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Decarbonising the Foundation Industries and the implications for workers and skills in the UK

The case of steel, glass and cement industries

September 2022

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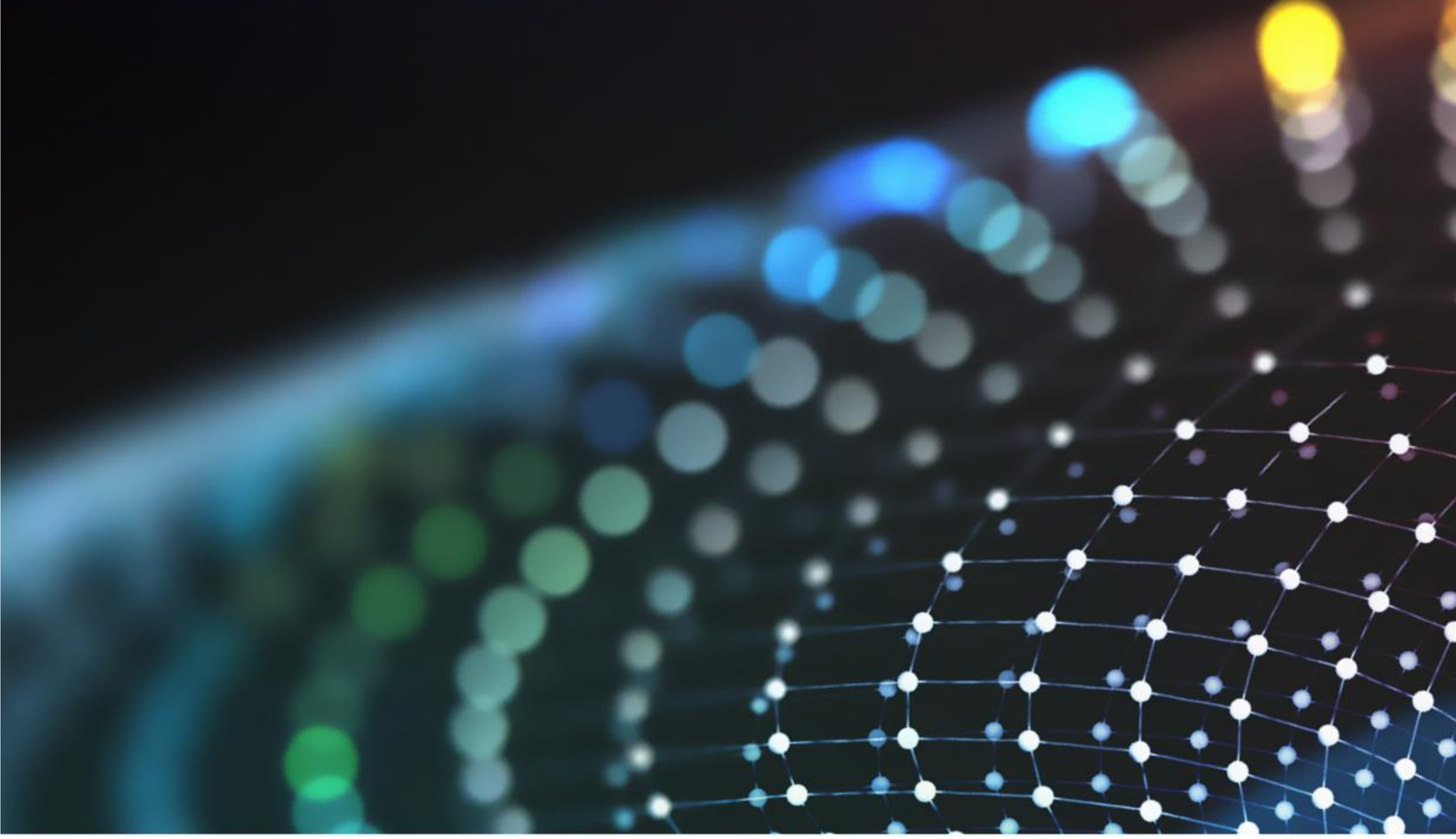

The full version of the report ***Decarbonising the Foundation Industries and the implications for workers and skills in the UK-* the case of steel, glass and cement industries** can be accessed via the following link or QR code.

https://business.leeds.ac.uk/downloads/download/281/decarbonising_the_foundation_industries_and_the_implications_for_workers_and_skills_in_the_uk

Executive Summary

About this report

- This report focuses on the energy intensive industries or Foundation Industries in the UK, the prospects for decarbonisation and related employment and skills issues. It includes a particular focus on the glass, cement and steel sectors and includes an analysis of key sector reports, data and interviews with 25 industry, academic and trade union experts.

- Foundation industries (FIs) in the UK account for 2.5% of GDP and over 10% of greenhouse gas emissions. Decarbonisation of those industries are therefore a priority if net zero is to be achieved by 2050. Progress is slow and insufficient funding for decarbonisation may lead to closures and job losses across the UK FI industries.

- Reductions in emissions to date has been made by energy efficiency gains. Further reduction is heavily reliant on future technologies including the electrification of industrial processes and innovations in hydrogen usage within these sectors and the introduction of Carbon Capture and Storage (CCS). As electrification and hydrogen infrastructure is proceeding slowly emissions reductions could take advantage of alternative solutions such as demand reduction, dematerialisation, and new business models.

- Decarbonising strategies for FIs are focused heavily on technological innovations with a limited focus on the skills pipelines needed to ensure adequately skilled workers are available to carry out these projects.

Decarbonisation pathways

- The UK government plans for decarbonizing industry as a whole focus on specific technological innovations, new infrastructure to support a switch to hydrogen and access to CCS targeted at geographical clusters where industrial emissions are concentrated. However, around half of all industrial emissions and many of the FI businesses are located outside these clusters. Lack of access to these key technologies may threaten their future viability.

- Electrification of industrial processes is likely to be crucial for glass and steel sector decarbonisation. However, the efficacy of this strategy relies on the expansion of the renewable energy sector sufficient to meet demand and considerably lower electricity costs.

- Material substitution, i.e., increased use of cullet (recycled glass) and alternative raw materials in cement production is also likely to be necessary.

- The potential of higher levels of circularity are underexplored in the foundation industries.
- A clear commitment to a green fiscal stimulus package is currently missing in the UK, despite pressure from a number of organisations to tackle the post COVID19 slump via a package of measures designed to support a faster green transition.

The skills provision for net zero Foundation Industries faces numerous challenges:

- There are already notable skills mismatches in the FIs. FI employers tend not to be focused on the longer-term needs of developing the skills required for competitiveness in a net zero economy, but on trying to combat the more immediate problems of hard to fill vacancies, a homogenous and ageing workforce and associated loss of technical knowledge. There is a lack of understanding of the scope of change needed to meet net zero targets in some parts of the FIs.
- There are some problems inherent to the training provision system including a lack of cooperation between FE and HE and FI businesses that hampers the development of adequate training. A more regional approach to skill development would benefit the FIs.
- Many of the regions where FIs are located have low levels of educational attainment. To ensure workers can benefit from net zero opportunities including the availability of high skilled jobs, more investment in education systems, access to careers guidance and training is needed. The specific skill sets needed for net zero are unclear as decarbonization pathways remain uncertain.
- Strategic planning on green skills is in its infancy and centres around the skills needed for new technologies, while future new business models will require other expertise. For example, retrofitting may lead to less demand for steel but requires experts in retrofit and digitalisation to understand material composition for planning reuse.
- Good practice examples of innovation, education and skills programmes are identified and promoted across the FIs, yet the lack of wider systemic supports inhibits the adoption of new approaches at the scale and speed required. This includes the need for more coordination that links support for innovation in FI decarbonisation technologies with related policy (often linked to other economic sectors or consumers) that promote material recycling and reuse.

The future of the Foundation Industries in the UK

- Total employment across the UK in the FI sectors is cautiously estimated at between 150,000 and 250,000 depending upon sector definitions. FIs in the past have seen major job decline (steel industry, chemicals, and paper in particular), and the decline has been steep compared to other OECD countries.

- The regional concentration of FI employment (with the exception of cement which tends to be dispersed) in areas where good quality well paid jobs are hard to come by, means that further job losses/growth have the potential to exacerbate/address regional inequalities. FI job loss would have implications for supply chains that support these businesses. More collaboration at local level and across the FI sectors is needed.

- The projections for job creation in the industrial decarbonisation cluster projects estimate a possible growth of over 10,000 direct permanent jobs, with up to 50,000 additional skilled workers needed during the construction phase of these projects. Severe recruitment challenges due to skill shortages are likely to slow the roll out of the industrial decarbonisation cluster projects.

- Workers are not yet participating in any systematic discussions around net zero in the FIs. Participation and engagement of workers will be vital to achieve net zero targets.

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1. Introduction

Decarbonising industry is crucial to achieving net zero. This report focuses on the energy intensive or Foundation Industries (FIs) which include the metals, chemicals, glass, cement, pulp and paper and ceramics sectors[1]. In the UK, the FIs account for around 50 million tonnes of CO2 emissions per year and face huge challenges in achieving net zero. They account for 10% of UK greenhouse gases and thus need to decarbonise at an unprecedented pace to allow the UK to meet its target of net zero emission by 2050 (UKRI, Foundation Industries, 2022c). The FIs are also economically and strategically important to the UK: they contribute £52 billion to the UK economy, or 2.4% of total GDP via the production of 28 million tonnes of materials (Griffin, Hammond, & McKenna, 2021). FI materials are all around us: around 75% of the materials we see on a daily basis were made by the FIs (UKRI, 2022a). Their products are predominately bought by other manufacturing or construction businesses (Lawrence & Stirling, 2016). For example, glass and cardboard is used as packaging by food and drink manufacturers and steel, cement, ceramics, and glass are used throughout the construction industry. They are also horizontally integrated and interdependent. For example, the chemical industry produces the caustic soda and sodium hydroxide used in pulp and paper making, and ground granulated blast furnace slag (GGBS) is a by-product of the iron making industry but is often used as a cement replacement in the production of concrete. In total, the FI sector employs around 250,000 people (ERC, 2021). The route towards decarbonisation for these industries is complex and will involve a mix of technological and socio-economic solutions.

Decarbonising FIs will have effects on employment and jobs which are not yet well understood. FI emissions originate from businesses which are located inside industrial clusters, as well as from sites which are considered "dispersed" i.e., located outside geographically concentrated groups of interlinked industries (see below for further discussion). In 2020, the UK Government launched the Transforming Foundation Industries Challenge. The intention is to build a collective sense of identity for the FI sectors and foster collaborative action to help make UK FIs internationally competitive, secure more jobs throughout the UK and grow the sector in an environmentally sustainably way (UKRI, 2022a). Interestingly, energy intensive businesses often themselves do not necessarily identify with the FI label. Until recently, they collaborated as the Energy Intensive Users Group[2] (EUIG), a lobby group which stresses the importance of lower energy prices for energy intensive industrial (EII) users. This issue is important as there has been a number of calls to support and shore up UK FIs by improving their access to finance, introducing more strategic procurement policies, and increasing R&D funding (Lawrence & Stirling, 2016) and clearly self-identification of businesses within this category is crucial for successful policy engagement.

[1] UKRI uses the 2007 SIC codes for the above sectors as the formal definition for the Foundation Industries. This definition focuses on primary producers rather than downstream users of basic products (SQW, 2021).

[2] www.eiug.org.uk

Table 1: Foundation Industry Emissions

Sector	MtCO2e in 2018
Glass	2.1
Other minerals (including ceramics)	2.2
Paper	2.3
Cement	6.8
Metals	12.9
Chemicals[3]	16.9
Total	**43.2**

Source: Element Energy, 2020

This report includes an overview of FI decarbonisation pathways and more in-depth case studies of three of the FI sectors: steel, glass, and cement. These were chosen as they cover a range of emission levels. Within the metals sector the steel industry produces the largest amount of emissions contributing 12% to all UK industrial emissions; cement, can be classified as a medium emitter; and the glass industry makes a significant but much smaller contribution (see Table 1 above). All three industries emit what are termed *process* and *combustion* emissions. Combustion emissions refer to the emissions associated with the energy and fuels input used to reach the high temperatures that the creation of these materials requires (e.g., melting steel/glass or making the key ingredient in cement), and process emissions refer to the production of CO2 as a by-product from industrial processes, primarily the raw materials used as inputs to production (e.g., limestone, coking coal etc.). The report draws on government, industry, and academic documents, alongside 25 interviews undertaken specifically for this study with experts in the glass, cement, and steel industries (see table 2). Where observations or quotations in the report draw directly from these interviews, the interview code number is highlighted.

We outline the likely decarbonisation pathways for three of the FI sectors in the UK and consider the implications for work, employment and skills needs. We pay special attention to decarbonisation policy proposals centred on industrial clusters and the implications for jobs and skills in the local economy, as well as how this particular approach to industrial decarbonisations will affect FI businesses across the UK. In the following section, we look first at the policy context surrounding FI decarbonisation strategy in the UK. This is followed by presenting the UK Government's approach to industrial decarbonisation in more detail, with a strong focus on the roll out of industrial decarbonisation projects. We then discuss the implications of UK decarbonisation plans for FI job security and skills demands generally. We also discuss sector specific decarbonisation strategies and challenges for glass, cement and steel, and the implications for employment and any changes for jobs and workers. In the final section, we review the analysis to critically assess UK industrial decarbonisation strategy and highlight the shortcomings with respect to FI decarbonisation trajectories putting an already fragile sector of the economy at greater risk.

[3] Includes ammonia, ethylene, lime, and other chemicals

Table 2: Stakeholders consulted

Stakeholder perspective	(Sub) sector	Code
Management representative	Glass	A
Management representative	Glass	B
Industry Body	Glass	C
Trade union representative	Glass	D
Trade union representative	Glass	E
Academic expert	Glass	F
Industry body	Glass	G
Industry body	Glass	H
Academic expert	Cement	I
Academic expert	Cement	J
Trade union representative	Cement	K
Trade union representative	Cement	L
Management representative	Cement	M
Management representative	Cement	N
Management representative	Cement	O
Industry body	Cement	P
Academic expert	Steel	Q
Trade union representative	Steel	R
Industry body	Steel	S
Trade union representative	Steel	T
Management representative	Steel	U
Trade union representative	Steel	V
Trade union representative	Chemicals	W
Regional focus	Skills Expert	X
FI focus	Skills Expert	Y

Source: Authors

2. Industrial decarbonisation strategy: UK Government action and proposals[4]

During the past 15 years, emissions reductions targets have been successively increased. In June 2019, the UK amended the Climate Change Act of 2008 and became the first major economy to commit to the target of net zero emissions by 2050. This target went beyond the earlier commitment of at least 80% of greenhouse gases relative to 1990 (BEIS, 2019a). Interim targets have been ratcheted up accordingly. In December 2020, the UK Government announced its aim of reducing emissions by at least 68% by 2030, this was followed in April 2021 by the aim of reducing emissions by 78% by 2035 compared to 1990 levels. For the first time, this would include emissions from aviation and shipping (UK Government, 2021). These targets are tough but extremely necessary. Boris Johnson, the former UK prime minister (2019-2022) backed a shift to a greener economy, at a rhetorical level at least, recognising in his UN climate speech pre COP26 in 2020 that: “we have the tools for a green industrial revolution, but time is desperately short”. The incoming Liz Truss government seems far less likely to take action to address climate change and has appointed Jacob Rees-Mogg as energy secretary despite his expressed scepticism on the seriousness of climate change (Crerar, Horton, & Mason, 2022).

The Climate Change Act 2008 also established the Climate Change Committee (CCC), an independent body that provides analysis of the data on climate change and options for decarbonisation pathways. These inform the options for the proposed series of carbon budgets that map the path to net zero by 2050. In its most recent report on the options for the sixth carbon budget, 2033-2037, the Climate Change Committee noted that for manufacturing and construction[5], sector emissions have declined and are now 56% below 1990 levels. However, 25% of this decline was due to output and structural effects (such as the closure of major emission sites such as Redcar steelworks). The report indicates that the main options for reducing emissions are resource efficiency, material substitution, energy efficiency, fuel switching and Carbon Capture and Storage (CCS) (Climate Change Committee, 2020b). The Government’s plans for reaching net zero were initially outlined in its *10 Point Plan for Green Industrial Revolution* (HM Government, 2020) setting out the approach government would take to ‘build back better, support green jobs, and accelerate our path to net zero’. The report focused predominantly on government support for ‘green industries’ such as renewable energy (notably offshore wind), hydrogen, carbon capture, ‘new nuclear’ and the greening of buildings, vehicles, and public transport.

[4] The analysis for this report was conducted in early 2022 and is thus not taking into account policy changes that might be happening under the new government with Liz Truss as Prime Minister.
[5] These two areas are treated as one aggregate sector by Climate Change Committee.

The *10 Point Plan* did not specifically mention the FIs although a section referred to Carbon Capture Usage and Storage[6] (CCUS) via a £1bn CCUS infrastructure fund and the plan for net zero industrial clusters or Superplaces. The co-location of industry in clusters means that decarbonisation infrastructure can be shared, reducing the unit cost for each tonne of carbon abated. Clusters often drive value creation in a region via the export of goods and services and can also create opportunities for resource and energy efficiency and learning and innovation sharing (HM Government, 2021). Table 3 shows the key UK Government Decarbonisation Policy documents of relevance to the FIs. A number of funding opportunities have been made available to help support the policies laid out in these documents (see Appendix A). These funding sources are focused on driving technological innovation and development of Front-End Engineering Design (FEED) studies for potential engineering and infrastructure projects. A small amount of money has been allocated to mapping potential skills shortage for putting in place pipelines, to ensure that skilled workers are available to carry the projects required for these decarbonisation initiatives to take effect.

Specific policy statements relating to industrial production were outlined in the Government's Industrial Decarbonisation Strategy (IDS) and the 'Build Back Better - Plan for Growth' both published in March 2021. The IDS built upon the Clean Growth Strategy of 2017 and the Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 which began in 2013 under the direction of the Department for Energy and Climate Change (DECC)[7] and Business, Innovation and Skills (BIS). The roadmaps, published in 2015, set out potential pathways for eight of the most heat-intensive industrial sectors to reduce greenhouse gas emissions and improve energy efficiency, namely: cement, ceramics, chemicals, food and drink, glass, iron and steel, oil refining, and paper and pulp. The need for strategy and organisational leadership, policy support on future energy costs and security, market structure and competition, Life Cycle Accounting and value chain collaboration supported by research and development and skills policy support were identified as priorities across the FI sectors. However, these documents did not set out a path towards net zero but rather, offered pathways towards maximum reductions of 73% if the 'maximum technology' pathway was followed (BEIS, 2015).

Table 3: Key UK Government Decarbonisation Policy Documents

Key UK Government Industrial Decarbonisation Documents	**Date Published**
Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050	Mar-15
The Ten Point Plan for a Green Industrial Revolution	Nov-20
Energy White Paper - Powering Our Net Zero Future (EWP)	Dec-20
Skills for Jobs: Lifelong Learning for Opportunity and Growth	Jan-21
Industrial Decarbonisation Strategy (IDS)	Mar-21
Build Back Better: Plan for Growth	Mar-21
Green Jobs Taskforce (GJTF)	Jul-21
UK Hydrogen Strategy (UKHS)	Aug-21
Net Zero Strategy: Build Back Greener	Oct-21

The IDS of March 2021 also developed further, the idea of a sequential place-based approach to industrial decarbonisation in which pre-existing industrial clusters are targeted for low carbon

[6] In this report we generally use the term CCS rather than CCUS, as the vast majority of the captured carbon will be stored rather than used. The only exceptions are when we refer to specific government funding schemes mentioned in reports which tend to use the term CCUS.

[7] In 2016, the DECC merged with BIS to form the Department for Business, Energy and Industrial Strategy (BEIS).

infrastructure first. It offered the CCUS Infrastructure Fund [8] £1bn, Heat Network Improvement Programme [9] (£320m) and switch to low-carbon fuels of hydrogen, electricity and biofuels setting out a staged approach for the 2020s including demonstration funding of the Industrial Energy Transformation Fund [10] (IETF, £315m) and Industrial Decarbonisation Challenge (IDC, £170m) and NetZero Innovation Programme [11] (NZIP, £1bn) coupled with the Transforming Foundation Industries (TFI) programme [12] (£66m).

In October 2021, the UK Government released their *Net Zero Strategy: Build Back Greener* (NZS) which contained further detail on policy investments, (but limited in additional funding allocations). The strategy again placed attention on the development of the growth of new 'green' industries and the encouragement of fuel switching, resource efficiency and carbon pricing tools and all targets are in line with the 2037 delivery pathway (NZS, 2021). The NZS highlights the proposed sequencing of the development of net zero industrial clusters and carbon capture from existing manufacturing funded by the IETF and Net Zero Hydrogen Fund (NZHF). The NZHF is £240 million for CCS enabled 'blue' hydrogen projects. This has 2 strands (both allocated 2022) one will support FEED and post-FEED costs the other will support low carbon hydrogen projects to take Final Investment Decisions for deployment by early 2025. The following section discusses decarbonisation pathways including the cluster-based approach in more detail.

The NZS also set out plans for consultation on a revised Emissions Trading System (ETS) scheme (to be launched at the end of 2023), proposals for regulatory oversight for the monitoring, reporting and verification of greenhouse gas removal and comments on how these important industrial projects will be funded. The term used is 'start to mobilise additional public and private sector investment', but how this will be achieved is not clear. With respect to the section of the report dedicated to industry, which includes plans for CCS, the hope is that the government will mobilise at least £14 billion, with respect to fuel supply and hydrogen £20-30 billion and around £20 billion for greenhouse gas removal. A significant component of this hoped for investment for greenhouse gas removal is likely to be directed towards Direct Air Capture Carbon Storage (DACCS) an engineering greenhouse gas removal technology which is currently unproven at scale and requires low-carbon energy inputs to ensure life-cycle carbon reductions. The speed of electricity grid decarbonisation is of vital importance to FI decarbonisation as many of the FIs hope to electrify processes currently powered by fossil fuels as we approach 2050. However, the use of electricity by FIs is currently limited by a lack of grid capacity [management representative INT O].

Prior to the IDS of 2021 in December 2020, the Government published its *Energy White Paper* (EWP) which reaffirmed commitments to nuclear power and committed the country to significantly increasing offshore wind capacity by 40GW to 50GW by 2030 [13] (BEIS, 2020). These ambitions were pushed further in the NZS which also included the stated aim that the electricity system would decarbonise completely by 2035, 15 years earlier than the target set in the 2020 EWP, whilst meeting

[8] https://www.gov.uk/government/publications/design-of-the-carbon-capture-and-storage-ccs-infrastructure-fund/the-carbon-capture-and-storage-infrastructure-fund-an-update-on-its-design-accessible-webpage
[9] https://www.gov.uk/government/collections/heat-networks-investment-project-hnip-overview-and-how-to-apply
[10] https://www.find-government-grants.service.gov.uk/grants/industrial-energy-transformation-fund
[11] https://www.gov.uk/government/collections/net-zero-innovation-portfolio
[12] https://www.gov.uk/government/news/transforming-foundation-industries-apply-for-a-fast-start-project
[13] This has subsequently been increased to 50GW of offshore wind by 2030 (HM Government, 2022a)

a 40-60% increase in demand although based on current progress this seems unlikely (Climate Change Committee, 2020b).

A clear commitment to a green fiscal stimulus package is currently missing in the UK, despite pressure from a number of organisations to tackle the post COVID19 slump via a package of measures designed to transition the country (ADEPT, 2021; Climate Change Committee, 2020a; Jung & Murphy, 2020; Wales TUC, 2020). In the 2022 spring budget, there were no new funding announcements made to help deliver net zero. However, given the urgency of a green transition, delaying investment does not make longer term fiscal sense. In 2021, the Office for Budget Responsibility has estimated that delaying climate action is likely to increase public sector debt, suggesting that it could reach 289% of GDP by the end of the century, as opposed to only 20% of GDP if action is taken earlier (OBR cited in Jackson & Jackson, 2021). The Climate Change Committee has stated ‘There is strong evidence, set out in our 2020 Progress Report to Parliament, to support a range of low-carbon and climate adaptation 'green stimulus' measures. Many can be delivered quickly and have high multipliers, high numbers of jobs created, and boost spending in the UK (Climate Change Committee, 2020a, p. 14).

Analysis of UK industrial decarbonisation policies has noted that there is a lack of integration and coordination between different elements including regulation, funding and carbon pricing, and that much greater ambition and synergy between policies is needed if the interim and final net zero by 2050 target is to be met (Garvey and Taylor 2020). While the route to the type of investment required for rapid decarbonisation remains contested, the current policy approach places emphasis on specific technologies and cluster locations with implications for the decarbonisation of the FIs and related employment and skills issues that these pathways imply. These technological and location specific developments are discussed in more detail in the following section.

3. Decarbonisation pathways: technological solutions and cluster-based approach

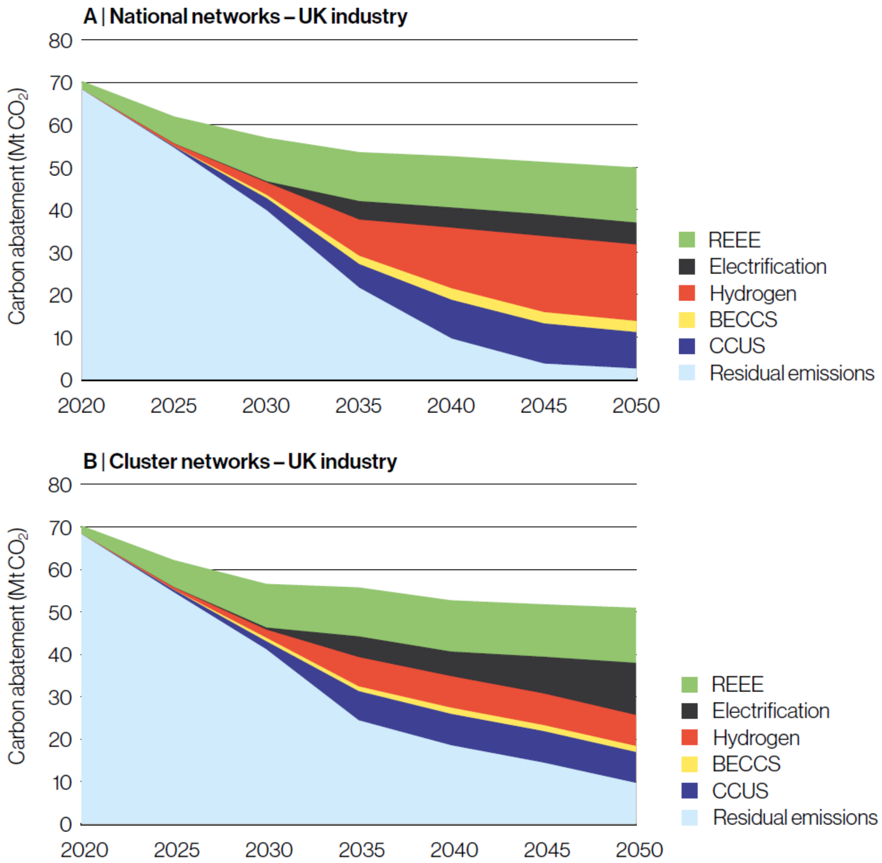
The UK Government has identified six high emitting industrial clusters which contain a variety of energy, as well as non-energy intensive industries. These are Grangemouth in Scotland, South Wales, Merseyside, the Humberside, Teesside, and Southampton (see Figure 1 below). The two clusters with the highest emissions are the Humberside and South Wales clusters. High emissions are primarily due to the presence of significant steel production capacity and oil refining in those areas. In March 2021, the UK allocated £171 million of funding via its Industrial Strategy Challenge Fund to nine projects which were investigating how net zero could be delivered by 2040 (UKRI, 2022b). In this section, we examine the UK industrial decarbonisation cluster projects in more detail as a number of high emitting FI businesses are located within industrial clusters. We outline the broad strategy for clusters, the key technologies around which investment is developing (hydrogen and CCS) and indicate which individual FI businesses are most likely to benefit from these developments.

Figure 1: Map of major UK industry cluster emission (2018)

Source: NAEI 2018 data. Does not capture non-Energy Trading Scheme emissions in a cluster (Industrial Decarbonisation Strategy, 2021)

Figure 2 below, taken from the Industrial Decarbonisation Strategy, illustrates the likely emissions trajectories of different pathways. The focus on hydrogen and CCS is being described as ‘low regret’ (HM Government, 2021) as these technologies are believed to be critical for the decarbonisation of industry and perceived as relatively technologically mature. Proponents of the CCS and hydrogen developments expect significant local economic boosts in terms of jobs and additional GVA as the projects progress (Vivid Economics, 2020a; CCSA/TUC, 2014).

The importance of hydrogen for industrial decarbonisation has only recently become clear. The *Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050* published as recently as 2017 saw only a very small role for hydrogen in industrial decarbonisation. At the time the roadmap was based on a target of 70% reduction by 2050. The more stringent net zero by 2050 target means that 66% reductions are required by 2035 and so the roadmaps produced by these documents are not compatible with a net zero emissions reduction pathways.



A: Extensive national infrastructure networks for CCUS and hydrogen and B: CCUS and hydrogen infrastructure confined to the clusters. Key: REEE – Resource efficiency and energy efficiency; CCUS – Carbon capture and storage; BECCS – Bioenergy with carbon capture

Figure 2: Pathways to net zero for industry

Source: Industrial Development Strategy, 2021

These developments mean that deeper decarbonisation strategies are required if emissions reductions targets are to be hit, and fuel switching to hydrogen is understood as the most viable option for many industries. Hydrogen production technologies have improved significantly in recent years and further it has become clear that there is insufficient biomass available to power full-scale industrial fuel switching projects (Brack, 2017; Phillips & Fischer, 2021). The *UK Hydrogen Strategy* published in 2021 indicates that the Government is considering using hydrogen as a fuel in power generation, transport, heating buildings as well as industry. Initially, signposted in the *Ten Point Plan for a Green Industrial Revolution,* the UK Government has committed itself to developing 5GW of low carbon hydrogen by 2030. The hydrogen strategy, like CCS plans, are closely linked to the decarbonising industrial clusters plans. This is because the first hydrogen produced will be primarily “blue hydrogen” made from steam reformation of natural gas (methane) by oil refineries already located within industrial clusters. CCS will be attached to eliminate the CO2 emissions that are a by-product of the production process. The UK Hydrogen strategy positions blue hydrogen developments as critical in the pathway towards developing a largescale hydrogen economy (HM Government, 2021a). Others suggest that there are powerful interests lobbying governments to support these costly projects, which once built, will lock-in a reliance on fossil fuels that will quickly become unnecessary as “green” hydrogen produced from water electrolysed by renewable energy becomes the cheaper technology (Vartiainen, et al., 2021; Rosenow & Lowes, 2021). The Government’s 2021 Hydrogen Strategy does not indicate what volume of hydrogen will be produced by electrolysis as opposed to steam reformation of methane by 2050. Although a seemingly large number of electrolytic hydrogen production sites are planned, no indications have been given on their likely size (HM Government, 2021a). It is probable that, at least in the short term, these developments will be dwarfed by the much larger blue hydrogen projects being rolled out via the industrial cluster decarbonisation projects. A further complication is that whilst blue hydrogen is being used, there is the possibility that methane leakages could undermine progress. Methane is over 80 times more potent a greenhouse gas than CO2, and so even small leaks could prove extremely damaging (Howarth & Jacobson, 2021).

The other critical technology which forms a key component of the UK industrial decarbonisation plans is carbon capture and storage (CCS). CCS itself requires a high energy input to achieve and has three stages to it. Firstly, CO2 is captured and from industrial processes or power generation and potentially cleaned of impurities. Then, it is compressed and transported either by pipeline, rail, road or shipping to the site of storage. Finally, it is injected into rock formations, often those previously containing hydrocarbons or saline aquifers where it is stored indefinitely. The uptake of CCS has been slow globally and the UK is no exception. In 2012, the government promised £1 billion of capital funding via the CCUS Commercialisation Competition. However, this was unexpectedly cut short in 2015 when it was announced that the funding was no longer available. Initially, the plan was to focus CCS on decarbonising electricity production because at the time fitting CCS to power stations was cheaper than investing in wind. However, as was indicated by the UK Trade Union Congress at the time (TUC 2015) and as is now more widely accepted, the advantage of CCS technologies is also their potential to decarbonise industrial production. This is particularly the case at sites facing challenges in reducing process emissions, or where the technological options for fuel switching are not yet fully developed.

A report by the TUC and the Carbon Capture and Storage Association suggested the CCS technologies could be developed in geographic clusters where these sites are concentrated. While the capital outlay might be more expensive than pre-existing plans to decarbonise major energy production sites, it was estimated that the cluster model could allow for significantly more carbon to be captured, reducing the cost per tonne of carbon captured[14]. This concept of building CCS cluster networks has developed into plans to make CCS available to a number of high emitting sites and has become a central plank of UK decarbonisation policy. Track One industrial clusters (discussed below) are under development in the Northwest of England via the Hynet project and Humberside and Teesside areas via the East Coast Cluster, with plans to develop an additional two industrial clusters by 2030 at the latest (HM Government, 2021a). However, this will not help many FI businesses as cement, glass, ceramics, and paper businesses are predominantly located outside existing industrial cluster sites, and not all business within a specific cluster will necessarily be able to connect to the industrial decarbonisation infrastructure which is being built. Some FIs businesses are located in or close to the UK's six industrial clusters (the case studies below indicate this picture more clearly for the glass, cement, and steel sectors). Half of all industrial emissions are concentrated in the proposed industrial clusters; 37.6 million tonnes in total CO2e, of which 12 million tonnes of CO2e come from the iron and steel industry and a further 13.8 million tonnes come from oil refining. The other half come from sites which are dispersed across the UK; 33.6 million tonnes CO2e, of which 4.2 million tonnes CO2e is the cement industry and a further 12.3MTCO2e other energy intensive industries such as those considered in this report (HM Government, 2021). This means that focusing decarbonisation on industrial clusters leaves a lot of emissions unaccounted for.

CCS is not a panacea with respect to emissions reductions. Some FI businesses (e.g., steel) produce CO2 streams from different locations throughout their operations making the logistics of CO2 capture more expensive and difficult and some contain high levels of impurities that may make them unsuitable for use with current technologies. Early applications of CO2 capture are focused on refineries and the chemicals sector, as these industries produce more concentrated CO2 streams and thus sequestration costs per tonne are lower and less variable, in comparison to cement and steel (Baylin-Stern & Berghout, 2021). Also, in the non-steel, cement, and chemical businesses the emissions from individual sites are much lower making the economics of CCS pipeline provision more difficult to justify. No glass, ceramic or paper sites are of sufficient size to feature in the UK Government's CCS deployment at dispersed industrial sites (Element Energy/BEIS, 2020) although much of the glass industry lies relatively close to the Humberside industrial cluster.

There is also significant uncertainty around how business models for CCS will function and policy choice will depend on institutional, political and market conditions (Rattle and Taylor, 2022). More specifically concerns have been raised around the high cost of capturing carbon in comparison to continued emissions (i.e., the low price of carbon), the interdependency of risk whereby the financial viability of pipeline operations depends on the continued emissions of the businesses that supply it and vice versa, and the indefinite period of liability in relation to future leakages of CO2 all make CCS unattractive to much private investment (Global CCS Institute 2020). In the UK's industrial cluster projects CCS and hydrogen need to be understood as intertwined technologies. The construction of hydrogen projects is creating a guaranteed revenue stream for the CCS projects as the production of hydrogen from methane creates large volumes of CO2 as a waste product.

[14] One case made was that instead of attaching CCS to Drax power station in Selby (the planned White Rose Project) a cluster could be built in the Humber (TUC, 2015). Although four times more expensive, (£20bn versus £5bn for the White Rose Project) nine times more carbon could be captured, making the price per tonne of CO2 captured two thirds cheaper (Benton, 2015).

A focus on CCS and hydrogen is in danger of eclipsing other important infrastructural developments. Research by the TUC has suggested that further electrification of industrial processes is crucial, and in the medium-term, UK energy policy needs to focus more on deep water floating turbines and it should aim to build 100GW of capacity by 2050. This is in comparison to the 2022 Energy Security Strategy which sets out an ambition of 50GW by 2030 of which 5GW is set to be floating wind (HM Government, 2022a). The advantage of deep-water floating turbines is that their construction needs fewer materials (e.g., steel and concrete) per KW/hr of energy produced (TUC/Unionlearn, 2020). A recent Rapid Evidence Assessment on best practice in industrial cluster decarbonisation has noted that CCS and hydrogen roll out may impede the progress towards electrification of industrial processes (Rattle & Taylor, unpublished). As we discuss in more detail later, access to cheap renewable electricity could also reduce emissions in sites outside the main industrial clusters, by allowing an increase in grid capacity, assuming the associated necessary connective infrastructure is made available.

The Scottish, Welsh, Humberside, Merseyside, and Teesside clusters all received funding from the Industrial Strategy Challenge Fund, to *plan* industrial transition projects involving a consortium of private partners, with the offshore and onshore aspects of the projects treated separately. The onshore projects which were given funding are Zero Carbon Humber[15] (ZCH), Humber Zero (HZ), Net Zero Teesside[16] (NZT), South Wales Industrial Cluster[17], HyNet Onshore[18] (Merseyside) and Scotland Net Zero Infrastructure[19] and the offshore ones are the Northern Endurance Project[20] (NEP), HyNet OffshoreEast and Scotland Net Zero Infrastructure Offshore. The NEP connects ZCH and NZT to offshore CO2 storage, the HyNet onshore and offshore projects are linked as are the two Scottish Net Zero projects. These cluster projects primarily involve the development of CCS and hydrogen technologies. In October 2021, it was announced that the East Coast Cluster[21], which includes Net Zero Teesside, Zero Carbon Humber and Northern Endurance Project and the HyNet Northwest Cluster (HyNet Onshore and Offshore) had been awarded “Track One” status, and if demonstrated to deliver value for money, will receive some support from the UK Government’s CCUS Programme (BEIS, 2021b). The funding programme ends in March 2024, at which time, the companies involved will take final investment decisions. The Scottish Cluster is a reserve cluster if a backup is needed (BEIS, 2021b). When assessments were made of the industrial decarbonisation plans submitted, Merseyside and the East Coast had an advantage, because these sites have easy access to undersea storage capacity which is available in Liverpool Bay and in the North Sea.

The Track One clusters are important as they create blueprints which other industrial areas will hopefully be able to follow on the road to net zero. Yet, some concerns remain. The CCS and hydrogen technologies planned are likely to be available to only some of the companies operating within the area. For example, the historic geography of Teesside chemical cluster means that businesses that occupy sites previously owned by ICI (Imperial Chemical Industries) already have access to some of

[15] https://www.zerocarbonhumber.co.uk/
[16] https://www.netzeroteesside.co.uk/
[17] https://www.swic.cymru/
[18] https://hynet.co.uk/
[19] https://www.neccus.co.uk/scotlands-net-zero-infrastructure-snzi-project/
[20] https://www.equinor.com/news/uk/20201026-nep
[21] https://eastcoastcluster.co.uk/

the pipework needed to deliver hydrogen and CCS to their businesses, drastically reducing the cost of adopting these new technologies. These sites are occupied by large multinational companies such as Sabic, Mitsubishi, Semcorp and CF Fertilisers. Smaller and medium sized chemical producers who cannot afford the cost of connection to the grid may be disadvantaged by these projects, ultimately putting jobs at these workplaces at risk [INT W]. Analysis of emergent CCS projects notes that Net Zero Teesside aims to safeguard 35-70 percent of energy intensive manufacturing jobs in the Tees Valley implying that medium term redundancies may be significant (Global CCS Institute, 2020).

FI sector stakeholders also note that industrial cluster projects are being developed within areas designated as Freeports which are a form of Free Enterprise Zone (EZ) (Gardham, 2021). EZs offer incentives such as business rates reductions, Enhanced Capital Allowances and simplified planning arrangements (Huggins, et al., 2018). Concerns have been raised over whether working conditions and employment rights can be upheld, and that EZs might also draw in employment from neighbouring locations, thereby affecting other local FI businesses and their associated communities. In response to concerns, unions such as Unite and GMB, have begun organising and liaising with local stakeholders (e.g., Mayors and MPs) to ensure that minimum standard frameworks are put in place [trade union representative INT W]. The proponents of largescale industrial decarbonisation projects stress the potential to regenerate local economies and protect and create jobs. Table 4 below shows the projected job creation figures according to reports commissioned in support of the projects.

Table 4: Job Growth due to Cluster Projects

Project	Estimated construction phase direct jobs	Estimated operation and maintenance jobs 2032-2050
East Coast Cluster	19,000	4000
HyNet	unknown	6000
Total	19,000	10,000

Source: (HyNet, 2020; Vivid Economics, 2020a)

Although the planning of cluster projects and conducting Front End Engineering Design (FEED) studies are a step in the right direction in terms of supporting innovation and technological change, the Government is still relying on the private sector to provide for the majority of funding for cluster decarbonisation projects. The development of CCS and hydrogen in Teesside, the northwest and the Humber has the potential to significantly decrease emissions from hard to decarbonise sectors, and to increase the availability of high skilled jobs in these regions, driving regeneration in local economies, but care needs to be taken that in the struggle to attract investment working conditions are not compromised, especially for lower paid workers, who often already have long days and antisocial hours to contend with. The section below discusses some issues and challenges identified in addressing employment and skills needs, that arise from industrial decarbonisation clusters and more widely across the FI sector in the UK.

East Coast Cluster

The East Coast Cluster is a collaboration between Zero Carbon Humber (ZCH) and Net Zero Teesside (NZT), and the Northern Endurance Partnership (NEP). The project hopes to capture up to 10MtCO2 from Teesside and up to 27MtCO2[22] from the Humber per year, as well as supplying up to 10GW of hydrogen by the mid-2030s (East Coast Cluster, 2021). The ZCH project is anchored by a large blue hydrogen project based at Saltend Chemicals Park, called Hydrogen to Humber Saltend (H2H Saltend) plus a CCS pipeline attached to VPI Immingham, a gas fired power station used primarily for industrial energy, and to Drax power stations (Vivid Economics, 2020a). The hydrogen production of ZCH will be scaled up to 6.5GW of hydrogen by 2030, some of which will potentially be used by a new hydrogen power plant: Keadby Hydrogen. There are also plans to build a new 0.8GW gas fired power station at Keadby (Keadby 3) with the emissions from that development also fully captured via CCS by 2030. The hope is that these new low-carbon energy projects will encourage new industries to locate to the area (Vivid Economics, 2020a). A dual hydrogen and carbon capture pipeline will be built to link Drax, the Keadby power stations, British Steel, and second blue hydrogen development project at Uniper's Killinghome power station, and then the Saltend Chemical Park, before going on to the Easington gas terminal, where it will be linked to the pre-existing pipelines managed by Endurance who will take the captured carbon to sequester it under the North Sea. Other potential nodes within this project are hydrogen storage capacity at Aldborough (Zero Carbon Humber, 2022) helping to decarbonise the Humberside steel and chemical sectors, as well as reducing emissions from power generation. The Net Zero Teesside element is smaller and involves building CCS pipeline accessible to high emitters in the Teesside area, including chemical industry businesses such as CF Fertilisers, BP, Sembcorp Utilities, Mitsubishi, BOC and Venator plus a new combined cycle gas turbine (CCGT) power station (Global CCS Institute, 2020) New blue hydrogen production facilities will be built at Seal Sands (Vivid Economics, 2020b). The Northern Endurance Partnership, who previously managed the gas pipelines bringing gas from the North Sea, will provide the infrastructure needed to transport CO2 from emitters in both Teesside and the Humber. These projects form part of wider initiatives to remake industrial areas such as Yorkshire and the Humber and Teesside, as key hubs in the green economy. Industrial areas face distinct challenges, as well as opportunities, as we move towards net zero (Diski, Chapman, & Kumar, 2021; Emden & Murphy, 2019). Industrial clusters in the region function as an ecosystem meaning that if large businesses are lost this can destabilise those for whom industrial clustering is critical to their success. Yorkshire and the Humber is already home to many renewable energy and promising green economy business projects, some creating new jobs, others increasing the demands of those in existing jobs.

[22] Emissions may be higher as the inclusion of blue hydrogen projects will significantly increase emissions at these sites. However, this is not stated in the cluster decarbonisation documents or on the project websites

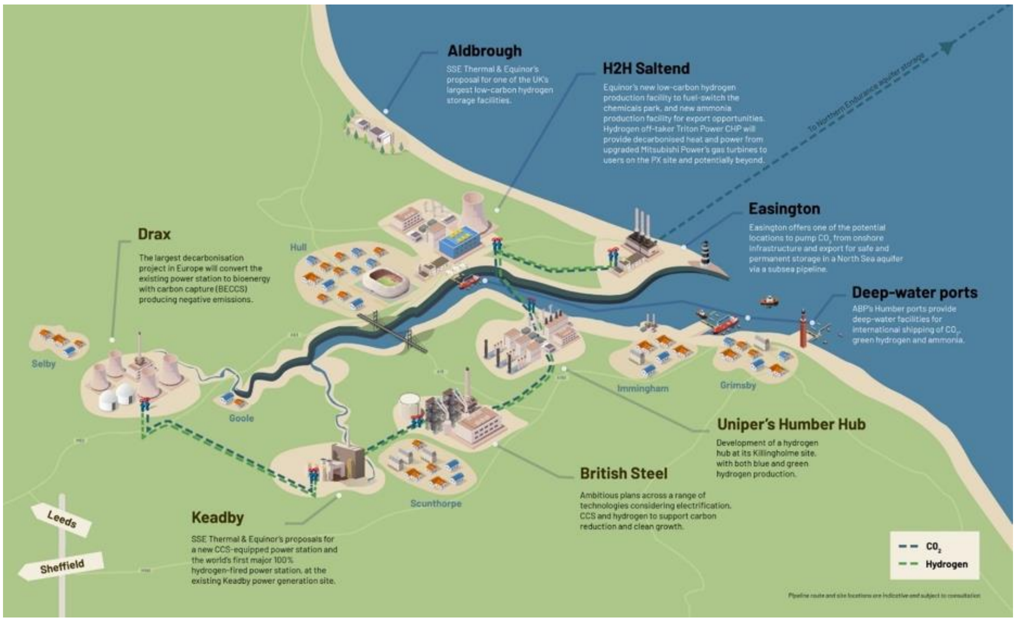


Figure 3: Schematic for Zero Carbon Humber Project

Source: https://www.zerocarbonhumber.co.uk

HyNet Project

The HyNet project is a CCS and blue hydrogen production project. So far 24 employers are hoping to cut emissions with the hydrogen provided by the scheme (HyNet, 2020). The HyNet Northwest Cluster is where the most significant hydrogen production capacity will be located with the hydrogen produced at Essar's Stanlow Manufacturing Complex (an oil refinery) and then piped to a number of industrial users and blending stations nearby. The resultant CO2 will be captured and added to the pre-existing industrial emissions and then stored in depleted gas reservoirs under the seabed in Liverpool Bay. The onshore pipelines to deliver hydrogen to businesses still needs to be built. HyNet's hydrogen capacity is planned to be 3.8GW by 2030, with the first plant in 2025 delivering 350MW and capacity increasing significantly over the five years as the hydrogen economy grows (HyNet, 2020). The project also intends to blend hydrogen with the natural gas (probably at quite a low level of around 5%) and deliver this into local networks supplying to homes and commercial buildings for heating and cooking. The HyNet Industrial Fuel Switching programme was awarded an addition £5.3M of funding from BEIS through its Energy Innovation Programme in February 2020. The HyNet Industrial Fuel Switching project is being developed to investigate the implications of increasing the percentage of hydrogen in gas fuel blends, as well as how furnaces perform when run entirely on hydrogen. If the project is successful, a number of glass making sites could eventually be connected to the hydrogen supply. As part of this project, the Pilkington's site at St Helens successfully ran a trial of the use of hydrogen to produce architectural glass in late August 2021. The project is believed to be the first large-scale demonstration of float glass production using hydrogen anywhere in the world (Pilkington, 2021). HyNet Project is likely to benefit two glass factories and one cement factory. Figure 4 shows a schematic of the project.

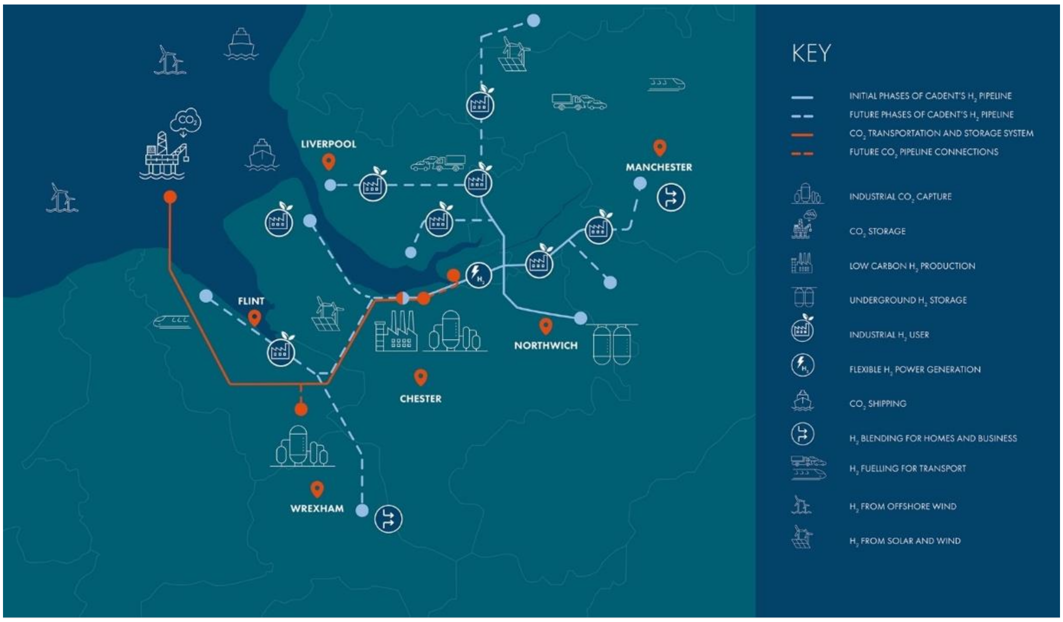


Figure 4: Schematic of the HyNet Project

Source: www.hynet.co.uk

4. Employment and skills challenges in the UK foundation industries

Employment trends

In the two decades up to 2016, the UK FIs share of GDP shrank by 43%. This is compared with an average decline of FIs across the OECD of 21%, which means the UK now has one of the smallest FI sectors relative to GDP in the OECD (Lawrence and Stirling, 2016). Figure 5 shows estimates of the related changes in employment across the FI sectors between 2013 and 2022[23]. The majority of job decline has been in the steel industry, chemicals, and paper. Employment in glass and cement has been broadly steady. Employment today in the FI sub-sectors is biggest in chemicals with over 45,000 workers, and over 30,000 workers in the steel and paper industries each. Whereas in cement and concrete, glass and ceramics employment numbers are much smaller with between 13,000 and 18,000 employees. The cement sector on its own employs 2,500 but many more once the concrete industry is included. This has implications for the ability of each sector to mobilise to protect jobs. With the exception of steel, the decline of these industries and union membership more generally has meant that workers tend not to be represented by one trade union. Rather, despite high levels of unionisation in steel, cement, and glass at least, members are represented across a number of large multi-sector unions, with officers who engage employers across a broad range of manufacturing activities.

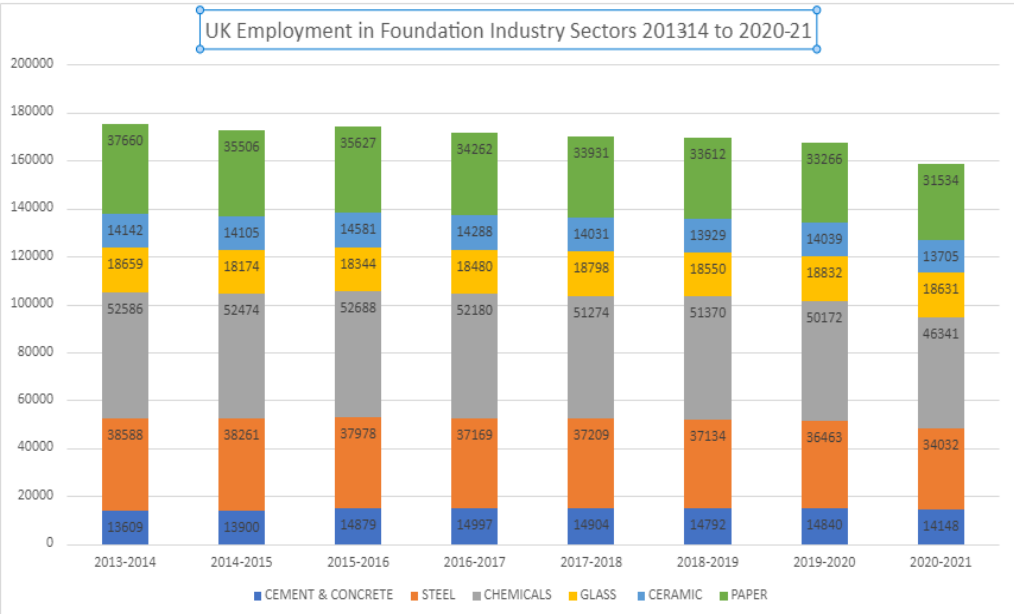


Figure 5: Fluctuations in FI employment between 2013-14 and 2020-21

Source: Various IBISWorld Reports C17-23 (2021)

[23] Research for this report reviewed data from a number of sources. The data in Figure 5 are from IBISWorld sector reports which contain figures for all the sectors of interest for this study. Yet we urge caution in the use of the results. There were considerable differences between alternate sources (Business Register and Employment Survey and EuroStat). See Appendix B for further details.

The FI sector has an aging and un-diverse workforce with a quarter of businesses reporting that more than half their employees are over 50 years old, with 41% and 37% of cement and glass businesses respectively reporting that they had no employees at all under 25 (ERC, 2021). Metals, glass, and cement are the least diverse of the foundational industries, with over 80% of all businesses having less than 25% female employees (ERC, 2021). The regional concentration of FI employment (with the exception of cement which tends to be quite dispersed) in areas where good quality well paid jobs are hard to come by, means that job losses/growth have the potential to further exacerbate/address regional inequalities (SQW, 2021). The proximity of FI businesses to decarbonised industrial clusters may well influence their future viability. One stakeholder commented that for some industries "it's a postcode lottery at the moment" [industry body INT G].

Recruitment, retention and training

The shrinkage of the FIs sector has destabilised it, reducing the ability of businesses to attract talent, in part due to the perception that the industry may not have a long-term future. This is compounded by nationwide technical and STEM skills shortages, and the difficulties associated with attracting workers into industries which are perceived as 'dirty' and 'unadvanced'. 40% of FI businesses report that staff recruitment and skills needs are a major obstacle to business success (ERC, 2021). Retention is also a challenge. In the chemicals sector, for example, the struggle to retain skilled workers was felt to be due to the draw of higher paying sectors such as the finance sector. Glass and ceramics also reported skills shortages, and concern was also expressed that digital data driven jobs in the City were leeching away potential talent that needs to be encouraged into heavy manufacturing [skills expert INT Y].

There are significant hard to fill vacancies and skills gaps that affect the FI sectors' capacity to recruit. For example, in the decarbonisation cluster areas, Teesside in particular has a weak labour market with youth unemployment rates 75% higher than the national average. There are simultaneously many job vacancies similar to those that will be created during the NZT construction phase: there were 1,000 vacancies for Skilled Metal, Electrical and Electronic Trades and 500 vacancies for Skilled Construction and Building Trades. There are also many vacancies for jobs similar to those that will be created during the operational phase: in 2019 there were 2,400 vacancies for Science, Research, Engineering and Technology Professionals, and 375 vacancies for Process, Plant and Machine Operatives (Vivid Economics, 2020b). Skills mismatches are already causing problems for employers. The skills gap is likely to be highest during the construction phase, with the closure of some industrial facilities such as the Hartlepool nuclear power station and the INEOS Seal Sands facility helping to reduce the gap during the operational phase (Vivid Economics, 2020b). This means that although jobs will be created, there is no guarantee that these positions will be easily filled. The problem was identified on earlier assessments of potential barriers to CCS roll out, with a report from 2012 noting that supplying the skills was likely to be a problem. This will be exacerbated by competition from other largescale industrial infrastructure projects such as the expansion of the nuclear, rail and wind industries (AEA, 2012).

The Foundational Industries Challenge programme that sits within the wider Industrial Strategy and is managed by UKRI, has initiated research into the innovation readiness and employment and skills requirements of the FI sector given its perceived fragility. Broadly speaking, FIs have not yet defined their research and development roadmaps or the technology requirements which will get them there. This means that an understanding of the skills requirements for a net zero economy is also underdeveloped. In the words of one interviewee: “They don’t know what their unknowns are,” and while Skills Fore-sighting is currently being developed nationally to address this problem, the lack of wider strategic planning limits the scope and impact of this exercise. The analysis of innovation readiness found that, despite the energy intensive nature of these businesses, the drive to increase energy and resource efficiency is not a common motivation for innovation (ERC, 2001, Hopley, et al., 2021). A core finding was that leadership acted as a key constraint on innovation activity, coupled with a perception that there is generally a resistance to innovation and reluctance to collaborate across the sectors (ibid). A follow-up study undertaken as part of the UKRI Foundation Industry programme focused on the future skills needs (SQW 2021). The need for better leadership and management skills was also raised in this study. Another general requirement across most FI industries is the need for engineers who are flexible across disciplines and so able to apply general engineering skills with a sustainability focus. There was found to be limited consideration of the digital and data analysis skills needed due in the digitalisation of FI processes that require the ability to operate and maintain complex digital equipment and capacity to analyse larger volumes of data. Specific examples are discussed in more detail in the case studies.

There has also been a tendency to subcontract out maintenance jobs in some strands of the FIs, particularly the steel and chemical sectors. This is ongoing, for example Sabic, a chemical manufacturer on Teesside recently completed a Transfer of Undertakings (Protection of Employment, TUPE) for maintenance workers as part of an effort to reduce “fixed costs”. However, according to our interviewees, when workers do not have a permanent contract within a specific company, the processes through which apprentices are brought in, trained up and employed can break down [trade union representative INT W; skills expert INT X]. Subcontracted maintenance organisations can have less incentive to train new recruits, as it slows down work which is paid by the job and the need to perform efficiently is prioritised to secure future contracts. This means insufficient apprentices are trained and there is a consequent shortage of workers able to perform electrical, mechanical and control instrumentation tasks. This can also increase the cost of securing these workers [trade union representative INT W; skills expert INT X]. An overall effect of these trends is that many FI employers are not focused on the longer-term needs of developing the skills required for competitiveness in a net zero economy, rather they are trying to combat more immediate problems of hard to fill vacancies, an ageing workforce and the associated loss of technical knowledge (Hopley, Drummond, & Akinremi, 2021; SQW, 2021)

Addressing jobs and skills needs

While the decarbonisation or net zero agenda was identified as providing an opportunity to generate interest in younger people, FI sector stakeholders noted a general dissatisfaction with the number and quality of graduates and professional applicants. This was felt to be compounded by a lack of bespoke, sector-specific training provided in FE and HE, with employers in the FIs often lacking scale to influence provision. The uncertain future of FI businesses also makes training more difficult as industry specific courses often struggle to attract sufficient students to run [industry body INT G]. There is also confusion over how to access the fragmented education and training system and patterns of international ownership that limit collaboration. Yet opportunities for improving coordination across relevant training pathways were noted. Recent advances in digitalisation are making online delivery a way to potentially widen participation [industry body INT G] and ensure the viability of courses. The FI sector focused research identified a number of interesting examples of good practice in the development of degree level apprenticeships, leadership programmes and collaborative PhDs or Knowledge Transfer Partnerships with the HE sector. The TFI programme is seeking to build upon these examples with a sector skills focused action plan that was consulted upon with stakeholders in late 2021 (Hopley, Drummond, & Akinremi, 2021).

National green jobs and skills policy

Nationally, the Government has a stated ambition of the creation of 2 million good quality, green jobs by 2050 and in 2020, the UK Government established a Green Jobs Taskforce charged with developing recommendations for an action plan for the Government's stated green jobs ambition. The Green Jobs Taskforce report (Green Jobs Taskforce, 2021) made a number of recommendations. The recommendations aimed to drive 'sustained' net zero investment in order to stimulate the demand for good quality green jobs, build pathways to good green careers, support worker voice mechanisms in the green transition and to embed environmental awareness and green skills and behaviours into curricula at all levels. It also suggested that national skills programmes such as Skills Bootcamps (short employer led courses lasting 12 to 16 weeks which aim to help meet critical skills needs, help adults retain, and top up skills or gain new specialist skills) and the Lifetime Skills Guarantee (which allows anyone who does not have a level 3 qualification, equivalent to A-levels, to gain a new qualification for free) could be expanded to support a just green transition (Department for Education , 2021).

The Government's net zero Strategy (ibid) outlined the core measures within the Post-16 Education Bill (Department for Education , 2021) focused on green jobs and skills. This includes a continued commitment to the development of apprenticeships in 'green sectors' and the growth of a network of Institutes of Technology (partnerships between FE, HE and employers around specific areas of technology), although the FIs are not specifically mentioned in those announced to date. The Post-16 Bill includes a Lifelong Learning Loan entitlement for NQF level 4-6 focused on adult up-skilling; schools careers guidance on net zero and the creation of a cross-cutting 'green skills' delivery arm across government departments with reps from industry, skills providers, and other stakeholders. Local Skills Improvement Plans (LSIPs) were introduced aiming to give employers, especially SMEs, a stronger voice in local skills planning.[24] LSIPs place a statutory duty on local partners to include consideration of the skills, capabilities or expertise required in relation to jobs that contribute to compliance with the Climate Change Act 2008 (UK net zero emissions target), adaptation to climate change, or in meeting other environmental goals (HM Govt 2022, p2).

Yet some commentators note that estimates for job green growth should be treated with some caution, given that the number of 'green jobs' as measured by the ONS fell in the period 2014-2020. Although the number of green jobs in manufacturing grew slightly in the same period, it has fallen by over 10% from a peak in 2018 (TUC/Unionlearn, 2020). The potential for job growth such as those projected for the industrial decarbonisation clusters is constrained in a number of ways. Crucially, in areas with forecast growth opportunities, local workers may not be able to access these jobs due to

[24]In the pilot LSIP areas, the designated employer bodies there were all local Chambers of Commerce https://www.gov.uk/government/publications/skills-accelerator-trailblazers-and-pilots/skills-accelerator-local-skills-improvement-plan-trailblazers-and-strategic-development-fund-pilots

low levels of formal education in the regions in which they are located. Teesside, Yorkshire, and the Humber have the lowest levels of educational attainment at GCSE level in the country (Webb, et al., 2022). In Grimsby, for example, a town on the south bank of the Humber estuary, local feelings of alienation from the project of remaking the Humber as a *SuperPlace* in the new green economy have already been observed (Institute for the Future of Work, 2021) and many of the workers who express their desire to work in green economy jobs, lack access to guidance and training to make this transition (Cutter, et al. 2021).

Within the FIs, attempts to address employment and skills needs have been at either the firm or sub-sector level. This is now changing and, supported by the FI Challenge programme, the FI industries are starting to recognise commonalities and the need to work together more closely to protect the jobs and businesses that remain. This is likely to involve the development of FI-wide courses (in place of those targeted more specifically at glass, cement, steel etc.) as there is considerable overlap in terms of the knowledge and skills required by workers in these industries [industry body representative INT G]. Sector interviews, however, raise concern that wider skills policy does not help facilitate this process. Criticism centres on the emphasis on new entrants and apprenticeships, while recognised as very important, this is not sufficient. Given that transformative decisions are made at higher levels within organisations, often where there is more apprehension to adopt and implement change, it is suggested that further advocacy and leadership development needs to target strategic decision-makers. In addition, given that 80% of the current FI workforce will still be active in 2030, greater emphasis is needed on the training and development of the existing sector workers. Furthermore, stakeholders noted that current skills strategy emphasises that it is ‘employer driven’. Yet this poses a challenge for articulating the skills and training needs in emergent sectors and skills requirements: there are currently very few employers operating in the hydrogen and CCS economies, but they will be central to industrial decarbonisation. If responsibility for articulating future skills needs and initiating training lies with employers that do not yet exist, it seems that the FI industry may struggle to find appropriately skilled workers to fill the jobs, potentially slowing down their expansion and the green transition overall. An ‘employer driven’ approach can lead to the atomisation of skill development and a focus on company specific skills, rather than more holistic learning [trade union stakeholder INT W], learning which allows the flexibility identified by the FI skills fore-sighting programme. Others are sceptical of the assumption that many of the new roles will be filled by workers exiting the fossil fuel economy (HM Government, 2021b, p. 238): many aspects of the fossil fuel economy remain in place (oil refineries are being retooled for hydrogen production and gas fired power stations equipped with CCS for example and the war in Ukraine is leading to greater emphasis on domestic fossil fuel production) meaning that the outflow of oil and gas workers with technical and engineering skills may not be as great expected in the critical period of transition up to 2030.

An alternative vision for the planning of jobs for the transition has been put forward by the UK Campaign Against Climate Change, Trade Union network (CACC_TU). Originally produced as a report in 2014 entitled *1m Climate Jobs*, the group has recently updated it and included an assessment of sector specific needs, including the jobs and skills needs for decarbonising processes and materials in industry. They emphasise skills needs stemming not from new technologies, but from new business models. For example, retrofit in housing will reduce the steel demand but will need experts in retrofitting, digitalization, an understanding of material composition for planning reuse and the rethinking of production driven by social purpose will need workers with digital skills (CACC, 2021). If the economic and employment benefits of these projects are to be fully realised by local communities, then strong locally targeted education and training support will be needed to address the skills gap of local workers (Vivid Economics, 2020a; Vivid Economics, 2020b). Creating pathways from local educational establishments and supporting workers to transition into jobs and build relevant skills is crucial to ensure UK FI viability. Unless significant investments are made in the local education systems in the regions where these large decarbonisation projects are being rolled out, these well paid high skilled jobs may remain out of reach for those in local communities (Local Government Association , 2021).

The skills ecosystem in the UK is currently not focused on the workforce challenges faced by the FI sectors, and there are limited mechanisms that can promote the dialogue needed between different stakeholders to ensure effective outcomes. The following sections outline the decarbonisation trajectories and related jobs and skills issues and initiatives in three sub-sectors, glass, cement, and steel, that illustrate the challenges and solutions currently being addressed and the scope for further action.

5. Sectoral Case Studies

5.1. Glass Industry Case Study

Net Zero Trajectory

The UK large scale glass manufacturing industry (i.e., producing more than 200 tonnes per day) includes 10 companies across 17 different sites. It is geographically concentrated in the M62 corridor, which runs from Hull in the Humber Estuary in the east, past Leeds and Manchester, to Liverpool and Cheshire in the west (British Glass, 2021). Figure 6 shows the regional concentration of glass flat and container glass manufacturing businesses. The total value to the UK economy is estimated to be £1.3 billion (BEIS/British Glass, 2017). There are two types of glass production: flat glass (e.g., windows) and container glass (e.g., bottles and jars). Only 3 of the 17 furnaces in the UK produce flat glass. In a typical year (i.e., prior to the COVID-19 pandemic of 2019–2021) the container and flat glass industries generated revenues of around £853 million and £316 million respectively (Griffin, Hammond, & McKenna, 2021). The estimated Gross Value Added per job in the glass sector is £69,139 which is substantially higher than the average of other jobs in the same region, which range from £45,497 in Sheffield City Region to £60,060 in Cheshire and Warrington (Ekosgen, unpublished), thus any job losses in the glass sector are likely to worsen regional inequalities.

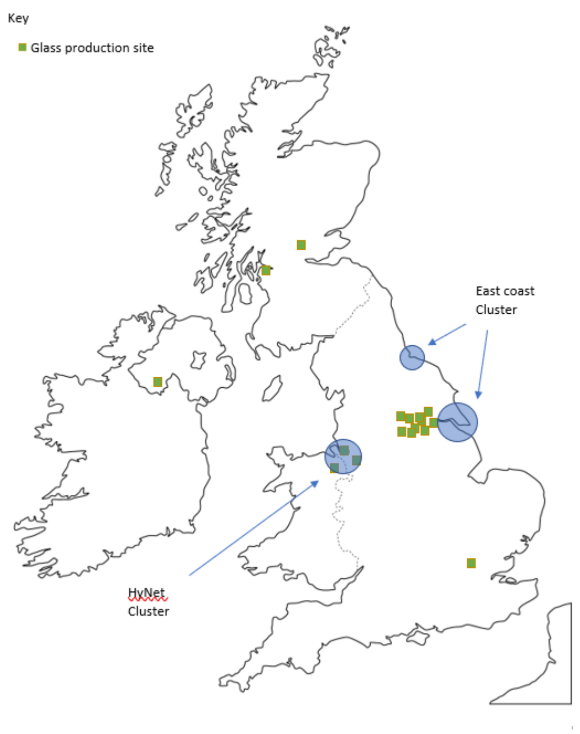


Figure 6: UK Distribution of glass production sites (squares) and Track 1 industrial clusters (circles)

Source: Authors

Glass manufacturing emissions comprise of process and combustion emissions. The combustion of fossil fuels to heat raw materials produces 75-85% of the CO2 emissions, whilst chemical reactions between raw materials during the production process (process emissions) produces the remaining 15-25%. The exact quantity of process emissions varies according to the percentage of recycled content used in the melt. Although glass industry emissions fell by 23% between 1990 and 2018 (British Glass, 2021) primarily as a result of efficiency improvements (Griffin, Hammond, & McKenna, 2021), much more radical changes are necessary if the industry is to meet the net zero goal. In the sections below, we lay out upcoming technology and policy challenges associated with reaching net zero as well as their implications for jobs and skills demands in the industry.

Energy efficiency improvements: digitalisation

The energy efficiency improvements seen so far in the glass sectors have been driven in part by the high cost of energy. They have included improved furnace designs and heat recovery which means using heat generated by production processes to preheat the raw materials, generate electricity or compressed air or to preheat fuel or oxidants (Griffin, Hammond, & McKenna, 2021). Oxyfuel combustion has also been used at some sites as this allows energy savings of 10-15% (British Glass, 2021).

In the coming years, the digitalisation of furnace operation will be an important new technology which will allow further significant energy efficiency gains. Digitalisation and emergent AI technologies now allow thousands of measurements to be taken by electrodes positioned throughout the furnace, with the data produced by these measurements used to optimise furnace processes far beyond what is currently possible by human operators. These new technologies will significantly reduce the energy demand of furnaces [skills expert INT Y; trade union representative INT E; industry body INT C]. New digital technologies also allow defects to be detected much earlier in the production process, meaning glass can be returned to the furnace while still hot offering further energy efficiency savings [skills representative INT, 23].

Container glass furnace electrification: The Furnace for the (distant) Future?

Currently, approximately 80% of the fuel consumed on a typical UK glass production site is natural gas (British Glass, 2021). However, there are plans to develop a new type of furnace which runs primarily on electricity as the route to the reduction of carbon emissions. The *Furnace for the Future* (F4F) was a large collaborative project developed in conjunction with 19 European and UK glass manufacturers representing 90% of European market share of container glass (FEVE, 2021; Ardagh Group, 2021). The project had hoped to receive a share of the EU's €10 billion Innovation Fund to help cover the CAPEX and OPEX associated with the project. However, their bid was not successful (FEVE, 2022). F4F aims to design and test a new type of furnace that uses between 20 and 80% electricity to heat the glass. Furnace operators would be able to control the fuel mix and increase the electricity use as local price conditions allow without requiring a furnace rebuild. The non-electric part of the furnace would initially run on an oxy-fuel gas blend, but the hope is that it will eventually be converted to hydrogen as it becomes available [industry body INT C]. The furnace would be able to process up to 400 tonnes of glass a day for container glass, and 600 tonnes per day of float glass (Hegeler, 2020).

Ardagh Glass was heavily involved and was planning to host the first furnace at a site in Germany but as a collaborative project, contributing companies would be able to visit the furnace and train their workers on how to use it, before eventually being able to install at their own sites. Whilst the development of such a furnace is an important step forward in the decarbonisation trajectory of the glass industry, switching to this technology was not viewed as imminent, or likely to affect the skills needed by workers.

"The furnace for the future – I don't see anybody changing in their job roles with that, if it's there. Plus the furnaces at the moment are lasting roughly fifteen to twenty years so if one's only five years old there would be no real requirement to rebuild it for a new energy saving one if this prototype is a success. I mean we're looking at three to four years before we know if this prototype is going to work and then on top of that they're only going to replace it with those when a furnace is due to be rebuilt. So I don't see a massive change in our industry for a good ten years, and that's just personally – I just can't see it." [trade union representative INT, 4]

A further significant barrier to the adoption of electrified furnaces is the cost of electricity in the UK: it is currently 4.5 times more expensive than gas[25] with the cost of both fuels rising dramatically since early 2021. Glass manufacturers feel that not enough support has been made available and are lobbying for an exemption from having to contribute to levies (Contracts for Difference (CfD), Renewables Obligation (RO) and Feed-in Tariffs (FIT) schemes) which help fund the roll out of renewable electricity and decarbonisation of the grid. At the moment, Energy Intensive Industries receive an 85 percent discount but they are pushing for 100 percent exemption (UK Parliament, 2022; BEIS, 2022a). Concern has also been expressed that except for glass fibre, the industry has been excluded from eligibility to claim compensation for indirect costs of electricity associated with the UK Emissions Trading Scheme UK-ETS) and the carbon price support mechanism (CPS). Exemption is directed towards those deemed to be at risk from Carbon leakage due to their operation in internationally competitive markets (GOV.UK, 2022). British Glass feels that the container glass industry should have been considered eligible. The high cost of energy reduces the likelihood that money will be available for transformative decarbonisation investments.

Converting furnaces from gas to electric would also increase the overall electricity demand. The glass industry melts around 3.5 million tonnes of glass per year, this uses 6TWh of natural gas and 1TWh of electricity. If the gas was exchanged for electricity, this would require around 1.2GW of wind production[26] (Energy and Climate Intelligence Unit, 2021; British Glass, 2021) which is a 2.4% of the 50 GW overall build by 2030 (HM Government, 2022a). It is possible that future electrification projects could be impeded by lack of capacity.

[25] Between January to March 2021 and January to March 2022 the average electricity price (excluding the Climate Change Levy (CCL)) in the non-domestic sector rose by 29% to 18.14 pence per kWh. Over the same period the average gas price (excluding CCL) rose by 71% to 3.95 pence per KWh (BEIS, 2022b).

[26] Assuming the same offshore wind loading factor as used by the Energy and Climate Intelligence Unit, 2021 which was based on government expectations.

The glass industry envisages a multipronged approach to combustion emissions reductions, and it is considering hydrogen, biofuels and hybrid fuel options as well as the electrification projects discussed above (Ireson, et al., 2019). A key actor in the development of a more sustainable UK glass sector is Glass Futures a not-for-profit company which supports innovation, training and the development of new low-carbon and resource efficient glass making processes (Glass Futures, 2022). The organisation is funded by its members and has also received £15 million for an experimental glass furnace facility at St Helens from UKRI, and £7.1 million to investigate low carbon fuels from BEIS, plus £9 million of support from Liverpool Combined Authority. This site will act as an important hub driving forward the sustainability of the UK glass industry.

Cullet collection: the economics of waste glass

A reduction in glass industry process emissions is most likely to come via increasing the amount of recycled glass added to the melt. Recycling glass also reduces the demand for raw materials, which often have a significant environmental footprint at the point of extraction: 1 tonne of cullet avoids the extraction of 1.2 tonnes of virgin raw materials. Every 10% additional cullet added to the mix reduces the energy demand of the furnace by 3% and CO2 emissions by 5% (FEVE, 2009). This is a challenge for the industry, caused in part by the economics of current recycling policy in the UK. In 2019, 71% of container glass was recycled in the UK, although this was 87% in Wales. Most glass collections in England are mingled with other materials which means that it arrives at the glass processing facility containing about 35% of materials such as paper, plastic broken plates etc. (British Glass, 2019) leading to lower volumes and lower quality cullet, than if it is collected separately as is the case in Wales. Current household glass recycling targets are ‘unambitious’ and so Industry is lobbying for a glass recycling rate target of 90%, rather than the current EU target of 70% by weight (British Glass, 2021; DEFRA, 2019) The UK has the highest tonnage of unrecycled glass of anywhere in Europe: 822,000 tonnes in 2015. One of the reasons for this is the approach taken to meeting the recycling target set by the Packaging and Packaging Waste Directive 94/62/EC which was the introduction of a tradeable permit system which renders recycling uneconomic once the target of 70% has been met, and reducing the incentive to recycle beyond the targets set by European Legislation (Lee, Eatherley, & Garcia, 2018).

Currently, very little flat glass waste is returned to the furnaces at end-of-life. Around 750,000 tonnes of flat glass are generated each year of which 500,000 tonnes go to landfill and 250,000 to aggregates (road filler) in the construction industry (British Glass, 2021). As such, the industry is also lobbying for policy changes which would facilitate the collection of waste glass from the auto industry, glaziers and building sites. As glass is considered a non-hazardous waste, it can be disposed of in landfills at only £3.15 per tonne (GOV.UK, 2022). It also has a very low market value in comparison to other waste materials. Glass is valued at around £6 per tonne[27] in comparison to waste aluminium which has a value of £1000 per tonne and waste plastic which is worth £200-600 per tonne. This means that when windows are replaced by glaziers the glass is often separated from the PVC frame which is worth £200 per tonne and so recycled, whereas the extracted glass is sent to landfill rather than recycled. In addition to the low value accorded to glass, there are high costs associated with the time taken to effectively separate glass from other waste [industry body INT G]. Reclassifying glass as hazardous waste would mean that disposal costs would rise to £98.60 a tonne and so may increase collection rates from building sites etc (GOV.UK, 2022).

[27] Glass prices vary month to month and between colours, see here for further details https://www.letsrecycle.com/prices/glass/glass-prices-2021/

Another important barrier to the increased use of cullet in the production process are consumer preferences. 64% of containers produced in the UK are made from clear glass and exported (British Glass, 2014). However, the largest market share in terms of consumption is green glass, in part due to the import of wine bottles and so there is an imbalance in terms of the type of cullet returned to glass manufacturers via recycling (primarily green/brown), and the glass needed by furnaces for their production orders (primarily flint/clear). Changing norms around glass packaging colours to make dark glass acceptable for products normally sold in clear packaging in the UK is one possible way to address this. EU countries are more accepting of slight clear glass colour contamination (British Glass, 2021).

Circular economy strategies in the round

The exact definition of a circular economy is contested but it is often contrasted with a conventional economic model in which the logic is *take-make-dispose.* In a circular economy, the use of materials is reduced, the lifespan of goods is extended, and potential wastes are reused, repurposed or recycled, preventing or reducing the need for new resource inputs on the system (Velenturf & Purnell, 2021; Reike, Vermeulen, & Witjes, 2018). The introduction of a genuine bottle re-use system would drastically reduce the amount of energy used by the glass industry. However, although downstream glass product users (e.g., the food packaging industry) are pushing for a higher content of recycled glass, standardised bottle sizes which would facilitate bottle reuse systems are not really on the agenda [industry body INT H]. Unlike in many European countries, the UK has for over 20 years had practically no refillable container schemes.

Although changes are being made to the way that waste packaging is handled via the introduction of the Extended Producer Responsibility[28] (EPR) for packaging, the EPR bill does not contain any targets for the use of refillable packaging. Instead, it notes that in future the government 'will take forward work to develop measures to encourage the use of re-useable/refillable packaging' with measures possibly to be introduced post-2025 (DEFRA, 2022).

Another upcoming change is the likely introduction of a Deposit Return Schemes (DRS) although this will be focused more on plastic than glass. An analysis, of how mandatory DRS affects recycling rates, has shown that these schemes do not predict high recycling rates and have displaced refillable in all countries where they have been introduced (Lee, Eatherley, & Garcia, 2018). DRSs do not involve reuse but rather they are an incentivised recycling scheme that competes with household collection and a bottle banks system. British Glass does not support the introduction of a DRS scheme for glass, as it is likely to lead to a shift away from glass packaging, as well as potentially reducing glass recycling rates overall by making the economics of household recycling more difficult for councils due to lower glass collection rates[29].

[28] The EPR scheme would to makes producers responsible for the cost of managing packing once it becomes waste (DEFRA, 2021).

[29] The economics of glass collection are already difficult due to is weight and low market value.

Implications of Decarbonisation Trajectories for Jobs and Skills

It seems likely that glass industry decarbonisation will involve sequential rounds of technological change. As a result, stakeholders foresee increased demand for engineers with strong project management skills. They also expect an increasing demand for electricians and welders and machine fitters who will be installing the new technologies. Once the new technologies have been installed, there will be continued demand for apprentices who specialise in mechanical, electric or control, and instrumentation which is a subdivision of electrical [management representative INT A management representative INT, 2; Industry body INT C]. As automation proceeds, robotic engineers will be in high demand [industry body INT C].

Equipping workers with the skills they will need in a post-carbon economy is often situated within broader concerns about how to maintain company competitiveness and prevent jobs (and carbon emissions) from moving abroad. Company approaches emphasised the wide use of the principles of 'Lean Manufacturing' and 'Kaisen Techniques' which focus on ever increasing productivity and the elimination of different forms of waste. Waste is broadly defined and can include waste of time, waste of capability, waste of energy, waste of space, waste of speed, as well as waste of resources. At one site, an apprenticeship covering these principles has been offered to all staff. The apprenticeship also covers topics such as Key Performance Indicators, data analysis, change management, SWOT analysis, and process flow analysis to look at linkages between procedures and practice, as it was felt that these skills would be crucial to maintaining competitiveness and adapting to the new technologies which decarbonisation will bring [Management representative INT B].

One interviewee commented that increased employee buy-in on the topic of efficiency and lean manufacturing, as a means to reduce energy and resource use and maintain competitiveness in a net zero economy, is unlikely to be successful until employees have a greater understanding of the implications of the climate crisis and the importance of their role in reducing emissions [Management representative INT A]. As such, training aimed at developing broader understanding of environmental and climate crises and the role of sector decarbonisation in mitigating this was considered necessary. At some sites there is a recognition that tapping into the tacit knowledge of workers may allow further efficiency savings to be made. As such, the role of Innovation Managers has recently been created to collect input on potential process improvements from shop-floor staff [management representative INT A]. At another site, it was reported that staff were relatively engaged on environmental issues and at one site, workers had made suggestions for emissions reduction which were then implemented and deemed cost effective. Suggestions included a switch to LED bulbs for lighting and the development of onsite renewables [trade union representative INT D].

In interviews, the perception was that across the glass sectors, workers would be relatively unaffected by the changes needed to achieve a net zero economy [trade union representative INT D; E; industry body INT C]. This suggests a degree of disconnect from the changes occurring. In the words of one union representative.

"No, it's not widely broadcast in the workplace what the company are doing or anything. They have it on their own internet site but very few people go on to that site at all. Your managers are more likely to look at that than the shop floor." [trade union representative INT D]

Another union representative noted that the drive towards achieving net zero was still in its infancy and actions were only just beginning to be taken, and so information had not yet filtered down to the shop floor:

> *"[Company X] have only just started the new zero by 2050 push but we've not had much involvement yet. I'd expect to be involved as a rep and they are hoping to get workers involved but it's early days as they have only just pulled a team together."* [trade union representative INT E]

During interviews it seemed that the industry is taking the net zero target seriously but only from a technology change perspective. Thinking through what decarbonisation would mean for workers was not particularly well advanced.

What next for UK Glass?

Trade union representatives from the glass industry noted that their facilities were already lean on manpower, suggesting that further job cuts were felt unlikely at the moment [trade union representative INT D; E] Other stakeholders commented that due to the harsh (hot) working conditions, the sector already struggles to fill the operator positions available at their factories and are thus pursuing automation as a means to reduce the labour demand [industry body INT G]. For example, at many plants the hot end[30] crew is already very lean (at one site there are only 2 hot end workers per shift) and the furnace role has already been incorporated into a combined batch house role [trade union representative INT E]. At the hot end, there is the possibility that the digitalisation of furnace processes could potentially lead to deskilling of the furnace operator role.

A move towards a genuinely more circular economy would require adjustments to glass production business models and may have implications for workers, as the reduction in the demand for glass products may reduce the need for labour. If refillable became popular, this could potentially displace market share from disposable packaging forms, such as plastic. Whilst this would have positive implications for job retention in the glass sector, it would bode less well for chemical industry workers. Although jobs would likely be created at the bottle wash plants, these would almost certainly be lower skilled than jobs in glass manufacturing.

[30] In a glass factory, workers who are employed near the furnaces are known as hot end workers, whilst those who collect the finished products as they come of the production line are known as cold end workers.

Process automation is also taking place at the cold end of the plant with quality control processes increasingly being automated [skills expert INT Y]. Again, this process requires digital rather than manual skills, and the integration of understandings around quality control with those of an instrumentation technician. In the much longer term, it is likely that robots will identify and pull-out defective glass pieces, but this type of technology is not imminent. Instead, an intermediate phase is likely whereby defects are identified by a machine, but it is up to the worker to go into a system look at the data and then go to the line to remove what needs to be discarded and can be reinputted to the furnace [skills expert INT Y].

To sum up, significant progress has been made towards emissions reductions in the glass industry, mainly due to efficiency gains. However, challenges remain unsolved in relation to how the industry will achieve net zero; in particular in the flat glass sector which has low recycling rates and tends to use larger furnaces which are less amenable to electrification. To decarbonise, regulations to increase and improve recycling, and reuse, are vital, in addition to funding and investments into new technologies. New skills will be needed in the future, particularly around digitalisation.

5.2. Cement Industry Case Study

The Net Zero Trajectory of the Cement Industry

Concrete is usually made from cement, water, sand, and gravel. In this mix, cement is the active ingredient that acts as a binder and allows the concrete to set. Around 90 million tonnes of concrete are consumed in the UK per year, the total value to the UK economy is estimated to be £18 billion (MPA: UK Concrete, 2020). The cement industry is highly vertically integrated, which means that cement producers own the limestone, shale, sand etc. quarries which produce the raw materials for cement and concrete production. A different branch of the same organisation often controls the facilities that produce some of the concrete sold on the market. Some also have business lines which produce finished concrete products, such as breeze blocks, paving slabs, beams, railway sleepers etc. There are currently 11 cement works operating in the UK. However, taking the cement and concrete industry together, there are 1665 firms in the sector, 90% of these are classed as micro or small, and together they employ nearly 37,000 people (Hopley, Drummond, & Akinremi, 2021) of which only around 2500 are employed directly in cement manufacturing (Griffin, 2021).

Most of the emissions related to cement manufacturing come from the production of clinker, during which limestone is heated to 1350-1450oC and which releases large quantities of carbon dioxide (Kusuma, Hiremath, Rajesh, Kumar, & Renukappa, 2022). In cement manufacturing combustion, emissions make up around 40% of total emissions with process emissions contributing the remaining 60%. In 2018, the cement industry produced around 7.3 million tonnes of CO2, 4.4 million tonnes from process emissions, and around 2.2 million from direct fuel combustion, with the remainder from the large volumes of electricity used to grind materials needed to produce cement (MPA: UK Concrete, 2020). Since 1990 cement and concrete industry emissions have reduced by 53% (MPA: UK Concrete, 2020), and further progress is likely to prove difficult. In the UK, 10 out of 11 cement production sites are "dispersed sites[31]", located outside industrial clusters.[32] The UK Government decarbonisation

[31] Dispersed in this context means located outside main UK industrial clusters.

[32] The South Ferriby site, which was moth balled in 2020, is also located inside an industrial cluster but as no operations are currently ongoing, this site has been excluded from the current discussions.

plans for dispersed sites remain in their infancy and this means they are unlikely to receive access to hydrogen and CCS networks in time to meet net zero targets.

Fuel switching to reduce combustion emissions: progress so far

Most of the combustion emissions reductions achieved so far have come from efficiency improvements and fuel switching. Fuel switching has involved replacing the coal used to heat the raw materials with "alternative fuels", predominantly Waste Derived Fuels (WDFs), made from both commercial and municipal wastes [management representative INT M]. The WDFs currently in use are a range of fossil (e.g., waste oil and solvents) biomass and fossil (e.g., household waste and chipped tyre) and biomass (e.g., bone meal and sewage pellets) based fuels (Element Energy/BEIS, 2020). Some newer plants use up to 80% alternative fuels, whereas older ones may continue to use 60% coal. Discussions with industry stakeholders suggested that whilst incremental reductions in coal use may occur, many plants have already proceeded, as a far as possible without significant investments, in more modern production facilities [management representative INT M; 13].

Figure 7 Use of Waste Derived Fuels (WDFs) in UK cement plants between 1998 and 2018

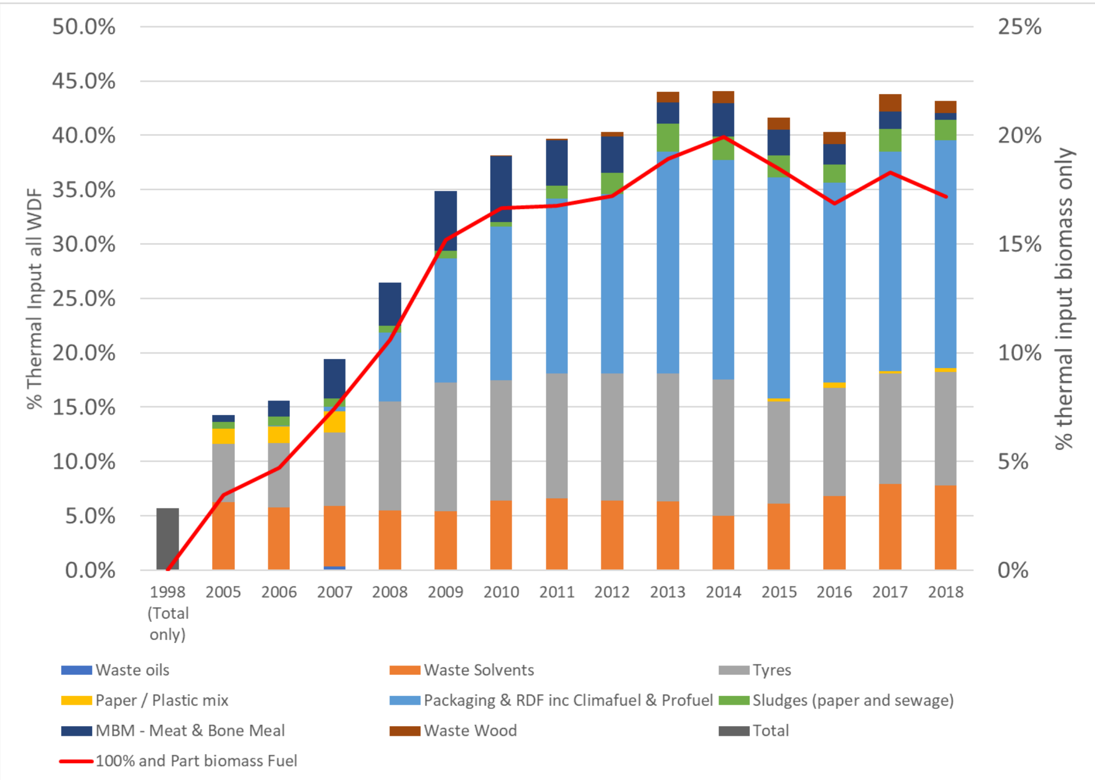


Figure 7: Use of Waste Derived Fuels (WDFs) in UK cement plants between 1998 and 2018

Source: (Element Energy/BEIS, 2020)

Figure 7 shows the use of different WDFs in the UK between 1998 and 2018. Sourcing sufficient WDFs is problematic because there are limited supplies of suitable wastes. The graph indicates that sourcing Meat and Bone Meal and Waste Paper/Plastic has been difficult for the industry in recent years. This is due to competition from other sectors as a result of their classifications as renewable energy sources by the UK non-domestic Renewable Heat Incentive (RHI) introduced in 2011, and offers financial support to businesses to encourage them to install renewable energy technologies for heating purposes. The RHI contributed to a reduction of the biomass input into cement production, which reached a peak of 20% in 2014 but by 2018 had declined to 17%. Cement producers have indicated that the RHI subsidy has prevented them from 'competing on the market effectively for limited biomass resources' [management representative INT 14] MPA/Cinar/VDZ, 2019, p. 18). The MPA has indicated that government support to access WDF is crucial if coal use is to be further reduced. Also, not all WDFs are sufficiently energy dense to meet kiln heating requirements. The graph also indicates that currently, the largest proportion of WDFs are mixed fossil organic wastes from Packaging and Refuse Derived Fuel (RDF). The long-term availability of this type of fuel would be uncertain, were the UK to move towards a circular economy in which single use plastics and other forms of consumer driven municipal wastes were drastically reduced.

Fuel switching: future options

Bearing these limitations in mind the cement industry is currently exploring a number of other potential pathways to a reduction in combustion emissions such as the use of hydrogen as an alternative fuel, or the (partial) electrification of kilns using plasma technology. For example, Heidelberg's CEMZero project is evaluating the potential for electrifying heat delivery. The advantage of this technology is that it would produce a purer stream of CO2 which is suitable for CCS (MPA/Cinar/VDZ, 2019; Brostrom & Eriksson, 2020). A £3.2 million project funded by BEIS recently demonstrated that it was possible to run a cement kiln burner on 100% net zero fuel. In the trial the mix of fuels used was 39% hydrogen, 12% meat and bone meal (waste from the rendering industry) and 49% glycerine (waste from the biodiesel industry) (The Construction Index, 2021). In this trial grey hydrogen (hydrogen produced from methane without CCS) was used but if this technology was adopted at scale, then blue or green hydrogen would be used. As the delivery of hydrogen via pipelines to cement sites is not currently a cost-effective solution, another option being considered is the production of hydrogen using onsite technologies. These production methods are not yet available at scale but are increasingly considered viable (Global Cement, 2022).

UK cement geographies and the challenge to CCS implementation

The two main routes to the reduction or elimination of process emissions are CCS of emissions or changes to the raw material inputs that produce the CO2 in the first place. The UK cement industry body, the Mineral Products Association (MPA), published a roadmap in 2020 which assumes that 61% of the emissions reductions required to meet net zero will come from CCS (MPA: UK Concrete, 2020). However, the location of most cement works outside the industrial clusters which are being targeted to receive CCS infrastructure by 2040 means that this assumption seems quite optimistic. Out of the total of 11 cement production sites, only 1 will get access to CCS via the Track One industrial cluster decarbonisation projects. Three further sites are located in areas which may possibly receive CCS and hydrogen networks at a much later date: the two sites located within a potential "Peak District Cluster" (Hope and Tunstead cement works) and the Aberthaw site located close to a port and the South Wales cluster (Element Energy/BEIS, 2020). This leaves 3.8 million tonnes of emissions from sites which are considered "truly dispersed" i.e., these 6 sites cannot be considered part of sub-clusters, which may possibly receive pipeline infrastructure at a later date. The figure below shows the distribution of cement production sites across the UK.

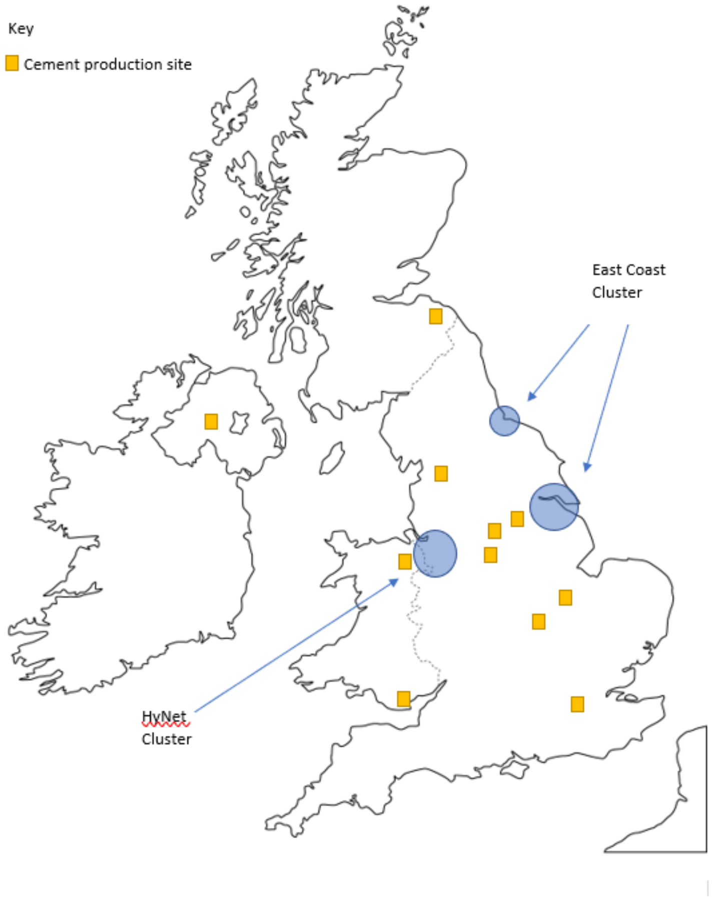


Figure 8: Distribution of cement production sites (squares) and Track 1 industrial clusters (circles) in the UK
Source: Authors

The alternative – CCS deployment at dispersed industrial sites with CO2 transportation into the national grid – is much more cost intensive. The investment and running costs associated with this strategy would be approximately double current levels [management representative INT O]. A government report, into the feasibility of CCS roll out at these sites, identified a number of practical and financial barriers including space and planning constraints, lack of skilled labour, high costs and transport logistics (Element Energy/BEIS, 2020). The incompatibility of the 2020 sector roadmap with likely emission reductions scenarios is further emphasised by the Government's own modelling scenarios. Their policy focus on cluster networks leaves around 40% of CO2 emissions unaccounted for, see figure 9 taken from the UK Government's Industrial Decarbonisation Strategy. A national CCS network linking up large, dispersed sites does not seem to be on the horizon. The MPA have indicated that for the cement industry to remain viable government policies to support access to CCS technologies are essential and need to be forthcoming immediately if the industry is to meet the 2050 net zero target (MPA, 2020)

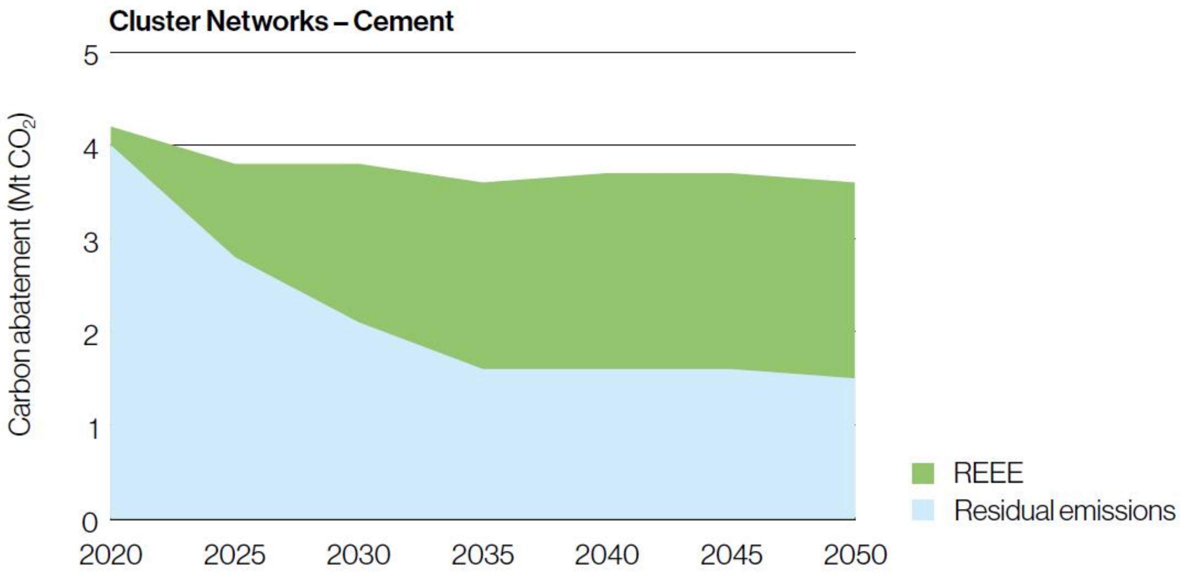


Figure 9: Residual emissions assuming decarbonisation via cluster approach (as opposed to national networks)

Source (HM Government, 2021)

Is process emission reduction via material substitution a viable solution?

There are two main types of cement used in the UK. CEM I (Ordinary Portland Cement) which has clinker content of above 95 percent and CEM II (Blended Cements) which has a clinker content between 65 and 95 percent. Although other types of lower carbon cement do exist, these are not currently being sold at scale (Lehne & Preston, 2018). Generally, the less clinker used in the cement the fewer embedded emissions the end product is allocated. Given the seeming lack of CCS for the UK cement industry, material substitution (i.e., a shift towards lower carbon cements) is likely to play an important role in decarbonising the cement industry. Material substitution includes changes the amount of clinker that is used to make cement (i.e., it can be reduced and replaced with other inert materials) and replacement of clinker with other pozzolanic[33] materials which have a low CO2 allocation as they are often industrial byproducts and/or require lower temperatures to be created than with Portland clinkerisation.

So far, reductions in carbon intensity have mainly occurred via a process whereby the clinker component of CEM II cements is reduced by blending with supplementary cement materials such as Pulverised Fly Ash (PFA) or Ground Granulated Blast Furnace Slag (GGBS) which have lower embodied carbon contents and are by-products of the coal fired power sector and steel sector respectively. The use of waste from other industrial processes as cement replacements for concrete production predates concern over carbon dioxide, and has historically been a way to cut costs given the large quantities of energy needed to produce clinker [INT N]. The MPA roadmap suggested that only 12% of CO2 reduction would come from lower-carbon cements (MPA: UK Concrete, 2020). However, recent studies have shown that the carbon intensity of cement can be reduced by 60% if clinker is

[33] Pozzolanic materials are able to act as a partial replacement of cement.

replaced by a combination of GGBS/PFA and ground limestone, producing what is termed a "multi-component or composite cement" [industry body INT P]. Previously, the carbon intensity of cement has been reduced by using either one or the other of these additions. This multicomponent cement has recently passed through a two-year battery of tests that have deemed it suitable for structural applications. The next stage is to get it accepted onto the British Concrete Standard, a process which is ongoing [industry body INT P]. Whilst using waste materials as inputs into the cement making process is commendable, and far better than using raw materials, the long-term viability of this strategy is uncertain, given that neither GGBS nor PFA will be readily available in a net zero economy. In the UK, domestic supplies of GGBS and PFA are already increasingly difficult and costly to source due to the closure of most coalfired power stations. Beyond 2040 it is possible that even imports will be insufficient to meet UK demand (Millward-Hopkins, et al., 2018; Scrivener, et al., 2017).

Another important development in low-carbon cements is known as LC3 or limestone calcined clay cements, in these cements up to 50 percent of the clinker content can be replaced with calcined clay and ground limestone. These ingredients are widely available and significantly, calcined clay becomes pozzolanic at lower temperatures (700-850oC) and does not release CO2 when heated (Papakosta, Kanavaris, Pantelidou, & Burr-Hersey, 2020).

Work is ongoing to determine the geography of calcined clays in the UK, as well as their kaolinite content (Myers, 2021). The areas being tested for the presence of suitable calcined clay deposits include those close to where tunnelling for HS2 is taking place and it seems likely that suitable deposits will be found (Papakosta, Kanavaris, Pantelidou, & Burr-Hersey, 2020). The use of excavated soil in this way has additional environmental benefits as currently these soils are transported long distances to be disposed of in landfills (Simon, 2021). It seems likely that London Clay, a commonly encountered geological formation in the Greater London area with a variable kaolinite content, will be able to offer comparable mechanical properties to Ordinary Portland Cement (OPC) (from about 7 days for a normal mix of concrete) although research to confirm this is ongoing (Papakosta, Kanavaris, Pantelidou, & Burr-Hersey, 2020).

Changing construction industry use practices: progress towards demand side solutions

Around 75%[34] of the cement sold in the UK is Portland CEM I cement, this is a much higher proportion than is sold in comparable European countries. This reflects the UK cement/concrete distribution system in which cements are blended at the concrete batching plants, i.e. the CEM I is blended with GGBS or Fly Ash at the concrete plants and therefore not sold as blended cements. Demand for lower carbon cements is low due to the slightly higher prices, longer setting times which can delay construction projects, uncertain long-term durability and low levels of understanding of both the emissions implications of different grades of cement and of more novel cement blends generally [management representative INT O; also Lehne & Preston, 2018]. Procurement policies, to make the use of lower carbon cement mandatory, could help increase demand downstream of cement factories and would receive strong support from cement manufacturers. Some work is ongoing in the concrete industry to increase understandings of low-carbon cement however it is relatively piecemeal and not proceeding at a pace sufficient to meet the challenge of net zero emissions by 2050.

[34] Figure from 2007 but more recent figures do not seem to be available.

Changes to the demand side of cement production are possible but do not appear to be on the horizon in the UK. Potential changes could include increased use of structural engineers at the design stage of a project. This would allow buildings and infrastructure to be designed more precisely, reducing overspecification which often leads to excessive use of concrete (Marsh, Velenturf, & Bernal, 2022; INT I). Civil and structural engineers could also be educated and encouraged to more carefully choose the materials needed for their projects. This means that cement grades would be more closely matched with their intended uses with the highest carbon/strength cements reserved for applications where they are strictly necessary (Lehne & Preston, 2018). The way in which concrete is mixed also impacts the amount of cement used to achieve a certain strength (Scrivener, et al., 2017). Greater awareness of cement and concrete chemistry throughout the supply chain would allow concrete to be used much more sparingly than is currently the case (Marsh, Velenturf, & Bernal, 2022; Lehne & Preston, 2018). Such changes, whilst important are broadly beyond the remit of cement producers and would need to be initiated by the large construction companies who build housing and infrastructure projects as well as the companies supplying ready mixed concrete to such projects.

Although attempts to reduce the overall demand for cement could also play an important role in reducing the industry’s emissions, an analysis of trends within cement and concrete decarbonisation roadmaps indicates that industry roadmaps tend to focus more heavily on the ‘cradle-to-gate’ part of the cement production, whereas non-industry roadmaps look more broadly at the less commercial aspects of concrete lifecycle and consider how service life can affect serviceability, recycling and reuse. For example, non-industry roadmaps are more likely to consider the reduction of over specification and improved structural design (Marsh, Dillon, & Bernal, unpublished). Whilst these differences in approach are in part a reflection of where industry feel most able to control emissions and make an impact, an excessive focus on these narrower sites of action could lead to significant carbon savings being missed. The development of business models that are less material intensive, whilst possible, does not appear to be part of UK cement manufacturing emissions reductions strategies at present.

Implications of Decarbonisation Trajectories for Jobs and Skills

The path towards net zero for the cement industry is complex and change is not occurring at the necessary speed. There are numerous strategies being proposed by the industry, but some are unaffordable for UK cement producers without government intervention (e.g., CCS) and others are not being adopted, due to the complexity of the supply chain and the difficulties of coordinating action across numerous diverse stakeholders (e.g. the adoption of lower carbon forms of cement). At the site-specific level, managers are increasingly investing in more advanced quality control mechanisms to give the highest possible level of product consistency, as this allows downstream users to have the confidence not to over engineer their concrete mixes, thus reducing the volume of cement that needs to be sold. This is likely to increase demand for electrical and instrumentation technician engineers able to install and repair technology which controls process consistency. This enhanced quality control process is also increasing the demand for technician level employees able to audit cements produced onsite. The decarbonisation projects discussed above were also deemed likely to increase slightly the demand for industrial chemists who were able to oversee the production of novel cement blends.

Some stakeholders [management representative INT M] were concerned that workers (contractors) who are recruited for around one to two months every year to work on maintenance projects could become difficult to source in coming years, due to the proliferation of largescale hydrogen and CCS infrastructure projects inside the industrial clusters. These projects would likely offer higher wages and may lead to the delay of maintenance projects which are essential to preserve and improve plant efficiency. One example given was the difficulty in sourcing workers who were skilled in slinging and rigging, as the pool of suitably capable workers has been diminishing as heavy industry has shrunk during recent decades.

In interviews, worker representatives felt that workers were not particularly well informed about issues of sustainability:

> "*I don't think they [shop floor workers] are up to date and as aware of things that are happening as we [union reps] are. We've been briefed a bit but previously I wasn't aware. I knew the damage occurring generally in relation to what is in the news but no I don't think that information is communicated enough for people*" [trade union representative INT L]

The perception was that the changes that were required for net zero would not affect their day-to-day duties at work:

> "*I know we burn alternative fuels, but I don't think they [workers] know much more because it doesn't affect their daily work. … obviously it does for management*" [trade union representative INT K]

The desire for better information about how net zero was likely to affect the cement industry, and a sense that the rising price of carbon might not bode well for them coexisted with the firm belief that the majority of workers had no role to play in the realisation of net zero targets and would remain unaffected as technology change proceeded around them:

> "*Workers might be interested in where they think we are going 'cos obviously tax on carbon is going up, CO2 is going up, so on an interest side but I personally think there is very little we can do. Outside work people do stuff but inside there is very little they can do.*" [trade union representative INT K]

This suggests that at the workplace level discussions of net zero are not really part of organisational culture yet.

What next for UK cement?

The UK cement industry has gradually reduced in capacity during the last 15 years. This means that around 22% of the cement used in the UK is imported, an increase from 10% in 2006 (MPA/Cinar/VDZ, 2019). Many UK cement works are relatively inefficient, which has made them vulnerable, this has led to closures during crises such as the financial crisis and the COVID-19 crisis. The closure of the Barrington and Westbury plants in 2008 and 2009 respectively led to a loss of 193 jobs[35], with a

[35] See https://www.wiltshiretimes.co.uk/news/4112046.waste-plant-plan-scuppered-by-factory-closure/ and https://buildersmerchantsjournal.net/cemex-to-close-barrington-cement-plant/

further 110 lost in 2020 at South Ferriby[36]. The high investment and operating costs of CCS makes the consolidation of existing cement plants into larger production units, one way to make such technologies more economically feasible. This may have implication for overall job numbers. Switching to alternative cement replacements, such as calcined clays, relies on the availability of such materials locally. While it is likely that job losses resulting from net zero changes are not imminent, net zero could easily lead to a reduction in British cement manufacturing capacity.

The analysis of cement sector reports and interviews suggest that management is reacting more or less with a business-as-usual response with moderate incremental innovation, and is putting a lot of hope into CCS. The lack of strategic sustainability orientated thinking has been identified as a barrier to a deeper transformation of industry work and production practices in other research reports on this topic (Hopley, Drummond, & Akinremi, 2021). In addition to this analysis by carbon market watch indicates that an over allocation of carbon credits via the EU-ETS between 2008 and 2015 may have reduced the incentives for deep decarbonisation initiatives (Brandt & Jong, 2016) helping to explain the relatively sluggish interest in lower carbon cement blends outside academia. Nevertheless, the discussion above indicates that the UK cement industry has the potential to make significant reductions in carbon emissions in the next 15 to 20 years. This will come primarily from the production of low-carbon grades of cement and fuel switching projects, which, whilst not allowing net zero emissions, will reduce the emissions intensity of production considerably.

5.3. Steel Case Study

The Net Zero Trajectory of the Steel Industry

The steel industry is the biggest industrial emitter of CO_2 in the UK. It produces 11.6 million CO2 emissions per year which represents 13.5% of greenhouse gas emissions from manufacturing, and 2.6% of the UKs overall emissions (BEIS, 2018). The industry is one the largest carbon emitters but is also a critical industry in the transition towards a greener economy as steel is required for wind turbines, electric vehicles, rail networks, and low-carbon buildings.

Currently 7 million tonnes of crude steel are produced each year in the UK, 70% of the UKs annual demand (Hutton, 2021). The industry contributes £2.1 billion per year to the UK economy (gross value added), and £4.8 billion, once supply chains are included (Energy and Climate Intelligence Unit, 2021). However, in the last 30 years its importance has declined, from a total output of 0.3% in 1990, to 0.1% of the total economic output in 2020 (Hutton 2021). Around 600 different businesses make up the steel sector and it provides more than 33,400 jobs, with a further 40,000 in the supply chain (The Green Alliance, 2021). The jobs are highly regionally concentrated, primarily in Wales and Yorkshire and the Humber but also in the West Midlands and the North East. Steel industry salaries are far above the average regional wage in regions where jobs are concentrated (MakeUk.org/UK Steel, 2021).

[36] https://www.constructionnews.co.uk/financial/cemex-to-close-plant-with-loss-of-110-jobs-14-07-2020/

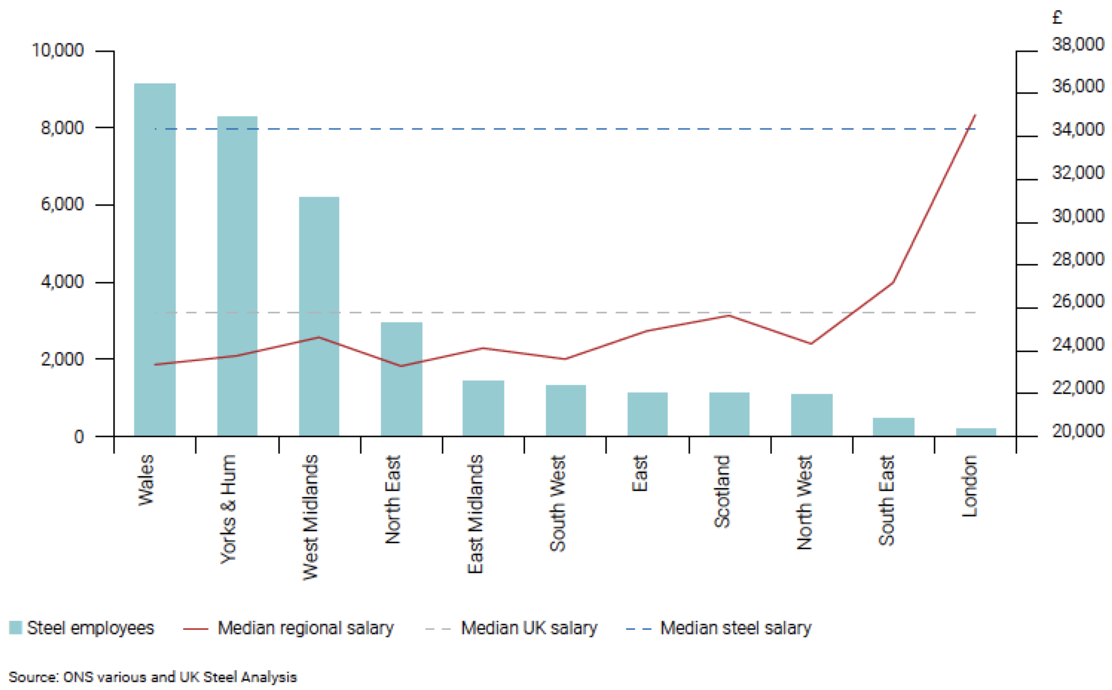


Figure 10: UK Steel sector employment and salaries by region

There are two types of steel production. One is primary production which refers to the production of steel from raw materials (coke, iron ore, and other minerals) by heating and melting. In the UK, this is currently carried out using blast furnaces, located in Scunthorpe in Lincolnshire, and Port Talbot in South Wales. Figure 11 below shows their location in relation to the planned industrial clusters discussed above. The other form of steel production is secondary steel production. This is steel produced from recycled scrap steel in electric arc furnaces (EAFs). This steel accounts for only 17% of UK production. The carbon intensity of production (the amount of emissions produced per tonne of steel) varies greatly between sites and according to production methods. In the UK, blast furnace sites emitted 1.97tCO2 per tonnes of steel compared to scrap-based production of 0.32tCO2 per tonne of steel in 2020 (MakeUK/UK Steel, 2021) Globally, the carbon intensity of production varies from 0.29 to 3.38 tonnes of CO2 per tonnes of crude steel. Despite higher emissions steel production from iron ore is still assumed to be rising (Allwood, et al. 2019).

Figure 11: Distribution of steel production sites (squares) and Track 1 industrial clusters (circles) in the UK

Source: authors

Electric Arc Furnace scale-up: cheaper electricity needed

The far lower emissions intensity of EAFs compared to blast furnaces means that they are likely to play an important role in reducing the carbon emissions of the steel industry. EAFs can use 100% recovered ferrous scrap metal as the primary raw material and produce emissions intensities around six times lower than those of a traditional blast furnace [INT S]. The emissions intensity of EAFs depends on their age and operational condition, as well as the extent to which the electricity grid has been decarbonised. In the UK, EAFs emissions intensity currently varies between 0.28-0.75tCO2/tonne (McDonald, Portet, & Spatari, 2021). When powered by entirely renewable energy EAFs produce close to zero emissions (Energy and Climate Intelligence Unit, 2021). EAFs also have greater operational flexibility which means that steel is produced in batches, allowing producers to make use of low-cost energy at times when the supply of renewable energy to the grid is plentiful (Peake, Brandmayr, & Klein, 2018).

A switch to EAF from blast furnace production would involve a five-fold increase in electricity usage. UK producers pay about 50-60% more for electricity than their main international competitors (MakeUK/UK Steel, 2021). In 2021, the average UK electricity prices steel companies paid was 60% more than that paid in Germany: £94.92/MWh compared to the estimated German price of £59/MWh, a price disparity which translates into £90 million additional cost to UK steel producers, compared to those in Germany per year (MakeUK/UK Steel, 2021). Business leaders argue that these lower profit margins in the UK may mean that global steel producers will relocate to more favourable economic climates (Griffin & Hammond, 2021) One consequence could be environmentally damaging carbon leakage.

Whilst EAFs could theoretically be deployed within 5-10 years, allowing the steel sector's emissions to be significantly reduced much sooner than 2035, there are a number of barriers to the increased roll out of this technology. First, it would require significant changes to recycling infrastructure and the process through which steel is certified. Globally there is a shortage of scrap. The UK produces around 10 million tonnes of scrap steel a year, more than its annual crude steel production; 7.3 million tonnes of this is exported, often to countries with lower environmental standards ending up in landfill, particularly if metal waste is mixed with plastic waste, and 2.7 million tonnes is recycled domestically. The domestic supply of scrap steel is expected to treble by 2050 (Serrenho, Mourão, & Norman, 2016). If the UK invested in EAF technologies, this would create a local market for scrap steel and keep an additional 4.1. million tonnes of scrap steel in the UK (Peake, Brandmayr, & Klein, 2018). It is also worth noting that a portion of the exported scrap is reimported back into the UK in the form of finished goods. Whilst not a barrier to the development of more EAFs, in terms of the negative environmental consequences of such transportation, the imperative to increase recycling within the UK, is clear.

Second, due to the difficulties of accurately separating different grades of scrap EAFs can produce more limited steel grades of more limited utility than those produced by primary steel making. Recycled steel contains impurities which mean that it cannot be used for some high-end applications such as motor vehicle manufacturing. To better separate grades of scrap would require massive investment in advanced sorting technologies and improved tracking/labelling of different grades of steel. Improving recycling infrastructures will be crucial increasing the circularity of UK steel production. Currently around 5% of structural steel is reused but this could rise to 50% [management representative INT U].

Third, running EAFs is hugely costly as electricity is very expensive in the UK. As previously explained, UK producers pay about 50-60% more for energy than their main international competitors (MakeUK/UK Steel, 2021). It is therefore estimated that would cost £198m more to operate an electrified steel sector in the UK than in Germany.

Hydrogen steel production: will the UK Government invest?

An alternative route to low carbon steel is hydrogen-based steel making (Pimm, et al. 2021). Blast furnace steel production produces carbon emissions due to the use of coal/coke in the blast furnace. In hydrogen-based steel production, hydrogen would replace coal as a (direct) reducing agent in the steel making process. The by-product of Direct Reduced Iron (DRI) is steam rather than CO2. Hydrogen can either be injected into existing blast furnaces, or used via the DRI method to produce sponge iron, a precursor to steel, this can then be made into steel in an EAF (The Green Alliance, 2021; Energy and Climate Intelligence Unit, 2021). Using DRI to produce the c.6 million tonnes of steel currently produced in the UK would mean that an additional 20 terawatt hours (TWh) of electricity generation would be needed, or the equivalent of 4GW of new offshore wind capacity and current planned capacity is unlikely to be sufficient to meet demand.

Steel production investment cycles are around 30 years and so the timing of the introduction of this new technology is crucial. The UK is currently lagging far behind other European countries in terms of the role out and funding of clean steel technologies, which require substantive investments. The two large UK blast furnace owners – British Steel Limited and Tata Steel – need to decide whether to invest in their coking plants, plus other costly blast furnace refurbishment projects in the near future. There is also uncertainty around long-term access to the iron ore needed for the DRI production (McDonald, Portet, & Spatari, 2021). Nevertheless, the announcement of largescale cluster-based hydrogen projects, discussed in detail earlier, make the decarbonisation of the British Steel Scunthorpe plant seem more likely than previously considered. The question is timing though. The commercialisation of hydrogen could take 20 years (Åhman, et al., 2019). Whilst there are 23 hydrogen steelmaking projects being demonstrated in Europe, there are no clear proposals for the same in the UK (ECIU, 2021). Therefore, Stevens et al. (2021) in their policy briefing does not take hydrogen as a viable option for quick decarbonisation of steel into account.

CCUS

Research assumes that it will be almost impossible to reduce emissions from steelmaking to net zero without CCS removal capacity (Garvey, et al. 2022). The industry is putting high hopes into CCS as this seems the only available technology able to reduce emissions from ore-based production significantly. Ore based production is considered vital for producing specific high quality steel grades. It is estimated that CCS can capture a large amounts of emissions. However, it would require a significant retrofitting/of the blast furnaces, by introducing more Hisarna or DRI furnaces which, by preheating coal, reduce the emissions by 20% (Tanzer, Blok, & Ramirez, 2020). The costs, however, for retrofitting blast furnaces in the UK are estimated to be around £1.8bn-2.25bn (UK Steel 2021).

Circularity – the neglected approach

Recent research highlights (Garvey, et al., 2022) that technological solutions alone will not be enough to reach net-zero, but that material efficiency will also be necessary. In addition to increases in scrap metal recycling, a shift to lighter materials, optimised design, material substitution and extending the lifetime of products by facilitating product repair and shared ownership of certain products can help drive down emissions. Some companies are experimenting with introducing new business models introducing more circularity, closing loops in the supply chain, via collaboration with demolition companies in order to reprocess demolition material and delivering it back via to the same site. This introduces new ways of organising recycling, encouraging resource utilisation by introducing transparency and tracking the value of the material through the supply chain, implementing the concepts of circularity. The value of a circular economy for decarbonising is not yet accounted for, not only in terms of emissions reduction but also in terms of economic value. For some of the experts interviewed, decarbonising the linear production of steel is the wrong approach. What is required is a shift to a circular economy. This would involve waste minimisation and emissions from it, valorisation of end of life of materials, quantification of critical resources, and encouragement of new solutions to recovery of resources and re-integration of them back into the economy, in order to reduce the overall environmental impact from steel production including the footprint associated with the production of iron ore [INT U]. Overall, the industry is not applying higher levels of circularity but mainly relying on recycling.

The financial challenge of green steel production

Decarbonising the steel industry is likely to prove very costly. Chris McDonald at the Materials Processing Institute[37] assumes £6bn-£7bn of investment per site is required, in addition to the cost of supporting infrastructure (Pfeifer, 2021). For all technological solutions, huge investments are needed (£400-£500m CAPEX for 1mt of steel), which is unaffordable by the UK producers, given their weak financial situation. So far, the UK Government's support for low carbon steel has been tepid. In 2019, they announced the £250 million Clean Steel Fund, however, this money will not be allocated to specific projects until 2023 and falls far short of the amount required. There is still £180m of sector money that was returned to the UK from the withdrawal from the European Research Fund for Coal and Steel following Brexit. The steel sector has been clear that this money should be ring-fenced and used to set up a research fund to support the innovation needs in the sector, but while under EU law these funds could not be appropriated to other uses, there has been no decision made by the UK Secretary of State on whether the money will be made available to the steelmakers. According to UK Steel, the government initiatives lack a clear strategy how to achieve decarbonisation in steel. Community, one of the major steel trade unions, considers that "There doesn't seem too much appetite or commitment from the government it's just a lot of words, without action, and so we are really concerned." [trade union representative INT R]. Or in the words of Lucy Powell, then Shadow BEIS Minister "Let us be honest: UK steel and steel communities have been betrayed by this Government, because they have no vision nor any plan".38 The recent statement by Tata Steel UK, that unless the UK Government funds half the £3bn estimated cost of replacing the blast furnaces of its Port Talbot steel works by EAFs, the works might close with the loss of thousands of jobs, reflects these issues in stark social as well as economic terms (Cornish, et al. 2022).

Steel prices are very sensitive to energy costs. EAF and hydrogen production as decarbonisation pathways are both heavily reliant on electricity. The sector can only become net zero if sufficient green energy is available at affordable prices. A switch to EAF from blast furnace processing will involve an increase of electricity needed by a factor of five, and with the current price disparity, it would cost £198m more to operate an electrified steel sector in the UK than in Germany. Switching to hydrogen-based production, for a comparably sized sector, this would cost almost £300m more to run in the UK than in Germany just in terms of electricity prices alone (Steel UK 2021). This price difference mainly impacts future investments. It is unlikely global steel producers will stay in the UK but rather, redirect their investment towards countries where profit margins are higher. UK producers are part of global corporations with sites in other European and Asian countries, in which decisions for investments have often been made on the basis of competition between sites. Tata Steel, where its Indian steel operations offer higher profit margins than its UK business, is a case in point. Thus, according to steel business leaders, if electricity prices are not reduced for UK steel producers, net zero strategy would equate to a sector that is not competitive on the global market. For the industry, it is vital that electricity costs are reduced if the production is to be kept in the country ((UK Steel A Barrier to Decarbonisation 2021). The reduction of the cost of electricity to the sector, has been a key component of government lobbying by industry unions and businesses for a number of years.

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[37] Not an interviewee

[38] https://hansard.parliament.uk/Commons/2021-03-25/debates/06785504-40D9-4E5A-886C-89917ABAA910/UKSteelProductionGreensillCapital

Steel companies reckon that it is vital to create a new business environment for steel a so-called low carbon steel market, which includes a commitment towards green public procurement (public institutions buying only low carbon steel produced in the UK), Border Carbon Adjustment mechanisms and Carbon Pricing. As the largest single purchaser and consumer of steel in the UK, the Government would have a powerful tool at its disposal with purchasing only low carbon (UK) steel, also influencing behaviour in the private sector. Border Carbon Adjustment would help prevent carbon leakage. It would involve taxes on imported steels, or a tax relief for products sold on the international market, so that steel products face a similar carbon price, regardless of whether produced in the UK or imported from third countries[39]. The industry organisation, UK Steel, is proposing the introduction of a product standard that would ban high emission cheaper steel from the UK market. As a milestone on this way to this goal, it is argued it would be beneficial, to introduce product labelling to obtain experience with data collection.

Carbon pricing is the imposition of a cost for emitting carbon to the atmosphere as a discouragement to the emission of greenhouse gases. At the moment, steel producers have free allowances for carbon pricing through the UK Emissions Trading System. But governments are reviewing these exemptions and the price of CO2 will also increase significantly. The current UK ETS prices are £80/tonne, and it is very likely to increase. Without global regulations, this is a potential threat to a UK steel industry. The Government signed a Breakthrough Agenda for Steel at COP26. This aims to make, 'Near-zero emissions steel' the 'preferred choice in global markets with efficient and near-zero emission production in every region by 2030 or earlier' (Purvis, 2021). Although the Agenda may allow a slightly more coordinated approach to disparate aspects of the steel climate transition (Purvis, 2021) it remains very general and does not commit to any of the above suggestions from industry [INT S].

Implications of Decarbonisation Trajectories for Jobs and Skills

The UK steel industry has seen major job losses since the 2000s as a result of a number of factors. Of significance, amongst these have been increased production from relatively new entrants into the international steel economy, UK Government industrial policy, (significant for high energy industries) and crucially, the hugely increased production capacity of China which has led to a fall in prices on the world market, making it harder for UK manufacturers to compete (House of Commons 2021, Steel Industry APPG). In 2015, major job losses occurred due to the plant closure of Redcar[40] in Teesside and there were major job losses at Tata (Evans, 2015; Griffin & Hammond, 2019).

The resilience of the UK steel sector continues to be a concern (Hutton 2021). Furthermore, due to decreasing demand during the pandemic and struggles with profitability, businesses are unsure how decarbonization will affect employment. Ongoing challenges include a high labour turnover due to stress in the industry (management representative INT U see also Meintjes 2019)) and attracting a younger workforce to an industrial sector with an aging workforce, given its locations in industrial towns. According to industry experts, many young professionals seek urban environments in which to be employed, and the industry is finding it particularly difficult to find data analysts or accountants. Thus, there is a substantial competition for workers within the steel industry, but also more broadly

[39] Steel is an intensively traded product. For example, the UK imports 6.6 million tonnes of steel per year around 60% of requirements and exports 3.5 million tonnes, just under 50% of its production.

[40]Following the closure of the SSI steel plant in Redcar, the South Tees Development Corporation was established in October 2015 to support economic growth in the area intending to create 20k new jobs (Hutton 2021).

for skills within the Foundation Industries. There are also skill shortages among skilled workers and apprentices, as according to business experts, much training provided by colleges: “is not fit for purpose, just bums on seats” [management representative INT U] and employer reskilling of apprentices is often necessary. Social dialogue and partnership between unions and employers has a strong tradition in the steel industry (Bacon/Blyton 1996, Mackenzie, et al. 2006) and is also considered vital from both sides for the green transition ahead. Unions, however, recognise that “we have to do much more and much better in the area of training” [management representative INT R]. There is an articulated interest in re-adjusting the skills system to better support the steel industry, a challenge apparently common to other foundation industries as well. According to the union Community, specific skills like advanced digital skills, entrepreneurship, sustainable development, and analytical thinking are undeveloped. So, it is crucial that workers are supported in advance of that transition [trade union representative INT R].

The industry though does not yet have a good understanding of what skills will be needed to decarbonise the sector, the skills agenda has not been a priority yet, as most focus has been on developing a favourable business environment [industry body representative INT S] There is some concern from business that “we just don't have enough of the right sort of people. Or at least the right sort of mindsets even regardless of the skills, because I think if you can adapt the current skillset to whatever the need is, but the issues are bigger” [management representative INT U].

Looking at a recent survey of steelworkers, this view might be too pessimistic as 85% of steelworkers think the green transition is necessary, 57% think the Green Transition will significantly change the skills and qualifications required for steel-making in the UK, and there are high hopes that the Green Transition will improve job security and employment opportunities in the industry (41%) and strengthen the competitiveness of the UK steel industry (48%) (Community 2021). According to this survey, workers are also very keen to get training in order to improve job satisfaction, safer working environment, and the transferability of skills (Community 2021). 8% of the workers are afraid their jobs will disappear with decarbonisation, and 22% think they will be deeply affected. The unions perceive that barriers to training mainly reflect costs and lack of suitable training offers (Community 2021).

Steel workers are, however, less dissatisfied with training than in other industries, with only 24% expressing dissatisfaction compared to 47% nationally; 27% think they will have to change jobs, 59% think they will have to learn new skills, and 30% of workers assume they will need to relocate (Trappmann and Cutter 2022). It seems though that the main barrier for an appropriate green skills agenda is the uncertainty about the future business environment. As long as it is unclear in what directions investments will go, “there will be no discussion around the skills needed for those investments” [industry body INT S]. From earlier studies looking at various EU countries though, we know, that in the steel industry more broadly, digital skills, soft skills and big data analytics are crucial to enhance energy efficiency and resource efficiency (Antonazzo, et al. 2021,) and for maintenance tasks, like use of drones for inspection of hard to reach or unsafe locations (Naujok and Stamm 2017; Stroud and Weinel 2020). The profile of the steelworker in the future looks at transferable skillsets to ensure a good level of flexibility and coordination within the different functional departments of companies (White Research, et al. 2020).

What next for UK steel?

The pathways for decarbonising the steel industry that are preferred options by industry (fuel switches, grid electrification and new technologies like hydrogen and CCS), are considered risky in terms of reaching medium-term emissions targets (Garvey et al. 2022). The lack of funding from government for these new technologies, the probability of commercially available implementation only in 2040, and the long investment cycles of the steel industry make this an insufficient route for decarbonising. (ibid.). A good illustration of this apparent weakness of national industrial strategy is that, despite being the largest point source of emissions and following two years of discussion with the UK Government, the UK Tata steel production site in South Wales has not received funding which will aid decarbonisation.

Theoretical modelling instead suggests that retrofitting existing systems with best available efficiency technologies is the most effective way of reducing emissions by 54-64% (Ibid.) A fuel shift, moving to a larger share of electric arc furnace (EAF) production and away from blast furnace and blast oxygen furnace (BF-BOF) production might lead only to 11-55% of emission reductions, and a switch to hydrogen and CCS might lead to 16-41% of emission reductions (Stevens, et al. 2021). The reliance on novel technologies whose availability is unclear might be reduced by more reliance on material sufficiency.

There is a strong case for maintaining domestic steel production, given its strategic importance for infrastructure projects needed for a green economy. For UK steel producers this requires commitment from government to increase investments, and lower the costs of electricity prices, but also create business opportunities for circularity of steel and new business models. The lack of investment has meant that the UK steel industry has fallen behind its international counterparts (BEIS, 2020). As long as this intervention is missing, the destiny of British steel is undecided.

6. Discussion and conclusion

This report has presented the main industrial decarbonisation strategies of the UK Government and analysed the decarbonisation pathways in three Foundation Industries, namely glass, cement, and steel. The UK Government has chosen a cluster-based approach to decarbonising, prioritising some regions over others, benefitting a minority of FI businesses which are located within those clusters, such as the Humber and Teesside chemical industries, British Steel, and a couple of glass production sites and one cement works. The uneven regional distribution of risk could further destabilise the FI sector and entrench regional inequalities. However, so far, the cluster decarbonisation projects do not have conclusive funding models in place.

To achieve net zero, government has placed its hopes in technological innovations such as electrification, hydrogen and CCS and thus has funded research and trials aiming to stimulate innovation in this area. The need to decarbonise the energy-intensive industries is huge, but concrete investments into the necessary technologies is slow and many of the infrastructure developments planned are unlikely to be completed for within the next 10 to 20 years. To reduce emissions as fast as possible the FIs must consider alternative solutions such as demand reduction, dematerialisation, and changes to business models.

So far, for the three FIs examined here, industry has achieved reductions in CO2 emissions mainly by energy efficiency improvements, through improved furnace design and heat recovery in all three industries, as well as through fuel switching in the cement industry. Aspirations for further emissions assume more efficient use of energy due to digital technologies and increased electrification of industrial processes (in particular for glass and steel) as well as potentially a move towards biomass fuels in the case of cement and glass. The use of hydrogen as a supplementary fuel is being considered by all three industries if/when it becomes available locally. All those options are not yet available so, to meet net zero, more rapidly accessible and more radical solutions are necessary, acknowledging that reaching net zero emissions will be a difficult task requiring significant investment. Research suggests that increased material efficiency and material reuse will be a promising way to reduce emissions in the short term. This will most effectively be implemented by means of additional regulation emanating from central government.

In the following, we summarise the challenges FIs face with decarbonisation.

Focus on technological solutions and their lack of funding: Hydrogen and CCS

Although the UK Government is placing great emphasis on CCS technology as a means to decarbonise heavy industry, the plans to roll this out sequentially and via clusters mean that most FI businesses will not receive access to this technology in time to meet net zero commitments. This seems particularly problematic for the UK cement sector, as 60% of emissions are process emission and so fuel switching options will have a much smaller effect. The UK Government's previous support for CCS is inconsistent. In 2012, it promised £1 billion of capital funding via the CCUS Commercialisation Competition. However, this was unexpectedly cut short in 2015 when it was announced that the funding was no longer available. The 2020 *Ten Point Plan for a Green Industrial Revolution* stated an ambition to capture 10 $MtCO_2$ per year by 2030 via the deployment of CCS in two low-carbon industrial clusters by the mid-2020s (HM Government, 2020). However, by the time the *Net Zero Strategy: Build Back Greener* had been published the following year, this had been scaled back to 6Mt per year by 2030 and 9$MtCO_2$ per year by 2035 (HM Government, 2021b). This promised funding does not come close to the figure required to operationalise any full-scale CCS projects.

While some authors suggest an early retirement of assets where there is a high net mitigation benefit (Gavey and Taylor 2020), this would have detrimental effects on FI employment. In July 2022 Tata Steel threatened to shut down its operations in Port Talbot if the Government does not agree to help provide £1.5 billion of funding to help reduce carbon emissions and transition to electric arc furnaces (Raval, Pfeifer, Dempsey, & Cornish, 2022). The only steel specific decarbonization funding made available so far is the 2019 Clean Steel Fund which offers £0.25 billion in total (BEIS, 2020).

A number of alternative interesting proposals have been developed for how largescale transformative green infrastructure projects could be advanced. Research by the Green New Deal Group has suggested that a combination of subsidy cancellations, changes to the way that individual savings accounts are taxed, and a newly created Green Investment Bank linked to the National Savings and Investment Platform could allow the government to borrow cheaply and offer an improved saving rates to consumers (Finance for the Future, 2021). Personal wealth has increased by over £6 trillion or 39% of UK national income between 2011 and 2018. This growth in wealth has produced what has been termed a 'savings glut' of around £14.6 trillion which is primarily held in tax incentivised assets such as tax-free saving accounts and domestic homes. Tax subsidies to individual savings accounts (ISAs) cost around £60 billion a year according to some research (Finance for the Future, 2021).

According to the Green New Deal group, 5% of the UK's annual GDP needs to be spent on infrastructure and training to ensure the UK is transformed into a greener and much fairer society (Green New Deal Group, 2019). They derive this figure by considering estimates of the cost of transitioning to a greener economy made by various think tanks (Climate Change Committee - £50bn a year by 2030; New Economics Foundation - £40 to 100bn; Green New Deal UK - £68bn; Greenpeace - £73bn over next three years and their own calculations which suggest £117bn a year through to 2030 (Finance for the Future, 2021).

Despite the lack of UK funding, CCS and hydrogen plans are generally more advanced in terms of detail than those in other European nations (Rattle & Taylor, unpublished). UK willingness to lead on this technological decarbonisation pathway we suspect is driven by the possibility of capitalising on the large volume of storage available in disused oil and gas reservoirs on the UK continental shelf. Also the A webpage for the Department for International Trade notes that 'The UK has a global leading geological advantage – having one of the greatest CO_2 storage potentials of any country in the world - the UK Continental Shelf, accounting for approximately 85% of Europe's CO_2 storage potential and which can safely store 78 billion tonnes of CO_2' (Department of International Trade, 2022). This suggests that there are hopes that this space could be sold to countries considering similar pathways once the technology has been effectively demonstrated. However, CCS technologies have also been criticised for enabling a sense of complacency. Their apparent simplicity suggests the net zero challenge is achievable without drastic and systemic changes to the ways in which we live and work. CCS projects will also take decades to come online and may reduce the rationale for more immediate interventions. They also assume that there will be very low levels of leakage which if not fulfilled, could have catastrophic implications (CACCTU, 2021).

Government plans for these technologies are focused on ensuring proper functioning of the new emissions reductions' projects, business acceptability, appropriate business models are in place e.g., that there will be sufficient market for the hydrogen, and that CO2 storage will increase GDP of the nation. Less consideration is being given to whether there will be sufficient and appropriately skilled workers available to carry out the work required in the areas where these projects are being built. Previous research has indicated that there might be a mismatch between where those new jobs are located and the skills level of local labour markets. In Teesside in particular, there is already the difficulty of filling existing vacancies in the local labour market, often for similar type jobs that will be created during a net zero transition, despite Teesside having a youth unemployment rate which is 75% higher than the national average. So, while there will be new jobs created, there is no guarantee that these positions will be easily filled. Both Teesside and Yorkshire and the Humber have among the lowest levels of educational attainment at GCSE level, so significant investment will need to be made in the local education systems where many of those new jobs are expected to be created. Otherwise, well paid, high skilled jobs will remain out of reach for the workers in the clusters.

Electrification of industrial processes

Although the electrification of industrial processes is likely to provide a long-term sustainable solution for many combustion emissions across the FIs, in many sectors these solutions are not commercially available yet. Increased use of electricity in industrial heating is not helped by the high price of electricity in the UK which businesses at a competitive disadvantage in the world economy. FI businesses would benefit from access to cheaper electricity. The current energy crisis is already leading some FI businesses (including those in glass and steel) to reduce production to save costs. Whilst high prices continue investment in fuel switching technologies is unlikely due to the financial pressure that the high prices are creating (TFI Network+, 2021). Here, action is required rather sooner than later to prevent disinvestment.

The likely long-term importance of electricity for industrial processes means that the speed of electricity grid decarbonisation has huge implications for the carbon intensity of FIs. Although the UK has led the field in terms of the shift away from coal fired electricity, fossil fuel use in the UK remains high with nearly 40% of the country's electricity still coming from gas fired power stations. Current models suggest that electricity demand could double by 2050 due to the electrification of transport and the increased use of electricity for heating (EWP, 2020). This surge in demand makes the decarbonization of the electricity grid much more challenging. Particularly if this is to occur by 2035 as the Net Zero Strategy indicated (HM Government, 2021b). The expected surges in demand for electricity from other sectors of the economy such as heating for buildings and transport means that decarbonisation projects may be in competition with each other. Current policy documents lack sufficiently ambitious renewable energy scale-up targets and credible funding sources are not in place.

Recruitment and skills: No pipeline for preparing the workforce for net zero

Independent of decarbonization plans, the workforce situation in the FIs is challenging. Across the UK, FIs have an aging workforce. Recruitment is a challenge, and many FIs already struggle to fill vacancies due to technical and STEM skills shortages. They also struggle to attract workers as these industries are perceived as dirty and basic, and associated with operational processes that are demanding and require antisocial hours of work due to the 24 hour nature of operations. Further, the uncertain policy environment surrounding the UK FI industries may affect the recruitment of younger workers who may wonder if these industries have a future in the UK. Reframing these industries, as part of the green economy could help attract more, younger and high-quality candidates into these workplaces. Many FI products will be essential as we transition to a greener economy: from glass for solar panels and thermally efficient windows to steel and concrete for wind turbines.

Current skills shortages include a lack of workers with digital, project management and engineering qualifications – with electrical, instrumentation and mechanical all in short supply. There is a huge competition for workers within the industries, but also more broadly for skills within the sector and between the FIs. Technical industry specific courses often struggle to attract sufficient students to run, and various strands of the FIs are only just beginning to cohere around the overarching FI label and to organise training courses collaboratively. These ongoing problems mean that many FIs are not focused on developing the skills required to maintain competitiveness in a net zero economy, but rather, they are trying to combat more immediate problems of an ageing workforce and the associated loss of technical knowledge.

Generally, net zero is perceived as a chance for industry to create new jobs, particularly around the new technologies such as hydrogen and CCS, but business leaders in our small sample did not expect significant changes in labour demand as a result of decarbonisation policies in the short term. In the medium term, though, they expected the demand for workers (both graduates and apprentices) with skills in electrical, mechanical and instrumentation engineering to remain high and to increase. As all industries will see increased electrification of processes, they will need skilled engineers able to implement and project manage technology changes as efficiency measures, fuel switching and later perhaps externally managed carbon capture and or hydrogen projects get underway. They expect to employ more people with skills in environmental auditing able to check that their businesses meet increasingly stringent targets. Inputs and outputs are also likely to become more tightly controlled as circular economy thinking becomes embedded into production processes, requiring increased technician level staff to oversee quality control. Data management and digital skills were also viewed as critical. Yet, whilst the technological pathways remain open, planning for the skills challenge needed to meet net zero is difficult.

Some observers claimed that there is a lack of understanding of the scope of change needed to meet net zero targets in some branches of the FIs. Given that UK workers are keen to work in the green economy (Cutter, et al. 2021), it seems vital to create skill pathways into jobs within the FIs and beyond. Currently, the skills ecosystem is not well equipped to deal with these challenges. Further, as 80% of the current workforce will still be active in 2030, transferring existing skills and retraining needs to be a focus for the green economy (Alvis, Fotherby, Bennett, & Avison, 2022). The Skills for Jobs White Paper (2020) laid out the planned reforms to the skills system including a Lifetime Skills Guarantee, offering more employer-led training and continued Vocational Education and Training. However, given that many of the future employers (e.g. in hydrogen and CCS) do not yet exist, this is a flawed approach for a skills initiative for green jobs: more extensive and coordinated state initiatives are necessary.

On a more general level, workers do not feel well prepared for a transition to net zero. In some workplaces, training on environmental issues is underway, in others it is not yet on the agenda. Our interviews indicated that although some information is filtering down the dissemination of information around net zero, it is primarily a passive rather than active process. Low levels of worker engagement on net zero are likely to make the targets harder to achieve and may prevent workers from making useful contribution to the overall decarbonisation trajectories. We know from previous research that workers in the UK do not feel consulted about decarbonisation (Cutter, et al. 2021).

Past rounds of restructuring of manufacturing though have shown that a strong tripartite approach can help mitigating effects of transition and improve skills and training agendas. However, unions recognise the need for an increased focus on training. An interest in re-adjusting the skills system to better support the FIs industries has also been articulated. The only long-term skills strategizing is being driven by unions in the steel sector only. This is possibly because steel workers have historically well-established bargaining machinery in the industry and sections of the main steel unions that have a fervent focus on the sector. This strategic interest by steel industry unions, is arguably being nurtured by the compact, with employers to jointly face the existential threats to the UK steel industry that have gathered ground over the last few decades. Such partnerships are made possible by the dense networks of industrial relations arrangements that have been constructed over generations. Although the once monolithic British Steel Industry and the more recent tentacle like Tata Steel UK have fractured into several independent steel companies, plant based industrial relations arrangements echo those of the former ‘conglomerates’, as do national steel industry industrial politics. In the context of the Green Steel agenda, although both locally and nationally, the different unions are attempting to develop an overarching strategy, the absence of government financial support has thus far, hindered the development of formal negotiations. Tata UK has made clear that the cost of green production can only be borne with government support. Without such support, the viability of its UK integrated steel works in Port Talbot, is at risk.

Material efficiency in a circular economy

Allwood, et al. (2019) suggest that steel demand could be met with an eighth of the steel currently used by ‘avoiding scrap’, avoiding ‘over-design’, and in producing ‘smaller goods’ with longer lifetimes. While this requires improvements in the design of products, it also needs new business models that stimulate demand reduction by remanufacturing and reuse of products, thus increasing resource productivity (Velenturf and Purnell 2021). Circular economy approaches, which would reduce emissions via decreased use of raw materials, or by reducing overall production levels, lack policy support at the national level. For example, the low landfill tax on glass means that flat glass recycling rates are low, 70% scrap steel is exported rather than recycled in UK and reuse schemes are only in the very earliest stages of infancy. Simple tweaks to waste management legislation such as the redesignation of certain categories of materials could have an important impact on flows within the economy. There are too few incentives for circularity or waste valorisation. Again, looking at the glass industry, although important changes to packaging legislation are about to take place, these are focused on the improvement of collection rates for recycling and do not set targets for a switch towards refillable systems which could prove a more efficient way to cut the carbon emissions of the glass industry. An easy win would be an active state procurement policy for low carbon products which could be used to mitigate the current lack of demand for low/lower carbon FI products. Dismantling the barriers that prevent industrial emissions reductions and ensuring a thriving UK FI sector, will involve national level policy changes and cooperation with diverse actors beyond the factory gate. We follow Garvey et al. (2022) in their assessment, that it seems best to implement available technologies alongside material efficiency strategies now, rather than 'wait' for commercialisation processes which may be delivered too late to address cumulative emissions from the sector and risk substantial job losses.

Policy recommendations

With regard to the main focus of this report, the impact of decarbonising the FIs on employment and skills, our research suggests a number of policy-relevant recommendations:

- Workers do not feel well informed about decarbonisation. Industry specific carbon literacy training should be offered to help workers understand their critical role in the realisation of net zero.
- The decarbonisation of the FIs depends on action taken throughout the FI supply chain. Decarbonisation initiatives and industry specific carbon literacy training is required both upstream and downstream of FI businesses themselves.
- Social dialogue and participation of workers in decarbonising plans is mainly absent from industrial relations processes and needs more attention by businesses and trade unions.
- The FI workforce is generally aging and homogenous. The FIs needs to better understand worker experiences if they are to attract a younger more diverse workforce.
- FI businesses in the UK need to start addressing strategically the skills gap required by a green transition.
- Further research should investigate workers' perspectives on decarbonisation.

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8. Appendix A: Key UK Government Decarbonisation Funding Opportunities for Industrial Sectors

Policy	Funding	Description
Industrial Decarbonisation Challenge (IDC)[41]	£210 million provided by BEIS from the Industrial Strategy Challenge Fund (ISCF) Wave 3 matched by £261 from industry. £171 of this fund was allocated to producing demonstration plans for industrial clusters.	Start to decarbonise industrial clusters. Help to lay foundation for low carbon industrial clusters. Funding available 2019-2024. Partners are Innovate UK and Industrial Decarbonisation Research and Innovation Centre (IDRIC)
Energy Innovation Programme (EIP)[42]	£505 million across 6 themes including £100 million for industrial decarbonisation and CCUS	Accelerate the commercialisation of innovative clean energy technologies and processes into the 2020s and 2030s. Investment available 2015-2021.
Carbon Capture and Storage Infrastructure Fund (CIF)[43]	£1 billion of which £40 million will go to the IDC	Deliver CCUS to at least 2 industrial clusters by the mid-2020s. Most of CIF will be allocated to Track 1 clusters project capture applications so contributing to the capital costs of establishing T&S infrastructure in early CCS projects.
Net Zero Hydrogen Fund (NZHF)[44]	£240 million for CCS enabled 'blue' hydrogen projects	This has 2 strands (both allocated 2022) one will support FEED and post-FEED costs the other will support low carbon hydrogen projects to take Final Investment Decisions for deployment by early 2025.

41 https://www.ukri.org/what-we-offer/browse-our-areas-of-investment-and-support/industrial-decarbonisation/
42 https://www.gov.uk/guidance/energy-innovation
43 https://www.gov.uk/government/publications/design-of-the-carbon-capture-and-storage-ccs-infrastructure-fund/the-carbon-capture-and-storage-infrastructure-fund-an-update-on-its-design-accessible-webpage
44 https://www.gov.uk/government/publications/net-zero-hydrogen-fund-strand-1-and-strand-2

Industrial Energy Transformation Fund (IETF)[45]	£289 million to invest in projects from £30,000 for feasibility studies to £30 million deep decarbonisation deployment projects. Engineering studies and energy efficiency deployment projects also permitted.	This is designed to help businesses with high energy use cut emissions by investing in energy efficiency and low carbon technologies. Funding awarded in 2 phases during 2021 and 2022.
Net Zero Innovation Portfolio (NZIP)[46]	£1 billion on 10 priority areas which include CCUS, hydrogen, industrial fuel switching, bio energy and future offshore wind. Succeeds the EIP	Accelerate the commercialisation of low-carbon technologies, systems and business models in power, buildings and industry
Transforming Foundation Industries Challenge[47]	£66 million in a partnership with UK businesses Including £5 million to be allocated to projects between £50,000 and £500,000. Projects must be collaborative fast start, short duration industrial research and development projects aiming to produce resource and energy efficiency improvements	Aims to develop technologies that can reduce the environmental impact of the FIs. This fund is part of the ISCF. Funding allocated 2020.

[45] https://www.find-government-grants.service.gov.uk/grants/industrial-energy-transformation-fund
[46] https://www.gov.uk/government/collections/net-zero-innovation-portfolio
[47] https://www.ukri.org/what-we-offer/our-main-funds/industrial-strategy-challenge-fund/clean-growth/transforming-foundation-industries-challenge/

9. Appendix B: Alternate figures on Foundation Industry Employment

	2008	2010	2014	2017
Manufacture of industrial gases	6,356	5,082	4,985	1,796
Manufacture of other inorganic basic chemicals	5,019	4,677	4,788	4,157
Manufacture of other organic basic chemicals	11,534	12,648	9,863	7,885
Manufacture of fertilisers and nitrogen compounds	2,412	2,354	2,318	1,857
Manufacture of plastics in primary forms	15,281	12,599	9,342	9,548
Manufacture of other chemical products n.e.c.	18,755	16,193	15,435	14,164
CHEMICAL TOTAL	**59,357**	**53,553**	**46,731**	**39,407**

Figure B1 Source EuroStat – data extracted by authors

	2009	2010	2011	2012	2013	2014	2015	2016	2017
Manufacture of flat glass	1,143	1,169	1,901	1,918	1,089	892	786	476	276
Shaping and processing of flat glass	12,309	9,805	12,803	11,444	10,480	11,137	10,513	10,118	13,622
Manufacture of hollow glass	3,899	4,201	5,005	5,044	4,746	4,829	4,726	4,788	5,208
Manufacture of glass fibres	2,764	2,301	2,570	2,161	2,338	3,076	2,488	2,556	2,987
GLASS TOTAL	**20,115**	**17,476**	**22,279**	**20,567**	**18,653**	**19,934**	**18,513**	**17,938**	**22,093**

Figure B2: Source EuroStat – data extracted by authors

Core Glass Sub-Sector Employment: Great Britain									
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2010-17 (%)**
Shaping and processing of flat glass	9,500	11,500	10,500	9,500	10,500	10,000	9,500	12,000	26.3%
Manufacture of hollow glass	4,500	4,500	4,500	4,250	4,500	4,250	4,500	4,750	5.6%
Manufacture of glass fibres	2,125	2,125	2,125	1,875	3,000	2,375	2,375	3,000	41.2%
Manufacture of other glass, including technical glassware	2,500	3,000	2,750	2,000	2,250	2,250	2,250	2,500	0.0%
Manufacture of flat glass	1,375	2,000	2,125	1,375	950	850	900	950	-30.9%
Total	**20,000**	**23,125**	**22,000**	**19,000**	**21,200**	**19,725**	**19,525**	**23,200**	**16.0%**
*Source: Business Register and Employment Survey (BRES) * BRES does not include Northern Ireland*									

Figure B3: BRES data taken from (Ecosgen, unpublished)

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