industrial emissions must be abated to a level that is compatible with the UK's carbon budgets. The successful decarbonisation of industrial clusters could have potential to support decarbonisation of dispersed sites, for example through market development, innovation and knowledge sharing, infrastructure provision, and more. The action plan would help the process of incorporating and embedding sector-based learnings across smaller or dispersed sites, both inside and outside of established industrial clusters.

- Ownership of this action plan falls under the purview of industry bodies, with DESNZ, professional institutions, industrial emitters, academic/industry collaborators, and local authorities as key stakeholders.

Develop an implementation roadmap for how to transition beyond the CCUS Cluster Sequencing Process, covering both business model eligibility (i.e., future contract allocation rounds) and when decisions might be made around grant funding or other capital support availability, if any. A clear implementation roadmap would provide more certainty for emitters on what level and type of support they would be eligible for, helping unblock investment decisions. To enable this, industrial clusters will need to provide more clarity on what information they need, when, to government– as many business models are fully developed and will require iteration between projects and government to formalise within contracts. Implementation of *Recommendation 3: Formalise an Industrial Cluster Advocate with strong government connections and develop a mechanism for ongoing coordination and communication with industrial clusters* and the proposed cluster taskforce can support this work.





- Ownership of this roadmap would be shared between DESNZ and industrial decarbonisation projects, as engagement is required on both sides. Other key stakeholders are UKRI and other public funding bodies.

Prepare for and consolidate the information required to produce the workforces of the future, including establishing forums for sharing knowledge within and between clusters. This links closely to *Recommendation 4: Develop actionable measures and timings of jobs and skills requirements needed for industrial clusters to decarbonise* and its associated action to analyse the occupations and competencies and the time at which the cluster plan projects require them. In addition to this, analysis should extend beyond the knowledge and skills required to deliver cluster plan projects and consider more broadly how workforces will need to grow and adapt to the needs associated with transitioning the entire industrial sector to net zero by 2050.

- Ownership of this action falls under the purview of professional and industry bodies, with industrial cluster members, the Department for Science, Innovation and Technology (DSIT), and the Department for Education (DfE) as key stakeholders.

Roles and responsibilities:

Bridging the gap between interim milestones and delivery of net zero will require concerted effort across all stakeholder groups, including national government, local government, industry, professional bodies, and research institutions.

Government actors are well positioned to provide strategic direction and enabling instruments at the national level, providing the frameworks within which industry can operate.

Industry action is required to inform government of what signals they need, by when, to implement their decarbonisation plans.

Professional bodies, research institutions, and other academic/industry collaborations will be instrumental in delivering research and analysis to support decision-making and the knowledge generation and transfer that the transition to net zero will require.

Implementation considerations:

Market development: While the supply side will take on many actions in the initial stages, attention should be given to creating a sufficient driver (e.g., incentives, standards, or other requirements) on the demand-side to develop a sustainable and robust market for low-carbon products, including hydrogen.

Technology agnosticism versus market signals: The gap analysis would need to consider how to maintain a degree of technology agnosticism and avoid prematurely "picking winners" while providing a clear enough signal of national priorities and plans. While this is certainly a challenge, this may reveal common dependencies between various pathways, and inform any required prioritisation exercise (see the following consideration). Market signals should be interpretable to the market (i.e., delivered with enough simplicity and clarity of message) to inspire confidence and unlock investment.

Prioritisation: As a counterpoint to the above, there may be an element of prioritisation that needs to happen, as not all interventions can be deployed at the same time due to resource and capacity constraints. Therefore, there is a consideration around what this sequencing process might look like and how to effectively prioritise while maintaining flexibility. Plans will need to be flexible enough to accommodate changes and improvements in pace or technology, with regular horizon-scanning to inform investment decisions.

Global emissions: As the UK works to decarbonise on a territorial basis, the impact of decisions on global emissions should be considered as well. Emission reductions purely due to de-industrialisation and offshoring will not support the global shift to a net zero economy if leakage occurs.

Knowledge transfer assumptions: In some cases, benefits may extend to remaining industrial sites organically, without further intervention – however, there may be some cases where additional assistance may be required. This is particularly relevant for the action plan for extending benefits of cluster decarbonisation to dispersed sites. Action on decarbonising dispersed sites should not wait until clusters have decarbonised; progress must be made at pace across the whole industrial sector. Commercial sensitivity may prove to be a barrier to knowledge sharing, both in terms of data to feed into national-level gap analyses and in sharing information to support skills development.

Political uncertainty and delays: Due to the long lead times for projects, any delay in communication or shift of government priorities may have knock-on effects to implementation and investment timelines.

Recommendation 2: Rationalise and expedite permitting for common infrastructure

Slow and inefficient permitting of infrastructure has a knock-on effect on the applicants' abilities to plan with certainty, attract investment, and advance to the deployment phase of projects. Common infrastructure, i.e., pipelines for CO_2 transport and hydrogen networks, is central to the decarbonisation plans of the industrial clusters. However, common infrastructure projects are amongst those impacted by the UK planning system's unpreparedness for the complexity and novelty involved with net zero projects.

The government is revising the *energy National Policy Statement*, which sets out the government's policy for the delivery of energy infrastructure and provides the legal framework for planning decisions[197]. The government has also published its *NSIP Action Plan* (February 2023), which sets out how the government will reform the consenting process to ensure the planning system can meet the demands of a greater number and complexity of cases[198]. However, the comprehensiveness of updates remains to be seen. It is critical that the planning system can respond promptly to changes in the regulatory environment, as well as efficiently and robustly process the applications from common infrastructure projects that are at the core of the cluster plans without compromising on health and safety.

Any national level measures should complement and work synergistically with local planning measures noting that the optimum approach for permitting the decarbonisation infrastructure on smaller, dispersed sites will differ from that of large, common infrastructure projects.

To capitalise on existing efforts from the government and other stakeholders to expedite the consenting process for common infrastructure, *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation* recommends the following next steps:

Ensure that planning system reforms go far and fast enough for the industrial clusters to realise their net zero targets, without compromising on local communities' ability to engage in the process. To support this action, UK government may consider prioritising common infrastructure projects for the fast-track permitting process outlined in the *NSIP Action Plan*, as well as enabling projects part-way through the permitting process to benefit from the rationalisation of the planning system. Furthermore, public entities involved in the regulation of infrastructure development can also engage with international counterparts and involve relevant experts to address challenges related to the permitting of novel common infrastructure projects in a way that benefits the communities that host them. Finally, a mechanism to capture and act on the learning gained from the consenting of novel projects can also help realise this recommendation in the UK industrial decarbonisation context.

- Ownership of planning system reforms would be infrastructure-related central government organisations such as DESNZ, the Department of Levelling Up, Housing and Communities (DLUHC), and the Planning Inspectorate. The Department for Environment, Food and Rural Affairs (DEFRA) should also be involved given their environmental permitting remit.

Proactively build public understanding of the need for, and acceptance of, the infrastructure and technologies required for industrial decarbonisation. This involves shaping the local and national narrative on the societal changes and infrastructure development needed for the UK to achieve industrial decarbonisation, as well as engaging with a broad group of stakeholders throughout the project lifecycle. Support for net zero infrastructure development, especially in host communities, cannot be assumed. Fostering understanding and acceptance of the necessity of industrial decarbonisation infrastructure may reduce opposition to proposed developments. Stakeholder engagement may help mitigate against delays due to challenges and objections that surface during the permitting process.

- This work would require ownership and involvement from DESNZ, IDC clusters, and infrastructure developers along with support from key stakeholders such as the National Infrastructure Commission.

Roles and responsibilities:

Government agencies and infrastructure developers both have roles to play in rationalising and expediting permitting for common infrastructure.

Government agencies set forth and follow a clear regulatory procedure on permitting infrastructure: establishing guidelines, coordinating between partner agencies, communicating with applicants, and conducting accurate, prompt reviews of requests. It is the role of regulators to maintain a holistic view of the system to avoid any unintended consequences, e.g., the dilution of standards around health and safety.

Infrastructure developers should be open, communicative partners, engaging with relevant agencies to provide feedback and constructive dialogue on ongoing changes needed in the permitting process.

Implementation considerations:

Holistic approach: A holistic approach to planning system reform, i.e., taking a system-level view, will benefit industrial decarbonisation infrastructure permitting as it could better respond to the difficult-to-predict consenting bottle-necks novel projects may face.

Coordination: Infrastructure permitting is a process that can become complex very rapidly. These complexities may stem from the various agencies involved as well as added layers if the project is based in, or partly in, a region with a devolved government. These variables elevate the importance of coordination between the relevant public entities; otherwise, the streamlining effort can be susceptible to delays and inefficiencies. In addition, permitting and planning can rely on commercially sensitive information, particularly with novel technologies, which is a potential additional challenge that needs to be managed through any revised processes and mechanisms.

Operational capacity: The number of decarbonisation related projects` that need to undergo a consenting process is likely to increase. Therefore, a key implementation consideration is the resourcing, capacity, and development of net zero infrastructure knowledge capabilities of the agencies involved in the process. It is important to monitor regulatory agencies' changing service demands and respond in a timely manner such that they can continue to process net zero infrastructure projects at the required rate.

Contingency planning: Contingency planning within the teams driving the consenting process forward on both the applicant and regulator sides is important given the typical multi-year timeframe involved in reaching a decision.

Recommendation 3: Formalise an Industrial Cluster Advocate with strong government connections and develop a mechanism for ongoing coordination and communication with industrial clusters

Industrial cluster decarbonisation has significant value to the UK. However, it also requires a notable amount of change from both industry and government across legislation, commercial arrangements, infrastructure provision, and industrial activities. As individual projects are funded, there is a risk that the benefits of the cluster approach are overlooked, and the project is evaluated and implemented in isolation from its broader potential impact on the decarbonisation of the region.

To encourage a continued holistic approach, the UK government and industry need clarity and alignment on roles and responsibilities, timeframes, and expectations to strike the right balance between public sector support and private sector led development. Where these are misaligned, the right policy settings may not be in place to spur private sector actions, resulting in delays in investment decisions and implementation. There may also be a default to the status quo with individual entities solely looking out for their own commercial interests as opposed to the synergies that benefit both themselves and the cluster at large.

The IDC has created a platform for collaboration and communication between government and the industrial clusters and demonstrated the value of intentional coordination in creating meaningful impacts on decarbonisation planning. However, the cluster plan portion of IDC has now ended with the successful publishing of the six plans. While some IDC clusters will continue to engage closely with teams in government on specific technologies, e.g., Track-1 CCUS clusters working with DESNZ, there is no ongoing formal channel for holistic engagement with clusters on their plans for decarbonisation. Given the integrated nature of the changes the clusters plan to implement as well as similarities in opportunities and challenges faced, government should continue to engage with the IDC clusters to ensure roadblocks are addressed and the cluster plan ambitions are achieved.

To take this work further, *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation* recommends the following next steps to support ongoing coordination and communication between government and industrial clusters on cross-cutting challenges:

Establish a formal Industrial Cluster Advocate with strong government connections to coordinate across the relevant departments and engage with the cluster taskforce (see subsequent next step). This involves identifying a senior leader, perhaps a government official, to take ownership of the relationship with the clusters and help navigate the relevant stakeholders across government that are responsible for policy, legislation, and funding levers for industrial cluster decarbonisation. The Industrial Cluster Advocate would serve as a centralised government lead for understanding, articulating, and safeguarding both cluster and government needs and priorities for decarbonisation. There should be sufficient independence such that the Advocate can truly represent the clusters' requests to government while also possessing enough authority to convene decision-makers across various government departments. Exactly where the Industrial Cluster Advocate should sit within, or adjacent to, government to best perform this role while maintaining the desired independence requires careful consideration.

This individual would be responsible for understanding the needs identified by the clusters, communicating what is actionable and appropriate for government support, and facilitating the right conversations between the cluster taskforce and the relevant parts of government. For example, the Advocate could identify synergies between government work programmes that would affect cluster decarbonisation and engage with the cluster taskforce on their effectiveness. The Advocate could also support clusters by facilitating the development of public messaging on the benefits of low-carbon industrial activity, which could be adapted to each region. Additional Advocate responsibilities would include stimulating interest in the skills and investment required for cluster decarbonisation, promoting best practice and ideas, and fostering information flow to ensure clusters have long-term certainty and confidence to make the investments necessary to deliver their net zero objectives.

- Ownership and support of establishing a formal Industrial Cluster Advocate falls under the purview of DESNZ. However, it is important to note that DESNZ may determine that the Advocate will be most effective by sitting outside of government and careful thought should be given to this. Ofgem, HM Treasury, Infrastructure and Projects Authority, and other departments are important stakeholders.

Establish a formal taskforce of cluster advocates to speak on behalf of the industrial clusters and collaborate with the Industrial Cluster Advocate from government. For the Industrial Cluster Advocate to work effectively, industrial clusters must establish designated delegates as well. This involves the clusters collectively identifying trusted representatives from within the clusters who can convey cluster plan progress and articulate their needs at a level of specificity that is actionable for government, e.g., the sequential nature of needs and interdependencies. The cluster taskforce should liaise regularly with cluster stakeholders to collate views and agree on a collective and prioritised set of requests to take to government. The taskforce will need to share data and insights with the Industrial Cluster Advocate, and other government departments as necessary, and communicate government priorities back to cluster stakeholders.

- Ownership of a formal cluster lead or leads should be discussed amongst the six cluster plan owners identified to carry the work forward. Though the initial focus will be representing the IDC industrial clusters, other industrial clusters would be expected to join the taskforce in the future.

Establish an agreed mechanism to support ongoing coordination and communication between the Industrial Cluster Advocate and cluster taskforce. This could involve regular meetings, e.g., quarterly, with additional collaborative workshops or briefings with a broader set of stakeholders bi-annually. Alternatively, it could be as formal as a Public Private Partnership, where government and the cluster taskforce enter into contractual agreements to deliver specific outcomes. The decision will be up to the cluster taskforce and Industrial Cluster Advocate to work together to identify the preferred mechanism for collaboration. Regardless, the mechanism should facilitate frequent and regular interactions between industrial clusters and government and bring the right individuals to the table so productive conversations and decisions can be made.

- Ownership of establishing and agreeing upon collaboration mechanisms belong to the Industrial Cluster Advocate and cluster taskforce. Broader government participation in collaboration efforts involve DESNZ, Ofgem, HM Treasury, Infrastructure and Projects Authority, and other departments, as necessary.

Roles and responsibilities:

Aligning the significant amount of change required across government and the industrial clusters to deliver decarbonisation necessitates ongoing engagement from both the government and industrial clusters.

Government actors can provide insight into the priorities and decisions made at the national level. They should also offer adequate opportunity for and be receptive to feedback from industrial clusters.

Industrial clusters can proactively inform government of what signals they need, by when, to implement their decarbonisation plans via the taskforce. While taskforce membership will be initially focused on those carrying forward the IDC cluster plans, additional cluster representatives may join in the future.

Implementation considerations:

Organisational configuration for the Industrial Cluster Advocate: Careful thought should be given to where the Industrial Cluster Advocate should sit to be the most effective. The Advocate should be in a position of authority and able to convene the relevant government departments while also be unencumbered to facilitate transparent coordination and communication with the cluster taskforce members. IDC will work with DESNZ to specify this role and support implementation.

Resource availability and funding: Ongoing engagement between government and the industrial clusters requires dedicated resourcing and availability. Both government and industry will need to commit to working together and dedicate the required number of resources to engage with each other, both in terms of time and funding.

Transparency with industry outside of clusters: While the purpose of these roles is to align the coordination between government and the IDC clusters, there should also be transparency with industry beyond those boundaries. Relevant information and key learnings should be made available to support decarbonisation of industry more broadly, including with dispersed sites.

Recommendation 4: Develop actionable measures and timings of jobs and skills requirements needed for industrial clusters to decarbonise

Cluster plans are operating on a compressed timeline to achieve the UK's 2050 net zero target. Many of the proposed projects will take place close to, if not at the same time, as one another to be able to actualise the emissions reductions by national deadlines. Both public and private stakeholders have acknowledged concerns around the pressures this timeline places on the supply chain for delivering industrial decarbonisation. The challenge to acquire the level of capital needed to realise projects, which business models can encourage, is recognised. However, the availability and allocation of UK labour to execute the required industrial cluster decarbonisation projects are equally urgent concerns.

Stakeholders across the public and private sectors have already started to identify what might be needed to secure an adequately sized and skilled workforce to deliver on the decarbonisation projects outlined in the cluster plans. However, more detail and coordination are required to provide a level of certainty that the cluster plans will have the workforce needed to action delivery.

To take this work further, *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation* recommends the following next steps to supply sufficient workers at the times needed to execute the industrial clusters' decarbonisation aspirations:

Systematise how industrial clusters identify the occupations, competencies, and timing required of the skilled workforce necessary to execute planned decarbonisation projects. Coordinate this analysis across IDC clusters to understand the aggregate need. This involves establishing a consistent method of modelling workforce and skills needs based on planned projects and mapping the regional requirements to understand the availability and allocation gaps. A starting point for this work could be validation of the analysis in the *Enabling Skills for the Industrial Decarbonisation Supply Chain* report from IDRIC[199], which was developed prior to the release of the full IDC cluster plans. Transparency on timing of project buildout to understand workforce demand after construction periods conclude and developments enter their operational and maintenance phase is also important to help develop a national view on industrial cluster needs.

- While individual IDC clusters should provide modelling inputs, a government entity such as DESNZ, national research centre such as IDRIC, or partnership between the two should compile the national view of industrial cluster skilled workforce needs.

Clarify and reinforce roles and responsibilities for clusters and government in developing and maintaining the UK's industrial decarbonisation labour supply. Given the substantial number of large-scale projects that must take place within industrial clusters, the UK government should ensure that industrial cluster labour needs remain a priority amongst efforts to support the net zero workforce more broadly. To assist, clusters should identify tactical ways the public sector, educational institutions, and other entities can help address their evolving labour demand and efforts that they can undertake as well. In this respect, UK government
and clusters can better align on expected roles and responsibilities for one another through regular dialogue.

- Ownership of this action likely falls within DESNZ's purview given their involvement in central government initiatives like the Green Jobs Delivery Group. Other government entities like the Department for Education may also support this recommendation. The Industrial Cluster Advocate proposed in *Recommendation 3* can also play a role in facilitating the exchanges between industry and government on industrial decarbonisation workforce needs.

Break down information silos on labour demands and skills supply. Securing a workforce with the skills to deliver net zero is as much about the successful coordination, reskilling, and allocation of existing workers as it is about developing new sources of supply. For IDC industrial clusters, this involves streamlining workforce planning efforts across industry sectors through transparent and timely sharing of labour market intelligence so that projects have the right workers they need at any given point in their development phase. This can be facilitated through the designation of a local entity (e.g., authority, commission, etc.) that would coordinate across cluster project timelines to anticipate periods of high labour demand and mitigate related resource constraints. To support this work, the entity would additionally coordinate with the organisations taking the cluster plans forward to mediate information sharing between industrials (e.g., normalising firm data on labour and hiring), promote labour market opportunities, and liaise with cluster workforce ecosystem stakeholders (e.g., employers, workforce development organisations, education institutions)

- This work is contingent on participation from industrial partners within IDC clusters and their ability to find shared value in taking a collective approach to executing decarbonisation projects. However, ownership of breaking down information silos sits with a more centralised regional body or broader industry group (e.g., Carbon Capture and Storage Association). Depending on the entity selected for coordinating this work, there may be space for local government entities such as combined authorities and devolved administrations of the regions in which IDC clusters are based to facilitate some aspects of the labour market intelligence. Academic and industrial collaborations or research institutions may have a supporting role.

Roles and responsibilities:

Successful implementation of this recommendation relies on both central government entities and cluster industrial partners.

Government should align on priorities and capitalise on opportunities for intergovernmental coordination (e.g., DESNZ, devolved administrations of Wales and Scotland, combined authorities of the regions in which IDC clusters are based, etc.). Government entities should also expect to coordinate with external organisations such as industry, community-based organisations, education, and training providers to effectively action recommendations.

Industrial clusters should be transparent, with each other and with the government, to ensure the smooth flow of sufficient data required to support targeted workforce planning and labour allocation efforts. They should also undertake efforts of their own to develop the skilled labour supply once roles and responsibilities with government are clarified.

Research institutions and programmes can take the lead on research and analysis or support government efforts in doing so.

Implementation considerations:

Time horizon required for investment: Labour is not a "just-in-time" asset. Accumulating skilled, experienced workers takes time. This adds complexity to meeting additional demand, particularly when many of the most productive UK workers in relevant fields are reaching retirement age.

Demand for skilled labour beyond clusters: Since all sectors of the UK economy will have to undergo emissions mitigation, the labour allocation problem not only encompasses the industries represented within the IDC Clusters, but also across the wider economy. As such, it is important to consider how needs from additional clusters, dispersed sites, and other major infrastructure projects may impact availability of skilled workers for industrial cluster decarbonisation.

Decarbonisation context: The type of skills needed for industrial decarbonisation may vary depending on context. At the planning and regulation level, there may be labour demands as well (e.g., additional capacity, learning). These various stages through which industrial decarbonisation skills should be considered are a critical part of facilitating a smooth and efficient transition to net zero.

Equity, diversity, and inclusion (EDI): Approaching industrial transition to net zero with a focus on EDI principles is critical in this evolution of UK industry. The prioritisation of equity in building and securing a skilled workforce for industrial decarbonisation helps ensure that all individuals and communities are empowered in the progress towards a more sustainable future.

Local community benefits: Recognising the spatial dimensions of workforce planning for industrial decarbonisation can help clusters adopt a place-based approach to solutioning. This increases opportunities for the local communities to retain more of the associated benefits.

Recommendation 5: Define and prescribe methodologies for decarbonisation impact estimating

IDC, including the development of the cluster plans, has been funded by the public sector to accelerate decarbonisation and achieve the UK's legally binding emissions targets. Aggregation of the estimated impacts of the projects is important to understanding the contribution that the cluster plans, and other publicly funded efforts, will collectively make to achieving the national target.

While the NAEI provides a consistent method for aggregating current direct emissions of sites that are required to report their emissions, including through use of large emitter point sources reported through the UK ETS, the way in which future emissions and emissions reductions are estimated varies from project to project, or cluster to cluster[xxiv]. While analysis, such as that undertaken by the CCC, may apply a consistent methodology across a sector-wide portfolio as a top-down assessment of how emissions may change, agreement on a bottom-up methodology for assessing future emissions impacts has not been widely agreed upon. Centralised ownership of prescribed methodologies, e.g., by a government body, could increase the effectiveness of impact modelling at the portfolio and national level.

Through review of the different approaches taken to emissions impact modelling by the clusters, *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation* recommends the following next steps to define and prescribe methodologies for decarbonisation impact estimating:

Require decarbonisation projects and plans to estimate their impacts using consistent methodologies with standardised baselines and assumptions, for example on applications for public funds. Projects reporting their impacts (such as GHG emissions, resource demands, and economic benefits) using a consistent methodology would enable like-for-like comparison of projects in the pipeline. This would be particularly important for considering funding allocation and understanding impacts on existing infrastructure, such as electricity networks. Making decisions with consistent information is likely to result in increasingly effective delivery of the UK's emissions targets. To this end, it is also important that projects provide sufficient access to and transparency of their impact estimates.

- Ownership of setting out this requirement belongs to DESNZ, UKRI, and other public funding bodies.

Develop a bottom-up emissions estimating methodology for projects that is consistent with national-level forecasting. Emissions estimates that can be aggregated across all projects would enable gap analysis against the carbon budgets and sector pathways, as set out by the CCC. This gap analysis between forecasts and required pathways would aid in hotspot identification for further support and funding. At a minimum, this must cover direct emissions but could be expanded to cover supply chain emissions where relevant to decision making.

- Ownership of defining the methodology belongs to DESNZ and CCC. They can be informed and supported by academic, research, or other scientific organisations.

Reduce the emissions reporting threshold over time for industrial sites to increase visibility of the large number of small industrial emitters. NAEI point source data has been used by many of the IDC clusters to establish their baseline emissions. However, this only presents the larger emitters and therefore does not represent all emitters that could be included in local decarbonisation efforts. Reducing reporting thresholds for the authorities that provide data to the NAEI would increase the understanding of the clusters' emissions and accurate representation of emissions that could be addressed within the cluster plans. This could also increase the number of organisations locally engaged in cluster decarbonisation.

- Oversight of reporting thresholds belongs to DESNZ, DEFRA inventory teams, and NAEI agencies.

Roles and responsibilities:

Defining and prescribing methodologies for decarbonisation impact estimating is primarily the responsibility of government.

The **progress tracker** (i.e., a government body or the CCC) should take ownership of creating these methodologies and establishing the requirements to use them.

Reporting entities should have input to the development of the methodology, to help determine fitness for purpose.

Academic, research, or other scientific organisations that can speak to best practice can provide additional support, particularly related to methodology development.

xxiv. See Appendix 2 for further details on the methodologies used by the cluster plans.

Implementation considerations:

Clarity of purpose: The purpose of the reporting exercise must be established prior to any methodology development as many of the differences in methodology taken by the clusters stem from variances in the fundamental objectives of their modelling. Articulating the purpose and its benefit of indicating industrial clusters' contributions toward national net zero goals may also contribute to buy-in.

Data constraints: Any methodology must take into consideration data constraints that may be faced at various stages of a project, with different levels of detail for each of the major project milestones. This may mean relying on industry-average factors and assumptions at initial stages and moving towards project or location specific data at later stages of project development.

Consistency: Where possible, any methodology should make use of, or align with, existing standards and other reporting mechanisms that projects may also be required to use, such as The Green Book[200], to reduce burden on projects while still maintaining utility.

Scenario modelling: Any methodology should include the definition of a few key scenarios, to understand the impacts of certain assumptions on the calculated impacts. This would allow the progress tracker to understand key tipping points, such as hydrogen costs or grid decarbonisation, and monitor or influence them.

Enforcement mechanisms: The ability to require all relevant projects to use the prescribed methodologies for impact estimating is key to understanding the industrial clusters' contributions to the national picture and identifying true gaps between plans and targets.

Evolution of technologies: Decarbonisation impacts may change according to the efficiency and efficacy of technology, which will change over time; this underscores the importance of keeping assessments up to date and clearly documenting assumptions for traceability.

Burden of reporting: When lowering the threshold for reporting, it is important for there to be a balance between the level of visibility needed and the effort required to gather and report this data. Based on the rate of tool and technology development in the emissions reporting space, it is expected that there will become a time when the burden is sufficiently low on reporting entities, and the benefits of the data visibility large enough, to justify the lowering of the reporting threshold.

Considerations for curbing industrial emissions beyond the cluster plans

The cluster plans' work has applications for decarbonisation beyond the current cluster-defined boundaries. Two distinct groups could potentially benefit: 1) emitters proximate to the cluster but not encompassed by the cluster plan and 2) emitters with profiles like those in the cluster plans but that are geographically dispersed.

Emitters in proximity to clusters can benefit from common infrastructure and access to emerging markets

Work by the Black Country Industrial Cluster illustrated that while the NAEI large point sources in the geography of the cluster amounted to 0.5 $MtCO_2e$ from 26 sites, the total emissions of the cluster are estimated to be closer to 3.2 $MtCO_2e$ from 2,800 sites when smaller emitters in the area are included[201]. As the Black Country region covers a wide geographic area, this ratio of NAEI to non-NAEI sites may not be representative of all clusters. However, the ratio does provide an indication of the number of smaller sites that could be within geographic proximity to an existing cluster.

These sites, although small, can benefit in the long-term from access to common infrastructure developed within a cluster. For example, this can reduce hurdles to accessing transportation and storage infrastructure for carbon capture or hydrogen produced elsewhere in a cluster, enabling hydrogen fuel switching. Inclusion in the cluster ecosystem, which provides access to these interventions, could accelerate the decarbonisation of these smaller sites.

Large emitters that are geographically dispersed can learn from early implementation in clusters and sector-specific insights

The *Industrial Decarbonisation Strategy* highlights that around 50% of industrial emissions from NAEI large point sources are in dispersed locations, i.e., not geographically close to a cluster. This shows the scale of the challenge outside the clusters. Dispersed sites typically face challenges around access to common infrastructure, but they could still benefit from the cluster plans' work.

While many of the interventions used within the clusters can be applied to multiple sectors, implementation within a specific process or asset type can provide excellent sector-specific insights for comparable sites outside the clusters.

For example, the application of CCUS to a specific process, such as cement calcination, would provide sector-specific insights for other cement plants. To understand which sectors can benefit directly from IDC cluster implementation learnings, an analysis of sector point source locations was undertaken. The analysis highlights those sub-sectors such as chemicals, iron and steel, and refining have a strong presence within clusters in the UK. Therefore, sites in these sectors operating on dispersed sites can assess whether learning from the cluster plans can be directly applied when developing their own decarbonisation strategies.

Where sectors are not well represented in clusters in the UK (e.g., cement, paper, and food and drink industries), or site differences eliminate the possibility for direct learnings, indirect learnings about types of non-sector-specific interventions, such as the use of hydrogen for heat, may be available. However, sub-sectors with minimal coverage in cluster plans may have to develop additional sector-specific solutions.

Black Country Industrial Cluster's concept of Zero Carbon Hubs can be applied as the foundation of decarbonisation plans for small groups of emitters

The Black Country Industrial Cluster's unique aspect, compared to the other IDC industrial clusters, is its objective to set out a replicable model for the decarbonisation of many small groups of emitters across a wide geography. The replicable methodology is primarily focused on manufacturing locations with an "anchor" site that is particularly energy intensive, which can form a "Zero Carbon Hub" with neighbouring manufacturing businesses. It is expected that 60 such hubs can be created within the Black Country region by 2040, with six initial hub masterplans created to develop and test the methodology.

Through knowledge sharing and collaboration, the Black Country Industrial Cluster's approach could be applied in other regions with high numbers of smaller emitters. The practical examples provided through implementation of the pilot Zero Carbon Hubs, and work undertaken by the new National Centre for Manufacturing Transition, will be key sources of learnings that can accelerate decarbonisation of small industrial hubs across the country.

Conclusion

The IDC cluster plans bring the UK one step closer to delivering its ambitions for industrial cluster decarbonisation.

Decarbonisation is the defining challenge of our time. Its complexity, urgency, and magnitude require unprecedented partnership and investment. Understanding this, the IDC has catalysed the partnership and planning required to achieve the UK's net zero targets, while also identifying reproducible models that boost the competitiveness of key industrial regions, drive inward investment, create jobs for a low-carbon economy, and grow the low-carbon export market.

The six cluster plans have initiated tangible momentum towards decarbonisation solutions. They are the result of multiple years of analysis by the IDC industrial clusters to understand their emissions, the options to abate them, and the impact decarbonisation could have on their businesses, local communities, and the UK. Their work reveals that there is no silver bullet for decarbonising industrial clusters, but collaboration, innovation, and investment are the starting point for success.

Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation has brought together the key learnings across the cluster plans, illuminated the practical realities of industrial cluster decarbonisation, and identified recommendations that will enable industrial cluster decarbonisation to scale across the local, regional, and national level. Now is the time for industry, government, and stakeholders to move from planning to implementation and deliver net zero.

Appendix 1: IDC cluster plans assessment

National strategy policy gap analysis

In the Industrial Cluster Decarbonisation Framework, the national strategy element encompasses the government policy, regulation, and funding that guides and supports all industrial cluster activity and influences the decisions that the clusters make. Each of the cluster plans highlight changes related to national strategy that could address barriers they face in decarbonisation. The aim of this analysis is to identify gaps between the existing national strategy and the national-level policy measures the cluster plans identify as being integral to their success.

The cluster plans for Net Zero North West and South Wales Industrial Cluster each referenced at least 20 needs that could be, at least partly, addressed by national-level interventions. The other four cluster plans mentioned 10 such needs or less. The extent to which the industrial clusters highlight changes in policy and regulation needed to support their decarbonisation was influenced both by the scope of decarbonisation options considered, which was in turn influenced by the level of funding received to develop their plans, and their decision as to what to communicate through their cluster plans.

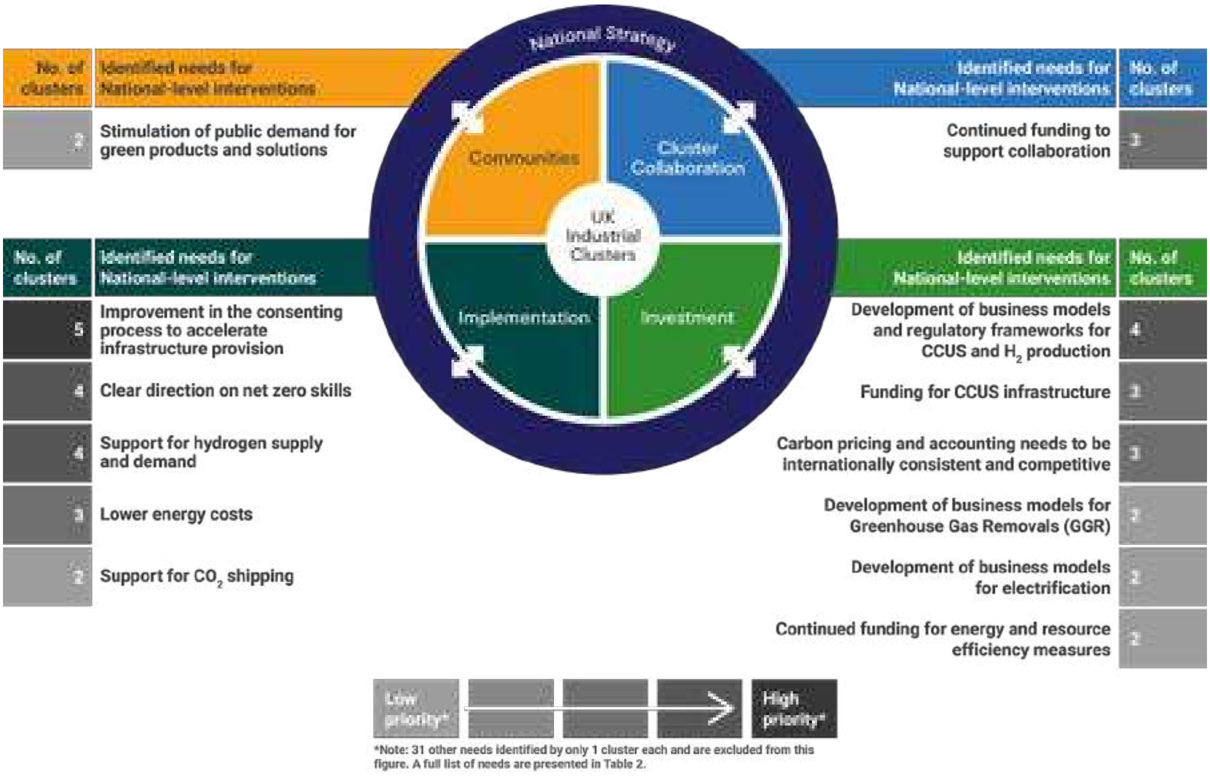


Figure 10: Major policy needs for unlocking decarbonisation potential as identified by cluster plans mapped to the Industrial Cluster Decarbonisation Framework. A complete list of policy needs raised appears in Table 1.

From the list of 44 unique needs raised in the cluster plans (see **Table 1** at the end of this analysis), 13 were noted by at least two industrial clusters. These are presented in **Figure 10**. A shortlist of the policy needs raised by most of the cluster plans, and therefore designated as high priority, are discussed in more detail below.

Please note that as this prioritisation of policy needs is based on number of mentions by clusters, it is not intended to represent the scale of the impact of the issues in question. The ranking of priorities for general UK-wide industrial decarbonisation would also differ from the one presented here. A case in point is that though only two IDC industrial clusters, i.e., *the Scottish Net Zero Roadmap* and South Wales Industrial Cluster, identified a need for support of CO_2 shipping, this is a high priority for UK industrial decarbonisation more generally, and specifically for industry located around Londonderry, Southampton, and Medway[202]. Nevertheless, there is generally good alignment between the high priority needs raised by the IDC industrial clusters and those identified by the Industrial Decarbonisation Research and Innovation Centre (IDRIC) in its *2022 Policy Synthesis Report*[203].

Policy need 1: Improvement in the consenting process to accelerate infrastructure provision

The consenting process in infrastructure development refers to the process required to obtain all the necessary approvals, permissions, and consents to start a build. Barriers relating to consenting were the most frequently raised in the industrial regional cluster plans, mentioned in all but one.

The government is clarifying the regulatory framework for net zero infrastructure consenting by revising the NPS and existing work between DESNZ and Ofgem to streamline processes[204,205]. The NPS sets out the government's policy for the delivery of energy infrastructure and provides the legal framework for planning decisions. Also, in the time since the finalisation of the cluster plans, the government published its *NSIP Action Plan* (February 2023) which sets out how the government will reform the consenting process to ensure it can meet the demands of a greater number and complexity of cases[206].

Analysis of the current policy provision and references to consenting in the cluster plans identified the following policy gaps:

Gap 1.1: Support for the extensive coordination required in the permitting and development of common infrastructure.

Common infrastructure is a feature of all the cluster plans and central to the national *Net Zero Strategy*. The Local Industrial Decarbonisation Plans competition 2023, for instance, focuses on common infrastructure as a key area[207]. However, common infrastructure development is associated with extensive stakeholder coordination. For example, the Tees Valley Industrial Cluster notes that common infrastructure for hydrogen transport is dependent on coordinated action across multiple stakeholders including a gas distribution network, a gas transmission company, and regional and national hydrogen development projects[208]. There are significant challenges associated with managing stakeholders' inputs into the consenting process and fully communicating how the project is both dependent on, as well as an enabler for, other infrastructure and yet-to-be established markets and technologies.

If common infrastructure projects are delayed, it can cause additional postponements to the decarbonisation capabilities they enable. For example, uncertainty as to whether shared CO_2 transport and storage infrastructure will proceed has led industry to delay necessary upgrades on their own sites[209].

Government has committed to enhancing the pre-application advisory service for NSIP to support early, meaningful engagement and the potential resolution of differences between key parties[210]. This, and the continued consideration of unique consenting challenges facing common infrastructure, will start addressing the complexity and necessary coordination associated with net zero infrastructure planning applications but should be monitored for effectiveness.

Gap 1.2: Insufficient resourcing for planning consent and permitting development.

South Wales Industrial Cluster raised the issue of insufficient regulator resourcing for planning consent and permitting development, which could deter industrial investment in the region[211]. Capacity and capability shortages are a constraint across a range of planning and consent activities nationally, impacting both local authorities and the Planning Inspectorate[212]. Regulators may have knowledge gaps related to net zero infrastructure technologies and markets, particularly related to hydrogen storage. Addressing any skills gaps would support the timely and consistent processing of planning applications. At a national level, the Department for Levelling Up, Housing and Communities (DLUHC) is leading the development of broad-based workforce strategies to address skills and capabilities gaps in government agencies. DLUHC is also conducting wider work to build skills and capacity in the planning profession, including through the Innovation and Capacity fund. While these efforts are ongoing, it is unclear whether and when the extra resources will be available at the scale needed to address the resourcing barrier.

Gap 1.3: Insufficient control of the costs associated with permitting and regulatory challenges.

Permitting and regulatory challenges can drive up the costs of consenting large infrastructure projects, as well as increase the uncertainty related to those costs. These challenges relate both to the general permitting process as well as the need to engage with regulators and other third parties during the process to address their queries and objections. The Black Country Industrial Cluster stated that the costs associated with permitting and regulatory challenges could influence technology deployment decisions[213]. In the Black Country Industrial Cluster's case, the logistical, permitting, and regulatory challenges associated with electrolytic hydrogen production influenced the preference for shared hydrogen production facilities over electrolyser deployment on individual sites in the cluster plan (i.e., the option requiring them to undertake fewer consenting processes).

Capturing and applying the learning gained from the consenting of first-of-a-kind projects could streamline the consenting process and help alleviate some of these costs. The government's plan to move towards full cost recovery in the planning system by 2024 will impact the uncertainty in, and overall scale of, consenting costs for net zero infrastructure developers[214].

Gap 1.4: Framework for delivering consistent community benefits to communities hosting net zero infrastructure.

As discussed further in the **communities analyses**, clusters recognise that the onus is on them to secure a social licence to operate. Societal understanding and acceptance of the trade-offs associated with net zero infrastructure development can mitigate against lengthy and costly challenges that can impact the success of consenting processes.

A framework for delivering consistent benefits to communities hosting net zero infrastructure could help standardise and build trust in the process of compensating communities that host such infrastructure[215]. While the electricity sector has such a framework, there is no similar one for other networked infrastructure, such as hydrogen transport or CCUS[216]. Such a framework could address concerns around the equitability of net zero infrastructure, improve public acceptance for the planned developments, and streamline the consenting process.

Takeaway

The above gaps highlight the importance planning system rationalisation has on the realisation of industrial decarbonisation. Complexities associated with net zero infrastructure consenting, i.e., the permitting of common infrastructure and the delivery of consistent community benefits, need to be addressed robustly by a resourced, cost-effective planning system.

Policy need 2: Clear direction on net zero skills

Cluster plans widely cite skills development as both a barrier and a beneficial outcome of their industrial activities. Four of the IDC clusters highlighted a need for further policy provision to support industry in accessing the skills needed to implement their net zero roadmaps.

The government recognises that workforce skills are likely to be a bottleneck as net zero infrastructure deployment ramps up and acknowledges that it has a role in identifying and working with industry to tackle net zero specific workforce challenges and skills gaps[217]. To that end, government has set up a Green Jobs Delivery Group, a joint endeavour between government, industry, and the education sector, committed to the continued implementation of the Department for Education's *Sustainability and Climate Change Strategy*[218]. Government is also driving the reform of apprenticeships to deliver on employers' net zero workforce needs. The development of short, intensive bootcamps will support apprentices, and existing employees, in gaining skills required for the net zero transition[219].

The following policy gaps were identified by analysing the current policy provision and references to skills development in the cluster plans:

Gap 2.1: Industry lacks clarity on government's net zero skills plan.

Industrial clusters anticipate that workforce shortages for engineers with relevant expertise, electrical and electronic tradespeople, process plant and machine operatives, and construction workers could impact their decarbonisation plans. Net Zero North West identifies the lack of a coordinated strategic plan for net zero skills development as a barrier and calls for piloting more innovative mechanisms for skills development[220]. While the government has committed to developing a strategy in collaboration with industry (i.e., the *Net Zero and Nature Workforce Action Plan*) it is not expected to be published until 2024[221].

Gap 2.2: Disconnect on whether, and to what extent, net zero skills development is the responsibility of industry as well as government.

Several cluster plans highlight barriers associated with skills development that could be addressed by national-level government interventions. South Wales Industrial Cluster sees a role for skills accelerator programmes to ensure a new generation can capitalise on the career opportunities presented by industrial decarbonisation[222]. Other proposals to alleviate the anticipated skills shortfalls include timely engagement with training and education stakeholders[223] and focused collaboration[224]. However, the government sees development of net zero skills as a joint responsibility for industry and government and expects large corporations to invest in the skills they need for the energy transition alongside the national interventions[225]. There is a potential disconnect between government and industry expectations of how the responsibility for net zero skills development will be shared.

Gap 2.3: Government requires a holistic view on the specific skills requirements for industrial cluster decarbonisation.

The government requires more granularity on the skills development needs of the industrial clusters to better target and scale any interventions[226]. Four of the regional industrial clusters (Humber, Net Zero North West, South Wales, and Tees Valley Industrial Clusters) reference research into skills in their cluster plans, but the extent of that research varies. The exercise of synthesising the findings of these research efforts to provide a more comprehensive picture of the specific skills needed for enabling industrial cluster decarbonisation for workforce planning at the national level remains outstanding.

Takeaway

The above gaps highlight the importance of collaboration and alignment between industry, government, and key stakeholders such as research partnerships (e.g., IDRIC) on developing and actioning a strategic plan for net zero skills development.

Policy need 3: Support for hydrogen supply and demand

Four cluster plans indicated that support for hydrogen supply and demand could benefit from additional national-level intervention. All cluster plans intend to scale up hydrogen use as one lever to reach net zero. However, the whole system change this entails requires coordinated action by public sector, private sector, and research stakeholders.

The government has provided a range of UK-level support to establish and expand the hydrogen market. On the supply side, the government is allocating funding through the Net Zero Hydrogen Fund (£240 million), and there is also innovation funding to accelerate the deployment of hydrogen from BECCS (£30 million)[227,228]. The hydrogen production and storage business models also set out how revenue support to private businesses operating in this space will be provided[229].

The UK government is also working on a hydrogen production delivery roadmap to provide longer-term clarity on issues such as the balance of blue versus green hydrogen and the pace of deployment to be targeted[230]. Furthermore, the Scottish Government's *Hydrogen Action Plan* already provides some commitments to stimulate the development, strengthen hydrogen production, and use markets, which is relevant to the *Scottish Net Zero Roadmap*[231].

The following policy gaps were identified by analysing the current policy provision and references to hydrogen market development in the cluster plans:

Gap 3.1: Clarity on government's position on how hydrogen should be deployed to meet the UK's net zero targets.

In general, the industrial clusters appreciate measures, including clearer government signalling, which reduce the uncertainty, and hence the risk, associated with developing hydrogen projects. South Wales Industrial Cluster suggested several specific government interventions that could support the expansion of hydrogen production ranging from early-stage funding to the setting of regional hydrogen production targets[232]. Tees Valley Industrial Cluster would like the government to address inconsistencies in the level of end-user market support for decarbonising off-grid and industrial fuels, which is perceived to be less than that on offer for the transport sector[233]. Until the publication of the government's hydrogen deployment plan, expected later in 2023, the industrial clusters lack clarity on the likelihood and timeliness of any such government interventions.

Gap 3.2: Certainty on the scale and timing of hydrogen demand.

Given the very early-stage of hydrogen market development in the UK, targeting support to achieve an appropriate balance of supply and demand can be difficult. Industrial clusters raised more concerns over the extent of demand side support than supply side support. Specifically, Net Zero North West and the *Scottish Net Zero Roadmap* both raised concerns that without demand-side policies and support, the market for hydrogen will not grow organically at the rate necessary to support their net zero targets. In *Net Zero North West's Electrolytic Hydrogen Recommendation* report, two demand scenarios were modelled to account for the uncertainty in the future policy environment associated with driving hydrogen demand[234]. The authors of this report identified the significant cost difference between hydrogen and natural gas as a challenge to establishing a sustainable commercial model for hydrogen.

It is yet to be seen if existing and planned government measures, including developing the role of hydrogen blending in piped natural gas and developing the evidence base on "hydrogen-ready" industrial equipment[235], will go far enough to provide the industrial clusters the certainty they need to secure investment. The government's upcoming hydrogen deployment plan may provide industrial clusters with the certainty they seek. Alternatively, transparency could be achieved by compiling the assurances from major off-takers as to the hydrogen demand they will account for, and by when.

Takeaway

The above gaps highlight the need for government to provide industry with clear signals on the national strategy related to long-term hydrogen supply and demand.

Policy need 4: Development of business models and regulatory frameworks

The fourth major national strategy intervention raised by the clusters was related to the development of business models and regulatory frameworks to support the markets and technologies required for industrial decarbonisation.

See the **investment analysis** for more detail on the industrial clusters' needs related to business models and a discussion of how the UK government's *Powering Up Britain* report and other documents released in March 2023 address some of the points the cluster plans have raised.

Gap 4.1: Finalisation of business models.

The Final Investment Decisions on the clusters' net zero technology and infrastructure projects are contingent on the finalisation of the government's business models. Multiple cluster plans, e.g., the *Net Zero North West Cluster Plan* and the *Tees Valley Net Zero Cluster Plan*, raised business model finalisation as a barrier. In the *Scottish Net Zero Roadmap*, the uncertainty over the timeliness of business case finalisation influenced their decision to consider alternative net zero pathways to allow them to better respond to different regulatory environments. Updates from government since the publication of the cluster plans include a consultation on revenue support regulations for hydrogen production and industrial carbon capture and a clarification on the government's preferred business model for bioenergy carbon capture and storage. While those provide additional clarity, there is still uncertainty surrounding the timeliness of relevant business model finalisation.

Gap 4.2: Extension of business models to cover additional net zero technologies and infrastructure.

The cluster plans identify the need to extend the business model support to a wider range of project types that face barriers associated with developing and financing the technology and infrastructure that are key to their net zero plans. While government updates since the publication of the cluster plans help clarify government's position and plans related to non-pipeline transport of CO_2 and supply chain decarbonisation, there have not been any updates to business model documents to date.

Takeaway

Many net zero technology and infrastructure projects in the cluster plans are contingent on the business model support government provides.

Policy need 5: Carbon pricing and accounting needs to be internationally consistent and competitive

Three cluster plans highlighted this barrier and called on the government to prioritise a fair and coherent carbon pricing system. Relevant details from the cluster plans are provided in the **investment analysis**.

Gap 5.1: UK ETS consistency and competitiveness, specifically related to the lack of carbon caps.

The UK ETS, and specifically its consistency and competitiveness with international equivalents, was raised in the cluster plans as a barrier, or a risk, to industrial decarbonisation that would benefit from national level-intervention. The *Powering Up Britain* report, published in March 2023, sets out the government's approach to addressing issues within the UK ETS. Additionally, the government is undertaking consultations to address carbon leakage risk and align the UK Sustainable Aviation Fuel (SAF) mandate with the UK ETS mandate[236]. These efforts will contribute towards rationalising the carbon pricing system as requested by industry. Recent reforms announced by the government go even further towards rationalising the carbon pricing system as requested by industry. In July 2023, additional specificity was provided as to the timelines for phasing out free carbon allowances, along with a decision to bring waste and domestic maritime into the scheme and confirmation that the intention is to use the UK ETS as the market for Greenhouse Gas Removal (GGR) technologies[237].

Takeaway

The government recognises the importance of resolving the issues within the UK ETS and reducing the pricing uncertainty facing industry.

Policy need 6: Continued funding to support collaboration

Implementing the cluster plans requires ongoing industrial cluster collaboration. Three cluster plans identify that further financial support would support this ongoing industrial cluster collaboration, as presented in more detail in the **collaboration analysis**.

Gap 6.1: Funding to support the establishment of self-sustaining entities responsible for realising the cluster plans.

The IDC clusters have benefited from the collaboration and knowledge sharing involved in the development of the cluster plans and recognise that sustaining these ways of working will be critical as they move towards implementation. Described in the **cluster plan management anslysis**, external funding is just one approach clusters can take to establishing a self-sustaining entity to implement their cluster plans. As demonstrated by South Wales Industrial Cluster, other sources of funding such as a membership model (i.e., where cluster members provide funding) can also complement external funding. To date, the government has not announced any further collaboration funding targeted at the IDC industrial clusters.

Takeaway

The implementation of cluster plans is at risk if responsibility for realising the plans is not managed by an appropriate entity with sufficient funding and resources.

Policy need 7: Funding for CCUS infrastructure

Measures to address the uncertainty related to the funding for CCUS infrastructure was a concern raised in three of the cluster plans. The main funding mechanism for CCUS, as detailed in the s, is the government business models and associated capital funds.

Gap 7.1: Lack of clarity on government's plans for CCUS infrastructure funding.

IDC clusters were unclear on whether and when the CCUS business models would be applied to projects outside the initial CCUS Cluster Sequencing Process. Uncertainty around CCUS infrastructure funding hinders technology options consideration, future project planning, and the attraction of investment. Since the publication of the cluster plans, the government has released several updates that provide additional clarity on the ongoing funding of CCUS infrastructure. This includes the CCUS Track-2 guidance and possible expansion opportunities for Track-1 clusters in an investment roadmap. For more detail, see the **investment analysis**.

Takeaway

Updates from the government after the publication of the cluster plans should help address the funding barrier for CCUS infrastructure raised by the industrial clusters but there are still questions around timing, sufficiency of funds, allocation, etc.

Policy need 8: Lower energy costs

Three cluster plans make the case for national support to lower energy costs. The high price for electricity, compared to natural gas, is one barrier to electrification of industrial processes discussed further in the **implementation** and **investment analyses**.

Gap 8.1: Energy price control measures for industry.

The historically high energy prices that the UK experienced during 2022 that have since abated undoubtedly shaped the need for energy cost support for industry raised in the cluster plans. Nevertheless, the Humber Industrial Cluster Plan suggests that reforming industrial electricity pricing could be a powerful incentive for encouraging industrials to electrify and take advantage of the UK's expanding low-carbon electricity supply[238].

Takeaway

The cost and price uncertainty of energy is a major consideration for industrial users and could be an important lever to drive uptake of lower-carbon energy.

Policy support	Framework element	HICP	NZNW Cluster	RtBC	SNZR	SWIC	TVNZ
Improvement in the consenting process to accelerate infrastructure provision	IM	1	1	0	1	1	1
Business models and regulatory frameworks for CCUS and H_2 production	IN	1	1	0	1	1	0
Clear direction on net zero skills	IM	1	1	0	1	1	0
Support for hydrogen supply and demand	IM	0	1	0	1	1	1
Carbon pricing and accounting to be internationally consistent and competitive	IN	1	0	0	0	1	1
Continued funding to support collaboration	CC	0	0	1	1	1	0
Funding for CCUS infrastructure	IN	0	1	0	0	1	1
Lower energy costs	IM	1	0	0	0	1	1
Business models for Greenhouse Gas Removals (GGR)	IN	1	0	0	1	0	0
Business models for electrification	IN	1	0	0	0	1	0
Continued funding for energy and resource efficiency measures	IN	0	0	1	0	1	0
Stimulation of public demand for green products and solutions	CO	1	0	0	0	1	0
Support for CO_2 shipping	IM	0	0	0	1	1	0
Direction on blending hydrogen into gas networks	IM	1	0	0	0	0	0
Innovation funding for new technology	IN	1	0	0	0	0	0
Business model for use of hydrogen in power applications	IN	0	1	0	0	0	0
Central-local government partnership to improve demonstration of social benefits	CO	0	1	0	0	0	0
Certainty around role of dispatchable power in future energy system	IM	0	1	0	0	0	0
Clarity on the National commitment to nuclear power	IM	0	1	0	0	0	0
Clarity on the National district heating policy	IM	0	1	0	0	0	0
Clearer distinction between green and blue hydrogen	IM	0	1	0	0	0	0
Funding for net zero skills	IM	0	1	0	0	0	0
Leadership on firm sectoral targets for energy efficiency	IM	0	1	0	0	0	0
Policy development for the hydrogen and EV markets	IM	0	1	0	0	0	0
Public-private partnership funding scheme for small and medium-sized enterprises	IN	0	1	0	0	0	0
Regulatory and market changes to facilitate the local supply and consumption of renewable energy	IM	0	1	0	0	0	0
Seed funding for community renewable energy schemes	IN	0	1	0	0	0	0
Seed funding for district heating infrastructure	IN	0	1	0	0	0	0
Seed funding for tidal energy	IN	0	1	0	0	0	0
Support for the creation of a hydrogen and CNG market for long distance transport	IM	0	1	0	0	0	0
Funding for BECCS	IN	0	0	0	1	0	0
Funding to support electrification of industrial processes	IN	0	0	0	1	0	0
Accelerated renewable power availability and options for storage to be progressed	IM	0	0	0	0	1	0
Business model timeframes to dovetail with the end of ITEF funding	IN	0	0	0	0	1	0
Business models for CCU	IN	0	0	0	0	1	0
Business models for non-pipeline CO_2 shipping	IN	0	0	0	0	1	0
Continued funding for IDRIC (or similar) to support ongoing industry driven research with universities	CC	0	0	0	0	1	0
De-risk port infrastructure Investment	IM	0	0	0	0	1	0
Greenlight additional freeports	IM	0	0	0	0	1	0
Maximise UK supply chains	IM	0	0	0	0	1	0
Production and use of low-carbon fuels to be incentivised	IM	0	0	0	0	1	0
Recognition of the importance of circular economy as essential component to net zero	CO	0	0	0	0	1	0
Support for negative emission technologies	IN	0	0	0	0	1	0
Business models for BECCS	IN	0	0	0	0	0	1

Table 1: Comprehensive list of national-level policy needs raised by the cluster plans
(Framework element legend: CC = Cluster collaboration, IN = Investment, IM = Implementation, CO = Communities)

Cluster collaboration analysis

The cluster plans demonstrate that collaboration was, and remains, critical for decarbonisation. Each discusses the partnership that went into plan development, as well as opportunities they intend to progress through implementation. Parties collaborated within the clusters to develop a shared understanding of, and consensus on, goals, roles, and benefits for effective working relationships. Clusters also worked with external entities to facilitate knowledge sharing and influence change, such as addressing policy barriers. The tables and analysis below outline the various collaboration approaches described by the cluster plans[xxv].

	Humber Industrial Cluster	Net Zero North West	Black Country Industrial Cluster	Scottish Net Zero Roadmap	South Wales Industrial Cluster	Tees Valley Industrial Cluster
Number of cluster collaborators [xxvi]	24	10	10	19	29	46
Ways of working highlighted in cluster plan	Established a core team to lead the development of the plan, complemented by Industrial Partners and Strategic Observers[239]	Brought industry together behind a shared purpose and vision, establishing a strong framework for future partnership[240]	Set up Community of Interest Networks and a Virtual Zero Carbon Hub to facilitate knowledge sharing between manufacturing companies[241]	Identified NECCUS as lead with other parties contributing funding, time, and resources[242]	Established a legal foundation between parties to enable knowledge sharing without breaching competition law. Separate bilateral non-disclosure agreements were also signed between specific parties[243]	Conducted 17 separate studies across the various parties involved and brought them together to develop the cluster plan[244]
Continuing collaboration beyond the delivery of the cluster plan	Agreed the Humber Energy Board will take responsibility for leading the strategic and governance aspects of the next phase of HICP. Options for the delivery body are still being considered[245]	Outlined that Cheshire and Warrington LEP will coordinate and convene activity between cluster partners and address barriers to drive the £30 billion investment[246]	Established the Centre for Manufacturing Transition, with initial funding for three months, to build on the outcome of the Repowering the Black Country Project[247]	Began discussions with the Scottish Government about enduring plan leadership and ownership[248]	Created the new Net Zero Industry Wales (NZIW) entity to support Wales' existing and emerging industrial clusters, sharing lessons learned from South Wales Industrial Cluster[249]	Set up a new industry group (Net Zero Leadership Group) for Tees Valley Industrial Cluster with the specific aim of ensuring that Net Zero will be achieved in the cluster[250,251]

Table 2: Collaboration within the IDC industrial clusters, as highlighted in the cluster plans

[xxv] UKRI is aware of additional collaboration activities carried out by the clusters as part of plan development; however, the analysis focuses on the collaboration highlighted in the plans themselves.

[xxvi] Cluster collaborators are the organisations that receive recognition in the cluster plans, excluding UKRI.

	Humber Industrial Cluster	Net Zero North West	Black Country Industrial Cluster
With the local community	Held focus groups with local community to understand their vision for the region and opportunities and challenges associated with industrial decarbonisation[252]	-	-
With industry outside of clusters	Intend to work with adjacent non-clustered industry to find solutions to their specific decarbonisation challenges[254] Identified need for greater collaboration across industry, particularly to support the development of modular and standardised components[255]	Invited industry in the region, not already in the cluster, to work with them to support broad decarbonisation in the area[256]	Created Community of Interest Networks (COINs) to share information and tools created as part of the project[257]
With other clusters	Highlighted the opportunity to collaborate specifically with Teesside given the geographic proximity, both on offshore CCUS and onshore on hydrogen distribution[259] Indicated intention to collaborate with other clusters to influence policy change to support operationalisation of industrial decarbonisation[260]	-	Worked with SWIC to develop policy solutions[261] Identified need to collaborate with coastal clusters on CCUS infrastructure[262] Set up the Centre for Manufacturing Transition, a central hub to support industrial clusters and dispersed sites[263]
With national partners	Outlined objective to engage with government to influence policy Highlighted need for focused collaboration between stakeholders (including central government, industries, business, education, and training) to accelerate the existing momentum on skills development nationally[269]	Highlighted intention to work with government to facilitate delivery[270]	Established the Centre for Manufacturing Transition[271], with initial three months of funding, to work with national and regional governments to develop and implement practical and policy solutions to support industry through the transition[272]
With international partners	Indicated intention to continue to be a catalyst for industrial decarbonisation globally[277] Identified opportunity to meet demand for CO_2 storage from Europe[278]	Incorporated lessons learned from international industrial clusters[279]	-

Table 3: Collaboration beyond the IDC industrial cluster partners, as highlighted in the cluster plans

Scottish Net Zero Roadmap	South Wales Industrial Cluster	Tees Valley Industrial Cluster
Conducted an "Industrial Decarbonisation Clusters: communicating with the public" series comprised of two webinars with academics to explore public awareness of CCUS[253]	-	-
-	Established NZIW to support emerging clusters, and work with infrastructure providers[258]	-
Noted the benefits of collaborating between clusters in the future so that the timing of transport and storage infrastructure is aligned with CCUS and hydrogen project investment[264]	Worked with the Black Country Industrial Cluster to develop policy solutions[265]	Identified future opportunity to have CO_2 shipped from South Wales to the Tees Valley and to export hydrogen to South Wales and Scotland[266] Shared carbon accounting work with South Wales Industrial Cluster and the Black Country Industrial Cluster[267]
Began engaging Scottish Government on enduring ownership of the plan[273] Highlighted need for national coordination on infrastructure development[274]	Established NØW SWITCH, which will nurture broader industry academic research partnerships, including with other UK research organisations Established NZIW, which will engage with both the Welsh and UK governments[275]	Confirmed intention to continue working with key national partners including government departments, the Carbon Capture and Storage Association, and the Multi Cluster Forum to drive decarbonisation in the Tees Valley cluster and share best practice[276]
-	-	Indicated possibility of international import of CO_2, particularly from Germany, as well as export of hydrogen[280]

The analysis of the collaboration efforts contained within the cluster plans demonstrates the significant amount of teamwork involved in their development. It also indicates that collaboration will continue to play a vital role throughout implementation. Other industrial clusters in early stages of planning may find common collaboration takeaways from the IDC clusters helpful:

1. The IDC clusters stressed the importance of having an **entity responsible for driving collaboration throughout implementation**. A centralised coordinator, or "plan owner," can help manage and align the different parties in the cluster to ensure efficient and ongoing delivery of the tasks set out in the plans. Having a plan owner improves the chances that synergies will be realised across the different companies in a cluster, and with organisations outside of a cluster. While all clusters recognise the benefit of having a plan owner, a subset have determined responsible entities and funding streams to enable it post-IDC funding.

Highlights from cluster plans:

- "The intention of the Cluster Plan was not only to set out a proposed pathway for industrial decarbonisation, but to also set up the structures required to be able to take the plan forward past the end of the project. It follows that one of the outputs of this project was the creation of the new Net Zero Industry Wales (NZIW) entity"[281].
- The National Centre for Manufacturing Transition "will be launched in March 2023 (with an initial three months of funding) with a view to securing the additional necessary sponsorship [… it] will build directly on the roadmaps and work developed by the Black Country"[282].
- To deliver net zero the *Scottish Net Zero Roadmap* outlined the need to "establish ownership and leadership of roadmap implementation" and "develop and operate a coordination mechanism to ensure all stakeholder groups are engaged and committed to delivery of the roadmap"[283].

2. **Sharing knowledge** within and between clusters generates benefits individual parties and clusters could not achieve alone such as the acceleration and coordination of research and innovation efforts. However, there is a natural tension between free flow of information and competition. The clusters, and the parties within them, can support each other by focusing knowledge sharing on the similar problems they face (e.g., skills shortage, infrastructure build). Establishing the appropriate legal frameworks between different parties can support more sensitive exchange of information and ensure companies are doing so in-line with the requirements of the Competition Act 1998.

Highlights from cluster plans:

- "Black Country Cluster has excellent ongoing working relationships including but not limited to those with the South Wales Industrial Cluster (SWIC); Teesside; Humberside and IDRIC […] the project has created a replicable methodology which is also effectively being used in SWIC with appropriate adjustment"[284].
- Humber Industrial Cluster will "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"[285].
- "Legal arrangements have allowed initial sharing of ideas, plans and information to kickstart momentum in a multitude of project areas. Through this legal framework, SWIC partners are continually building trust and confidence in businesses that they would never have previously engaged with. The value of this piece of work cannot be overstated"[286].

3. **Influencing national policy settings** to support industrial decarbonisation is a priority for all six IDC clusters, and there are opportunities increase coordination and effectiveness. As mentioned above, many of the industrial clusters are trying to solve similar problems and have shared areas of interest regarding changes to national policy. Currently, IDC clusters have been engaging with various parts of government at different times on topics ranging from hydrogen to skills. A few clusters have also indicated they intend to take the lead on representing or coordinating input from across the six clusters, however, it remains unclear which group is truly representative. Coordinating efforts and engaging strategically with government on a prioritised set of issues would allow clusters to engage more efficiently in government processes. This would also help government focus its time and effort on matters that would make the greatest impact across clusters.

Highlights from cluster plans:

- "We will continue to take a lead role in the Multi Cluster Forum – the group of all industrial clusters in the UK – to share experiences and coordinate mutually beneficial activities"[287].
- Humber Industrial Cluster 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"[288].
- "A key output of the project has been to identify the vital policy drivers needed by industry and the further work required. We have developed a list of 30 policy drivers for the UK and Welsh governments"[289].

4. **Collaborating with local communities** can support the implementation of cluster plans by improving public acceptance[290]. The stakeholders residing in the communities proximate to industrial clusters need to buy in to the changes associated with the decarbonisation transition. By engaging proactively with local stakeholders, clusters can understand community priorities and identify opportunities to provide benefits that improve public acceptance of the transition and accelerate implementation of the cluster plans. Although only one of the IDC clusters demonstrated direct engagement with members of the local community in the development of the plan, other cluster plans acknowledged the benefits of doing so.

Highlights from cluster plans:

- There is a need to "help the public understand and accept the technologies and infrastructure that will be needed to decarbonise industry and society in general"[291].
- "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"[292].
- "The deployment of major infrastructure needed for deep decarbonisation can only be successfully achieved with social acceptance. […] (i) the general acceptance of the technology by the wider public and, importantly, (ii) acceptance by the community(ies) that will host the facilities or infrastructure"[293].

Collaboration has been integral to the development of the cluster plans. Now, successful implementation will rely not only on the relationships and trust that have been built but also on ongoing and new partnerships. The IDC industrial clusters are prepared to continue their collaboration efforts as they enter this new phase. With the conclusion of IDC cluster plan funding, however, they will need to resource themselves to broaden and deepen the collaboration that implementation requires. The funding challenge is discussed further in the **cluster plan management analysis**.

Investment analysis

Industrial clusters comprise various sectors, emitters, and decarbonisation project types, and the operational model of those projects will, therefore, vary significantly. Operational model, as described in this analysis, includes the financial profile of the project during operation, i.e., the revenue streams the project has access to and the project's cost profile. These factors are critical to a project's ability to raise capital and its overall viability.

In some cases, projects may be able to have high confidence in commercial feasibility (including operational revenues) based on established markets and may not rely on significant additional government guidance or intervention. For example, an industrial emitter seeking to improve the energy efficiency of its operations through the application of technology currently available on the market, or looking to optimise its process efficiency, may demonstrate the business case for such a solution without the need for additional government action.

Where this is not the case, the UK government can offer schemes to support the development and deployment of solutions that are subject to market barriers (e.g., TRL leading to high risk premiums, lack of a sufficient carbon price to incentivise low-carbon alternatives, lack of incentives to develop common infrastructure). A notable example of where the UK has successfully implemented such a scheme is via Contracts for Difference, established to support the deployment of renewable energy[294].

To support industrial and power sector decarbonisation, the UK government is developing business models for those industries and sectors where incentives, risk-sharing mechanisms, or revenue support is required, notably for carbon capture, utilisation, and storage and low-carbon hydrogen. These business models will be offered through a competitive process, with successful projects able to access business model support via the government's CCUS Cluster Sequencing Process.

The term "business model" in the context of industrial decarbonisation in the UK therefore often specifically refers to the government-developed "business models" for carbon capture, usage, and storage. As of July 2023, the UK government business models are set out in **Table 4**. Updates regarding several business models were released as part of *Powering Up Britain*, including the launch of a consultation on revenue support regulations for Hydrogen production and ICC business models; the consultation scope includes direction to offer to contract, information publication, and eligibility[295]. These business models will be underpinned by the Energy Bill[296].

Category	Relevant business model	Applicable technologies	Government capital fund	Contract length	Status as of July 2023
Cross-cutting, including CCUS and hydrogen					Energy Bill guidance updated June 2023
Hydrogen	Hydrogen Production[297]	New low-carbon hydrogen production	Net Zero Hydrogen Fund and Hydrogen Revenue Support	15 years	Head of terms published December 2022 Consultation on revenue support regulations published May 2023
	Hydrogen Transportation and Storage[298]	Transportation and storage of hydrogen	Not yet confirmed	To be determined	Consultation closed November 2022, commitment to design business models by 2025
Power Generation	Dispatchable Power Agreement	Power (natural gas) plus CCS	CCS Infrastructure fund	10-15 years	DPA Terms and Conditions and business model summary published November 2022 Intention to consult in 2023 on the need and potential design options for market intervention to support hydrogen to power
	Power BECCS	Power bioenergy with carbon capture and storage	Not yet confirmed	To be determined; consultation proposed 10-15 years	Government response to consultation published March 2023[299]
	Contracts for Difference	Power (renewables)	N/A	15 years	Fully operational; four auctions held to-date
Industrial Carbon Capture	Industrial Carbon Capture	Industrial emitters plus CCS	CCS Infrastructure fund Industrial Decarbonisation and Hydrogen Revenue Support	10 years plus up to 5 years extension	"Broadly final" ICC Contract published December 2022 CIF Grant Funding Agreement for ICC terms and conditions published December 2022 Consultation on revenue support regulations published March 2023 Indicative heads of terms published in June 2023
	Industrial Carbon Capture (Waste ICC Contract)	Waste management plus CCS	CCS Infrastructure Fund Industrial Decarbonisation and Hydrogen Revenue Support	10 years plus up to 5 years extension	Summary of differences with ICC Contract published December 2022; full form Waste ICC Contract due for publication in 2023 CIF Grant Funding Agreement for waste ICC terms and conditions published December 2022 Consultation on revenue support regulations published March 2023
CO_2 Transport and storage	Transportation and storage Regulatory Investment Model[300]	Pipeline* transport and storage of CO_2	CCS Infrastructure Fund	To be determined; split into regulatory periods	Indicative heads of terms published in June 2023[301]
Greenhouse gas removals	Greenhouse Gas Removals[302]	• DACCS • Other non-BECCS GGR	Net Zero Innovation Portfolio	To be determined	Consultation closed September 2022 Government response and request for information published June 2023

Table 4: UK government business models and associated capital fund as of July 2023

*The January 2022 Business Model Update for the TRI model notes that "we are continuing to develop the licence conditions and business model arrangements so that non-piped sources of CO_2 can be accommodated by the TRI model."

The details of the government business models will define critical operational parameters for many of the IDC industrial cluster decarbonisation projects, including operational revenues. Cluster plans have highlighted various dimensions in which the government business models will impact them:

1. Finalisation of business models represents a **critical milestone in cluster plan timelines,** without which many cluster plan projects are unable to make significant progress.

- Net Zero North West stated that the HyNet project, their anchor project, is expected to be operational by 2025, "subject to consenting and Government Business Models for Low Carbon Hydrogen and CCUS"[304].
- Tees Valley Net Zero reported that "other organisations are currently awaiting business models for power BECCS (Bio-Energy with Carbon Capture and Storage) and are not willing to invest until the business model is published"[305].

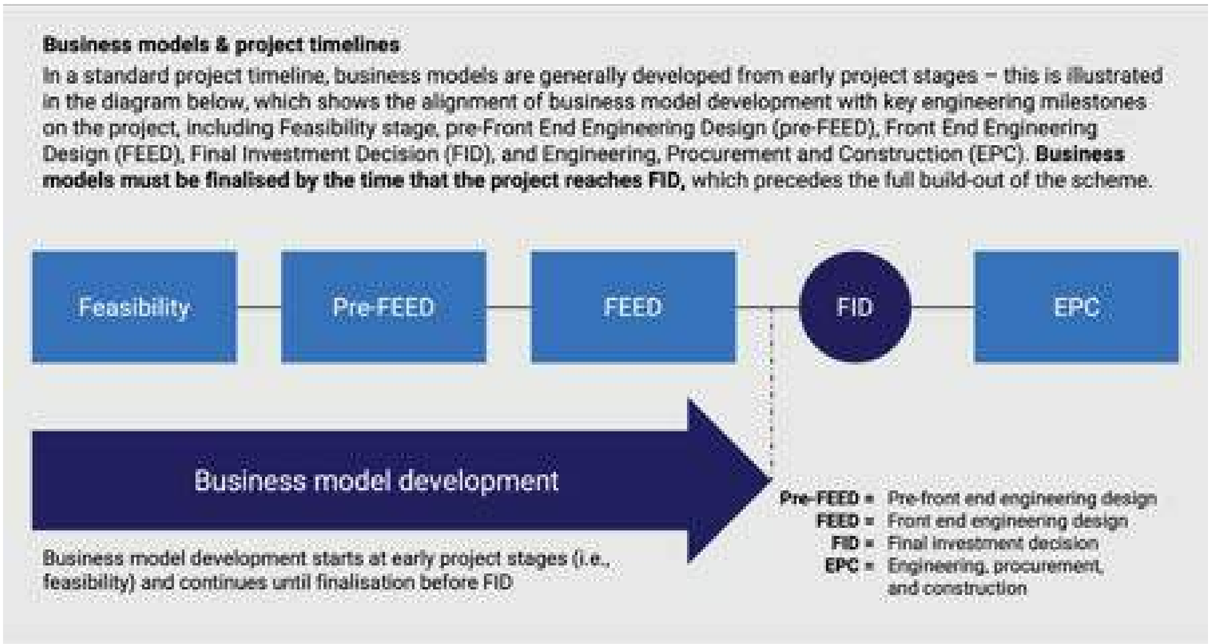


Figure 11: Business model development timeline and project engineering milestones

Figure 11 above provides information on typical project development timelines and how business model development aligns with such timelines. Final Investment Decision requires the business model to be in place, after which the full build out of the scheme can commence.

UK government business models are therefore being developed to align to this timeline and be available in time for project investment decisions.

In some cases, clusters have highlighted that they are relying on these business models to progress with some elements of their plans.

Highlights from cluster plans:

- The *Scottish Net Zero Roadmap* identified two primary branches for its net zero pathway, one as "pipeline pathway" and one as a "non-pipeline pathway." The pipeline pathway (preferred) will be influenced by the business, policy, and regulatory environment for CO_2 removal. The *Scottish Net Zero Roadmap* notes that "an appropriate financial model for common infrastructure" is critical; the non-pipeline pathway will rely on business models for vehicular movements of CO_2[303].
- Tees Valley Net Zero highlighted that the "biggest risk to decarbonisation is if the Net Zero Teesside project does not go ahead"[306]; this project relies on the successful application of the Business Model for pipeline transport of CO_2.
- The *Scottish Net Zero Roadmap's* policy analysis noted that there is "limited policy support" for hydrogen transport and assess its status as red within the RAG review[307].

2. IDC industrial clusters have noted that the **future applicability of business models outside of the initial CCUS Cluster Sequencing Process** remains ambiguous. Some clusters stated that if business models become available to projects that have not been successful in or eligible for the CCUS Cluster Sequencing Process, this would inform project planning and help support additional projects in achieving their carbon reduction plans.

Highlights from cluster plans:

- Net Zero North West mentioned that it is unclear whether the commercial framework will be available for plants outside of the CCUS Cluster Sequencing Process[308] for future projects.
- The *Scottish Net Zero Roadmap* noted that "further support to come for subsequent projects, beyond those shortlisted in Track-1, is unclear. Peterhead Power Station will likely act as a key dispatchable generator for the Scottish Cluster, and continued support beyond Track-1 projects will likely encourage the CCS investment needed in the Power Station"[309]. *Note that due to publication dates, this does not reflect the latest announcements from the government on Track-2 eligibility.*
- Repowering the Black Country observes that there is a lack of clarity on whether the current Hydrogen Business Model would be applicable to industrial sites in the region, rather than coastal clusters[310].

One of South Wales Industrial Cluster's top 6 priorities is inclusion in Track-2 of the sequencing process and its ability to use a business model for CO_2 shipping[311]. The most recent updates relating to these challenges, published after the cluster plans in *Powering Up Britain*, included publication of the CCUS Track-2 guidance, which confirms an objective to select two new CO_2 clusters and that Acorn and Viking transportation and storage systems are able to meet Track-2 eligibility criteria[312]. DESNZ is also conducting an Expression of Interest for additional potential bidders. It further mentions Track-1 cluster expansion opportunities provided in the April 2023 *CCUS Net Zero Investment roadmap*[313], and in *Powering Up Britain*[314], with specific reference to projects within Humber Industrial Cluster.

3. IDC industrial clusters have noted that some project types **within their plans would benefit from a defined government business model**. Specific project types mentioned include **non-pipeline transport of CO_2, electrification, carbon capture and utilisation**, and business models for attracting private investment finance into **decarbonisation of UK supply chains**.

Refer to the **national strategy policy gap analysis** for the list of national-level policy needs raised in the cluster plans, including business model development. Illustrative examples of business model needs raised by project type are outlined below:

Non-pipeline transport of CO_2

Non-pipeline transport of CO_2 covers both shipping, road, and rail transport.

- This is noted as a requirement for *Scottish Net Zero Roadmap's* "branch 2: shipping and electrification" pathway, specifically for "motivation for development of rail and road routes, and ensuring policy permits appropriate attribution of emissions removals"[315].
- This is also one of the primary policy drivers that South Wales Industrial Cluster has indicated is necessary to enable the success of its carbon capture projects.

Non-pipeline transport (NPT) received attention in the *Powering Up Britain* publications. In particular, the CCUS Track-2 guidance states government's view is that "it is for industry to develop the necessary physical NPT infrastructure such as handling terminals and facilities and transportation methods"[316], but that they intend to "progress development of NPT in due course," including changes to business models and CCS Network Codes where relevant"[317].

The *CCUS Net Zero Investment Roadmap*, published in April 2023, also recognises that providing timelines for NPT of CO_2 is a barrier to investment[318]. It references the need for "working with industry and clusters located away from pipeline transport solutions to develop an NPT strategy" and "continuing to engage with industry and international counterparts on their NPT position to learn from the approach of others and understand NPT requirements"[319].

Electrification

- The lack of a business model for electrification is noted in the Humber Industrial Cluster Plan, which recognises that "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"[320].
- South Wales Industrial Cluster noted the importance of a business model for electrification as well – this is one of SWIC's 6 priorities[321].

Carbon Capture and Utilisation

- This was one of South Wales Industrial Cluster's 6 priorities[322].
- The *Scottish Net Zero Roadmap's* policy analysis included this as red within its RAG review, noting that there is little policy support for CO_2 utilisation; the analysis opines that it is likely to be commercially driven[323].

While a solution being commercially driven is not an issue, the question appears to be more about the rate and scale of the emissions reductions that solution could deliver compared to the rate and scale of commercial viability and investment. In other words, whether commercial solutions will become viable at too late a stage. While additional business models would likely accelerate adoption of this solution, this would need to be subject to a prioritisation assessment, with the support deployed first to areas with the highest potential for emission reduction and highest barriers to market.

Decarbonisation of supply chains

Some clusters cite the development of markets and supply chains as being important to achieving their ambitions. In the case of the Black Country Industrial Cluster, "business model" may not specifically refer to the existing government business models for CCUS and low carbon hydrogen.

- The Black Country Industrial Cluster proposes "business models for attracting private investment finance into decarbonisation of UK supply chains; minimising carbon leakage and attracting inward investment"[324].
- Net Zero North West commented that the business model "must be structured to increase consumer demand from a very low base in a way that enables rapid market expansion…"[325].

While no specific business model has been set out, various initiatives for UK supply chains are mentioned within the April 2023 *CCUS Net Zero Investment roadmap*[326].

4. Some cluster plans note **the current form of the UK ETS is a barrier,** specifically the lack of carbon caps and the pricing structure.

Highlights from cluster plans:

- Tees Valley Net Zero specified that "issues with the UK ETS were quoted by more than a quarter of the industrial cluster companies [within the Tees plan]" and that "renewable fuels industrials in the cluster highlighted the lack of carbon caps in the UK ETS"[327].
- Tees Valley Net Zero also highlighted: "in specific sectors such as hydrogen, there was much uncertainty surrounding the pricing structure"[328].
- South Wales Industrial Cluster further enforced this, saying "a carbon charging policy that is fair and ensures an internationally competitive industry" as a policy driver, with specific reference to challenges with the UK ETS putting UK companies at a disadvantage[329].

The *Powering Up Britain* publications announced the launch of a consultation on addressing carbon leakage risk. It also includes an outline of planned changes to existing carbon leakage mitigations (free allowances in the UK ETS) and refers to Carbon Border Adjustment Mechanisms, product standards, and other instruments[330]. This is part of a wider notice that government will work with the UK ETS authority to set out "a long-term pathway for the UK ETS" later in 2023[331].

Implementation analyses

With the cluster plans now published, the IDC industrial clusters must shift into implementation of the plans to ensure that the required emissions reductions are achieved. However, without the structure of IDC, how each cluster will make this transition is varied and, in some cases, not yet defined.

The clusters' plans are ambitious and identify several challenges associated with the various aspects of implementation, particularly around cluster plan management, deployment of technology and infrastructure, and establishment of suitable and resilient supply chains.

Cluster plan management analysis

Ongoing management of the cluster plan is a topic discussed by many of the IDC clusters and closely related to collaboration. Since funding for the cluster plan development ceased in March 2023, funding for ongoing IDC cluster activities is linked to the anticipated management structure. Many of the clusters have established some form of plan "owner" to take responsibility for the transition to implementation. These owners are typically groups of highly engaged stakeholders, representing the key organisations involved in the decarbonisation implementation and regional stakeholder presence.

- Several cluster plans, including those produced by Net Zero North West, the Black Country Industrial Cluster, and South Wales Industrial Cluster, have identified the involvement of public entities, such as LEPs, as central to the management of implementing the plans. As a result, public entities are expected to be involved in most of the emerging ownership groups. The *Net Zero North West Cluster Plan* sets out that "the size and scale of the challenge combined with the need to work at pace requires a new delivery model to create the enabling environment for investments, whilst harnessing new partnerships between the public and private sector"[332].
- In some cases, such as the *Scottish Net Zero Roadmap*, a specific mechanism for implementation management has not been identified but the need for one has been highlighted. The *Scottish Net Zero Roadmap* is working with key stakeholders, notably the Scottish Government, to define what a path forward could look like.

Across the different plans, IDC industrial clusters are considering a range of options for both management and funding for ongoing cluster activities. These options are closely related to the type of cluster plan that has been developed (**Figure 12**).

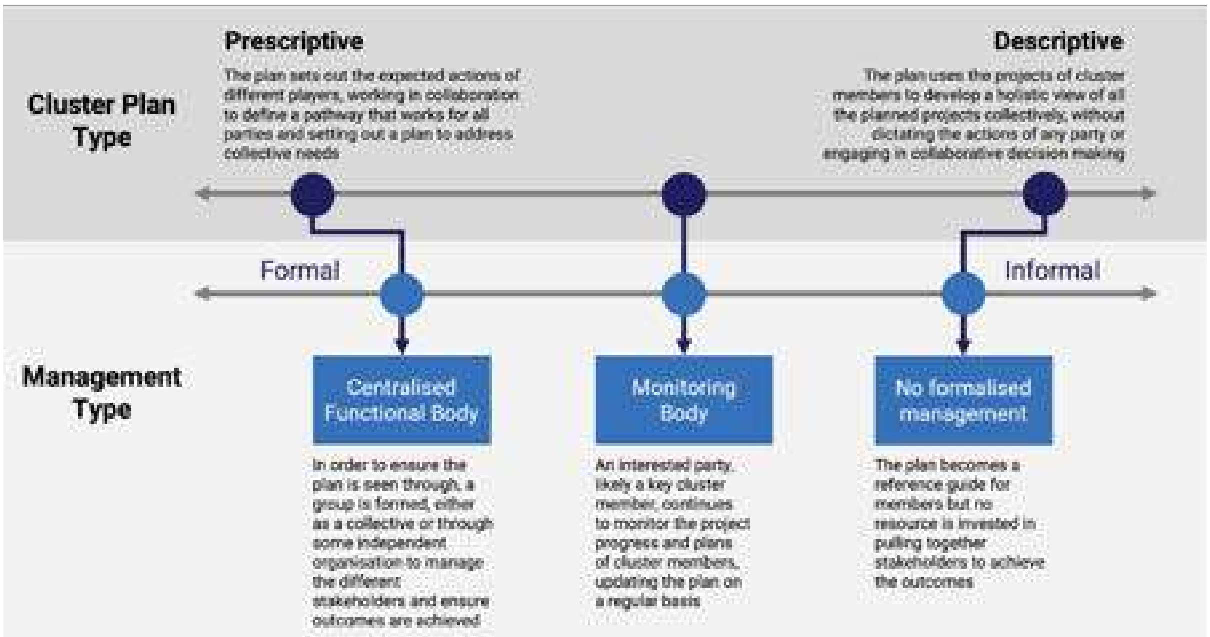


Figure 12: Illustration of the spectra of Cluster Plan Types and Management Types

Cluster plans range from fully prescriptive to fully descriptive as defined in **Figure 12**. Based on the level of prescription, there is a natural link to the type of management that is likely to be used for the implementation phase. This could be a very informal arrangement, such as an organisation "self-managing" using the cluster plan as a reference guide, which is most likely to emerge from a plan that is fully descriptive. At the other end of the spectrum, this could be highly formalised management that would lend itself well to a highly prescriptive plan that requires stakeholders to be held to account. The bottom half of **Figure 12** outlines how these management types might manifest based on cluster plan type.

Of the six cluster plans developed through the IDC, there are examples across the spectrum. Towards the prescriptive end, Humber Industrial Cluster undertook wide stakeholder engagement on the range of pathways to net zero that work across the cluster portfolio. The plan not only identifies the planned projects expected to contribute to its achievement, clearly setting expectations for delivery, but it also draws out recommendations for different actors, including stakeholders beyond the immediate cluster participants to enable the plan. Net Zero North West created a more descriptive plan that highlights the projects that are planned in the area and will contribute significantly to emissions reductions. This plan uses reported emissions savings from the individual projects, rather than developing one collective model for understanding pathways to net zero.

Although these cluster plan management types are not directly tied to different types of funding, budgetary constraints may impact the choice of model, and the form of management is more likely to lend itself to certain types of funding within a range of options. Based on the IDC clusters' work and consideration of international peers, three key sources of formalised funding for management of a cluster plan have been identified. These are set out in **Figure 13.**

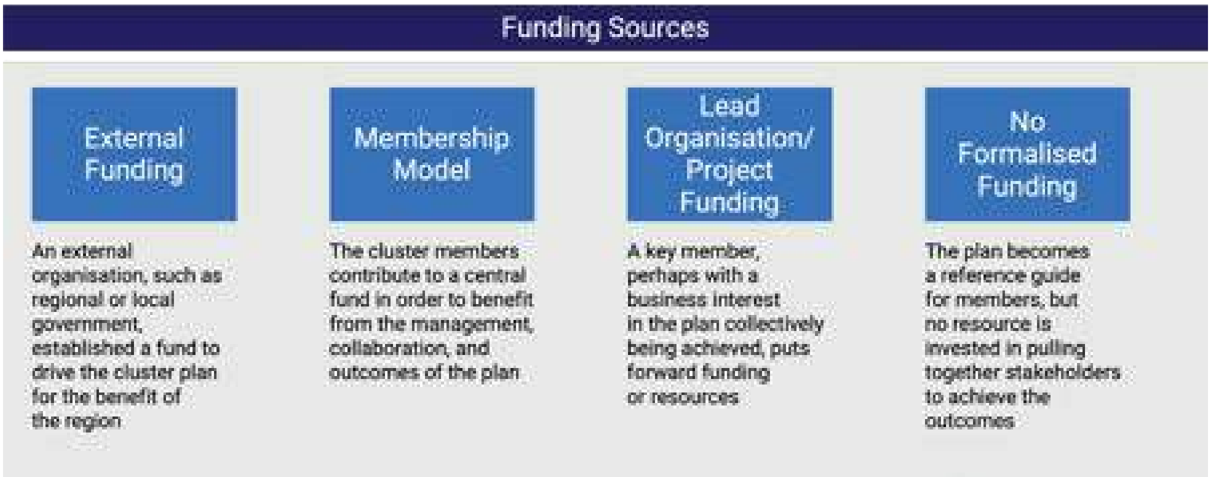


Figure 13: Key types of funding sources possible for cluster plan implementation

External Funding: Like the IDC funding for the cluster plan development, a cluster might seek external funding, such as from local public funds, to continue the work into the implementation phase. This would enable the cluster to set out further detail on how to deliver the plan and establish early projects without upfront financial commitment from cluster members for management of the plan.

Membership Model: As cluster members are likely to all benefit from elements of central coordination, such as shared learnings and coordinated investment efforts, they may find value in contributing to the funding of the central organisation to access these benefits.

Lead Organisation and Project Funding: Where a cluster is based around a major project, such as a piece of significant common infrastructure that relies on other cluster members engaging with the project, the major project developer may see benefit in providing funding for a cluster plan management body. This could help to ensure "off-takers" or "suppliers" for the major project, managing some of its key risks while also helping to accelerate decarbonisation of the area in line with the cluster plan.

The cluster plan "owner" will likely seek multiple sources of funding. For example, South Wales Industrial Cluster has established both external funding from the Welsh government, which will be used primarily to cover the cost of employing a chief executive to provide overall oversight of the cluster plan, and a membership model, which will further support the "steering team" and its associated working groups. Net Zero North West has taken a decentralised approach and delineated that the collaborators that developed the cluster plan will not form an entity that will raise funding centrally. This suggests that individual organisations and projects are expecting to source their own funding on a case-by-case basis instead.

Regardless of funding source, there is a need for continuity for ongoing resourcing, which the clusters are collectively still addressing. As a result, funding and plan management are areas to watch closely in the coming years for additional lessons learned.

Technology and infrastructure analysis

The six IDC industrial clusters are well positioned for early development of technologies and deployment of decarbonisation infrastructure with shared assets such as hydrogen pipelines and renewable energy generators. Adoption of a variety of technologies is a vital component of industrial decarbonisation, as certain technologies have advantages within different industrial processes (e.g., the application of low-carbon hydrogen to decarbonise the heat requirement of cement production and the use of CCS to capture the direct emissions from the cement chemical reaction). Therefore, the technology and infrastructure deployed within clusters underpin the emissions reductions at the heart of each cluster plan.

As a result, understanding the portfolio of technologies and infrastructure that the cluster plans are relying on is essential to understanding how best to enable the clusters' implementation of their plans. This analysis examines the variety of technical interventions within the plans and how this might present challenges in the implementation phase.

To develop an understanding of the technologies being deployed, it is first important to recognise that locational factors influence technology selection. For example, locations with suitable offshore geological storage for the captured CO_2 have lower barriers to implementing CCS at scale. The cluster plans indicate that significant work has gone into researching their individual strengths and challenges, resulting in a breadth of technologies across the IDC clusters.

Technical interventions

While there is a breadth of technologies included across the cluster plans, most carbon mitigation is achieved within four categories of technical intervention: CCUS, hydrogen usage, resource efficiency and energy efficiency (REEE), and electrification. Other intervention types, where used, do not address large shares of cluster emissions and are typically specific to a limited number of projects.

Figure 14: Relative proportions of cluster plan emissions being addressed by the four main intervention types shows the range of proportions of cluster emissions that the plans set out to mitigate through each intervention type. There is a high level of reliance on CCUS, with some IDC clusters expecting it to mitigate over half of their emissions. While this concentration clearly indicates where focused effort is needed, it also poses a risk from a decarbonisation standpoint with respect to the technology portfolio, as there is a greater reliance on a single intervention type. However, the government has prioritised CCUS and low-carbon hydrogen production as core technologies for decarbonisation[333], followed by REEE

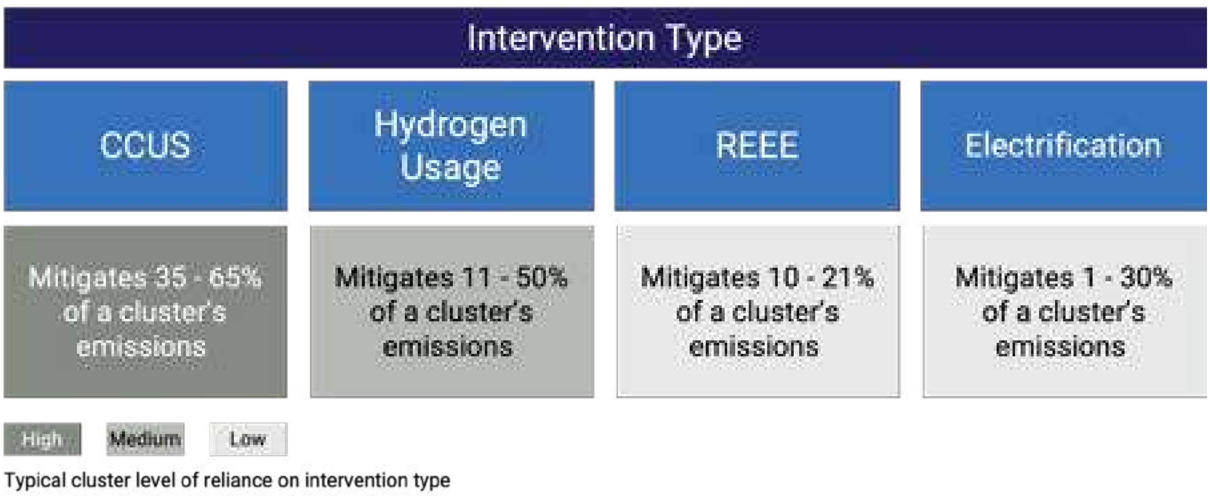


Figure 14: Relative proportions of cluster plan emissions being addressed by the four main intervention types

and electrification. The figure below indicates that the cluster plans are in alignment with UK policies.

Overview of the technology map

The technology map (**Figure 15: Map of technologies included across the six published cluster plans**) shows the spread of technologies and decarbonisation solutions included across the six published cluster plans, grouped by the intervention categories set out above. The map illustrates the technologies that will be used to decarbonise different cluster activities based on available information from the plans. It is not intended to be a complete list of all technologies deployed in each cluster to 2040.

While the level of detail given for technologies varies within each cluster plan, the technology map is intended to allow readers to identify which clusters are implementing different technology types and determine from where relevant learnings may be gathered. Based on the technology map analysis, there are several key observations on the portfolio of technologies proposed within the cluster plans.

- The specificity of technologies across the plans is generally limited. For example, while all IDC clusters have specified that green hydrogen production is planned, there is limited further information about the type of electrolyser being considered. However, this is not surprising given the cluster plans are public documents that are also managing significant uncertainties due to the long planning horizon.
- Under the hydrogen intervention, more information has been provided on the production methods that are intended than the technologies that are expected to be implemented to allow usage of the hydrogen at different sites.
- While REEE and electrification are intended across all the IDC clusters, specification of how REEE will be achieved, and which processes are planned to be electrified, is limited.
- Net Zero North West have proposed many low-carbon hydrogen production methods as part of their study in potential technology options and considering its proximity to low-carbon energy generation such as nuclear. The diversity of technology deployment they have proposed includes blue and green hydrogen, biohydrogen, hydrogen from plastic waste and pink hydrogen (using a small modular nuclear reactor).
- Storage capabilities for captured CO_2 vary based on cluster locations. Humber Industrial Cluster, Net Zero North West, the *Scottish Net Zero Roadmap*, and Tees Valley Industrial Cluster have access to storage options, whereas South Wales Industrial Cluster would need to ship CO_2 to another cluster, due to a lack of suitable geology nearby, and the Black Country Industrial Cluster has limited options due to its inland location.
- All six cluster plans have highlighted the deployment of various combustion technologies using low-carbon fuels. For example, combined heat and power (CHP) generation using bioenergy or syngas.
- With respect to engineered Greenhouse Gas Removals (GGRs), the *Humber Industrial Cluster Plan* and the *Scottish Net Zero Roadmap* are the only cluster plans that mentioned the deployment of direct air carbon capture (DACC). The *Humber Industrial Cluster Plan* has set out the most ambitious position on negative emission potential, expecting to deliver this through BECCS, mainly from Drax.

The following sections explore the technologies within the four main intervention types across the cluster plans: CCUS, hydrogen, REEE, and electrification. A section on engineered GGRs is also included after the main intervention types as several clusters have identified that absolute zero carbon emissions cannot be achieved, and therefore some negative emissions solutions are required to achieve net zero.

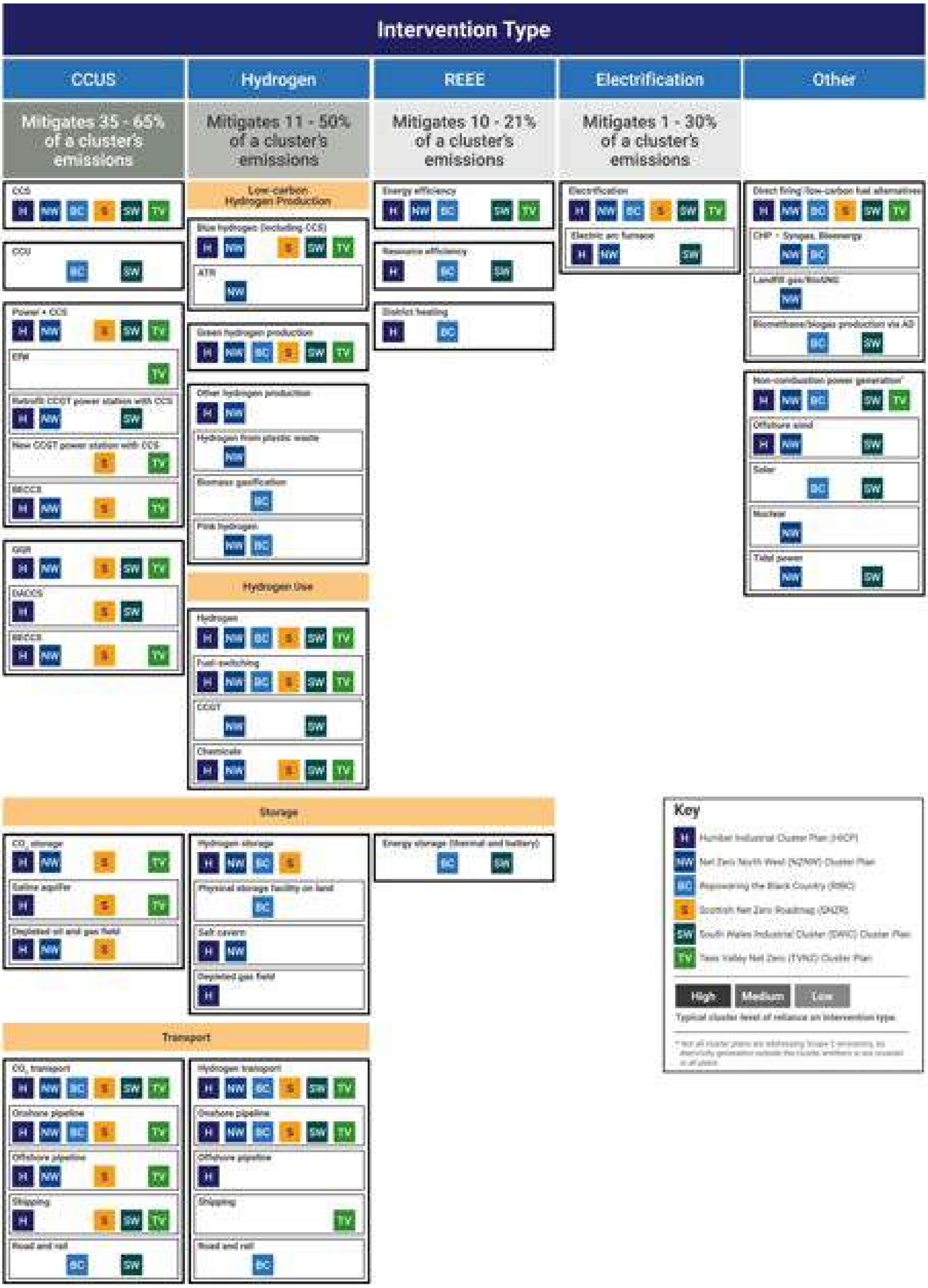


Figure 15: Map of technologies included across the six published cluster plans

CCUS

CCUS is the process of capturing CO_2 from industrial and power sources by gas separation, treatment, and transportation for utilisation in industrial products or for long-term storage.

CCUS plays a vital role in industrial emissions reduction. According to the UK *Net Zero Strategy*, the ambition is to "deliver 6 $MtCO_2$ per year of industrial CCUS by 2030, and 9 $MtCO_2$ by 2035"[334]. Based on the cluster plans, five of the IDC clusters have committed to the deployment of CCS with limited expectations set for utilisation of captured CO_2 across the clusters. The Black Country Industrial Cluster is the exception as it does not anticipate CCS will be utilised within the Zero Carbon Hubs.

There is a heavy reliance on CCUS, primarily CCS, to reduce carbon emissions compared to other intervention types, which may be due to its wide applicability to industrial emissions, including but not limited to hydrogen production. Based on the cluster plans, anywhere between 35-65% of a cluster's emissions will be mitigated through CCS[xxvii] where it is used. The IDC clusters set limited expectations for utilisation of CO_2. The *Scottish Net Zero Roadmap* notes that the lack of largescale demand for CO_2 in industry poses a challenge towards commercial viability of carbon utilisation[335].

The flexibility and applicability of CCS across different industries provide opportunities to reduce emissions from industries that are hard to decarbonise, such as existing power generation from natural gas and cement manufacturing. However, it is important that efforts are made to actively reduce direct emissions from industries prior to establishing a case for capturing and storing CO_2, in line with the widely accepted emissions reduction hierarchy[336].

The barriers and enablers associated with CCS highlighted by the cluster plans show the importance of system-wide infrastructure beyond the carbon capture technology. Challenges developers of CO_2 pipelines face include acquiring planning permission and accommodating environmental restrictions[337]. For example, the *Scottish Net Zero Roadmap* highlights technical risks associated with pipelines such as "corrosion from impurities (due to contamination in anthropogenic CO_2), asset integrity and pressure control"[338], though there are guidance and standards, as well as relevant experience from other regions and applications, to mitigate this risk[339].

Furthermore, the *Humber Industrial Cluster Plan* have mentioned that supply chain constraints have been identified for carbon capture and CO_2 import capabilities[340]. These challenges are due to the pace of deployment, and so, solutions are emerging. For example, according to the *CCUS Delivery Plan 2035* from the Carbon Capture and Storage Association (CCSA), the permitting challenges can be overcome by improved transparency, visibility, and clear permitting process communicated to stakeholders for accelerated and efficient planning[341]. The CCSA have also published an analysis of the benefits to regional economies investment in CCUS can provide[342]. The wide applicability of CCUS means that it is the only technology that can deliver deep emissions reductions in hard-to-abate industrial sectors in the short-term and remains a necessary technology to accelerate decarbonisation of industrial clusters.

Hydrogen

Fuel switching from fossil fuels (typically natural gas) to low-carbon alternatives is a method to reduce emissions at the source, reducing or eliminating the need for CCS in some cases. The use of low-carbon fuels, such as electricity from low-carbon sources, low-carbon hydrogen, and bioenergy are key contributors to deliver net zero, with an expectation that 20 TWh per year of fossil fuel use will be replaced with low-carbon alternatives in 2030[343]. Based on the cluster plans, all six IDC clusters have committed to deployment of fuel switching options, including low-carbon hydrogen.

Low-carbon hydrogen production is the process of producing hydrogen in a way that creates little or no GHG emissions. The two most common production methods are blue hydrogen, which is based on methane reforming of natural gas, with CCS applied, and green hydrogen, which is based on some form of electrolysis using zero carbon electricity. The plans also identify a small share of other production methods, but these are typically specific to a limited number of projects and clusters, and blue and green hydrogen are the most prevalent.

Low-carbon hydrogen plays a critical role in industry with various applications, such as replacement of natural gas and use as a feedstock for chemical production. Low-carbon hydrogen production methods are expected to replace existing methods of hydrogen production, which are significantly higher in emissions. According to the *Industrial Decarbonisation Strategy*, the expected "consumption of hydrogen as a fuel in 2030 ranges from 10 TWh per year to 16 TWh per year. By 2050, the potential for hydrogen fuel switching in clusters alone is around 24 TWh and UK wide could be as high has 86 TWh by 2050"[344]. By comparison, the *Scottish Net Zero Roadmap* and Net Zero North West expect that they could produce up to 45 TWh per year in 2030, based on their demand projections.

The updated UK ambition for hydrogen production, as outlined in the *Energy Security Strategy* (2022) is 10 GW by 2030[345]. In comparison, the Humber Industrial Cluster, for example, expects to deploy 5.2 GW of hydrogen production just within their cluster by 2030[346].

After CCUS, low-carbon hydrogen consumption represents the next largest portion of a cluster's mitigation plans[xxviii]. Based on the cluster plans, about

[xxvii] This includes blue hydrogen production.
[xxviii] A portion of this hydrogen consumption will be blue hydrogen, which is dependent on CCUS.

11-50% of a cluster's emissions will be mitigated through low-carbon hydrogen usage. The clusters expect to be able to produce the low-carbon hydrogen required to meet their own demand, with some clusters, such as Net Zero North West, identifying potential to increase their production capacity to accommodate exports of low-carbon hydrogen to dispersed industrial sites and other users.

The versatility of low-carbon hydrogen as an energy carrier offers greater opportunities to accelerate the decarbonisation of different industries such as ammonia production and steel manufacturing.

The drawbacks of low-carbon hydrogen technologies include scalability and commercial maturity. These limitations could impact the rate of deployment and application of low-carbon hydrogen in some industries such as chemical production. In addition, significant requirements for water and electricity supply have been flagged as a challenge in some clusters. For example, the *Humber Industrial Cluster Plan* identified green hydrogen emerging as the highest water demand in the cluster, with additional demand from other technologies such as carbon capture. To manage this constraint, *Humber Industrial Cluster Plan* expects to have to develop a more circular approach to water usage[347]. On the electricity front, Tees Valley Net Zero has highlighted "infrastructure restrictions" National Grid have raised in their area, which will directly impact the cluster's ability to implement the plan if these are not resolved in a timely manner[348].

Some of the barriers and enablers highlighted in the cluster plans show that all clusters are also experiencing technical challenges associated with low-carbon hydrogen technology development, such as improving the performance to boost production efficiency. Net Zero North West notes that practical challenges in switching fuel from natural gas to hydrogen for domestic use[349], and retrofit ability, such as the use of hydrogen gas in turbines[350], are key barriers to progress in the end-use of hydrogen.

However, the *Scottish Net Zero Roadmap* mentions that some of these challenges could be solved through learnings from the oil and gas industry. Challenges associated with the retrofit ability, long-term integrity, and monitoring of aging existing gas infrastructure can be overcome by piping and network modelling currently used by the oil and gas industry, improving the resilience of the hydrogen value chain[351].

The production of low-carbon hydrogen has the potential to play a significant role in the decarbonisation of the IDC clusters. The flexibility of hydrogen as a fuel enables the decarbonisation of multiple parts of the energy system and value chain including fuel switching capabilities.

Resource efficiency and energy efficiency (REEE)

Resource and energy efficiency measures will also be crucial in getting industry to net zero by reducing the demand for energy and resources. The government believe REEE will be a major contributor to the decarbonisation of clusters. Estimates show that REEE could contribute "up to 13 $MtCO_2e$ of annual emissions reductions by 2050 and reduce the overall cost of decarbonisation by lowering the amount of energy that needs to be converted to cleaner sources and reducing operational costs"[352]. All six IDC clusters have committed to improve resource and energy efficiency in their cluster plans.

Resource and energy efficiency measures include but are not limited to transitioning towards a circular economy model, procuring high thermal conductive materials to reduce heat losses, and implementing energy management systems. Based on the cluster plans, about 10-21% of an IDC cluster's emissions will be mitigated through REEE. This is lower in most IDC clusters than the contribution expected from CCUS, which differs from the view presented in the *Industrial Decarbonisation Strategy* on the proportion of emissions REEE measures will mitigate. The *Industrial Decarbonisation Strategy* anticipates that in cluster networks, around 25% of abatement in 2050 will come from REEE and only about 20% from CCUS (including BECCS). In some cases, such as the *Scottish Net Zero Roadmap*, this reduced role is due to REEE being considered good business practice, and therefore it is not explored specifically for its emissions mitigation role. As a result, this may be under reporting the clusters' actual abatement from REEE.

The *Industrial Decarbonisation Strategy* highlights key barriers in industry and actions to accelerate efficiency savings to align with net zero. The lack of accurate measurement (i.e., via sensors and meters), poor energy management data, and limited access to expertise and advice about technical solutions are limitations which impact the implementation of efficiency savings.

As REEE would enable industry to maintain the same level of output while using less energy and fewer resources, it should be pursued as far as possible. This is likely to have greater potential in certain sectors, as "heat recovery, process and equipment upgrades [are] most relevant for energy-intensive sectors, and further savings possible in less energy intense sectors"[353].

Electrification

Rather than seeking to replace use of fossil fuels with low-carbon fuel use, electrification seeks to replace fossil fuel use with electricity consumption. The emissions savings related to electrification typically rely on the decarbonisation of the UK grid, which is expected to be fully decarbonised around 2035[354]. The potential for emissions reduction by electrification of UK industry is estimated as "between 5 $MtCO_2e$ and 12.3 $MtCO_2e$ per year by 2050"[355].

Electrification is an attractive option for many industries as innovative technologies reach commercial viability and renewable electricity prices continue to decrease. However, it is still perceived that "the main barrier to electrification is the large disparity in the price of natural gas and electricity, resulting in high operating costs"[356]. A further challenge is flexibility and capacity of the UK's electricity networks, which will need to accommodate the increase in electricity demand for industrial processes and electrification in other sectors. Electrification may be most beneficial for dispersed sites (with potential emissions savings for electrification at dispersed sites projected to be 12 $MtCO_2e$ per year, nationally) because of the potential constrained access to low-carbon hydrogen at viable prices[357].

Across the IDC clusters, there is a lower reliance on electrification to reduce emissions. Based on the cluster plans, only about 1-30% of a cluster's emissions will be mitigated through electrification. This may be a result of the high proportion of capital assets within industrial clusters for which fuel switching to hydrogen could be applicable, which would support the retrofitting of existing assets.

Electrification, of course, raises demand for electricity in a cluster and some clusters are already aware that this will cause constraints in their area, or that timelines for establishing the capacity required put the implementation of the plan at risk. This is addressed both by Tees Valley Net Zero[358], which is working with Northern Powergrid to overcome these issues, and by Humber Industrial Cluster, which highlights that "electrification could be seriously constrained by current capacity limitations of the electricity network"[359].

Engineered Greenhouse Gas Removals (GGRs)

GGR is the process of actively removing GHGs from the atmosphere and storing it, using technologies such as DACCS and BECCS.

The UK has an ambition to deploy "at least 5 $MtCO_2$ per year of engineered GGRs by 2030"[360]. Humber Industrial Cluster and the *Scottish Net Zero Roadmap* have plans to deploy DACCS, and Humber intend to use bioenergy with CCS (BECCS, discussed below) to generate negative emissions. Between these deployments, it is expected that over 8 $MtCO_2$ per year of engineered GGRs will be delivered across the clusters by 2030, mainly from Drax and its BECCS technology which is targeting 8 Mt per year of carbon removals by 2030[361], exceeding the UK's 2030 target[xxix].

GGRs play a significant role in the decarbonisation of clusters and the need to offset small amounts of residual, fugitive, and hard-to-abate emissions. GGRs offer the opportunity to achieve negative emissions and supplement other intervention types mentioned above, which can drive and accelerate the speed of decarbonisation. However, the financial barrier of large upfront investment, low technology, and commercial maturity of GGRs pose a risk on the viability of different GGRs.

Based on the cluster plans, there is a lower priority in deploying GGRs as a decarbonisation method due to limited investment and resources compared to other effective measures. Clusters have prioritised efforts to reduce carbon emissions from industry sources (e.g., use of low-carbon hydrogen fuel in steel manufacturing rather than natural gas) instead of "removing" carbon using negative emissions, such as via DACCS or BECCS. Hence, there is a key focus on low-carbon hydrogen production, CCUS, and REEE, with investment and resources allocated more towards these intervention types.

Bioenergy

Bioenergy is the process of producing renewable energy from organic materials. This has the potential to achieve negative emissions when combined with CCS, due to the CO_2 sequestered being of biogenic origin. However, given the limited sustainable biomass supply, allocation of biomass use will need to be prioritised to maximise the value towards decarbonisation of industrial clusters[362].

The six IDC clusters have highlighted the use of biogas, syngas or waste biomass for direct fuel combustion, CHP, and energy from waste. These bioenergy types may be most beneficial for dispersed sites as biogas offers flexibility and can be treated similarly to natural gas. Due to the challenges of bioenergy, environmental concerns, and uncertainty around the use of organic material excluding waste biomass as a fuel to produce energy, there is less attention and focus on bioenergy as there are higher risks and costs which affects the viability of bioenergy.

Other decarbonisation solutions

Other decarbonisation solutions have been highlighted in the cluster plans including, but not limited to, energy storage capabilities, advanced conversion technologies (e.g., e-methanol, e-ammonia), etc. However, these typically have niche applications within the cluster plans and are not expected to contribute significant emissions abatement. These technologies are often linked to the cluster offering low-carbon products or services to other industrial consumers, reducing the manufacturers' Scope 3 (Use of Sold Products) emissions, rather than their Scope 1 emissions.

[xxix] Note that this is based on the cluster plans and does not consider the impact of the outcome of CCUS Cluster Sequencing Process shortlisting.

Characterisation of the supply chain challenge

All six IDC clusters have highlighted supply chain as a vital component in delivering their respective decarbonisation targets. As delivery of key technologies, including CCS and hydrogen production, is ramped up globally, particularly in the United States of America and European Union, competition for resources is expected to increase, with growing constraints on the supply chains of UK projects.

Humber Industrial Cluster's Supply Chain Study highlighted three key risks to capacity and resilience of the required supply chains:

- *"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"*[363].

Net Zero North West is set to capitalise on these needs across the UK by developing a regional hydrogen economy. It expects that this development and "the diversity and scale of HyNet North West will enhance the region's supply chain with opportunities for new and existing businesses and expand the reach of local subcontractors across North West England and Wales"[364]. Other plans have also highlighted the opportunities in their regions, including the *Scottish Net Zero Roadmap* which expects the required investment of up to £9 billion to create a massive opportunity for Scottish supply chains[365].

The *CCSA Delivery Plan 2035*, which analyses the delivery of CCUS across the UK, particularly industrial clusters, has highlighted significant risks and opportunities in this area at the national scale. While clusters could face significant delays and price increases from imported goods and labour, the lack of a "healthy supply chain" in the UK for CCUS would put the government's 2030 and 2035 deployment ambitions at risk[366]. While the government's *CCUS Supply Chain Roadmap* set out activities required to develop the domestic supply chain, it appears that the planned supply chain mapping report, noted in the *CCSA Delivery Plan 2035*, has not yet been published. This work was expected to map existing and potential capabilities to the project pipeline and therefore highlight areas to focus investment. This remains an outstanding 'urgent action' in the *CCSA Delivery Plan 2035*.

Across the cluster plans, the following recommendations have been made to tackle supply chain challenges, both domestically and internationally:

- Growing cross-industry collaboration, to aid in accelerating the matching of demand and supply and highlighting opportunities for growth[367,368];
- Developing modular and standardised components for key technologies, to maximise supply chain flexibility for projects and reducing bottlenecks[369];
- Providing an opportunity for new industries to come to the region, as the growth of domestic and regional manufacturing industries is vital to support and facilitate the deployment of low-carbon technologies for clusters[370];
- Improving the accessibility and sharing of assets, particularly infrastructure (e.g., pipelines, and storage), to benefit from economies of scale in the supply chain[371];
- Increasing levels of innovation spending and supportive policies to expand the level of UK content in CCUS projects and generate more direct benefits for the UK[372].

Alongside these recommendations, several clusters have taken concrete steps in this area, most notably the Black Country Industrial Cluster's establishment of the National Centre for Manufacturing Transition. This cluster has set an objective to "work with other industrial clusters and dispersed sites across the UK, and with the UK and regional governments, to develop and implement practical and policy solutions which support UK manufacturing supply chains through the transition to net zero and the energy cost crisis"[373]. This could provide a focal point for development at the national level, pooling knowledge, and resources to effectively increase supply chain resilience.

The supply chain concerns are not limited to equipment but also the availability of skills. While this does present a risk to cluster implementation, many of the IDC clusters have recognised the opportunity to deliver local benefits in addressing this need. All cluster plans recognise the importance of skills development to increase local involvement in the supply chain and create lasting jobs in their region.

Attention on the required net zero workforce has been increasing for some time. This focus has grown over the last year with the release of numerous publications by UK government and other stakeholders that emphasise the need for further inquiry into jobs and skills for net zero[xxx]. In parallel, IDC cluster plans have considered the risks and opportunities that jobs and skills present in their respective decarbonisation contexts.

[xxx] Such as, the *Independent Review of Net Zero* report (January 2023), HM Government's *Powering Up Britain - The Net Zero Growth Plan* (March 2023), CCC's *A Net Zero Workforce* report (May 2023), IDRIC's *Enabling skills for the industrial decarbonisation supply chain* report (November 2022), the Welsh government's *Stronger, Fairer Greener Wales: Net Zero Skills Action Plan* (February 2023)

On risks, clusters have noted several overarching labour market developments that impact their ability to secure the right type and number of workers to support decarbonisation projects.

- **Demographic shifts:** IDC clusters play host to sectors with aging workforces. As these worker transition away, they take skills and experience with them without an infill of commensurate new labour necessarily taking their place. In one employer survey conducted by a South Wales Industrial Cluster partner, "[h]alf of all businesses reported that between 25% and 50% or greater of their workforce were over the age of 50," while a quarter of respondents noted that "only 10% of their workforce were under the age of 30"[374].
- **Equity, diversity, and inclusion considerations:** A related concern on workforce composition relates to the overall gender distribution of workers. The same survey of industrials located in the South Wales Industrial Cluster (SWIC) Cluster Plan noted that "[o]ver fifty percent of all business survey respondents reported that a quarter or less of their employees presented as female"[375]. While just one example, South Wales Industrial Cluster's finding is reflective of a larger symptom of the industrial workforce at large. That is, in addition to protecting current workers throughout the transition to net zero, new entrants into the labour pool should be integrated so that clusters are building net zero workforces that are accessible and equitable, in accordance with UK government's Levelling Up aspirations[376].
- **Volume of the labour shortage:** IDC clusters have investigated to varying degrees the size of the labour shortages anticipated as cluster plans unfold over the next several decades. In terms of size of the problem, national figures are expecting as many as 480,000 jobs will need to be filled to enable economy-wide decarbonisation by 2050[377]. At the cluster level, plan estimates tend to be in the tens of thousands in terms of the jobs that could be created and safeguarded by their proposed decarbonisation activities over the next several decades. While smaller, these gaps are significant.
- **Timing of specific skills requirements:** Some of the IDC clusters have performed more detailed modelling to indicate the breakdown of jobs impacts by sector and occupation, with engineering and construction jobs of most immediate concern. Humber Industrial Cluster's skills study, for instance, notes that "a significant increase in skills demand over the next 2 years for Net Zero projects to start and be delivered on time" is expected of the region's "Engineering Construction Industry" (ECI) workforce, which as of 2021 is estimated to comprise around 5,400 roles in the Humber[378] These regional employment demands being highlighted by cluster plans are only a part of the picture[xxxi]. From now through 2050, demand for decarbonisation skills is expected to rapidly increase across the entire UK economy (**Figure 16**). This reinforces the need for greater efficiency and coordination between IDC clusters in workforce planning, so that the right workers are available to execute on planned decarbonisation activities, at the right time.
- **Increasing job vacancy rates:** Tees Valley Industrial Cluster's skills planning analysis identified "skilled metal, electrical and electronic trades" and "process plant and machine operatives" as key industrial decarbonisation occupations with unfavourable growth trends in the Tees region. To further substantiate this analysis, the Tees Valley Net Zero Cluster Plan also cites the *Tees Valley Job Vacancies Report*, which has found vacancies in these occupations to be increasing over the last year[380].

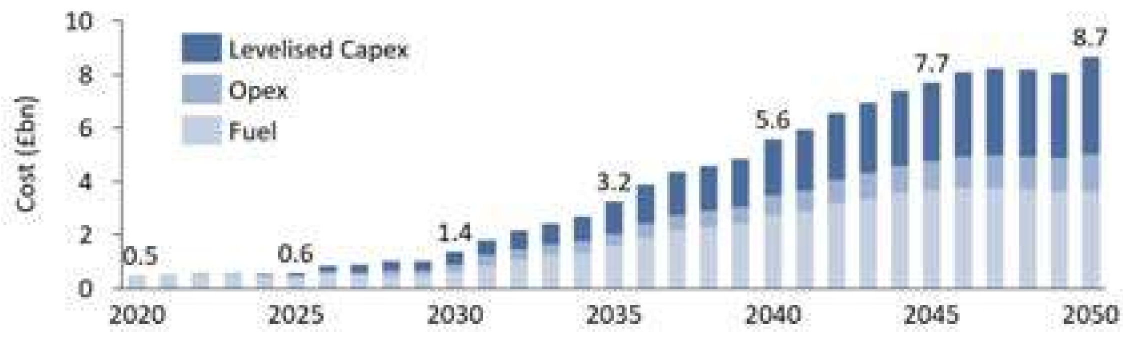


Figure 16: Annualised costs of abatement technologies[379]
Source: CCC, Deep Decarbonisation Pathways for UK Industry (2020)

[xxxi] Though outside the remit of this report, the international element of the supply chain for industrial decarbonisation is also significant. For instance, there are real opportunities for the UK capture spillover social and economic benefits (e.g., from exporting goods and services emerging from industrial decarbonisation overseas).

The IDC clusters understand the complexities of he workforce challenge and have started to explore options to fill the gap. Specific examples include:

- **A skills escalator program in South Wales:** South Wales Industrial Cluster's proposed Net Zero Wales South Wales Industrial Transition from Carbon Hub (NØW SWITCH) will "…support a skills escalator programme, embracing skills development from school leavers into apprenticeships, degree apprenticeships, undergraduate and postgraduate courses and workforce upskilling programmes, that bring local education providers and employers together to capitalise on these future career opportunities"[381].
- **A "Net Zero Skills Charter", as well as a "HyNet Skills Academy" in the North West:** Conceived by the North West Business Leadership Team, with input from Net Zero North West, Manchester Metropolitan University, and the University of Chester, the Skills Charter is intended to help businesses signal their commitment to supporting this skills system needed to achieving net zero[382]. Complementing this work, the HyNet project has also announced plans to partner with the University of Chester to develop a "HyNet Skills Academy," which looks to "equip current and future generations with the knowledge and experience needed to address the opportunities in the clean growth agenda"[383].

Communities analyses

Local benefits assessment

Cluster plans have identified a wide-ranging set of local benefits associated with successful decarbonisation of industry. One of the primary ways clusters understand their relationship with local communities is based on the benefits industrial decarbonisation may generate. To explore this linkage, a targeted literature review of cluster plans and supporting documents was conducted to identify how clusters discuss the benefits communities can experience from decarbonisation. These insights were classified based on the wider benefits type they encapsulate and aggregated by cluster. To be able to develop a cluster-wide perspective, the counts of benefits areas were normalised and summarised in a benefits map (**Figure 17**) to visualise which local benefits areas are topics of focus for the cluster plans.

Ten key local benefits areas were identified and classified into four core benefits categories: Economic, Environmental, Social, and Cultural:

- **Economic**
  - **Jobs:** Benefits that pertain to the impact that industrial decarbonisation projects in cluster plans may have on employment in terms of creating and safeguarding jobs in industries that comprise the cluster.
  - **Local Growth:** Benefits that speak to the potential that industrial cluster decarbonisation is expected to realise in terms of spurring local economic development (e.g., from retaining local employers, attracting new skilled workers).
  - **Skills:** Benefits area covering topics around

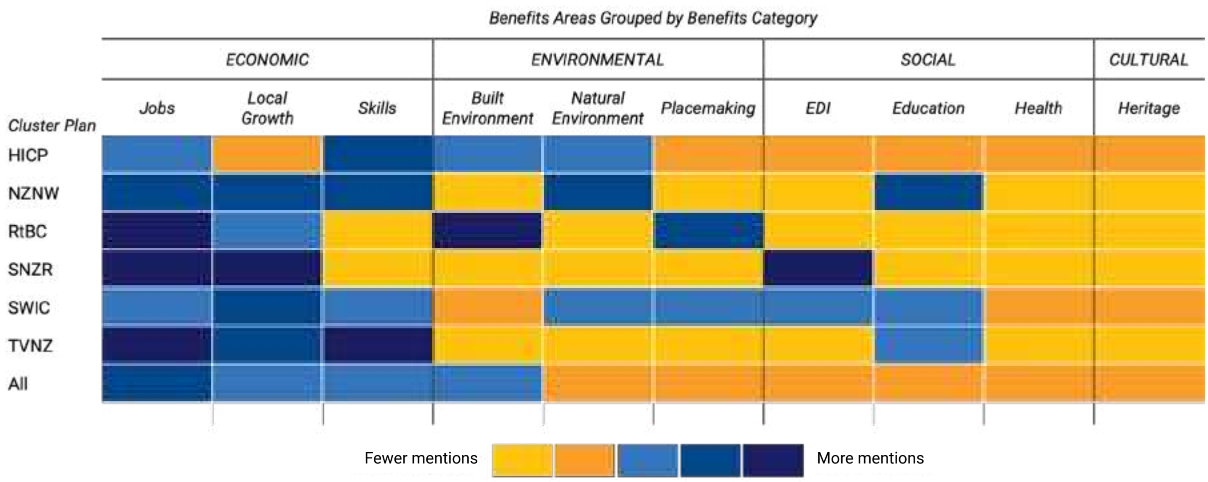


Figure 17: The IDC cluster plan local benefits map illustrates the relative mentions of benefits by category. Benefit areas are coded based on their primary category

how industrial decarbonisation can impact the local workforce- particularly around the provision of new skills, reskilling, and upskilling work that is anticipated to be needed to execute planned decarbonisation projects within the clusters.

- **Environmental**
  - **Built Environment:** Benefits described in cluster plans that pertain to all the physical aspects of communities such as industrial and commercial developments, transportation infrastructure, grid systems, gas networks, etc.
  - **Natural Environment:** Benefits associated with the preservation and improvement of natural assets (e.g., revitalising green space, habitat protection, etc.) in local communities around the industrial cluster.
  - **Placemaking:** Benefits encompassing the ways cluster activity enables and strengthens the sense of place within a community.

- **Social**
  - **Equity, Diversity, and Inclusion:** Benefits related to the prioritisation of underrepresented or disadvantaged populations in enacting industrial decarbonisation activities.
  - **Education:** Benefits that mention education and training institutions, usually in the context of readying the workforce for roles demanded by decarbonisation initiatives.
  - **Health:** Benefits statements found in cluster plans that allude to the positive health impacts that local communities can experience from industrial decarbonisation (e.g., reduced pollution, improved quality of life).

- **Cultural**
  - **Heritage:** Benefits that touch upon how industrial decarbonisation can help strengthen community identity and pride in the local area.

Key observations:

1. **Economic benefits is an area of emphasis across all cluster plans.** Relative to all areas surveyed, almost all the cluster plans have the greatest number of references to the "Jobs" and "Skills" benefits. Local jobs and skills benefits highlighted in the cluster plans include:
   - "…ensure[ing] 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"[384].
   - "support[ing] a skills escalator programme, embracing skills development … and workforce upskilling programmes that bring local education providers and employers together to capitalise on these future career opportunities [through NØW SWITCH]"[385].
   - "driv[ing] the growth of skills required categories such as science, research, engineering, technology professionals and associate professionals…" through new decarbonisation projects[386].

2. **Cluster plans highlight jobs and skills as key components of the value proposition of industrial decarbonisation for communities but have limited their exploration in scope and method thus far.** In the cluster plans, economic benefits for communities are mostly defined through qualitative, high-level explorations. For example, Humber Industrial Cluster conducted interviews with their industrial stakeholders to understand their expectations for labour[387]. Another method was leveraged by Tees Valley Industrial Cluster, which used an economic model to project demand for certain occupations. This led to the plan's focus on boosting construction trades and increasing science, research, engineering, technology competencies[388]. However, it stopped short of additional detail beyond these broader occupation categories. That said, almost all clusters have acknowledged that more work is needed around understanding what industrial decarbonisation's demand for skills will look like over the next several decades. A key opportunity for the UK is to support work that can further disaggregate how and when demand for industrial green skills will manifest in local labour markets.

   However, clusters and their stakeholders would not be starting from a blank page. In the fall of 2022, IDRIC produced an *Enabling Skills for the Industrial Decarbonisation Supply Chain* report that begins to profile the workforce needed- its occupational compositions and competencies- to achieve net zero by 2050. To take this effort further as cluster plan projects progress, an initiative to link workforce planning with on-the-ground data from industrials and private stakeholders spearheading developments can help provide more granular indication of what is needed on jobs and skills to secure their associated benefits at the local level.

3. **Cluster plans mention the remaining benefits areas in the following decreasing order: local growth (economic benefit), environmental benefits, social benefits, and finally, cultural benefits.** This trend ties in with another observation that some clusters have identified a wide range of benefits areas, while others place greater emphasis on a few specific ones. For example, Humber and South Wales Industrial Clusters include a wide spread of mentions

across the benefits areas in their cluster plans and supporting documents. In comparison, the Black Country Industrial Cluster has a more focused distribution of benefits and places a greater emphasis on how the cluster can generate benefits for its communities in the "Built Environment" area.

Overall, the findings from this analysis highlight the breadth of impact that the successful implementation of the cluster plans can have for the local communities that are set to host these developments. In the next section, key takeaways from the complementary analysis of how clusters are thinking about on-the-ground engagement of local stakeholders are presented.

Key takeaways for local stakeholder engagement

Intentional and open engagement with communities can help clusters reduce public challenge against their work. Some IDC clusters have considered how to best engage different local stakeholder groups on what decarbonising industry means for their communities. Highlights from the cluster plans on the who, why, and how of local stakeholder engagement are below:

1. **Engagement with the community involves interactions with a wide range of stakeholders including residents, local government entities, other local organisations, and institutions.** Throughout the development of the cluster plans, IDC industrial clusters have already encountered many of the key players: local governmental entities (e.g., combined authorities, devolved government), education institutions and training providers (e.g., universities, trades organisations), as well as community members themselves. From these interactions, cluster plans have identified additional considerations for determining the set of stakeholders that should be engaged on the topic of industrial decarbonisation. In its "Social Innovation Study" for instance, *Humber Industrial Cluster Plan* notes the additional benefit of engaging with "a greater diversity of young and disadvantaged groups, as well as "the voluntary and community sector…in order to reduce resistance to, and accelerate the delivery of, the industrial energy transition"[389]. The study also specifies outreach to establish relationships with "deprived or marginalised communities" as another important stakeholder group. Through these efforts, cluster plans act on the opportunity that IDC presents to usher in an industrial transition that increases the accessibility of industry to a wider, more diverse set of the communities.
2. **Obtaining community consent for industrial decarbonisation activities is a core driver of clusters' desire to engage.** The cluster plans also address the importance of community engagement for supporting industrial clusters' "social license to operate," and ability to obtain consent for their infrastructure developments. The *Humber Industrial Cluster Plan* and *Scottish Net Zero Roadmap* took steps, as part of their cluster plan development, to understand which stakeholder groups to engage with to support implementation. More details are provided in **Table 3**.

As the *Scottish Net Zero Roadmap* noted, social acceptance of the cluster work is an effective way to mitigate against potential opposition that clusters may face at the local level: "The deployment of major infrastructure needed for deep decarbonisation can only be successfully achieved with social acceptance. Social acceptance in this context refers to (i) the general acceptance of the technology by the wider public and, importantly, (ii) acceptance by the community(ies) that will host the facilities and infrastructure"[390].

Beyond that, local engagement also serves as a channel to intentionally deliver value for local populations. Regarding how decarbonisation investment decisions are generally made, the Black Country Industrial Cluster points out that "local voices in these decisions are relevant but are often whispers in a room full of vocal elephants"[391]. A significant aspect of engagement is about providing local communities a "seat at the table," so benefits generated as industry transitions are more likely to be experienced locally.

Relatedly, local engagement also presents an opportunity for clusters to set the narrative on who will be involved in driving the UK's industrial transition forward. The Black Country Industrial Cluster, for instance, is looking to continue its "policy of positive discrimination in marketing material and case studies" as it looks to further spread awareness of, and interest in, its Zero Carbon Hub ambitions[392]. By doing so, the cluster helps its messages around industrial decarbonisation resonate more widely across local audiences. This generates interest and excitement in cluster decarbonisation activities among populations that have historically been underrepresented in these industries, making the next iterations of these regional economies greener, certainly, but also more inclusive and diverse as well.

3. **Cluster plans promote a local stakeholder engagement style that is context-aware, easy to understand, and intentional.** Across cluster plan documentation reviewed, the *Humber Industrial Cluster Plan* and the *Scottish Net Zero Roadmap* have supplementary reports that provide more in-depth consideration of the mechanics of engagement. Highlights from these documents include the following:

   - Humber Industrial Cluster's social innovation study emphasises that information shared with the public should be "accurate, impartial and unbiased"[393]. This information should also be accessible to a layperson audience (e.g., such that they are able to differentiate between various technology options). The study also suggests that messaging for community benefits should emphasised given its higher degree of relevance and therefore, interest, amongst local stakeholders. It calls out the areas of "employment, jobs, skills development, infrastructure, [and] transport"[394] as specific topics that deserve clear messaging for what community and individual benefits may look like in each industrial decarbonisation context.

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   - Key takeaways from the *Scottish Net Zero Roadmap's Community Engagement Messaging* report are centred more around messaging delivery. For instance, the report notes that clusters benefit from engaging communities early on to start the trust-building process. In contacting local communities, the community messaging report emphasises the importance of understanding who the audience is, noting: "[t]echnology deployments often tend to be in peripheral areas, in or near communities with poor infrastructure, lack of employment opportunities and low incomes. A good project will respond to these"[395]. Furthermore, it recommends that clusters be aware of the history and context of a place: "[a] detailed understanding of target communities is vital to developing and implementing appropriate engagement strategies that properly reflect the specific cultural and historical context if those communities"[396]. All these practices can be supported by enlisting the help of local expertise and community liaisons. By having communications and messaging come from an internal, trusted voice, industrial clusters may be able to secure buy-in and belief from the community in a timelier manner than if they were to rely on external sources during the implementation of their plans.

Appendix 2: IDC cluster plan emissions modelling

Each IDC cluster plan has undertaken some form of GHG emissions calculations as a means of establishing and illustrating its environmental impact. The way in which the emissions modelling has been approached varies across the IDC clusters, but they can be grouped into three types of emissions models.

1. **A project-based savings model:** This type of model takes reported emissions savings from individual projects within the IDC cluster and subtracts them from the current level of emissions calculated for the cluster. The level of transparency that the overarching model creator has is key to the accuracy of this model type. If the "counterfactual" against which each project within the model calculates its savings is not consistent, there is significant risk to the accuracy of the outputs.
2. **A source-based optimisation model:** This type of model breaks down the current calculated emissions for the IDC cluster by the type of source they come from, e.g., whether the emissions are from burning of gas for heat, chemical processes, or other sources. In some cases, the model will also project how the sources of emissions may change over time, e.g., due to growth of industrial activity. The model then typically "assigns" a "solution" to each of the sources of emissions, which results in an assumed reduction in the emissions from that source. These solutions may be deployed in a pre-determined order or during a specific period, determined by cluster assumptions. Depending on the sophistication of the model and information available to the modeller, the proposed solution implementations can also be optimised for cost and timing, based on market assumptions, to meet the overarching objectives.
3. **A key-site illustrative model:** This type of model is more indicative than others, looking key sites within an IDC cluster as a proxy for wider emissions. Typically, this is due to limited information availability or at early stages of development when many variables are still changing. The model then sets out assumptions around changes to the emissions at the key sites to indicate when material changes to the clusters' emissions can be expected.

In some cases, IDC clusters have undertaken more than one type of model, to achieve different objectives and provide a variety of insights to the development of the plans. Based on the three model types set out above, the model types used by the IDC clusters are categorised as shown in **Table 5**. While the cluster models may align with a category, there are significant differences between all the models and the nature of these is discussed further below.

In addition to the three high-level types of emissions models, there are additional cross-cutting differences across the modelling methodologies that are important to consider when interpreting anticipated emission reductions from the implementation of cluster plans:

Model Type	Humber Industrial Cluster Plan (HICP)	Net Zero North West (NZNW) Cluster Plan	Repowering the Black Country (RtBC)	Scottish Net Zero Roadmap (SNZR)	South Wales Industrial Cluster (SWIC) Cluster Plan	Tees Valley Net Zero (TVNZ) Cluster Plan
A project-based savings model		X				
A source-based optimisation model	X	X	X	X	X	X
A key-site illustrative model					X	

Table 5: Categorisation of cluster plan model types

- establishing baseline emissions,
- model boundaries,
- GHG scope inclusions, and
- underlying assumptions.

Baseline emissions: Baselines are important to all these model types, as they set out "the challenge" for the cluster, i.e., the amount of GHG emissions that need to be abated through interventions. Different approaches have been taken to developing baselines across the IDC clusters. Many have opted to use reported figures, e.g., NAEI large point sources database, from a recent year as the size of emissions that need abating, whereas others have developed a view of how the emissions would develop over time without and technical interventions within the cluster (i.e., a counterfactual, as developed in the *Tees Valley Net Zero Cluster Plan*). The latter includes consideration for cluster growth and changes to the sectors in the cluster, which may provide a more realistic view of the challenge. However, the accuracy with which a counterfactual can be produced is difficult to pin down.

Model boundaries: It is also important to note that the boundary of the baselines (i.e., which sources of emissions are included) varies across clusters and between different assessments of the clusters. For example, most of the clusters report larger "baseline" emissions than have been calculated by DESNZ utilising the NAEI 2019 large point source data. This is likely due to differences in the list of specific industrial sites that have been included under each calculation. This could result from the decisions made on which industrial sites to include and depends to some extent on the objective of the modelling exercise for each individual cluster. For example, the Black Country Industrial Cluster have specifically collected data on non-NAEI point sources as the cluster has many small emitters that are not included in the NAEI. As a result, the Black Country Industrial Cluster's reported baseline emissions from their modelling is about six times larger than the DESNZ figure based on NAEI data. While the NAEI data for the cluster amounted to 0.5 $MtCO_2e$ from 26 sites, the total emissions of the cluster are estimated to be closer to 3.2 $MtCO_2e$ from 2,800 sites when smaller emitters in the area are included[397].

GHG scope inclusions: Across these types of models, there are also differences in scope for the emissions accounting. Most of the IDC clusters have focused on direct emissions, which are emissions resulting from fuel consumption and chemical processes in the cluster. This approach is common for industrial decarbonisation; however, it may be useful to consider indirect emissions (i.e., those associated with purchased electricity, steam, heat, and cooling, and supply chain emissions) where consideration of such emissions might impact decision-making. An example of this may be where there is the potential to increase the focus on efficient use of electricity, or the need to transition from grid electricity to certified zero carbon electricity.

Underlying assumptions: In addition to utilising distinct types of models, IDC clusters have also used different underlying assumptions to build their models. The models that have developed different scenarios to test the sensitivity of the outcomes to different variables present a robust view of different ways the cluster may develop. These often include different assumptions on the speed of development of different technologies and markets (e.g., hydrogen development) in the UK.

Several clusters have also used underlying assumptions published by the government, as these are easily available and commonly used across industry. This is a good approach when more specific, project verified data is not available for inclusion, which is typical until plans for the individual implementations are quite mature. Over time, accuracy of a model could be increased through switching to project specific assumptions which would represent specific equipment performance parameters, rather than the "average" factors published by the government.

To monitor the progress of the clusters, it would be beneficial to establish a consistent baseline across all industrial clusters and a modelling methodology that can be unilaterally applied for the purpose of comparison (see **Recommendation 5**).

Appendix 3: IDC cluster plan economic impacts modelling

The IDC cluster plans include measures of the economic impact of decarbonising industrial clusters. The approaches used to capture these impacts can be characterised as either modelling or non-modelling-based methods, i.e.,

1. **Modelling-based:** The cluster plans contain economic impact estimates derived from an economic model (e.g., input-output model). In these cases, clusters investigate how changes in expenditure related to cluster plan projects will spread through the economy and impact economic indicators such as jobs and gross value added (GVA).
2. **Non-modelling-based:** The cluster plans do not formally model the economic impacts of planned projects. Instead, they include other measures of how a cluster's regional economy could be impacted with the successful realisation of planned activities (e.g., project level capital expenditure and employment expectations, illustrative time series of employment levels comparing a decarbonisation vs. a deindustrialisation regime, etc.).

Table 6 contains a cluster-by-cluster summary of the approach taken to develop measures of economic impact by each IDC cluster plan.

Approach Type	Humber Industrial Cluster Plan (HICP)	Net Zero North West (NZNW) Cluster Plan	Repowering the Black Country (RtBC)	Scottish Net Zero Roadmap (SNZR)	South Wales Industrial Cluster (SWIC) Cluster Plan	Tees Valley Net Zero (TVNZ) Cluster Plan
Model-based	X	X		X		X
Non-model based			X		X	

Table 6: Categorisation of cluster plan approaches to developing economic impact estimates

Humber Industrial Cluster Plan (HICP): An input-output (IO) based model was employed to develop economic impact estimates of industrial cluster decarbonisation for the *Humber Industrial Cluster Plan*. The period modelled is understood to range from 2022 to 2040[xxxii]. For each decarbonisation scenario, projected expenditures (CAPEX + OPEX) required to realise a given scenario were estimated based on expected equipment costs. Expenditures were then mapped across industry sectors and sector multipliers applied to estimate the impact of the investment across the UK economy[xxxiii]. The application of type 2 multipliers implies that direct, indirect, and induced effects were considered in the calculation of jobs and GVA metrics. Multipliers are derived from ONS national input-output tables. As such, resulting estimates had to be scaled down to the Humber region. To do so, HICP partners applied "sector specific local content shares" to estimate how much economic activity will stay within the Humber[398].

Net Zero North West (NZNW) Cluster Plan: The *NZNW Cluster Plan* partners also developed an IO-based model to inform the development of economic impact estimates for the *NZNW Cluster Plan*. A similar focus was placed on GVA, jobs, and expenditures, with values estimated for the period 2023 to 2065[399]. CAPEX and OPEX estimates were calculated based on projects considered for inclusion in the cluster plan's scenario development process. These expenditure values were then used as inputs in GVA and jobs demand modelling, with CAPEX and OPEX estimates split into "design," "construction," and "manufacturing" sector items. In addition to expenditure values, the model also converts investment into GVA, and GVA into jobs, using ONS sectoral data and labour productivity estimates respectively[400].

[xxxii] Not explicitly stated in cluster documentation; range was determined based on review of those included in figures from https://www.humberindustrialclusterplan.org/files/HICP_Lot_1_Final_Report.pdf
[xxxiii] For an explanation of sector multipliers, including the "type 2" multipliers used here, see explanation from the Office of National Statistics: ons.gov.uk/economy/nationalaccounts/supplyandusetables/articles/inputoutputanalyticaltables/guidanceforuse

Across two stages in the model, direct GVA and jobs demand were estimated. For the estimation of indirect GVA and jobs demand impacts, ONS sectoral GVA and job indirect multipliers were applied. Induced effects were not considered in the NZNW approach[401]. The final jobs and GVA impact estimates presented in the *NZNW cluster plan* are thus representative of direct and indirect impacts.

Repowering the Black Country (RtBC): RtBC's estimates were developed using a non-model-based methodology centred around the Zero Carbon Hub (ZCH) concept. For each hub, the cluster plan estimated of the cost to create the hub, as well as the anticipated jobs that the hub would create and retain. There are master plans for six ZCHs referenced in RtBC's exploitation plan, along with a note that as many as sixty could be required to deliver a net zero industrial cluster[402].

Scottish Net Zero Roadmap (SNZR): The SNZR includes economic impact estimates derived using an IO-based model. The model constructed for SNZR estimated how various cluster decarbonisation scenarios affect GDP, GVA, and employment. Like other modelling-based approaches, the analysis took estimates for the additional investment (CAPEX + OPEX), needed to achieve net zero across the SNZR's emitters, and mapped it to sectors as defined in the Scottish input-output tables. Based on the multipliers for the selected sectors, direct, indirect, and induced effects of the initial investment were estimated.

South Wales Industrial Cluster (SWIC) Cluster Plan: SWIC did not build a conventional economic model (e.g., input-output, general equilibrium, etc.) to estimate GVA and jobs impacts. Instead, jobs were estimated based on industry knowledge of what it would take to transition large emitters in the region to operate under a net zero regime.

Tees Valley Net Zero (TVNZ) Cluster Plan: The *TVNZ Cluster Plan* features economic impact estimates derived using the "Local Economy Forecasting Model" developed by Cambridge Econometrics[403]. Model inputs included data on industrial investment projections collected through a survey of local industrial partners. The model processed this investment data to derive economic estimates including employment and GVA. These values were forecast over the period 2022 to 2040. Modelled scenarios included direct, indirect, and induced effects, with assumptions around the degree to which effects would manifest within the Tees Valley region (i.e., local content share) applied.

In the approaches described above, the IDC clusters' methods to produce economic estimates demonstrate some nominal similarities. However, sufficient differences limit further aggregation of impact estimates across all six clusters. Two examples of the differences in approach that hinder the aggregation of the modelling-based estimates produced by the IDC clusters are:

- **Timeframe modelled:** The period over which economic impact estimates are calculated for each cluster varied. Timeframes modelled ranged from less than twenty years (e.g., TVNZ) on the low end to more than forty on the upper end (e.g., NZNW).
- **Type of effects included:** Most modelling-based impact estimate approaches employed by the IDC clusters used input-output modelling principles to develop measures of how employment and GVA would be impacted by cluster activities. In IO models, direct, indirect, and induced effects can be included[xxxiv]. Across the IDC clusters, decisions on which of these effects to include differed, with some clusters' models choosing to only include direct and indirect effects, while others choosing to factor in induced effects. With the inclusion of induced effects by some models, an additional complication arises around ensuring that impacts are not double counted (i.e., net effects) at the national level (i.e., estimates presented in cluster plans are presented without consideration for how the potential increase in employment/GVA in their cluster region may displace employment/GVA in other regions).

While economic impact estimates may be reasonable and valid in the context of each IDC cluster plan, the same is not necessarily true when considering economic estimates in aggregate. As a result, each IDC industrial cluster's economic impacts are featured individually in *Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation* and only aggregated at a high level to provide a sense of magnitude of the opportunity presented by the implementation of the IDC cluster plans at the national level.

[xxxiv] Direct effects encompass impacts associated with realising cluster plan projects only (e.g., the number of jobs needed to employ a new hydrogen plant within a cluster). Indirect effects include downstream supply chain effects of realizing proposed decarbonisation projects (e.g., contractors hired to provide legal services during the development of the new hydrogen plant). Induced effects include economic impacts that proliferate across the wider economy because of the initial expenditure (e.g., the wages that employees at the new hydrogen plant spend on other products and services in the economy).

Appendix 4:
IDC cluster plan documents referenced

Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation was informed by many documents. While the endnotes provide comprehensive citations, the documents listed below were the primary sources for IDC cluster plan analysis.

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QR code links

For more information about the Industrial Decarbonisation Challenge (IDC) or the six IDC cluster plans, use your digital device to scan the QR codes below to be taken to their respective websites.

IDC

https://www.ukri.org/what-we-offer/browse-our-areas-of-investment-and-support/industrial-decarbonisation/

The Industrial Decarbonisation Challenge (IDC) supports development of low-carbon technologies and infrastructure while contributing to clean growth through its support of the UK's largest industrial clusters.

The IDC is led by Innovate UK and funded the development of the cluster plans listed on this page to lay the foundation for developing at least one low-carbon industrial cluster by 2030 and the world's first net-zero cluster by 2040.

HICP

https://www.humberindustrialclusterplan.org/files/Cluster Plan 9 March.pdf

The Humber Industrial Cluster Plan (HICP) showcases the results of a two-year, collaborative journey towards demonstrating how the Humber can achieve net zero and contribute to removing greenhouse gas emissions from the atmosphere.

The document also sets out the region's plan to remain attractive for investment and drive opportunities for employment and economic growth.

NZNW

https://api.netzeronw.co.uk/uploads/NZNW_Cluster_Plan_Y2_Summary_FINAL_fcba0b7233.pdf

The Net Zero North West (NZNW) Cluster Plan highlights the significant pipeline of net zero infrastructure investment centred around the Dee Estuary in North West England.

The cluster plan sets out how the industrial cluster will work together to drive energy security, create jobs, and generate economic value in the local and wider economy.

RtBC

https://zerocarbonhubs.co.uk/zero-carbon-hubs.html

Repowering the Black Country (RtBC) Cluster Plan addresses the challenges of decarbonising the relatively disperse and low-emitting manufacturing supply chain companies that make up the majority of UK industrial activity in terms of GVA.

RtBC set out how zero carbon industrial hub, a scalable and replicable methodology, will support widespread realisation of the benefits associated with achieving net zero.

SNZR

https://www.tmdassets.co.uk/client_assets/NECCUS/SNZR_final.pdf

The Scottish Net Zero Roadmap (SNZR) sets out how a cluster of the largest industrial emitters in Scotland can move towards net zero by 2045.

The project partners worked together to explore net zero pathways and, through evidence development and extensive consultations, determine which was optimal in terms of risk, cost, and timeliness.

SWIC

https://www.swic.cymru/clusterplan-reports

The South Wales Industrial Cluster (SWIC) Cluster Plan is the culmination of extensive collaboration between 47 organisations to establish how they will achieve a world-leading, truly sustainable industrial cluster.

SWIC sets out how they will work with external stakeholders, and navigate the policy and regulatory environment, to make the plan a reality.

TVNZ

https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/03/Net-Zero-TV-Key-Findings-Document-8.pdf

The Tees Valley Net Zero (TVNZ) Cluster Plan sets out how the industries inside the Tees Valley Combined Authority will achieve net zero through decarbonisation rather than deindustrialisation.

The cluster plan explores opportunities, including through collaboration with other UK regions and the development of international markets for hydrogen, while also considering skills and supply chain constraints.

UK Research and Innovation