UNIVERSITY OF CAMBRIDGE
INSTITUTE FOR
SUSTAINABILITY LEADERSHIP

Technical Report

The role of demand-led innovation in supporting decarbonisation in foundation industries:

Challenges, opportunities and policy implications

ACHIEVING ZERO

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Executive summary

This report presents the results of a collaborative research project involving representatives from energy companies, foundation industries and companies that are major users of foundation industry materials. The key objective of the project was to examine how demand-led innovation could support industrial decarbonisation in the UK by creating market demand for low carbon technologies. The primary focus was on iron and steel, cement and glass.

Foundation industries are vital to the UK economy, supporting local economies and producing materials for essential infrastructure and downstream industries. However, their production processes account for nearly 15 per cent of the UK's annual carbon dioxide (CO_2) emissions (HM Government, 2021a). The decarbonisation of these sectors is essential to avoid carbon leakage and import dependency as the UK economy transforms to achieve its climate neutrality target by 2050 (BEIS, 2019). This is not an easy task because of the presence of high process emissions, the risk profile of experimental technologies and the high capital cost of production assets.

Demand-led innovation is innovation that is incentivised by a gap in the market for a product or a service that consumers or buyers want to have access to and for which they would be willing to pay. Many of the technologies needed to decarbonise foundation industries are not yet available at commercial scale, are in the very early stages of the piloting process or have yet to be invented. Certainty about the demand for low carbon products and materials from downstream companies would reduce the risk of investment in the research and development (R&D) of new products and services, improving the economic feasibility or innovation and commercialisation of new products and production processes.

At present, market demand (or market pull) for low carbon materials and products is not high enough to incentivise substantial investment in new low carbon innovation, or to scale up the demand for existing low carbon technologies. However, as more than 90 per cent of global gross domestic product (GDP) is being covered by net zero targets, the markets for clean technologies and products are expected to grow rapidly in the coming decades, creating new employment opportunities and generating economic growth. In this context, companies' ability to adapt to the new competitive sustainability paradigm will determine their survival and ability to thrive in the global markets. Large economies such as the USA and the EU have acknowledged both the huge economic benefits and the competitive advantage that early investment in low carbon innovation and adoption can deliver, and are investing in supporting the private sector in this transition. These commitments are reflected in the US Inflation Reduction Act (IRA) (EPA, 2023) and the EU's Green Deal Industrial Plan (GDIP) (European Commission, 2023a) and Net-Zero Industry Act (European Commission, 2023b), which seek to support the scaling up of the manufacturing of clean technologies in these jurisdictions. The UK lags behind its major competitors in this regard.

The absence of a clear policy framework for supporting industrial decarbonisation in the UK creates uncertainty over how fast future market demand for low carbon materials and products will grow. This uncertainty increases the risk of investment in innovation, experimental low carbon technologies and new low carbon technologies that are available but require high capital investment or incur higher operating costs. Although the 2021 Net Zero Strategy, the Industrial Decarbonisation Strategy and the so-called 2023 Green Day strategy package set sectoral and economy-wide emissions reduction targets – and indicate which types of technologies could be deployed to achieve them – they fail to address the crucial question of how the process of technology adoption will unfold in practice.

Demand for low carbon materials produced by foundation industries is key to delivering the targets and technology adoption rates assumed in various decarbonisation strategy documents. By responding to demand from consumers and companies further down the value chain (such as automotive manufacturers, property developers and their component suppliers) for materials with low embodied carbon content, foundation industries create the demand for sustainably mined and transported raw materials, clean energy such as green hydrogen and renewable electricity, and technologies such as electric arc furnaces and carbon capture and storage solutions.

Our research identified four key decarbonisation pathways to achieve net zero aligned emissions reductions in the UK foundation industry value chains: (1) electrification, (2) circular economy solutions, (3) novel technologies, and

(4) innovative products, processes and practices. These pathways are not mutually exclusive: considering the urgency with which industrial emissions need to be aligned with the UK's climate targets, all available levers will need to be deployed. In each decarbonisation pathway, there is a need for varying degrees of policy innovation, process innovation, technology innovation, product innovation and business model innovation.

The viability of every decarbonisation pathway depends on sufficient customer demand for low carbon products across the value chains, and contextual conditions that facilitate effective supply-side response to demand signals. There are actions that businesses can take and have taken, independently, in collaboration with value chains and by joining buyers' alliances (such as SteelZero (Climate Group, 2023a) and ConcreteZero (Climate Group, 2023b)) or cross-sectoral collaborative initiatives (such as the Carbon Call (The Carbon Call, 2023)). Progressive business action is illustrated in the case studies included in this report.

The research revealed five key challenges to decarbonisation that cut across all foundation industries and all decarbonisation pathways: (1) a supply–demand catch-22, (2) the high capital cost of production technologies, (3) a lack of standardised data collection and reporting on embodied carbon emissions, (4) exposure to trade, and (5) a lack of familiarity or engagement with new materials and production technologies among downstream users. These challenges reduce companies' ability to make major investments in low carbon technologies, and are thus fundamentally important issues for government policy to address. In the report, these challenges are discussed in relation to the different decarbonisation pathways (Section 4) and policy interventions (Section 6) that could address them. Contextual factors, such as outdated product standards, the limited availability of scrap, and the pricing and availability of electricity and other low carbon alternatives to fossil fuels (such as green hydrogen), also reduce the incentives for companies in foundation industries to invest in low carbon innovation and the scaling up of innovative technologies or approaches.

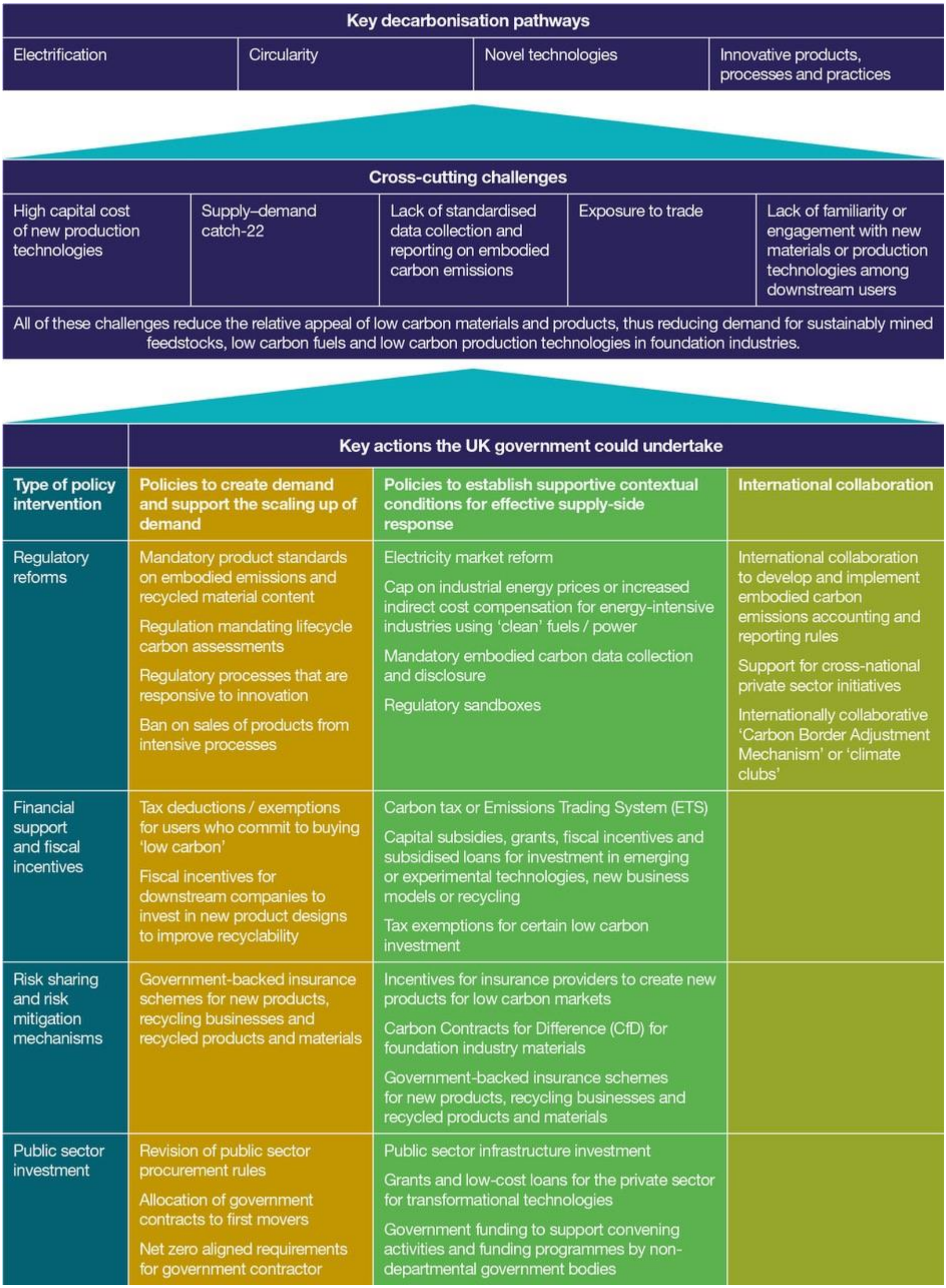
The most complicated of the cross-cutting challenges, the supply–demand catch-22, refers to a situation whereby an upstream company does not have a large enough market demand to upscale the production of low carbon materials or the technologies to produce them, and downstream companies cannot risk investing in alternative technologies before they have a stable supply of upstream low carbon materials or products. The supply–demand catch-22 can emerge between foundation industries and the upstream companies, reducing the pressure to improve the sustainability of mining operations and upscale the production of clean energy. Moreover, uncertainties among foundation industries over the future availability and quality of scrap material can prevent a shift to more circular production models in the glass and steel industries.

Policy intervention and innovation are needed to support the emergence and growth of demand for low carbon technologies, and to establish contextual conditions that encourage an effective supply-side response across value chains, ie innovation and scaling up the production of innovative products, processes, technologies and practices. **Drawing on existing literature and discussions with our industry partners, we identified three urgently needed actions that the UK government could undertake to support demand-led innovation in UK industry in pursuit of the UK's climate targets. These include**:

1) Designing and implementing **policies to create demand for low carbon products and materials.**
2) Designing and implementing **policies that support contextual conditions to encourage innovation or support the scaling up demand for innovative technologies and approaches** by businesses across the foundation industry value chains.
3) Establishing **international collaboration to accelerate demand for low carbon materials and products globally.**

In addition to government action, non-governmental organisations and non-departmental government bodies can play an important role in supporting private sector decarbonisation efforts by bringing companies together, facilitating dialogue and information sharing, and encouraging higher ambition. Moreover, grants and loans to support knowledge generation and collaboration between academic institutions and the private sector to address specific challenges can facilitate the emergence of new insights, best practices and innovative solutions. The key results from the research, discussed in this report, are summarised in Table 1.

Table 1: Summary of the challenges and solutions for foundation industry decarbonisation



Key decarbonisation pathways			
Electrification	Circularity	Novel technologies	Innovative products, processes and practices

Cross-cutting challenges				
High capital cost of new production technologies	Supply–demand catch-22	Lack of standardised data collection and reporting on embodied carbon emissions	Exposure to trade	Lack of familiarity or engagement with new materials or production technologies among downstream users
All of these challenges reduce the relative appeal of low carbon materials and products, thus reducing demand for sustainably mined feedstocks, low carbon fuels and low carbon production technologies in foundation industries.				

	Key actions the UK government could undertake		
Type of policy intervention	**Policies to create demand and support the scaling up of demand**	**Policies to establish supportive contextual conditions for effective supply-side response**	**International collaboration**
Regulatory reforms	Mandatory product standards on embodied emissions and recycled material content Regulation mandating lifecycle carbon assessments Regulatory processes that are responsive to innovation Ban on sales of products from intensive processes	Electricity market reform Cap on industrial energy prices or increased indirect cost compensation for energy-intensive industries using 'clean' fuels / power Mandatory embodied carbon data collection and disclosure Regulatory sandboxes	International collaboration to develop and implement embodied carbon emissions accounting and reporting rules Support for cross-national private sector initiatives Internationally collaborative 'Carbon Border Adjustment Mechanism' or 'climate clubs'
Financial support and fiscal incentives	Tax deductions / exemptions for users who commit to buying 'low carbon' Fiscal incentives for downstream companies to invest in new product designs to improve recyclability	Carbon tax or Emissions Trading System (ETS) Capital subsidies, grants, fiscal incentives and subsidised loans for investment in emerging or experimental technologies, new business models or recycling Tax exemptions for certain low carbon investment	
Risk sharing and risk mitigation mechanisms	Government-backed insurance schemes for new products, recycling businesses and recycled products and materials	Incentives for insurance providers to create new products for low carbon markets Carbon Contracts for Difference (CfD) for foundation industry materials Government-backed insurance schemes for new products, recycling businesses and recycled products and materials	
Public sector investment	Revision of public sector procurement rules Allocation of government contracts to first movers Net zero aligned requirements for government contractor	Public sector infrastructure investment Grants and low-cost loans for the private sector for transformational technologies Government funding to support convening activities and funding programmes by non-departmental government bodies	

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Abbreviations and glossary

AI	Artificial intelligence
BBP	Better Buildings Partnership
BEIS	Department for Business, Energy & Industrial Strategy (UK government)
BF-BOF	Blast furnace-basic oxygen furnace (used in iron and steelmaking)
BRE	Building Research Establishment
CAPEX	Capital expenditure
Carbon leakage	An increase in emissions in a jurisdiction with less-stringent climate policies because of industrial relocation incentivised by climate policies, such as carbon tax
CBAM	Carbon border adjustment mechanism
CCC	UK Climate Change Committee
CCUS	Carbon capture, utilisation and storage
CfD	Contracts for Difference
CO_2	Carbon dioxide
DESNZ	Department for Energy Security and Net Zero (UK government)
DPP	Digital product passport
DRI	Direct reduced iron
E3ME	Macroeconomic model designed to assess global policy challenges, owned and maintained by Cambridge Econometrics
EAF	Electric arc furnace
ETS	Emissions Trading Scheme
Foundation industries	Energy-intensive industries that produce basic materials, such as cement, ceramics, paper, steel, bulk chemicals and glass
GDIP	EU's Green Deal Industrial Plan
GDP	Gross domestic product
GHG	Greenhouse gas
Green hydrogen	Hydrogen produced by splitting water into hydrogen and oxygen using renewable electricity
Green industries	Industries that use near-zero emission technologies
GVA	Gross value added
IDDI	Industrial Deep Decarbonisation Initiative; a collaboration of national governments co-led by the UK and India, working to stimulate demand for low carbon industrial materials by standardising carbon accounting methods
IEA	International Energy Agency
Industrial Decarbonisation Strategy	UK strategy on how industry can decarbonise in line with net zero targets
IO	Input–output (an approach used in modelling)
IRA	US Inflation Reduction Act
LCA	Life-cycle assessment (of all emissions associated with the material content, manufacturing and use of products)
$MtCO_2e$	Million tonnes of carbon dioxide equivalent
Net zero	Atmospheric state where total emissions of greenhouse gases are offset by the removal of greenhouse gases, resulting in a net zero increase in these gases
Net Zero Strategy	UK Strategy that sets out policies and proposals for decarbonising all sectors of the UK economy to meet the economy-wide net zero target by 2050
NMMP	Non-metallic mineral products (including cement, glass and ceramics)
ONS	UK Office for National Statistics

OPEX	Operating expenses
PPA	Power purchase agreement
PV	Photovoltaics (used to describe a type of solar panel)
R&D	Research and development
REE	Rare-earth elements (used for example in batteries)
SBTi	Science Based Targets initiative
SCM	Supplementary cementitious material
SMART group	Sustainable Markets Advisory Roundtable; the advisory group for this project, consisting of representatives from energy industries, foundation industries and material user industries, as well as business groups and advocacy groups
TRL	Technology readiness level
UKGBC	UK Green Building Council
UKRI	UK Research and Innovation

1. Introduction

As many governments and businesses accelerate climate action worldwide, global and national economies are transitioning from a fossil-fuel-based economy to a low carbon one to ensure that they meet the nationally determined contribution and align with the targets set in the Paris Agreement. A key policy priority of this paradigm shift is that decarbonisation does not compromise growth and industrial competitiveness. In that regard, foundation industries[1] (Innovate UK KTN, 2023) present a particular policy conundrum because of the multiple challenges associated with cutting emissions from them.

Decarbonisation of the foundation industries is crucial to facilitate the economy-wide transition to climate neutrality. Currently, the process and energy emissions from these industries account for approximately a sixth of the UK's total greenhouse gas (GHG) emissions of 405.5 million tonnes carbon dioxide equivalent ($MtCO_2e$) (BEIS, 2022b), ie ~67.5 $MtCO_2e$ annually. Most of these emissions, ~50 Mt (Innovate UK KTN, 2023), are CO_2, with the rest coming from other GHGs. In 2021, foundation industries were responsible for nearly 15 per cent of the UK's annual CO_2 emissions of 341.5 Mt (BEIS, 2022a).

However, products manufactured by foundation industries can enable the reduction of operational and embodied emissions in other sectors (European Commission, 2023c) of the economy, including transport, construction and power generation. By decarbonising their operations, UK-based foundation industries could supply low carbon materials such as steel, cement and glass that would reduce the carbon footprint of a wide range of products, from wine bottles and jam jars to washing machines, cars, trains and buildings. Ensuring that the emissions reductions from UK industry result from more efficient UK production, rather than 'offshoring' production to other countries (ie 'carbon leakage') (CCC, 2021), is crucial. Without domestic foundation industries, the UK will depend on imports and industrial decarbonisation in other jurisdictions to access low carbon basic materials in the future. It will also miss out on the economic benefits (BEIS et al., 2023a) that are likely to accrue to the technological first movers – ie companies that gain a competitive advantage by being the first to introduce a new product, service or technology. Therefore, it remains in the economic interest of businesses and policymakers to work collaboratively to facilitate this transition and ensure that they harness all of the potential benefits that will accrue from it. This report discusses how demand-side policies can be a potent policy tool in that regard and aid decarbonisation and related innovation.

Decarbonisation of foundation industries is challenging because the production assets are capital-intensive, the technologies to fully decarbonise production processes do not yet exist (or are commercially available), adoption of experimental technologies is risky, and exposure to international trade means that industries need to remain globally competitive. It is crucial for policy to create enabling contextual conditions that make decarbonisation financially viable for foundation industries (Innovate UK KTN, 2023). Demand-led innovation can play a pivotal role in facilitating this process. The concept of demand-led innovation refers to innovation that is incentivised by a gap in the market for a product or a service that consumers or buyers want to have access to and for which they would be willing to pay. The demand-side signal from consumers needs to be strong enough to provide assurance to manufacturers that they can generate financial returns by designing a new product or a service, and for bringing it to the market. Demand for low carbon materials and products from downstream value chain companies reduces the risk of investment in the research and development (R&D) of these products and services, bringing down the cost of capital and making the investment in innovation easier to justify to shareholders. In other words, it improves the economic viability or innovation and commercialisation of new products and production processes.

The UK's 2021 Industrial Decarbonisation Strategy (HM Government, 2021b) sets an ambitious target for the foundation industries to reduce their emissions by at least two-thirds by 2035 and by at least 90 per cent by 2050. To meet these targets, the foundation industries need to replace their most commonly used processes, material inputs and technologies with new approaches. However, beyond expected emissions mitigation through certain

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[1] Foundation industries include basic materials manufacturing such as iron and steel, cement and non-metallic mineral products (including glass and ceramics, such as brick making), basic chemicals, aluminium, and pulp and paper

technologies (such as green hydrogen and carbon capture, utilisation and storage, or CCUS), the current strategy does not explain how the government intends to support private sector companies to adopt and scale up the use of these technologies, or the deployment of other solutions such as more circular business models or electrification. Although the Industrial Decarbonisation Strategy acknowledges the need for policies to create demand for low carbon materials to incentivise investment in structural changes that enable deep emission abatement, the government has not yet taken significant steps to provide the private sector with the appropriate incentives.

There is a pressing need for the UK policymakers to implement measures that drive the technological and business model development required to put industry on a path towards rapid decarbonisation. The two main policy priorities are:

1) to support the market creation and scaling up for low carbon materials and products
2) to establish enabling contextual conditions for progressive companies across the foundation industry value chains to make substantial investments in decarbonising their operations, including their scope 3 emissions.

To date, the cornerstone of the industrial decarbonisation policy in the UK has been the EU's Emissions Trading System (ETS), which was replaced by the UK's own ETS after Brexit. Since the ETS's implementation in 2005, GHG emissions from power generation and energy-intensive industries across the EU declined by almost 43 per cent (Hockenos, 2020), and further reductions are expected after the revisions proposed by the European Commission in July 2021 take effect. However, most of these emissions cuts were derived from the power sector (Hockenos 2020), driven primarily by the reduction in coal use and increased deployment of renewables (which was also supported and incentivised by other policy instruments, such as the Renewables Directive and Energy Efficiency Directive). Due to contextual conditions and the design of the ETS, the system discouraged companies that rely on capital-intensive production methods, such as the foundation industries, from drafting long-term decarbonisation plans and making the big and risky structural investments that are needed for deep decarbonisation (Sato et al., 2022; EEA, 2022).

Although the detailed design of the UK's post-Brexit ETS remains unclear (BEIS & DESNZ, 2022), the phasing out of free allowances seems necessary for the UK to achieve its 2035 and 2050 climate targets. With 2050 being only one investment cycle away, setting out a clear direction of travel and communicating it to UK companies in the foundation industries and related value chains is becoming urgent. A strong set of policies is needed to help progressive businesses to overcome the barriers that currently prevent industry from securing investment to decarbonise, and to support proactive industry efforts to facilitate decarbonisation (such as the formation of cross-sectoral, low carbon material buyers' clubs). A comprehensive policy framework to create and scale demand for low carbon materials and to enable a swift supply-side response would send a signal to UK-based companies and others, ie that the UK government is committed to supporting the decarbonisation efforts of energy-intensive industries and their value chain companies.

This report focuses on how policymakers can harness demand-side measures to support innovation for decarbonisation in these foundation industries, particularly focusing on learnings from cement, steel and glass. The publication was produced in close collaboration with industry representatives from energy companies, foundation industries and companies that use large amounts of foundation industry materials.

The report is divided into seven sections. Section 1 introduces the topic, the research and the current policy context. Section 2 discusses the theoretical underpinnings of the analysis. This includes a discussion of key concepts such as innovation, technology learning, how industrial competitiveness and net zero goals are aligned as well as making a compelling argument for how the government can facilitate this. Section 3 provides an overview of the key considerations for decarbonisation in foundation industries. This section introduces the end-to-end value chain approach (which was designed during the research project to illustrate why the entire value chain needs to be targeted for effective decarbonisation), the challenges that necessitate this approach, and where and why demand creation can help mitigate the key challenges to industrial decarbonisation.

Section 4 identifies four key decarbonisation pathways to achieve net zero aligned emissions reductions: (1) electrification, (2) circular economy solutions, (3) novel technologies, and (4) innovative products, processes and practices. These pathways are not mutually exclusive: considering the urgency with which industrial GHG emissions need to be aligned with the UK's climate targets, all available levers will need to be deployed. In each decarbonisation pathway, there is a need for varying degrees of policy innovation, process innovation, technology innovation, product innovation and business model innovation. Section 5 provides examples of how demand can drive low carbon innovation in the cement, glass and steel sectors, with illustrative examples of sector-specific challenges. This section draws heavily on the Sectoral deep dives that were carried out as part of the research project, and which cover sector-specific decarbonisation pathways, challenges and policy interventions in detail. These deep dives are available online from the project publication page.

Although a robust long-term business case for clean production investments depends on market-based demand for products made from the efficient use of climate neutral materials (CISL & Agora Energiewende, 2021), a certain degree of government intervention is needed to enable, support and facilitate business engagement in foundation industry decarbonisation. Section 6 outlines how regulatory reforms, financial and fiscal incentives, risk mitigation mechanisms and public sector investment could help to:

1) create demand for low carbon products and materials
2) establish supportive contextual conditions to encourage innovation or support the scaling up of demand for innovative technologies and approaches by businesses across the foundation industry value chains
3) foster international collaboration to accelerate demand for low carbon materials and products globally.

Finally, Section 7 supplements the entire discussion by providing econometric evidence to support the findings of the report. We use the multisectoral E3ME model to illustrate the macroeconomic benefits that early investment in low carbon foundation industry technologies can have. Focusing on non-metallic minerals (ie cement, glass and ceramics), this modelling shows that economies can obtain substantial employment and competitiveness gains, as well as achieve emissions reductions, by investing in policies that incentivise industrial decarbonisation by creating, and guaranteeing, a demand for materials and products with a lower embodied carbon content. Section 8 outlines the key findings and presents some concluding remarks.

Throughout the report, we use business case studies, which were drafted together with members of our project advisory group (Sustainable Markets Advisory Roundtable, or the SMART group), to illustrate the actions that businesses can take and, in some cases, have taken. Some of these case studies also highlight specific challenges and areas where considerable policy intervention or innovation is needed. As the discussion and findings of this report demonstrate, climate neutrality and industrial competitiveness are not mutually exclusive. Businesses and policymakers can take actions in tandem to effectively support this transition.

2. Background

2.1 Industrial competitiveness and net zero

As more than 90 per cent of global GDP is covered by net zero target (Mace, 2022), the markets for clean technologies and products are expected to grow rapidly. According to one study, the value of green industries is expected to exceed US$10 trillion by 2050 (Portala, 2023). In this context, industrial companies' ability to adapt to the new competitive sustainability paradigm will determine their survival and ability to thrive in changing global markets (CISL, 2020; CISL, 2022). Companies that are among the first to develop cost-effective ways to produce materials and products with a lower embodied carbon content will benefit by avoiding the cost of a rapidly increasing carbon price, as well as from gaining a larger market share and from selling their intellectual property to others.

However, what we have at the moment is an *expectation* of growing demand in the future (Portala, 2023), as countries will need to align their consumption and production patterns with the net zero targets, rather than a large-scale market pull. Yet, because of long investment cycles (IEA, 2022), the investment in innovation and scaling up of new technologies and production processes in foundation industries must take place now to ensure that low carbon materials will be available in sufficient quantities when the production using the incumbent technologies becomes increasingly unsustainable.

Private sector companies cannot deliver this transition alone – government policy to ensure that decarbonisation presents an economically viable pathway for them is key to protecting economies against carbon leakage and industrial decline. Policy measures will need to create markets for low carbon materials and products and to establish enabling conditions to encourage and incentivise progressive businesses to take action. Incentivising, supporting and enabling innovation in this field, including innovative business action, will be essential to prevent carbon leakage.

Increasingly, countries are beginning to recognise the huge economic benefits and competitive advantage that early investment in low carbon innovation and adoption can deliver. As acknowledged in the UK's Net Zero Strategy (HM Government, 2021a), and Chris Skidmore's independent review of it (BEIS et al., 2023a), the development of the necessary technologies to decarbonise the basic materials production presents an enormous, but currently largely untapped, opportunity for UK industry. A similar understanding in the USA has informed the design of the recent Inflation Reduction Act (IRA), provoking the EU to announce plans (Stolton, 2023) to offer tax breaks and simplify permitting processes for new clean technology production sites, and eventually culminating in the publication of its Green Deal Industrial Plan (GDIP) (European Commission, 2023a) and the Net-Zero Industry Act (European Commission, 2023b) to scale up the manufacturing of clean technologies in the EU. Some EU member states, such as France, have also called for the state aid subsidy rules for business within the block to be relaxed (Politico, 2023) and for more state aid to be directed to support EU industry's competitiveness in the light of the IRA focusing specifically on low carbon technologies. These benefits, and how they emerge, are illustrated in reference to the cement, glass and ceramics industries in the modelling exercise in Section 7 of this report.

The relaxation of the EU state aid rules would enable the UK government to also offer more direct support to businesses.[2] However, the UK's 2021 Net Zero Strategy (BEIS & DESNZ, 2021), the 2021 Industrial Decarbonisation Strategy (HM Government, 2021b) and the 2023 'green day' announcements (Holder & Stone, 2023) have been widely criticised for failing to map out a credible pathway to net zero (LSE & Grantham Institute, 2023) and neglecting an opportunity (Monbiot, 2023) to urgently accelerate decarbonisation and the transition to a more sustainable economy in the UK (Carbon Brief, 2023; Reuters, 2023; CLG UK, 2023). Most notably, these strategies

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[2] The EU–UK Trade Agreement obliges the UK to follow the EU rules for state aid (subsidies for business) and competition if it wishes to enjoy tariff-free access to the European markets following Brexit

and plans do not provide comparable incentives or certainty over the future direction of travel for companies' UK operations, compared with those included in the US IRA and the EU's GDIP and Net-Zero Industry Act, raising concerns that UK companies will not be able "compete on a level playing field" (BBC, 2023a).

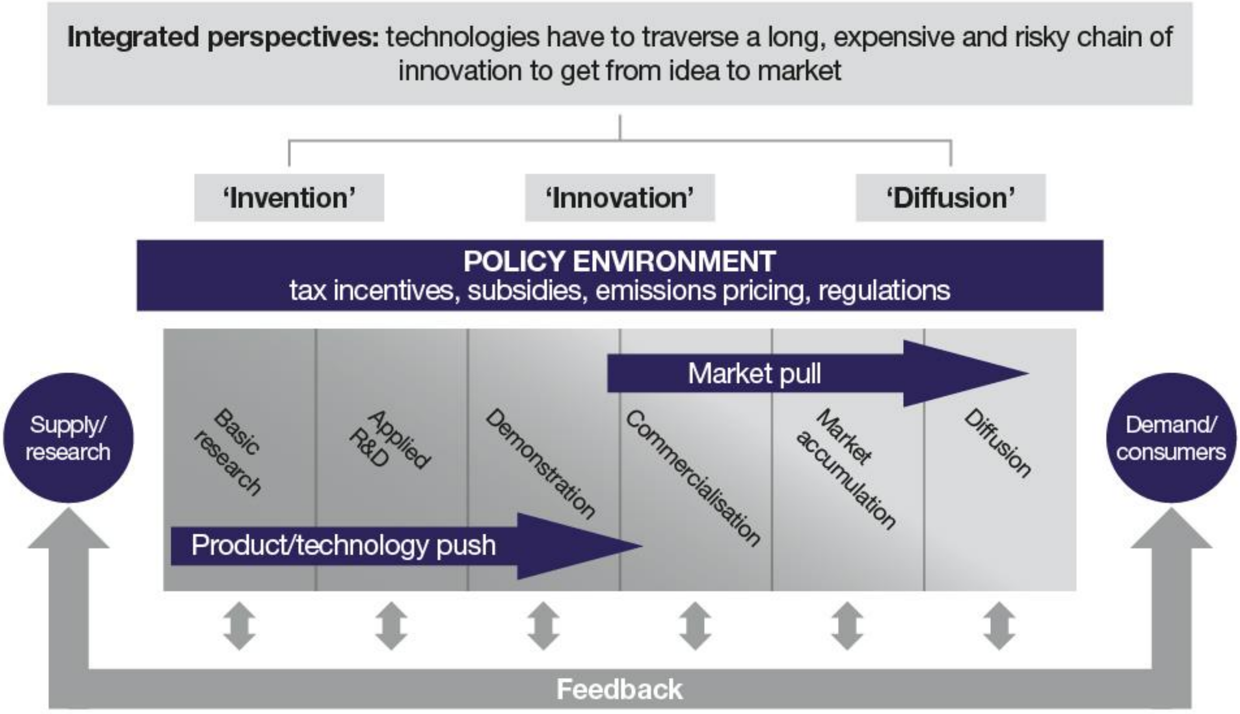
2.2 The innovation process

The Merriam-Webster dictionary (2023) defines innovation as a new idea, method, or device, or the introduction of something new, such as "a device, contrivance, or process originated after study and experiment." In other words, innovation is the process of developing the application and the necessary technology to derive tangible benefits from an invention. As Michael Grubb et al. (2014, p. 316) put it "Invention takes brains and imagination. Innovation takes time and money." Diffusion – the process of the innovation spreading through the market(s) – requires (more of) both.

In relation to business operations and business models, the term 'innovation' is generally used to refer to new processes, ideas, services, products, workflows or methodologies. Innovation can also involve applying existing technology in a way that it has not been used before. Innovation is demand-led when a new approach, technology or operating model is designed in response to an identified need.

Innovation involves a complex (non-linear) chain of phases, with each phase involving a different set of actors, barriers and policy influences. This process is illustrated in a simplified format in Figure 1. Having a good concept and proving that it *could* work in practice is only the start of a long journey. Even if a new concept or technology is successfully demonstrated to have potential, this does not necessarily lead to successful commercialisation of the product. The transition from the early 'technology push' phase of the process (basic research, applied R&D and demonstration – ie the first five technology readiness levels, often referred to as TRL, 1–5) to the 'market pull' phase (commercialisation and beyond) is a notoriously difficult gap to bridge (TWI Global, 2023).

Figure 1: The innovation process



Source: Adjusted from Grubb et al. (2014, p. 325)

Commercialisation is the phase of the innovation process during which policies that drive demand for the innovation become increasingly important, especially if the new product does not have superior performance qualities or a lower cost. Many technologies fail to make this transition, while technologies that do succeed often take decades to make it to the mass market. It is only through a successful commercialisation process that a new innovation may eventually lead to market accumulation and diffusion of the technology on a large scale. Historical examples of innovative technologies that revolutionised the market include the printing press, the motor car and the light bulb, while more recent examples include mobile phones and online streaming services. For each of these innovations to become 'the new normal', certain enabling conditions needed to emerge, such as access to petrol, electricity and the internet.

In foundation industry value chains, the commercialisation and market diffusion of low carbon innovation depend on downstream companies' willingness to purchase these materials. Without such demand, the case for investing in the innovation and demonstration of new deep decarbonisation production technologies is not economically viable for most foundation industries. However, incremental emissions reductions across the value chains through investment in innovative processes and practices might still prove to be economically viable, especially if they also reduce operating costs.

2.3 Technology learning

Reinforcing feedback loops through demand growth and technology learning is key to accelerating the innovation and adoption of low carbon production technologies and approaches in foundation industry.

At the moment, incumbent (carbon-intensive) production technologies are more readily available and cheaper to purchase (and, in some instances, to operate). As a result, lower carbon products and materials incur a so-called market premium (ie a higher sale price than more carbon-intensive equivalents), which companies further down the value chain must be willing to pay to enable producers further up the value chain to make a viable business case for investing in low carbon production processes and material inputs. Unless downstream companies are both willing and able to do this at scale, additional support is needed to address specific challenges and opportunities in the development of low carbon supply chains that companies may struggle to address or consider too risky to tackle (Bataille, 2019).

However, higher adoption rates of new technologies would reduce their per-unit production costs over time, leading to cost parity with incumbent technologies, or even a lower cost altogether (Grubb et al., 2014; see also the modelling study in Section 7 of this report). This so-called technology learning process, whereby the cost of per-unit production declines as production volumes grow, leads into a virtuous cycle whereby the lower production costs are reflected in lower sale prices, thus accelerating the quality and adoption rate of a new technology.[3] In other words, the price decline both causes, and is caused by, the increasing number of installations, while increased demand facilitates more investment that enables further quality improvements.

The technology learning process is particularly well illustrated by the solar photovoltaics (PV) industry during the past 10–15 years. As globally installed capacity has grown, the levelized cost of solar PV technology has substantially decreased. This is shown in Figure 2 below, where the left panel shows levelized cost changes between 2010 and 2021, and the right panel the capacity additions between 2011 and 2021.

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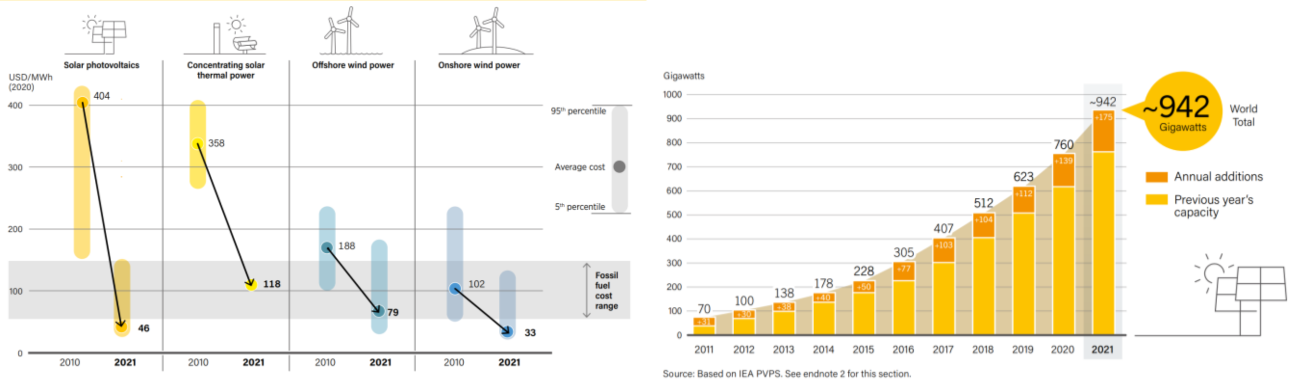
[3] Mercure, J.-F., 2012. FTT:Power: A global model of the power sector with induced technological change and natural resource depletion. Energy Policy, Special Section: Frontiers of Sustainability 48, 799–811. https://doi.org/10.1016/j.enpol.2012.06.025

Figure 2: Technology learning process illustrated



Source: Renewables 2022 Global Status Report; left – p. 154, right – p. 126 (Ren21, 2019)

A similar process of technology learning could accelerate both the demand and supply of low carbon steel, cement and glass (as well as other foundation industry materials), enabling new low carbon solutions to capture a growing share of the market and economies of scale to develop. As shown in Figure 2, the advances in solar PV technology increased confidence in renewable electricity technologies, increasing demand also for onshore and offshore wind power and bringing down the per-unit costs of these technologies. A similar process in the foundation industries could see technological advances in one sector increasing consumer confidence and acceptability of low carbon materials more broadly. Over time, this could translate into a growing demand for different types of low carbon materials, eventually pushing down the cost of low carbon production technologies, material inputs and production technologies across the value chains, from mining to product disassembly, material decontamination and adoption of more circular solutions. Section 7 of this report illustrates how faster adoption of low carbon production technologies in the cement, glass and ceramics industries in the UK could generate various macroeconomic benefits.

3. Decarbonisation pathways: where and why demand is needed

3.1 Emission scopes

A crucial aspect of decarbonising whole value chains is a focus on scope 3 emissions, ie emissions that are generated within the upstream value chain (such as the production of materials and components going into the manufactured products) or through the downstream activities (such as the usage of products). For many companies, scope 3 emissions are much larger than the scope 1 emissions (direct emissions from their own operations) and scope 2 emissions (indirect emissions from the generation of purchased energy). However, scope 3 emissions are generally much more difficult to mitigate because they are determined by other companies upstream and downstream the value chain.

For example, a car manufacturer can electrify its operations and purchase renewable electricity, reducing its scope 1 and 2 emissions. However, its scope 3 emissions come from the embedded CO_2 in the material inputs (such as steel, cement, plastic, aluminium and batteries – and components made of these materials) that go into each car. To mitigate these, the car manufacturer would need producers up the value chain to produce components and materials that have low embodied CO_2 emissions.

Downstream scope 3 emissions can also be difficult to control. Although a car manufacturer can reduce the operational emissions from its products by making cars energy efficient and operatable with low carbon energy, the manufacturer cannot ensure that the energy that consumers use to operate its vehicles comes from renewable or low carbon sources. Even an electric vehicle can have reasonably high scope 3 emissions if the electricity used to charge it is generated from coal.

Scope 1 and 2 emissions from each company in the value chain contribute to the upstream scope 3 emissions of the downstream companies (ie companies that use the materials or products). What this means in practice is that each company must address its scope 1 and 2 emissions to enable the downstream companies to estimate their upstream scope 3 emissions and take steps (through selective procurement) to reduce them. At the same time, the downstream scope 3 emissions of each company are affected by the operators further down the value chain: a low carbon basic material such as low carbon steel could be used to manufacture highly polluting technologies, such as coal power plants. The actions that businesses can take to address their scope 1, 2 and 3 emissions – and the challenges they often face in this process – are illustrated in Case study 1: Rolls-Royce – The decarbonisation journey of Rolls-Royce facilities and supply chain (below).

Controlling scope 1 and 2 emissions is difficult for many foundation industries, as well as the upstream companies that operate in mining and energy and fuel production. In the foundation industries this is because the prevalent production methods rely heavily on fossil fuels to achieve extremely high temperatures and, in some instances (especially in cement production), unavoidable process emissions arise from the use of carbon-intensive feedstocks. Although some technologies exist to reduce scope 1 and 2 emissions from certain energy-intensive production processes, these often require very high levels of capital investment, new types of feedstocks (such as recycled material inputs) and clean energy in quantities that can be difficult or cost-prohibitive to access. New and experimental technologies may also be risky investments, unavailable at market scale or difficult to insure – all of which are factors that increase the cost of capital that companies need to purchase them.

Case study 1: Rolls-Royce – The decarbonisation journey of Rolls-Royce facilities and supply chain

As a member of the UN Race to Zero coalition, Rolls-Royce is committed to ensuring that its products will be compatible with net zero operation by 2050.

So far, Rolls-Royce has made substantial progress in relation to scope 1 and 2 emissions targets through investment in onsite renewable energy installations, procurement of renewable energy, and investment in energy efficiency improvements. These actions are illustrated by the extensive sustainability improvements to the company's Bristol site, which include (but are not limited to):

- Building management system improvements, optimisation of the energy efficiency of the buildings and operations, lighting upgrades (T8 / metal halide to LED) and electronically commutating (EC) fan upgrades to air-cooled chillers.
- Installation of renewable / low carbon energy (solar, microgrid, combined heat and power) technologies. Energy from photovoltaics (PV) generates 10 per cent of the site's energy demand (excluding furnaces).
- Procurement of alternative renewable fuels for furnaces / electrification of furnaces and procurement of zero carbon electricity and carbon credits (100 per cent renewable energy on this site).

As a result of these upgrades, energy use at the Rolls-Royce Bristol site has declined by ~50 per cent since 2016. Direct emissions (scope 1 and 2) were cut by 90 per cent. Rolls-Royce is also exploring pathways to address its scope 3 emissions by decarbonising its supply chain through procurement practices, pioneering new breakthrough technologies and ensuring that Rolls-Royce products can be used in a way that is compatible with net zero by 2050.

One key action to reduce scope 3 emissions is a move towards circular economy by recycling and remelting metal from the machining swarf (pieces of metal that are the debris or waste resulting from machining), offcuts and used components of engines to make 'new' material. Already, over 30 per cent of the titanium and nickel and over 50 per cent of the rhenium that the company buys is made of recycled material. By 2027, suppliers representing 50 per cent of the company's GHG emissions will need to have science-based targets.

Rolls-Royce is also advocating for the necessary enabling environment to facilitate global decarbonisation of energy-intensive materials and products and engaging with its supply chain partners to drive progress and share best practice. This includes a sustainability working group of key material and component suppliers.

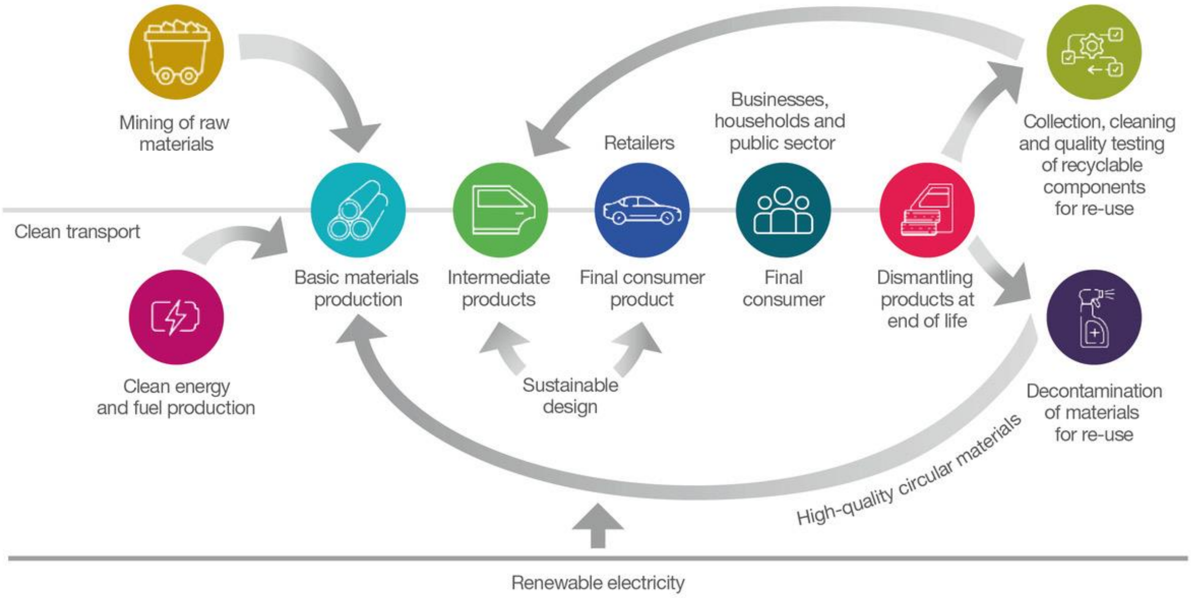
However, decarbonising the complex and critical systems within which Rolls-Royce operates is not without its challenges. The cost of decarbonising operations in the company's own sites is substantial: retrofitting the Bristol site alone to net zero required investment in excess of £10 million, and the company operates dozens of sites in 50 countries. Cost considerations present a substantial challenge also to the decarbonisation of supply chains, as materials such as low carbon steel remain considerably more expensive than carbon-intensive alternatives.

There are also uncertainties around the availability and suitability of net zero alternatives to natural gas in manufacturing processes (furnaces, ovens, etc). The extent to which Rolls-Royce's manufacturing processes can be electrified is currently unclear, and the company has concerns about the availability and affordability of alternative fuels, such as green hydrogen (H_2), by 2030. Moreover, electrification and the use of alternative fuels may also affect product quality for material and products suppliers. For example, low carbon alternatives are currently not available for all steel grades that meet the aerospace application standards. Transparency in the supply chain and the availability of supplier data on embodied emissions present a further challenge. Regulatory frameworks and standardised methodologies for emissions accounting and reporting would need to be used by all suppliers to enable a company such as Rolls-Royce, which uses large quantities of various energy-intensive materials, to make informed choices over how best to reduce their scope 3 emissions.

3.2 The end-to-end value chain approach

In this report, we use a so-called end-to-end value chain approach to identify how demand plays a role in driving decarbonisation across value chains, focusing specifically on the value chains for iron and steel, cement and glass. This approach is illustrated in Figure 3. As this figure shows, a transition to a value chain that enables materials and products to be kept in use for longer and reused at the end of product lifespan does not require a fundamental rethink of the value chain itself, but instead a set of actions that make products and their components more recyclable. However, for the necessary operations and business models to emerge in the waste management and recycling industry, there must be demand for recycled materials and products from the users (ie foundation industries), which are located further up the value chain.

Figure 3: End-to-end value chain for low carbon foundation industry



In this whole value chain approach, each company along the value chain has two functions: it is a consumer of upstream products and materials, and a producer for downstream operations. To create a more circular economy, this applies also to individuals, households or public sector agencies that are typically referred to as 'end users'. In a more circular model, these so-called end users are proactive agents that provide scrap for circular primary production and recyclable components for manufacturing, thus playing an important role in enabling decarbonisation through greater circularity. Foundation industries also become users of scrap material, creating demand for recycling, product disassembly and material decontamination services. This demand will then enable profitable business models to emerge in the recycling industry.

The end user is a critical component in the operation of the value chain. Their needs, values and opinions significantly influence the decisions made by suppliers, and it is essential for suppliers to take these into account to remain competitive in the market. Ultimately, understanding and meeting the demands of the end user is crucial for success. How these processes work for the three basic materials covered in this report – glass, steel and cement – is discussed in more detail later on in this section of the report, and also in the Sectoral deep dives that are available from the report landing page.

3.3 The role of demand

The whole value chain approach depicted in Figure 3 illustrates the crucial role that demand plays in enabling material producers and manufacturers to accrue economic benefits from switching to low carbon production. Because the companies along the value chain are all connected to the upstream and downstream companies, actions are needed along the entire value chain to generate enough demand for a widespread transition to the decarbonisation of industry, value chains and business models (CISL & Agora Energiewende, 2021). What this means in practice is that each company across the value chain needs to implement selective procurement practices to support decarbonisation further up the value chain and to enable decarbonisation further down the value chain. The decarbonisation efforts of a single company or operator are generally insufficient to drive large-scale change unless it holds a very large market share across multiple industry value chains.

Demand signals need to flow upstream, from the final consumer product, through the intermediate product producers, all the way up to the basic materials producers, mining of raw materials, and clean energy and fuel production (as illustrated by the end-to-end value chain in Figure 3) (CISL & Agora Energiewende, 2021). At the moment, the challenge to foundation industry decarbonisation is that, in current markets, the demand for low carbon materials and products with a low embodied carbon content is undeveloped and, in some cases, absent entirely. In this context, if enabling conditions prevail, businesses can take action themselves, for example by setting up cross-sectoral low carbon buyers' coalitions.

The idea of low carbon buyers' coalitions is endorsed in the UK's 2021 Industrial Decarbonisation Strategy, which states that "We [the government] want to help private companies combine their purchasing power by facilitating the formation of voluntary buyers' alliances" (HM Government, 2021b, p. 44). These coalitions can have an even greater impact at an international scale, if material consumers from several different countries join in. Such large cross-national efforts to consolidate demand could radically change the investment landscape for low carbon material producers, improving investors' confidence in decarbonisation, thus easing access to low-cost finance for foundation industries to invest in low-cost production and its upscaling.

By joining forces, companies can leverage their joint buying power to develop sufficient demand for a certain material or product to enable the manufacturer to make the business case for investment, and to benefit from economies of scale, which will bring down the per-unit production costs. Examples of demand-side business initiatives are illustrated in Case study 9: SteelZero – A demand-side business initiative and Case study 10: ConcreteZero – A demand-side business initiative in Section 5 of this report. These types of demand-side initiatives can play a crucial role in enabling upstream companies to decarbonise by reducing the risk associated with the major investments they need to make. For example, a steel producer would need to incur substantial capital costs to switch to electrified production processes to produce low carbon steel. In the current UK energy market conditions, it would also face higher operating costs due to high electricity prices. However, certainty about the scale of demand from various customers, who have also committed to growing this demand over time, could enable the producer to make the business case and start decarbonising its production assets in stages, one furnace at a time. At the same time, because the cost of material inputs comprises only a small proportion of the price of many consumer products, switching to low carbon steel would increase the cost of these products by only ~2 per cent in the medium term (World Economic Forum, 2021).

3.4 Challenges to low carbon innovation and upscaling

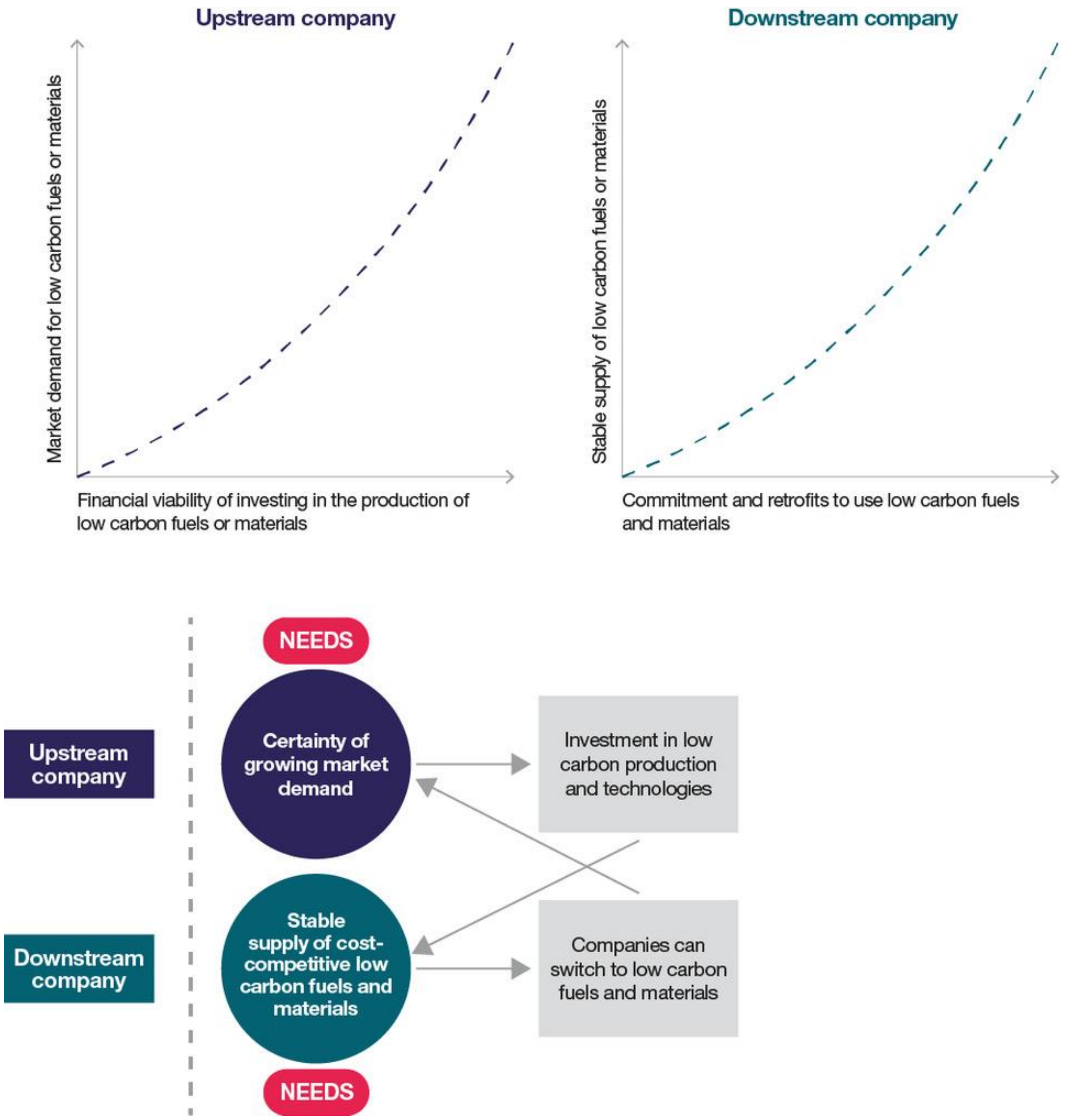
As mentioned in the introduction, there are five cross-cutting challenges to the upscaling of low carbon innovation in the foundation industries. These include:

1. **High capital cost of production technologies.** Long product lifespans mean that decisions about modifications, retrofits or an entirely different type of technology to facilitate fuel switching to green hydrogen, electrification or CCUS will need to be made when existing assets reach the end of their lifespan and need either extensive maintenance or replacing. Once a production asset has been installed, replacing it before such time could be prohibitively expensive unless the operating costs of new technologies decline

substantially below the operating costs of the installed technologies. This means that companies will need to decide to make their assets compatible with decarbonisation pathways before some of the new technologies, such as green hydrogen or CCUS, are available at commercial scale and before the critical mass of the market is willing to pay a premium for materials with a lower embodied carbon content.

2. **Supply–demand catch-22.** This refers to a situation whereby an upstream company does not have a large enough market demand to upscale the production of low carbon materials or the technologies to produce them, and downstream companies cannot risk investing in alternative technologies before they have a stable supply of upstream products. The supply–demand catch-22 can emerge between foundation industries and the upstream companies, reducing the pressure to improve the sustainability of mining operations and upscale the production of clean energy. Moreover, uncertainties among foundation industries over the future availability and quality of scrap material can prevent a shift to more circular production models in the glass and steel industries. The supply–demand catch-22 is illustrated in Figure 4 (below).

Figure 4: A graphical illustration of the supply–demand catch-22



3. **Lack of standardised data collection and reporting on embodied carbon emissions.** Lack of transparency and clear benchmarks, including the absence of shared embodied carbon accounting and reporting standards, can make it difficult (or even impossible) for potential low carbon material purchasers to compare different 'low carbon' alternatives and compromises their ability to market their own products as 'demonstrably' low carbon. This causes severe challenges for companies that are serious about decarbonising their operations and have signed up to the Science Based Targets initiative's (SBTi) net zero standard, meaning that they are expected to reduce their emissions by 90 per cent across all scopes (including scope 3) by 2040. However, because of a lack of high-quality, comparable data on embedded emissions in upstream basic materials and intermediate products, companies that use large amounts of basic materials are finding it extremely difficult to estimate their scope 3 emission – and to control them.
4. **Exposure to trade.** This becomes a problem primarily if cheaper imports are available alongside domestically produced materials. Most of the major foundation industry material consumers, such as automotive manufacturers, need to compete against imported products in the domestic market, which constrains their ability to pay the 'green premium' for lower carbon materials and their ability to pass the higher costs of low carbon material inputs to their consumers.
5. **Lack of familiarity or engagement with new materials and production technologies among downstream users in foundation industries and value chains are interlinked.** This can lead to concerns over their performance and thus reluctance to choose them over familiar alternatives. Lack of familiarity of new technologies can also increase the cost of debt finance or make products more difficult to insure.

These challenges reduce the foundation industries' ability to invest heavily in low carbon technologies, making them fundamentally important issues for government policy to address. Moreover, they can make the cost of low carbon materials higher to the consumers (including companies down the value chain), compared with materials that are produced using incumbent technologies or feedstocks that are more readily available. This is often linked to the higher risk profile and capital investment cost of low carbon technologies, but can also be caused by the higher operating costs of these technologies (as green hydrogen and electricity are more expensive than fossil fuels).

Overall, creating demand (and certainty of demand growth in the future) for low carbon materials is key to incentivising increased use of circular materials and low carbon fuels and investing in innovation, such as the possibility of using different material inputs, within the foundation industries. **Demand is one of the most important factors enabling foundation industries to provide the business case for large investments in the production of low carbon materials.** While some demand signals are beginning to emerge from downstream companies, this demand is currently not widespread enough to make substantial investment in decarbonisation profitable: if large-scale demand had already materialised, foundation industry companies would already be producing low carbon materials at scale.

4. Decarbonisation of the whole value chains: how demand can help

The decarbonisation of materials and value chains requires radical innovation across primary energy, technology, infrastructure, business models and behaviour. The decarbonisation of virgin material production will necessitate a shift in the energy sources and feedstocks used by industry, moving from high carbon to clean, climate neutral production methods. In heavy industry, this challenge is focused primarily, but not exclusively, on the need to develop new process technologies and cleaner feedstocks, and to bring them to the market at scale and speed. Manufacturing industries, in turn, will need to revise their product design and manufacturing processes to reduce their products' embodied carbon content by switching to low carbon virgin materials, using more recycled materials, improving material efficiency and, in some instances, replacing carbon-intensive materials with low carbon alternatives. Product designs will also need to be altered to improve the recyclability of the various materials used in product production.

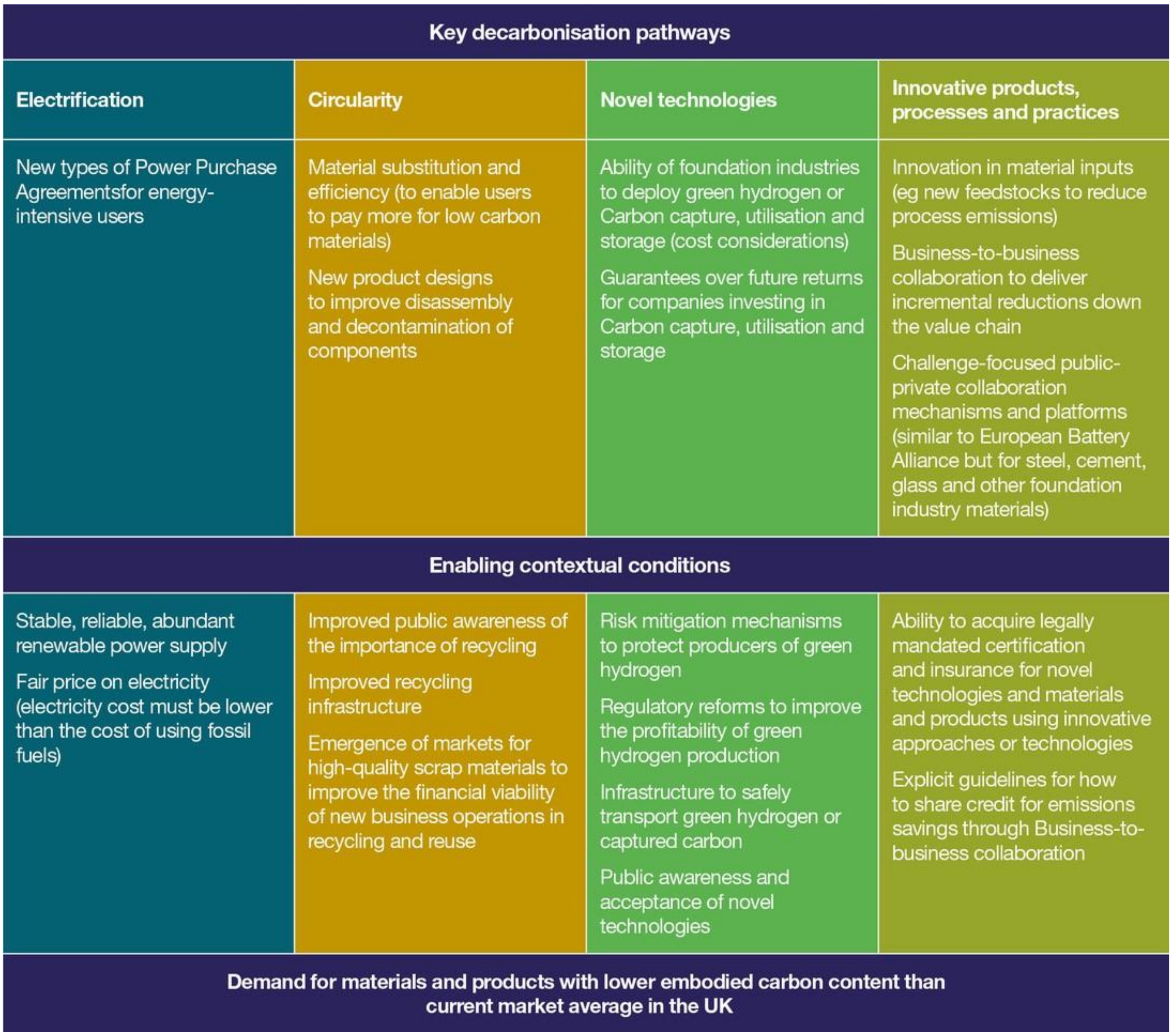
During the course of the research, in collaboration with our industry partners, we identified four key decarbonisation pathways, which could help to support foundation industry decarbonisation. These pathways are listed in Table 2 (below), which also identifies the contextual conditions that will need to be met to maximise the decarbonisation potential of each pathway, focusing on key areas where further innovation (including policy innovation, process innovation, technology innovation, product innovation and business model innovation) is still needed. In most instances, new policies are needed to create customer demand for low carbon products across the value chains and to establish contextual conditions that encourage innovation and support the scaling up of demand for new innovation.

The first of these pathways is direct electrification. The second is circularity. A lot of innovation – from product design to new business models and technological solutions to disassemble and decontaminate recyclable materials – is required to transform the UK's largely linear economy into a circular economy, whereby materials and products are reused, repaired or recycled. The third is novel technologies, which we define as technology that can transform a system or process, as opposed to technology resulting in an incremental change. The fourth is innovative products, processes and practices, whereby emissions reduction is achieved by the use of foundation industry materials, in some instances in collaboration with downstream value chain partners, rather than by the decarbonisation of the foundation industry materials.

These four pathways are not mutually exclusive: considering the urgency with which industrial GHG emissions need to be aligned with the UK's climate targets, all available levers will need to be deployed. In other words, although novel technologies and technological innovation are important, technological solutions alone are not sufficient to achieve decarbonisation of heavy industry. This section explores the opportunities and challenges for innovation under each of the four pathways. Some challenges, and therefore areas where further innovation is needed, are similar across several foundation industries. Some challenges, however, are sector-specific and require targeted action.

Throughout this section, we use business case studies to illustrate what actions businesses can, and have, taken. Some of these case studies also highlight specific challenges and areas where considerable policy intervention or innovative policy instruments are needed.

Table 2: Key innovation pathways for UK foundation industry and contextual conditions needed to enable them



<table>
<tr><th colspan="4">Key decarbonisation pathways</th></tr>
<tr><th>Electrification</th><th>Circularity</th><th>Novel technologies</th><th>Innovative products, processes and practices</th></tr>
<tr><td>New types of Power Purchase Agreementsfor energy-intensive users</td><td>Material substitution and efficiency (to enable users to pay more for low carbon materials)
New product designs to improve disassembly and decontamination of components</td><td>Ability of foundation industries to deploy green hydrogen or Carbon capture, utilisation and storage (cost considerations)
Guarantees over future returns for companies investing in Carbon capture, utilisation and storage</td><td>Innovation in material inputs (eg new feedstocks to reduce process emissions)
Business-to-business collaboration to deliver incremental reductions down the value chain
Challenge-focused public-private collaboration mechanisms and platforms (similar to European Battery Alliance but for steel, cement, glass and other foundation industry materials)</td></tr>
<tr><th colspan="4">Enabling contextual conditions</th></tr>
<tr><td>Stable, reliable, abundant renewable power supply
Fair price on electricity (electricity cost must be lower than the cost of using fossil fuels)</td><td>Improved public awareness of the importance of recycling
Improved recycling infrastructure
Emergence of markets for high-quality scrap materials to improve the financial viability of new business operations in recycling and reuse</td><td>Risk mitigation mechanisms to protect producers of green hydrogen
Regulatory reforms to improve the profitability of green hydrogen production
Infrastructure to safely transport green hydrogen or captured carbon
Public awareness and acceptance of novel technologies</td><td>Ability to acquire legally mandated certification and insurance for novel technologies and materials and products using innovative approaches or technologies
Explicit guidelines for how to share credit for emissions savings through Business-to-business collaboration</td></tr>
<tr><th colspan="4">Demand for materials and products with lower embodied carbon content than current market average in the UK</th></tr>
</table>

4.1 Electrification

Direct electrification allows renewable electricity to replace fossil fuels in many energy-intensive operations, in theory providing near-zero emission energy at a very low marginal cost. Electrification has already been proven to be a technologically viable pathway to decarbonisation in certain sectors, such as the steel industry and many other downstream manufacturing sectors. However, the dominant fully electric technology in the steel industry (the electric arc furnace, or EAF) requires scrap (ie recycled steel) as the material input, linking the feasibility of electrification in the steel sector closely to the improvements in recycling practices, infrastructure and regulation described below in reference to the circular economy practices (see Case study 2: Liberty Steel and High Value Manufacturing Catapult – The UK's scrap steel opportunity).

In collaboration with our industry partners, we identified three major challenges to electrification in the foundation industries. To address these challenges, government intervention is urgently needed. First, industrial electrification would significantly increase electricity demand, requiring new power generation capacity, plus transmission and distribution infrastructure. Second, the current pricing structure in the UK energy market does not reward consumers for making cleaner choices, highlighting the need for energy market reform that would enable energy-intensive industries to benefit financially from committing to using clean energy to power their processes (Ofgem, 2021). Decoupling the cost of cheap, clean renewable power from the volatile and high gas prices through new approaches to energy pricing, such as the Green Power Pool (Grubb et al., 2022), would allow energy-intensive industries to harness the benefits of the expansion of cheap renewable energy, making clean production processes more financially viable. It would also reduce the need for major financial interventions from government to alleviate the impact of soaring electricity costs on the competitiveness and economic viability of low carbon foundation industry operations, such as electrified steelmaking. At the moment, the combination of high electricity prices and insufficient indirect cost compensation to support energy-intensive industries that have already electrified have caused significant financial problems and halted production by Liberty Steel's EAFs, leaving the future viability of the company's UK production unclear.

Third, the electrification of existing plants will require considerable capital investment in new facilities that are compatible with more circular, electrified, production methodologies. Tata Steel estimates that it would cost ~£3 billion to convert just one of its coke-fuelled blast furnace-basic oxygen furnaces (BF-BOF) into an EAF (see the Steel Sector deep dive for more details on different production technologies). A recently announced plan by the UK government to subsidise the conversion of one of Tata Steel's and one of British Steel's blast furnaces by £300 million each may not be sufficient, covering only ~10 per cent of the costs (BBC, 2023b).

Case study 2: Liberty Steel and High Value Manufacturing Catapult – The UK's scrap steel opportunity

The use of scrap steel to make new steel is good for the climate and the environment. However, the viability of this depends on the availability of competitively priced renewable electricity and high-quality steel scrap.

Abating emissions from domestic steel production is imperative to the UK's climate commitments: the sector is responsible for 14 per cent of the country's manufacturing GHG emissions (ONS, 2022). Two steelmaking routes exist: the blast furnace-basic oxygen furnace (BF-BOF) route, which mainly relies on coke and iron ore, and the electric arc furnace (EAF) route, which primarily relies on electricity and scrap steel. The scrap-based EAF steelmaking route can reduce emissions by 90 per cent if powered exclusively be renewable energy, emitting 0.16 t CO_2/t crude steel, compared with 1.79 t CO_2/t crude steel emitted by the conventional BF-BOF route (using the best available technology) (Mission Possible Partnership, 2022). Currently, emission-intensive BF-BOF production dominates the UK steel industry, with 82 per cent of the ~7.2 Mt of annual steel production using this technology (UK Parliament, 2022a).

Although the steel produced in the UK has a lower average carbon intensity (of 1.58 t CO_2/t steel compared with the global average of 1.89 t CO_2/t steel) (World Steel Association, 2022b), this 'relatively cleaner' production is an underwhelming improvement over the past few decades, suggesting that the emission reduction potential in the UK steel industry has hardly been realised.

Optimising local scrap resources will be advantageous for UK steel sector decarbonisation. Eighty per cent of scrap steel is exported, whereas iron ore is imported (from Canada, Brazil and South Africa, in addition to Sweden) (OEC, 2023). Currently, 2.6 Mtpa of scrap is used in domestic production but this could increase to 6.1 Mtpa just by full utilisation of existing facilities (Hall et al., 2021). Underutilised production capacity is common; Tata Steel is producing ~3 Mt of steel annually but has capacity to produce 5 Mt. While the BOF is often charged with a portion of scrap (typically 17 per cent of the charge), the EAF can be charged with 100 per cent scrap. With the installation of new EAF facilities, conversion of all 11.3 Mtpa of available domestic scrap could serve almost the entirety of the UK's steel demand (Hall et al., 2021).

One of the biggest barriers for industrial change is cost: it is capital intensive to invest in new EAF facilities and retire existing BF-BOF facilities. This shift to EAF-based production in the UK is advantageous, considering potential production-based emission reductions and resource availability. However, it requires significant capital investment in new facilities and integrated supply chain management to assure high-quality and consistent scrap flows within the UK.

The clean energy transition in the UK is made more complex by the current unfavourable economics of steelmaking in the UK compared with a competitive international market. Liberty Steel's EAF in Rotherham has been producing only one-off orders for aerospace and defence customers for the past 18 months, primarily because of the soaring prices of electricity. China produces over 50 per cent of the 2 billion tonnes of crude steel produced globally (World Steel Association, 2022a) and accounts for 14 per cent of global exports, advantaged by cheap coal and labour, plus large economies of scale. The true profitability of the state-owned Chinese steel sector is, however, contested, with definitive anti-dumping regulations imposed by the EU and UK (Global Trade Alert, 2016; UK Trade Remedies Authority, 2022).

However, the steel sector is an essential supplier to the construction, automotive, aviation and defence industries, which are critical to the UK's economy and national security. Considering the downstream supply chain and employment that rely on UK steel, the argument for making the industry more sustainable becomes increasingly compelling. Moreover, the UK steel industry has the ability to produce high-quality diversified steel products and lead the world in clean steel production if the right support and demand signals are made. Investing in and promoting the growth of EAF production is crucial to establishing a sustainable steel industry in the UK, but two key conditions must be met to make it financially feasible. These are:

1. Cheap, reliable and abundant renewable electricity supply

The EAF route requires just 8 per cent of the thermal energy requirement of the BF route, but five times more electrical energy (0.703 vs 0.128 MWh/t) (Lopez et al., 2022). A stable renewable power supply is therefore needed to support electrification and decarbonisation of steel manufacturing. To achieve this, the national electricity grid capacity needs to increase, and energy sources switched to renewables, and/or captive, islanded renewable energy systems developed specifically for high-demand uses, such as the steel industry. As the EAF works in a flexible batch mode, it can be integrated with variable renewable energy to optimise available resources as a demand–response management technique to balance the power grid.

However, current industrial electricity tariffs in the UK (£137/MWh, including taxes) are 40 per cent higher than the EU median and 120 per cent above US prices (DESNZ, 2022). Globally, electricity accounts for ~12 per cent of EAF steel costs (Steel On The Net, 2020), but this percentage would be much larger in the UK. Electricity market reform will be required to appropriately reflect the growing share of cheap renewables: electricity auctions for UK offshore wind are reaching £48/MWh (in today's money) (Carbon Brief, 2022) for production in 2026–27, which is more than 60 per cent below the current industrial electricity tariffs. Nearly half of the UK's delivered power in 2020 was zero carbon, with renewables accounting for 43 per cent and nuclear for 16 per cent (National Grid, 2023a), and the UK government has committed to complete decarbonisation of the power grid by 2035. Novel renewable electricity contracts such as long-term power purchase agreements (already in place) and green power pools (recently proposed) (Grubb et al., 2022) may be successful in supporting low carbon electricity generation and consumption, and maintaining efficient supply–demand market dynamics.

2. High-quality scrap recycling

To improve the retention and use of scrap steel in the UK, circular practices must be improved across the supply chain and a strong domestic demand market created. Improving the quality of secondary material flows will be critical; scrap steel is 100 per cent recyclable, but inherent material losses (1 tonne of scrap steel yields about 0.91 tonnes of new crude steel) and inadequate recycling practices reduce the actual recycled rate of end-of-life (EOL) scrap to ~85 per cent (Tata Steel, 2023). Scrap is produced at various points throughout the supply chain, and is classified into three categories: home scrap, produced within the steel mill; prompt scrap, generated by industrial customers (eg the automotive and construction sectors) within manufacturing / construction processes; and end-of-life or post-consumer scrap (Bataille et al., 2021). Home and prompt scrap are pre-consumer and generally of very high quality as the steel has not been contaminated by other elements, unlike post-consumer scrap, which is commonly affected by residual elements such as copper, nickel, chromium and tin. (Dworak et al., 2022) Scrap pre-treatment technology would help to reduce impurities, alongside comprehensive recycling standards and regulation. Impurities may also be diluted by charging a portion of metallic iron directly into the EAF.

Reducing the influence of residual elements is important to preserve scrap quality, and hence downstream product potential. A common misconception exists that recycled BF-BOF steel is good quality, whereas EAF steel is poor quality and therefore suitable only for certain applications such as reinforcement steel in construction and packaging. However, if high-quality, low-impurity scrap is fed into the EAF (which does come at a price premium), the crude steel produced will consequently be of similar quality, especially as some impurities can be removed via EAF slag (but this does come with added costs in electricity demand and slag formers, eg limestone). As a testimony to this, Liberty's EAF facility in Rotherham is a specialist manufacturer of high-end alloys and stainless steels, serving the aerospace and defence sectors and specialist engineering applications (Liberty Steel, 2017). Admittedly, some elements cannot be removed in the EAF slag (termed ‘tramp elements’), including tungsten, molybdenum, cobalt, nickel, tin and copper – of these, tin and copper are the most concerning because they are not alloying elements (Nakajima et al., 2011). Contaminant control in scrap recycling is essential to expand typical EAF product lines.

4.2 Circularity

Circular economy solutions could allow materials and products to be kept in use for longer, reducing emissions and environmental damage from energy- and material-intensive production and extraction processes (Geissdoerfer et al., 2018; Camilleri, 2019; Benachio et al., 2020). Circular products and materials are created from recycled materials (scrap) or from components that can be repaired and reused. The circular economy process, and how it could work in foundation industry value chains, is illustrated in Figure 3 of this report. It is worth noting that the reduction of material consumption through improved material efficiency is an approach that is often classified under ‘circularity’. In the foundation industries, material efficiency could improve the ability of downstream companies to pay a premium for low carbon materials, thus increasing demand for them. However, in this report, we use ‘circularity’ to refer exclusively to reuse and recycling.

To transition heavy industry from a linear to a circular economy, business models and design strategies must be aligned. To facilitate the emergence and growth of circular approaches in the UK, intermediate and final product manufacturers must develop innovative designs that reduce material contamination and make disassembly and recycling of the different materials and components more feasible and cost-effective (Bocken et al., 2016). However, considering the scale and urgency of the challenge, policy interventions may be required to address the issue of UK low carbon products and materials being outcompeted by cheaper carbon-intensive materials and products. Some suggestions are provided in Section 6 of this report.

At present, one of the main barriers to greater circularity in foundation industry value chains is the lack of sufficient quantities of high-quality recycled materials. The potential benefits, alongside the challenges and how they affect the emergence of more circular practices in the steel and glass industries, are illustrated in Case study 2: Liberty Steel and High Value Manufacturing Catapult – The UK’s scrap steel opportunity and Case study 3: Waste container glass. The ‘pent-up demand’ demonstrated in these case studies provides another example of a supply–demand catch-22 situation: because there is limited market demand for materials with the low embodied carbon emissions that can be achieved via the use of scrap, only a few foundation industry manufacturers are actively seeking better access to scrap. As a result, business models around material decontamination and recycling have not emerged to produce high-quality scrap in large quantities for the UK foundation industries.

To address the challenge of pent-up demand, new business operations need to emerge, possibly with government support through start-up grants and low-cost loans, to collect, clean and quality-test recyclable components for reuse, and to decontaminate materials for recycling. For an example of a collaborative arrangement involving two businesses across a value chain, see Case study 4: Rolls-Royce / Schaeffler – Refurbishment and recycling of steel components in the aerospace industry (below). However, new business models around recycling can only emerge if the collection of recyclable materials is improved, and domestic markets for scrap develop to make these new business operations financially viable. In some instances, technological innovation is also needed to improve the recyclability of energy-intensive materials and rare-earth elements (REEs) (see Case study 5: High Value Manufacturing Catapult – Recycling of rare-earth elements in electric motors).

Case study 3: Waste container glass

Glass is infinitely recyclable. This means that the value of waste container glass (known as ‘cullet’ in the glass industry), primarily from the food and beverage industry, can be retained indefinitely through closed-loop recycling, whereby waste glass is crushed and melted down to create glass – again and again.

Using technologies that are available today, glass produced using 100 per cent cullet could reduce the embodied carbon of glass by 58 per cent (FEVE, 2016) compared with glass with no cullet (see Figure below). These savings arise primarily from the reduced demand for carbon-based energy (natural gas, electricity) used in glass production, carbon-containing materials (limestone, soda ash) within the raw material mix, and carbon-based fuels used in quarrying, processing and transporting virgin materials. The Federation of European manufacturers of glass containers (FEVE) conducted a life-cycle analysis (LCA) (FEVE, 2016) which showed that, on a cradle-to-cradle basis, every tonne of cullet can mitigate ~670 kg of CO_2 (EU average).

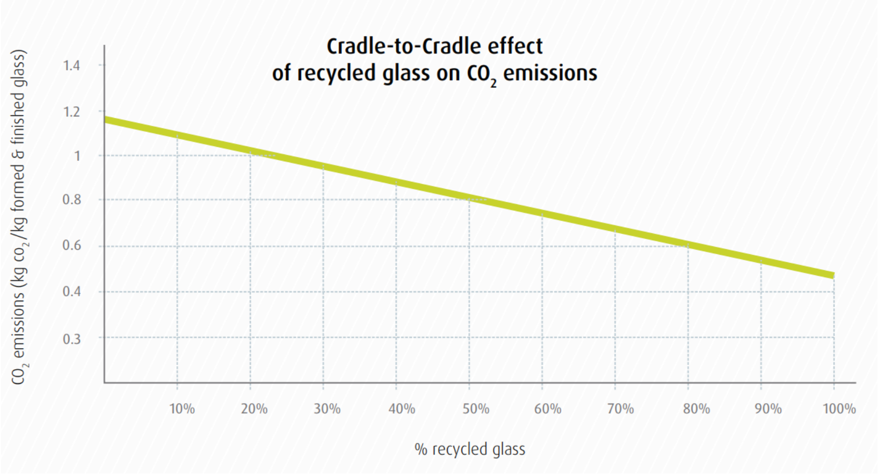


Figure 5 – Cradle-to-Cradle effect of recycled glass on CO_2 emissions. Extracted from FEVE, 2016 (38 per cent average recycling content = ~0.9 kg CO_2/kg glass)

Although greater use of cullet offers a significant decarbonisation resource to glass manufacturers, the UK has not yet realised the full potential of cullet. In 2019, 71 per cent of waste container glass on the market was recycled (1,824 kt), with 29 per cent being lost to landfill (750 kt). Moreover, just 36 per cent of cullet was returned to glass container manufacturing (925 kt), while 5 per cent was recycled in other remelt applications (132 kt), 18 per cent down-cycled as aggregate in construction (475 kt) and 11 per cent exported (292 kt). The balance between waste glass supply and new glass demand results in an average recycled content rate in new glass products in the UK of 38 per cent (Zero Waste Europe & Eunomia, 2022).

The melting down of cullet for reuse should be maximised in a circular, low carbon economy. Closed-loop recycling, whereby products are recycled into the same products repeatedly, is preferable to recycled material being used as an input in other sectors (such as low-grade cullet being used in construction), as it enables the highest possible value-adding potential of waste, maximising the emission and energy reduction potential. It is for this reason that the glass industry has targets for remelting as well as recycling: DEFRA has proposed a recycling rate target for 2030 of 83 per cent and a remelt target of 80 per cent (Eunomia, 2022). British Glass, the trade association for the UK’s glass industry, which is leading the Close the Glass Loop (2020) project, seeks to achieve a 90 per cent glass recycling rate by 2030. The aim is to improve the quantity of glass scrap that is collected to increase the share of it that is suitable for remelt, ultimately increasing the recycled content of glass packaging.

To achieve these targets, and thus to help the glass industry reduce its emissions, the UK’s waste management system must undergo some important changes.

First, waste contamination must be minimised by separating waste glass at source rather than mixing it with other recyclables – a practice that currently reduces the quality of cullet and therefore the share of recycled glass that can be used as an input in closed-loop glass manufacturing. The UK's glass container collection avenues are: (55 per cent) kerbside co-mingled, (32 per cent) kerbside as a separate waste stream, (10 per cent) bring banks (a communal waste deposit location with separate stream collection), and (3 per cent) household recycling centres. In the UK (as in many other countries), co-mingled collection of glass is inferior to separate collection services in supporting closed-loop recycling; less than half (44 per cent) of co-mingled collected glass is reusable by the glass industry, compared with nearly all (90 per cent) of separately collected glass (Zero Waste Europe & Eunomia, 2022). Shifting kerbside co-mingled collection to separate waste streams and expanding the use of bring banks have proved successful in increasing the amount of high-quality cullet in countries such as Austria and Spain (Lee et al., 2019).

Second, there is a need for regulation to support shared consumer–producer responsibility to drive efficient recycling systems. The current UK regulations focus on downstream demand with partial extended producer responsibility (EPR) regulations, where obligated packaging recyclers are required to purchase packaging recycling evidence known as packaging waste recovery notes (PRNs) or packaging waste export recovery notes (PERNs). These regulations do not cover all types of glass containers or enable consumers to play an active role in supporting a shift towards greater circularity. Consumer-centric deposit return schemes (DRS), whereby consumers pay a small fee for 'loaning' a container, which is paid back when the container is returned to a collection point or retail centre, have achieved success in certain countries, including in Norway, where 92 per cent of all bottles and aluminium cans were returned via the DRS in 2020 (Infinitum, 2020). For glass, however, the scheme's ability to effectively prevent waste has not been proven (Agnusdei et al., 2022), and received strong objections from the UK's glass industry (British Glass, 2021) (flared by Scotland's recent announcement of commitment to the scheme, which is due to commence in August 2023) (Zero Waste Scotland, 2023) – primarily because of the narrow focus on glass bottles. The industry has a strong preference for a holistic glass recycling scheme that maximises the amount of high-quality cullet that could be reused in glass manufacturing.

Finally, the sharing of knowledge at local authority level will be integral to best practices and educating the public on how to recycle glass effectively. Increased consumer awareness of the emission- and energy-saving benefits of glass recycling will be crucial to mobilise consumer engagement in facilitating glass industry decarbonisation through improved circularity.

Case study 4: Rolls-Royce / Schaeffler – Refurbishment and recycling of steel components in the aerospace industry

Schaeffler is committed to climate neutral production by 2030, and a climate neutral supply chain (upstream scope 3 emissions) by 2040. The company is also committed to help its customers reduce their upstream scope 3 emissions.

One possible way to achieve a reduction in downstream scope 3 emissions for Schaeffler and upstream scope 3 emissions for its customers is the refurbishment of products. Since 2004, the Schaeffler Aerospace division has made significant reductions to CO_2 emissions through the Maintenance, Repair and Overhaul (MRO) of engine bearings. The refurbishment of a bearing can save up to 81 per cent of CO_2 compared with the manufacturing of a new bearing, which is comparable to the emissions of an average refrigerator over 2.5 years.

The refurbishment and recycling of used bearings require co-operation between the producer of the bearings and either the Original Equipment Manufacturer (OEM) or the end customer, or both. When the engine bearings have signs of use, such as scuffs, dents and marks, refurbishment is possible and economic. Restoring used bearings back to their original ‘in condition as new’ can be done quickly and cost-effectively. However, the rolling elements are not refurbished at present, but instead recycled, remelted and used as raw material for other industries.

In the area of goods and services, the use of steel accounts on average for well over 60 per cent of the emissions in the supply chain. Encouraged by the success with the refurbishment (MRO) of engine bearings, Schaeffler is now looking for additional ways to reduce the emissions of the steel used to produce bearings. Specific avenues that Schaeffler is looking at involve working with Rolls-Royce in the following areas:

- Optimising the recycling route.
- Specific recycling, including preservation of the alloying elements.
- Waiver of crude steel and use of advances in steelworks technology.
- Use of green steel and availability of relevant grades used by Rolls-Royce.
- Investing in ceramics and enhancements to steel components to improve load capability, minimise weight, reduce heat and optimise the aero-engine.

Both companies are heavily invested in thinking about future engines, including future potential design to enable a radical change. A sustainable long-term reduction of the CO_2 emissions from motors can come from their improved efficiency and design of their components.

Schaeffler has a long tradition of continuously improving the energy efficiency of the bearings that it produces. For example, the company’s new aircraft engine ball bearing system was nominated for the German Aviation Innovation Award in the category ‘Emission Reduction’ in 2019. This system combines several highly sophisticated technologies, and by reducing friction achieves a significant reduction of 15 kW in the energy losses of the main shaft bearings.

The new ball bearing system also enabled improvements in the design of the engine to achieve a further reduction in operational emissions by downsizing several oil system components, which could save at least 1 kW more and ~16 kg of component mass. These reductions can be translated to both kerosene and CO_2 emissions reductions. Based on data from the test bench, the yearly savings would amount to ~23,500 tons of kerosene and 74,000 tons of CO_2 emissions for a fleet of 1,000 engines.

However, the implementation of such a new technology in aircraft engines requires a long approval process, which sometimes can hinder their quick application. For this reason, it is important to invest in innovation now to have these solutions in place, approved and ready for scale-up as soon as possible to support progress to the UK’s net zero target for 2050.

4.3 Novel technologies

Electrification and circular solutions alone cannot solve the industrial decarbonisation challenge: some 'virgin' material manufacturing will still be needed by 2050 to meet the growing demand caused by population growth and increasing wealth globally. The UK's Industrial Decarbonisation Strategy (HM Government, 2021b) is heavily reliant on the deployment of novel technologies, in particular (but not exclusively) CCUS and hydrogen, to achieve net zero.

According to the Industrial Decarbonisation Strategy (Ibid), CCUS technology is expected to mitigate CO_2 emissions by 8 Mt per year by 2050 (current foundation industry emissions are ~50 Mt CO_2 per annum). However, CCUS is still at the development stage and unready for deployment. The economic and technical viability of the CCUS technology remains uncertain, and may be complicated if plants have multiple emissions points (for examples from the steel industry and cement industry, see Sectoral deep dives here). However, because of the capital-intensive nature of foundation industry production assets and their long life cycles of 30 to 40 years, all new and renovated plants must be ready to fit CCUS technology when it becomes commercially available, especially in the cement industry where fuel switching could not remove the substantial process emissions. This means that companies may need to spend considerable amounts of capital to make their assets CCUS ready, without having any guarantee that the technology will ever be available or affordable for them. At the same time, optimistic assumptions regarding CCUS availability in future markets can disincentivise foundation industry manufacturers from exploring other decarbonisation pathways, locking the industries into emission-intensive pathways.

The key innovation areas needed to make CCUS economically viable include technological solutions to reduce costs, ways to capture carbon emissions from multiple emission sources at a plant, and secure transportation and storage of the captured carbon. Any measures that can cut emissions through efficiency improvements or innovation in terms of material use and process emissions, such as new circular economy technologies that improve the recyclability of materials, will help to reduce the amount of CCUS that is needed.

Alongside CCUS, the use of renewable energy sources is a crucial step in the decarbonisation of energy-intensive industry value chains (Daehn et al., 2021). Fuel switching from fossil fuels to green hydrogen is another novel technology that is endorsed in the UK Industrial Decarbonisation Strategy (HM Government, 2021b) but not yet available at commercial scale. Green hydrogen, produced using 100 per cent renewable electricity, has the potential to contribute significantly to the government's decarbonisation goals, particularly in sectors that are hard to electrify, such as heavy industry and heavy goods vehicles (HGVs). It is already being piloted by the steel industry in Sweden (SSAB, 2021).

However, the viability of the so-called hydrogen economy has been subject to extensive debate. Although the UK's Hydrogen Strategy (UK Government, 2021) sets an ambitious target of 10 GW low carbon hydrogen production capacity in the country by 2030 (up from the current 0.7 GW of predominantly carbon-intensive hydrogen, and subject to affordability and value for money, with at least half from electrolytic hydrogen), green hydrogen is currently not produced in the UK at commercial scale, making the abatement potential and sustainability of this route the subject of significant debate (Romano et al., 2022). Moreover, the recent Powering Up Britain energy security plan (DESNZ, 2023) states an intention to direct government subsidies to hydrogen production with CCUS, presumably using methane or natural gas – a process that will incur efficiency losses (as will the production of green hydrogen) and lacks certainty over its future emissions abatement potential. In the absence of green hydrogen, companies that switch from natural gas to hydrogen will increase rather than decrease their emissions due to the low efficiency of hydrogen as a fuel carrier, while also incurring higher costs.

Within energy-intensive industries, there are concerns about the availability and affordability of green hydrogen, especially within this decade. These concerns are due to the continuing lack of green hydrogen manufacturing in the UK and the need for new infrastructure: the UK's existing gas grid is largely unsuitable for transporting hydrogen

(BEIS, 2022c). Further investment and technological innovation are needed to ensure that the hydrogen transport network is leak-proofed, fit for purpose and extensive enough to service those industries with the greatest need for green hydrogen. However, the cost of developing such infrastructure may require hydrogen-using industries to co-locate, which is costly for the companies and requires suitable sites to be identified.

Upscaling the supply of green hydrogen to align with the government targets may also be challenging. At the moment, developers of green hydrogen projects face regulatory and policy barriers, which need to be addressed for the hydrogen sector to realise its potential. These barriers include network access costs, policy costs, the regulatory framework around metering and lack of compensation for system balancing (see Case study 12: Scottish Power – Regulatory and policy challenges for green hydrogen). The supply–demand catch-22 may also slow down the transition to green hydrogen as the future fuel of UK industry: while suppliers need certainty over future demand, it is risky for the foundation industries to upgrade their plants to operate with hydrogen without having a guarantee that they can access a stable, adequate and affordable supply of green hydrogen.

To reduce the business risk, innovation is needed to design new types of power purchase agreements (PPAs) specifically for hydrogen use in energy-intensive processes. A government-backed insurance scheme may also be needed to protect foundation industries if production processes are disrupted due to insufficient supply. Government funding mechanisms, such as Contracts for Difference (CfD) type approaches that have been used in the renewable electricity sector, have also been proposed for low carbon hydrogen production (FTI Consulting, 2022). However, the subsidies available for hydrogen producers currently cover less than half of the investment costs (Ibid), meaning that large-scale investment in green hydrogen (which would be needed to instigate fuel switching further down the value chain) still remains a risky endeavour for the energy companies, especially as long as hydrogen transport infrastructure is underdeveloped and energy-intensive industries do not have production facilities that are designed to run on hydrogen. However, the UK government's recent certification scheme to verify the sustainability of low carbon hydrogen may help to build transparency and confidence across the sector (BEIS et al., 2023b).

Case study 5: High Value Manufacturing Catapult – Recycling of rare-earth elements in electric motors

The global drive towards net zero has fast-tracked the use of electromobility. By 2030, the sale of new internal combustion engine cars and vans will end in the UK. By 2035, all cars and vans must be zero emission at the tailpipe / exhaust pipe (HM Government, 2021) to ensure the UK reaches net zero by 2050.

The push towards electrification in the automotive, aerospace, machinery and other sectors means that new components and materials have entered the product life cycle. Electric motors, for example, include several rare-earth elements or high-value materials such as aluminium, copper, iron, steel and rare-earth alloys. The global supply of these materials is dominated by China, which is expected to reduce the supply to global markets as demand increases.

In this context, the recovery of rare-earth elements and high-value materials from electric motors is essential to mitigate import dependency, the global environmental consequences of raw material extraction, and emissions from processing and manufacturing. This is particularly important in the UK, which has very limited domestic resources of these materials. However, the recycling of electric motors is extremely complex because of the vast array of materials being used in different ways and under different operating conditions, in each type of motor. A manual disassembly method is required for each component of every type of motor, making the process costly and inefficient. Shredding, which is currently the preferred method for disposing of electrical devices, produces large amounts of ferrous metal waste that contains rare-earth elements but they are too diluted for extraction.

At present, the UK has a limited rare-earth elements processing industry, and the recycling rate for them and high-value materials used in electric motors is less than 3 per cent. Although recycled rare-earth elements are expected to play a pivotal role in total rare-earth element supply by 2030, there are currently no economically feasible methods to recycle components such as permanent magnets (ie magnetised materials that generate their own persistent magnetic field, used in electric motors). Thus, new technologies must be urgently developed to recycle permanent magnets (Rademaker et al., 2013).

To address this challenge, Warwick Manufacturing Group (WMG) part of the High Value Manufacturing Catapult (HVMC) network are currently working on a project to extract, recycle and reuse rare-earth element permanent magnets from electric motors, to help improve a domestic supply chain network of rare-earth elements in the UK. The piloted approaches include metallurgical processes to recover the rare-earth elements in permanent magnet scrap at various technology-readiness levels (TRL). However, none of these approaches is commercially viable, or suitable for industrial use. Further research and innovation are urgently needed to identify solutions to address the challenges, such as the downgrading and low purity of the metals after recycling, wrong elemental composition of magnets once reformed, high cost of processes, large energy and time demand, inability to remove permanent magnets from the rotor and inability to extract the coating around the magnet without contaminating of the magnet. Finding solutions to these challenges will be crucial to enable the UK to develop a domestic supply chain to meet at least some of its requirement for rare-earth elements and high-value materials that will be needed for large-scale electrification to achieve net zero by 2050.

Novel digital technologies, such as blockchain and artificial intelligence (AI), could be deployed in the future to allow companies to accurately calculate the embodied carbon content of their products and securely share these data across value chains. Access to high-quality, verifiable, reliable and comparable data on the embodied carbon content of different materials is a necessary precondition for policies such as mandatory embodied carbon standards for products, and instruments such as digital product passports (DPPs), to be implemented. Access to high-quality embodied carbon content data is also needed by companies to calculate their scope 3 emissions and to take measures to reduce them in line with any future regulations or requirements, as well as existing (voluntary) business initiatives such as the SBTi, SteelZero (see Case study 9) and ConcreteZero (see Case study 10). Moreover, downstream companies are unable to promote their products as ‘low carbon’ unless they can access data from upstream value chains for verification purposes.

4.4 Innovative products, processes and practices

The final one of our four key areas for innovation – innovative products, processes and practices – refers to a range of actions that can help to reduce (but not eliminate) emissions from any foundation industry or its downstream value chain. These solutions typically emerge in situations where the opportunities to revamp the existing technologies used to manufacture the basic material are constrained by the factors discussed above, but changes in some operational functions are more feasible in the short term. Some of them, such as innovative product design that allows materials to be pulled apart and decontaminated, the technological innovation to decontaminate materials (see Case study 5) and production methods that allow components to be reused multiple times (see Case study 8: Tata Steel – Innovation in construction products), support the emergence and upscaling of circular solutions.

The innovative processes, practices and products can help to reduce demand for ‘virgin’ materials by enabling materials or even large components to be reused multiple times (see Case study 8) or to cut transport-related emissions in major downstream industries (see Case study 7: Encirc’s 360 service – Inviting partners to join the journey to a greener supply chain). However, this category also encompasses non-technological innovative solutions, such as changes in material inputs, that reduce emissions from material manufacturing without necessitating substantial changes to the production technologies (see Case study 6: Ecocem – Reducing cement emissions through the reduced use of clinker). New business models, such as service-based business models (whereby consumers pay for the right to use rather than to own products), could also fall into this category.

Case study 6: Ecocem – Reducing cement emissions through the reduced use of clinker

Conventional cement relies heavily on the use of clinker in a manufacturing process that produces ~600 kg of CO_2 per tonne of cement, of which clinker is responsible for ~95 per cent of the carbon footprint. Reducing the amount of clinker needed to produce a tonne of cement through the use of alternative materials such as supplementary cementing materials (SCMs) and fillers (eg crushed limestone) could reduce CO_2 emissions from cement production to ~170 kg – an greater than 70 per cent instant reduction in cement's carbon footprint. However, these options remain largely unexploited despite their potential.

Historically, the scalability of low carbon cements has been a challenge. However, recent advances in cement technologies have made it possible to develop cement that has a significantly lower clinker content and instead consists of ~70 per cent of SCMs and inert fillers, without compromising the quality of the product (UNEP, 2017). These technological advances would allow low carbon cement technologies to be produced at a scale that meets the demands of the concrete and construction sectors in the UK.

Ternary cement, developed by Ecocem, is one example of a new generation, low carbon cement. It is made of a blend that has a clinker content of 20–25 per cent, combined with SCMs (eg slag, fly ash, clays, accounting for 25–35 per cent of the content) and fillers (40–55 per cent of the content). By comparison, the average European and British cement contains ~75–77 per cent clinker. This advanced cement technology has been proven to work efficiently with concrete and achieve the workability and performance standards required. It can be produced, with fairly minor changes to existing production plants, by maximising the use of cementitious / filler technologies that are already widely utilised in the cement sector. As a result, transitioning a plant to produce low clinker, high SCM and filler cement instead of traditional cement is more immediate, cheaper, less disruptive and less energy intensive than the deployment of CCUS technology.

The new cement technology will:

- Reduce CO_2 emissions by over 70 per cent, which will generate financial savings through the avoidance of costly CO_2 credits (European Commission, 2023d; John et al., 2018) and substantially reduce the scale of CCUS required.
- Lower energy use: thermal energy demand is reduced by ~75 per cent and electrical energy by ~30 per cent.
- Reduce water demand in concrete manufacturing by ~35 per cent per cubic metre, which is important especially in water-stressed regions.
- Reduce toxic emissions (sulphur dioxide, nitric oxide) in line with CO_2 reductions.

However, current UK policy framework does not sufficiently support innovation in the cement industry or the scaling up of new low carbon cement technologies. The following changes are needed:

- Policies should support near-term solutions, which can significantly reduce cement carbon emissions, including solutions that enable a reduction in cement's clinker content. Focusing on CCUS as *de facto* core decarbonisation technology for cement is not sustainable when alternative low carbon technologies, which produce less CO_2 in the first instance, are much cheaper, speedier to deploy, and less energy intensive and disruptive to current operations.
- The process of changing standards needs to be faster and more responsive to technological change. Current standards for cement / concrete are no longer fit for purpose. Performance-based standards would be more technology neutral and incentivise innovation. Some countries are moving faster than others in this regard.
- Urgent public funding is required to accelerate the industrialisation of low carbon cement technologies. Policymakers need to level the playing field and increase their expertise in these technologies so that pilot / demonstration projects, first-mover industrial facilities, etc can be developed.

Case study 7: Encirc's 360 service – Inviting partners to join the journey to a greener supply chain

Encirc is a leading UK glass bottle manufacturer, filler and distributor. The company's 360 solution (Encirc, 2023) is an example of a unique supply chain service that allows stakeholders from across the beverage industry to work together towards a significantly greener operation.

Cutting emissions from the shipping of beverages that are sold in glass bottles presents a key challenge to the global beverage industry. Encirc's 360 service shows how innovative thinking at the systemic level can help to cut emissions not only from the manufacturing of glass bottles, but also through improved supply chain management. It involves transporting liquid in bulk from producers around the world to Encirc's UK site, where the beverages are bottled using a closed-loop system in containers manufactured using industry-leading technology and experience. The bottles are then stored in a warehouse, where artificial intelligence (AI) and automation are used to package them in bespoke, consolidated loads (ie mixed pallets) for direct shipping to retailers.

The 360 service reduces emissions and waste through breakage at various points of the supply chain. Transporting liquid in bulk instead of glass bottles directly targets a major source of emissions in the beverage industry by tripling the quantity that can be transported in a given space and weight compared with shipping pre-filled bottles on pallets. Bottling onsite once the product has arrived in the UK also reduces waste from breakage and spoilage during transit.

The automated warehouse operations used by Encirc make it possible for wine and carbonated beverages to be sent to retailers in mixed pallets that contain drinks from multiple producers, cutting the number of journeys between producer and retailer. Analysis commissioned by Encirc from Carbon Intelligence (Accenture, 2023) found that wine producers from New Zealand, Chile, Argentina and South Africa could nearly halve their transport-related emissions by switching from transporting their products in glass bottles to the 360 service when shipping their products to the UK. For Encirc customers, this equals 31,000 tonnes of CO_2 equivalent savings per year.

The 360 service is a key component of the efforts that Encirc and its parent company Vidrala (Vidrala, 2023) are making to implement their science-based targets for 2030, and also to empower others in the industry to decarbonise and to reduce the carbon footprint of the glass and beverage industries.

"By combining our pioneering sustainability initiatives with our unique 360 programme, we are able to work with our partners and the wider sector to build a more environmentally-friendly industry as a whole. Working with like-minded partners from across the world, we're helping to decarbonise the sector and showcasing the necessity of bulk shipping for the future of how we work." (Fiacre O'Donnell, Director of Sustainability, Encirc).

Case study 8: Tata Steel – Innovation in construction products

Tata Steel UK (TSUK) produces ~3.6 million tonnes of steel a year, primarily for the automotive, engineering, packaging and construction sectors. More than 50 per cent of TSUK's steel is destined for the construction sector.

TSUK is committed to sign up to the Science Based Targets initiative (SBTi) and aims to be a net zero steelmaker by 2045. The company is also seeking ResponsibleSteel certification for its primary UK steelmaking site at Port Talbot in South Wales. It is also engaging with its downstream supply chains to support the design, adaptation or development of new products to help their customers reduce their environmental impact.

For several years, TSUK has worked with the automotive sector to improve productivity and material efficiency by driving standardisation in developing vehicle platforms, with excellent results. However, the construction sector supply chain has been slower to adopt new practices, and driving change in this sector has been challenging. In order for the construction sector to achieve similar progress to that made in the automotive sector, change is needed in three main areas:

1) Collaboration and standardisation, ie developing standard ways of reporting and costing buildings, shared data templates or passports, and common designs.
2) Finding ways to demonstrate the ability to manufacture safely offsite with rapid onsite manufacturing style assembly.
3) Demonstrating the benefits of designing and building with the waste hierarchy truly reflected in any building assessment from cradle to cradle (reduce, reuse, recycle).

These challenges are all addressed in the SEISMIC project (Specific, 2022), which was set up in 2020 to develop a platform-based construction approach. This approach enables standardised building components to be used in construction at scale and offsite, across unrelated projects. For example, a component designed in the same way can be used for a school, a hospital or a prison. It also enables faster adoption of new technologies and manufacturing solutions as they become available.

The SEISMIC approach was initially developed in response to the Department for Education aspiration to improve the construction of schools, focusing on the design of a standardised, lightweight steel frame and universal connector block. A second phase of the project involved designing and constructing core components to work with the frame system, including wall, floor, ceiling and roof cassettes, offering an 'all-in-one' solution for customers.

The SEISMIC approach was designed to meet the UK government's Construction 2025 targets, which it already exceeds, making it possible to complete a building 75 per cent faster than traditional methods allow, and with a 70 per cent lower carbon impact and 47 per cent better value. These achievements have been enabled by the consortium structure of the project, with three manufacturers working independently on the same building. The demonstrator building shows this to good effect, incorporating systems from the McAvoy Group, the Elliott Group and TSUK.

5. Sector-specific examples

In this section, we provide illustrative examples of how demand could drive decarbonisation across UK steel, cement and glass industry value chains, enabling these foundation industries to decarbonise without unduly risking their competitiveness.

5.1 How demand could drive low carbon innovation in the UK steel industry

Strong demand-side signals are needed to support effective and efficient decarbonisation of the UK steel industry. These signals must flow through the entire value chain and all sectors that use large quantities of steel (such as construction, transport, appliances and the intermediate products going into the manufacturing processes). This, in turn, will support the development of low carbon, resource-efficient steel markets. To cultivate and sustain a reinforcing loop between value chain actors who push for sectorial decarbonisation, strategic innovation and policy mechanisms are needed. These could include circular business models and supply chain collaboration (IPCC, 2022) through building high-quality scrap recycling competence, improvements to renewable energy capacity and industrial process flexibility, scaling up of low carbon technologies (Energy & Climate Intelligence Unit, 2021; Richardson-Barlow et al., 2022) and establishing transnational green steel supply chain alliances (for more detail, see the Steel Sector deep dive here).

Typically, 'demand' in the steel industry is considered to be the end user of the final steel-containing product, but this definition is narrow. We broaden this definition to include all across the whole steel industry value chain, creating a more holistic view of demand-led innovation. For instance, automotive manufacturers that are keen to reduce the embodied emissions of their products create demand for automotive manufacturing components that are made of low carbon steel, which then incentivises intermediate product manufacturers to use low carbon steel instead of more carbon-intensive steel. This translates into demand from steel producers for low carbon production technologies (such as electric arc furnaces) and inputs (eg renewable electricity and green hydrogen) and transition financing.

This demand from the steel manufacturers, in turn, creates demand throughout the value chain, including the production of supporting infrastructure (eg solar panels, wind turbines, electrolysers, upgraded power grids). The causal sequence is cyclical: the greater the product demand, the greater the demand for raw and intermediate materials, supporting financing, and physical and administrative infrastructure. This then drives up the supply of low carbon steel, leading to greater demand as supply chains become more efficient, economies of scale are realised and costs decline (see technology learning curve example in Section 2.3 of this report). For low carbon steel production to operate successfully at a large scale, actors across the whole value chain must be aligned, working in parallel and in collaboration with each other to implement and sustain the low carbon steel production ecosystem.

The first movers in demanding low carbon steel products have been in the automotive sector, such as Volvo (2022) and BMW (2022), who have sought to be the 'first' in fossil-free vehicle manufacture. However, the steel industry's demand markets are far more diverse: global steel demand in 2021 totalled 1,839 Mt (World Steel Association, 2023), split between buildings and infrastructure (52 per cent), mechanical equipment (16 per cent), automotive (12 per cent), metal products (10 per cent), other transport (5 per cent), electrical equipment (3 per cent) and domestic appliances (2 per cent). Stimulating demand for low carbon steel in all steel-consuming industries, especially construction, is vital, to create economies of scale to bring down the per-unit manufacturing cost of low carbon steel.

The building industry has already made important progress. Life-cycle assessment standards and certifications for low carbon buildings governed by the UK Green Building Council (UKGBC, 2023) and the Building Research Establishment (BRE, 2023) (who implement BREEAM) support demand for low embodied carbon assets. Collective action industry groups are also emerging and growing, such as the UK's Better Buildings Partnership (BBP, 2023) for property owners who seek to construct more sustainable commercial buildings. In May 2022, the UK's first Net Zero Carbon Buildings Standard was launched to determine a single, agreed methodology to account for built asset emissions, championed by UKGBC, BRE, BBP, the Royal Institute of British Architects and the Carbon Trust, among others (NZC Buildings, 2023).

Multiple global initiatives also exist to stimulate demand for low carbon industrial materials, including the Clean Energy Ministerial's Industrial Deep Decarbonisation Initiative (IDDI) (Clean Energy Ministerial, 2023). The IDDI is a collaboration of national governments co-led by the UK and India, which works to stimulate demand for low carbon industrial materials by standardising carbon accounting methods, establishing ambitious private and public procurement targets, and incentivising project investments.

Customer relationships are crucial in supporting steel industrial decarbonisation, especially when green premiums exist. The main consumer-facing steel-containing products are buildings, vehicles and food containers, which are affected by market expectations to decarbonise production supply chains. Demand for low carbon steel can stem from multiple internal and external drivers, and is not necessarily the same across different uses and user groups. For example, buyers of top-tier cars may be willing to pay more for a zero carbon vehicle, while governments (and therefore taxpayers) may be less prepared to pay such a premium for a zero carbon bridge, tunnel or school. Subsequently, policy and regulation will be critical enablers to shift business-as-usual in steel-consuming industries.

Case study 9: SteelZero – A demand-side business initiative

SteelZero is a global demand-side steel industry decarbonisation initiative led by the international non-profit organisation Climate Group and run in partnership with ResponsibleSteel, a non-profit multi-stakeholder standard and certification programme.

SteelZero brings together leading organisations across the entire steel value chain to speed up the transition to a net zero steel industry. Businesses that join SteelZero make a commitment to use, buy or specify net zero steel by 2050, with an interim commitment of using 50 per cent responsibly produced steel by 2030. Collectively, SteelZero sends a strong demand signal for net zero steel, shifting global markets and policies towards responsible production and sourcing of steel. The membership in February 2023 was 31 companies – and forecast to grow – including: international construction firms such as Mace Group, Lendlease and Skanska; the automotive maker Volvo Cars; Siemens Gamesa from the renewable energy sector; and the global shipping giant Maersk.

The partnership with ResponsibleSteel is central to the commitment. ResponsibleSteel is the industry's first global multi-stakeholder standard and certification initiative. With members from every stage of the steel supply chain, ResponsibleSteel is developing an independent certification standard to assure businesses and consumers that the steel they use has been sourced and produced responsibly at every stage. For SteelZero members, purchasing ResponsibleSteel-certified steel is one key pathway to achieving their 2030 and 2050 commitments. ResponsibleSteel certification is also playing a crucial role in defining a global standard and definition for 'net zero' steel, which is needed to speed up the global transition to net zero steel, as outlined by SteelZero in May 2022 (Climate Group, 2022).

SteelZero is following the same model as other Climate Group demand-side initiatives, such as RE100, which brings together businesses committed to 100 per cent renewable electricity. When RE100 launched in 2014, the cost of renewable electricity was prohibitive for many companies. Now, more than 300 RE100 members represent an electricity demand greater than the UK or Italy, fast-tracking the global transition to zero carbon grids. Climate Group holds similar ambitions for SteelZero, which is gaining traction. When British Steel announced that it would be adopting science-based targets in 2021, it cited SteelZero as a critical factor in driving this transformative decision. The SteelZero commitment framework has also been partially adopted by a climate-focused European investors group, which is looking at integrating it into their own engagements with their members, showing the strength and reach of the SteelZero initiative all along the value chain. Given that we have less than ten years to halve global carbon emissions to get the world on track to reach net zero by mid-century, this kind of engagement and innovation across the value chain is vital and urgently needed.

5.2 How demand could drive low carbon innovation in the UK cement industry

To successfully reduce carbon emissions in the UK cement industry, it is essential to have strong demand-side strategies that reach all parts of the supply chain and industries that use large amounts of cement, in particular construction and transport. These strategies will encourage the development of low carbon and efficient cement markets. To achieve this, collaboration across the cement value chain will be essential to reduce emissions through improved energy efficiency and technological innovation. Although the challenges facing individual players in the industry are significant, those that take early action to address sustainability across the value chain have a better chance of remaining competitive (McKinsey & Co, 2022).

The UK has outlined a set of low carbon technologies to reduce emissions from industry in the Industrial Decarbonisation Strategy (2021). However, when working towards a cement and concrete industry that is climate neutral, it is essential to have a systemic approach across the entire value chain. This involves considering factors beyond the factory gates, including the infrastructure and the entire lifespan of the product. For example, utilising circularity and life-cycle approaches and decarbonisation across the value chain will be crucial. However, reducing carbon emissions in the cement industry is currently challenging because of the lack of economic incentives for available CO_2 mitigation strategies (Rumayor et al., 2022).

For the cement industry to be able to decarbonise, the demand for low carbon cement needs to increase. By 2030, it will be necessary for carbon-neutral or carbon-negative construction to become the standard. To make this happen, there must be a significant surge in the use of construction materials that have zero or negative embodied emissions soon (Chatham House, 2018; Rockström et al., 2017). Globally, the cement industry is the second-largest contributor to CO_2 emissions and the third-largest consumer of industrial energy. The demand for cement and concrete is on the rise due to population growth, urbanisation and infrastructure development needs, which puts more pressure on reducing the carbon footprint of cement production. Even if countries stick to their carbon mitigation commitments and energy-efficiency targets, the cement sector's direct CO_2 emissions would still increase by 4 per cent worldwide by 2050, with a projected 12 per cent growth in cement production during the same period (IEA, 2018). It is imperative that the widespread use of low carbon cement becomes the norm – and urgently. We cannot depend solely on technologies such as CCUS and electrification to provide us with potential emission reductions in the future.

Greater use of supplementary cementitious materials (SCMs) is the most viable way, at the moment, to reduce emissions from cement production. Replacing a portion of the clinker content in cement with other materials could have a greater impact than currently anticipated. The share of clinker needed can be further reduced in specific applications, leading to a potential decrease in CO_2 emissions of 70–90 per cent (Chatham House, 2018). To decarbonise cement production, it is crucial to reduce the use of clinker, and SCMs such as blast-furnace slag and fly ash can assist with this goal. However, currently, SCMs make up only 15 per cent of cement production, but there is room for growth to increase this figure to 30–50 per cent and promote the use of SCMs to decrease the amount of clinker (Habert et al., 2020). Despite the increasing usage of SCMs in cement production, there are still some limiting factors. One of these factors is the difficulty of cost-effective transportation logistics, as SCMs are often not available locally and need to be transported over long distances, sometimes across the globe. Additionally, the limited availability of fly ash and blast-furnace slag has also hindered their usage in cement production. Investment in R&D is necessary to enhance the effectiveness of implementing SCMs in cement production. This includes developing high-quality SCM technologies that can improve the robustness of SCM use in cement production. Most importantly, however, it is necessary to revisit regulatory requirements that may present a barrier to greater use of cement made from SCMs at the moment (CISL & Agora Energiewende, 2021).

In addition to changing the production process and material inputs for new cement, emission reductions can be achieved through the scaling up of circular business models and improved material efficiency. To this end, we need strategies to explore how innovations in the built environment will affect upstream sectors, including where material efficiency strategies in the cement industry have the potential to decrease the demand for cement by using minimalist designs, increasing the lifespan of products, promoting reusability, and recycling while ensuring the control of contaminants (Allwood & Cullen, 2015; Bataille, 2019). This can be achieved through design strategies such as minimising material use from a life-cycle GHG-intensity perspective, lengthening the life of structures to minimise re-build cycles, and making structures flexible for multiple potential end-uses.

Regulations that hold retailers and property demolition companies responsible for recycling such products may be necessary, along with infrastructure and public sector services to make recycling feasible for households and small businesses. Innovative business operations and models in waste management and recycling can also help enhance closed-loop material circularity in the steel sector and reduce the quantity of materials required to serve the same function over a period. Enhanced collaboration across value chains, including standardised embodied carbon content accounting and reporting, can support the circular economy in practice, such as using DPPs that provide detailed information on the recyclability of components and materials used in each product.

Last, but not least, the cement industry value chains can benefit from better sharing and utilisation of best practices. The utilisation of best practices has shown that operational changes can reduce emissions without the need for large capital investment, such that UK industry can reduce GHG emissions by using management strategies to do more with less (Lavery et al., 2013). For example, digital tools can be used to share effective techniques for improving specific concrete mixtures using materials found in the area, or to enable a worker at the construction site to easily access information on how certain SCMs and admixtures can work together. Improved sharing of knowledge will play a crucial role in making it easier to use innovative cements and higher blends in developing markets. Developing and offering tools for implementing best practices in the cement industry, such as global standards for decreasing clinker, demolishing and storing concrete, can also contribute to decreasing levels of embodied carbon.

Case study 10: ConcreteZero – A demand-side business initiative

At present, a globally agreed standard for low emission concrete does not exist. However, such a definition needs to be developed to align the industry and to build the collective action that is needed to get the concrete industry to net zero. One key barrier to developing a shared definition is the lack of data on the level of carbon emissions associated with the concrete that is currently being used and produced. These data are needed to develop a good understanding of the embodied carbon emissions of concrete in a business-as-usual scenario against which progress could be measured.

International non-profit Climate Group's ConcreteZero campaign brings businesses together to create a market for sustainable concrete, and to drive greater transparency on carbon emissions across the concrete industry value chain. Members include major companies in the property and construction industries including Thornton Tomasetti, Lendlease Europe and Multiplex. The focus is concrete, which is a mix of materials, including cement. The embodied carbon content of concrete is determined by the ratio in which cement and other ingredients are added to the concrete mix. Therefore, focusing on concrete allows maximum flexibility in reducing the carbon emissions associated with its materials, as multiple processes can be addressed.

Businesses that join ConcreteZero commit to using 100 per cent net zero concrete by 2050, with two ambitious interim targets of using 30 per cent low emission concrete by 2025 and 50 per cent by 2030. They also sign up to a 'baseline' commitment to report the volume and carbon intensity of concrete consumption through a digital platform, which will allow data to be shared (anonymously) among members. The design of this platform is well under way and will provide a standardised methodology for benchmarking performance and recording the improvements members are making. It will allow more accurate targets to be set based on seasonal, geographical and structural use of concrete, while also enabling policymakers to set meaningful parameters for operation.

Solutions to reduce the embodied CO_2 of concrete exist within the UK, but they require early engagement and an innovative, collaborative approach from construction companies and concrete producers. Aspiration and collaboration through initiatives such as ConcreteZero are key to unlocking fledgling technologies that need uptake today to provide tomorrow's solutions.

5.3 How demand could drive low carbon innovation in the UK glass industry

As illustrated in the modelling study in Section 7.2, basing the implementation of low carbon technological solutions solely on their price competitiveness can lead to long delays in the technology emerging and being adopted by industries. The modelling results suggest that policies that create demand for specific low carbon materials, such as glass (and the technologies to produce such low carbon materials), can accelerate the price decline of these types of products and production technologies by enabling producers to achieve economies of scale much faster than is currently the case.

The 'conscious consumer' plays an important role in glass sector decarbonisation and the impact it can have on emissions from other sectors. Demand for glass products, both plate glass (such as windows) and containers (such as bottles and jars), can be driven by consumer demand. For example, consumers (including households, businesses and property developers) may decide to buy thermally efficient windows to improve the energy efficiency of homes and other buildings (British Glass, 2021, p. 7), or choose a recyclable or reusable glass container over other alternatives, provided that these are available.

Markets for low carbon glass can also be supported by policy interventions, such as regulations that create demand across the value chain. As discussed throughout this report, demand for low carbon production technologies and materials is driven by all actors across the industry value chain, rather than just the end user of a consumer product. According to ONS input–output analysis data, 63 per cent of the products of the glass and ceramics industry are purchased by the construction industry, 9 per cent by beverages manufacturers and 6 per cent by households directly, while the rest is distributed across other economic sectors (ONS, 2022a). This distribution suggests that the construction industry and to a lesser extent beverage companies and households have the biggest potential to accelerate decarbonisation at the glass production point through their demand pressures.

Construction companies that are committed to reducing their scope 3 emissions can explore opportunities for more efficient use of materials, including steel, cement and glass. They can also commit to purchasing the most thermally efficient building materials that reduce operational emissions from the properties they develop. In terms of glass, they can demand window glass that has a low embodied carbon content, selecting to buy their windows from manufacturers that purchase the plate glass from low carbon manufacturers. Construction companies themselves face demand pressures from real-estate asset managers and owners. This trickle-down demand pressure can drive forward glass producer investment in fuel substitution, electrification, energy efficiency, waste heat recovery, and carbon capture and storage. However, for glass manufacturers to make these (often substantial) investments in new production technologies, they need to be confident that the demand for glass products with a low embedded carbon content will grow over time. In other words, although the changes in production technologies are largely in the hands of glass producers, the technology choices that they make are driven by demand further down the value chain as well as the cost and supply of low carbon fuels or cullet.

Several contextual conditions affect the financial and physical viability of certain solutions, such as electrification, circularity and fuel switching. Circularity, for example, is enabled (or disabled) by the availability of cullet, which in turn depends on consumer behaviour and recycling infrastructure. At present, the reuse of plate glass and containers is challenging because of the geographical disconnect between supply and demand and product specificity, including beverage producers using non-standard containers. As illustrated in the waste container glass case study above, the recycling of glass has huge potential for reducing both energy and raw material demand and emissions. However, it requires glass producers to adjust their production processes to create demand for recycled glass, as well as other actors in the value chains to supply the glass scrap for recycling . For this to work, the final product consumers, property demolition and car scrappage services need to work with used product or waste glass collectors, sorters and transporters to get the cullet back to glass producers. The system can become truly circular only if all actors along the value chain participate in the recycling process, and the enabling infrastructure to avoid contamination of glass scrap is widely available.

Similarly, operational emissions, such as those from transporting products, are dependent on actions of various actors across the value chain. Encirc's 360 service is a good example of innovation in this area (see Case Study 7 in Section 4.4). Given that the glass industry is interlinked with many other industries (primarily in the property development and beverage industries), there is great scope for broad-based business-to-business collaboration to decarbonise embedded as well as operational emissions from glass.

A vital facilitating aspect to demand-led decarbonisation and its positive feedback loops is data collection, gathering, reporting and disclosure to allow embodied emissions data to be understood, traced and compared. Therefore, investment and innovation in data collection and processing is essential. Improved data collection will both require and support enhanced regulatory frameworks and standardised methodologies for emissions accounting and reporting. These shared accounting and reporting standards will need to be used by all suppliers to enable companies further down the value chain that use large quantities of energy-intensive materials to make informed choices about how best to reduce their scope 3 emissions. Ideally, these standards will be aligned internationally to make it easier to compare the embodied carbon content of materials and intermediate products in multiple countries, ensuring that product standards are sensible, carbon border adjustments are accurate, and the risk of carbon leakage is low. The EU has already announced plans to implement a mechanism for information sharing, the digital product passport (DPP); however, this is not (yet) complemented by a shared standard for embodied carbon accounting and reporting.

Case study 11: NSG – Building for the future glass industry's journey towards decarbonisation

NSG Group (Nippon Sheet Glass Co., Ltd and its group companies) is one of the world's leading suppliers of glass and glazing systems in the architectural, automotive and creative technology sectors, and has principal operations around the world and sales in over 100 countries. The NSG Group is committed to reducing its greenhouse gas (GHG) emissions by 30 per cent by 2030 compared with 2018 levels – a target certified by the Science Based Targets initiative (SBTi) – and achieving carbon neutrality by 2050. These reductions will come from emissions directly associated with manufacturing and carbon produced in the company's upstream and downstream value chain.

However, the flat glass industry has a long road ahead towards decarbonisation. No one specific technology is known to be the most effective to decarbonise glass production, so the NSG Group is trialling several different routes to explore which pathways might be most viable for scaling up in the future.

At present, the company is testing several new technologies and methods. These include collaborative landmark trials of alternative fuels. In 2022, Pilkington United Kingdom Limited, part of the NSG Group, became the world's first flat glass manufacturer to fire its furnace on 100 per cent biofuel, resulting in the creation of 165,000 m^2 of lower carbon glass. This innovative trial was part of a multimillion-pound project, which demonstrated how biofuel can present a realistic alternative to natural gas.

This achievement built on the progress made towards decarbonisation in 2021, when float glass was successfully manufactured using hydrogen in another world-first trial. A project with KEW Technology will pilot onsite fuel switching from natural gas to KEW's syngas, which is produced by onsite modular gasification units.

The potential use of carbon capture technology in glass manufacturing is also under review. Alongside these specific initiatives, the NSG Group is exploring how it could use more cullet (ie recycled glass) in the manufacturing of new glass, to enhance energy efficiency and to reduce the embodied carbon content of their glass products.

Pilkington United Kingdom Limited has manufactured glass for decades with thermal insulation and solar control properties that contribute to a building's energy efficiency. These high-performing architectural glass products are essential to improve building energy efficiency and living comfort in the UK, and to help deliver the government's decarbonisation targets for the buildings sector. The pioneering innovation at Pilkington UK means that thermally efficient glass products with lower levels of embodied carbon are becoming accessible to architects.

A significant amount of research and investment will be needed before hydrogen, or perhaps even electrification, becomes a feasible alternative to natural gas for powering glass furnaces. However, some early, important strides are being made through the collaboration of pioneering manufacturers like the NSG Group, innovative specialists in sustainable solutions and the backing of government. These developments in the glass industry will play a fundamentally important role in enabling decarbonisation of the UK's building stock in line with the 2030 and 2050 targets.

6. Supporting demand-led innovation: What policies can help and how

Policies can play a crucial role in driving the development and adoption of new low carbon technologies, by creating demand for new products, and thus reducing the risk of losses to companies that invest in their development and production. Considering that we are now only one investment cycle away from 2050 – by which time the UK foundation industries should have reduced their emissions by at least 90 per cent – new policies to create markets for low carbon basic materials are badly needed to incentivise innovation and to remove barriers to the scaling up of new, innovative solutions that are currently being piloted. To be effective, these policies will need to address all stages of the industrial production value chain (CISL & Agora Energiewende, 2021), including incentivising innovation and facilitating market diffusion through increased demand in the downstream sectors, such as property development and automotive manufacturing. This includes removing barriers to the deployment of new low carbon materials and products by downstream industries.

The UK's 2021 Industrial Decarbonisation Strategy (HM Government, 2021b) contains plans for several calls for evidence and sets out preferred options for some funding mechanisms. It also sets out a number of measures to improve resource efficiency, including (i) exploring low carbon product standards and labelling that will consider embodied carbon, as well as broader environmental impacts, and (ii) a £30 million UKRI Circular Economy Research Programme aimed at working with industry to develop new approaches to resource efficiency (CCC, 2021). However, it does not provide specific policy frameworks with explicit technology-led roadmaps (UK Parliament, 2022a) for how the long-term targets will translate into strong market demand that will make the innovation and uptake of low carbon solutions in the foundation industries economically viable.

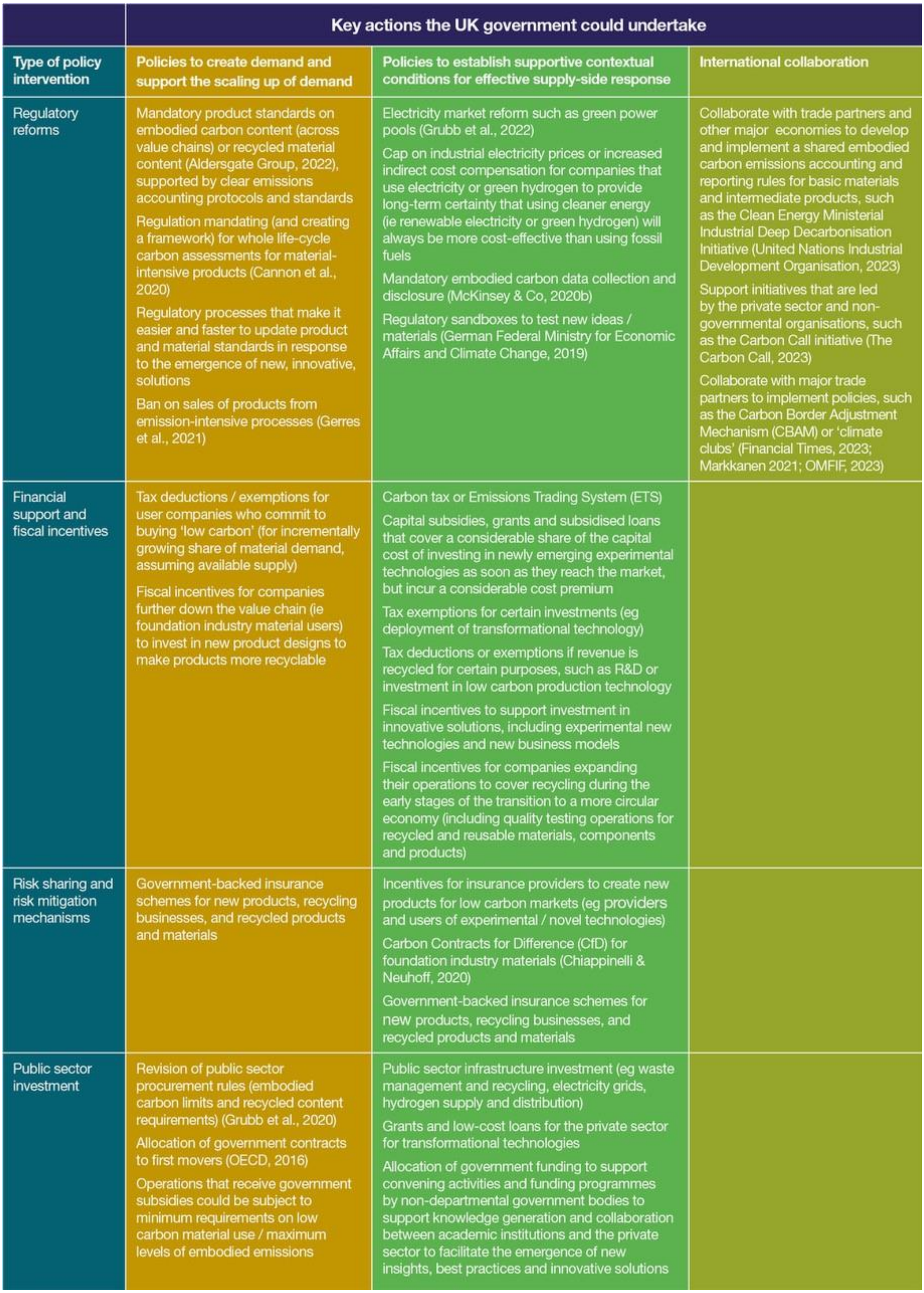
Demand-side policies to incentivise decarbonisation in the UK have so far been non-existent, with the ETS being the sole policy mechanism applied to directly reduce industrial emissions. Yet, due to several factors including contextual conditions and the design of the ETS, the system has been largely unsuccessful in incentivising the development and scaling up of new technologies and low carbon alternatives to material inputs. This **lack of incentives to design and adopt low carbon technologies (instead of simply improving the efficiency and thus reducing the per-unit emissions from current production facilities) has slowed down decarbonisation, keeping the cost of low carbon technologies relatively high (compared with incumbent technologies)**. This has been the case especially in sectors that face greater outside competition and have continued to receive free allowances, such as most foundation industries. In conjunction with each other, a volatile carbon price, political uncertainty and how the allocation of free allowances was determined discouraged companies that rely on capital-intensive means of production from drafting long-term decarbonisation plans and making the significant and risky structural investments needed for deep decarbonisation (Sato et al., 2022).

Drawing on the existing literature and our discussions with our industry partners, we identified several actions that the UK government could undertake. They are:

1) Designing and implementing **policies to create demand for low carbon products and materials.**
2) Designing and implementing **policies that support contextual conditions to encourage innovation or support the scaling up of demand for innovative technologies and approaches** by businesses across the foundation industry value chains.
3) Establishing **international collaboration to accelerate demand for low carbon materials and products globally.**

These broad actions and policy objectives can be addressed through a set of policy measures, falling into four main categories (see Table 3 below): regulatory reforms; financial support and fiscal incentives; risk sharing and risk mitigation mechanisms; and public sector investment. Some key policy measures under each category are discussed below the table.

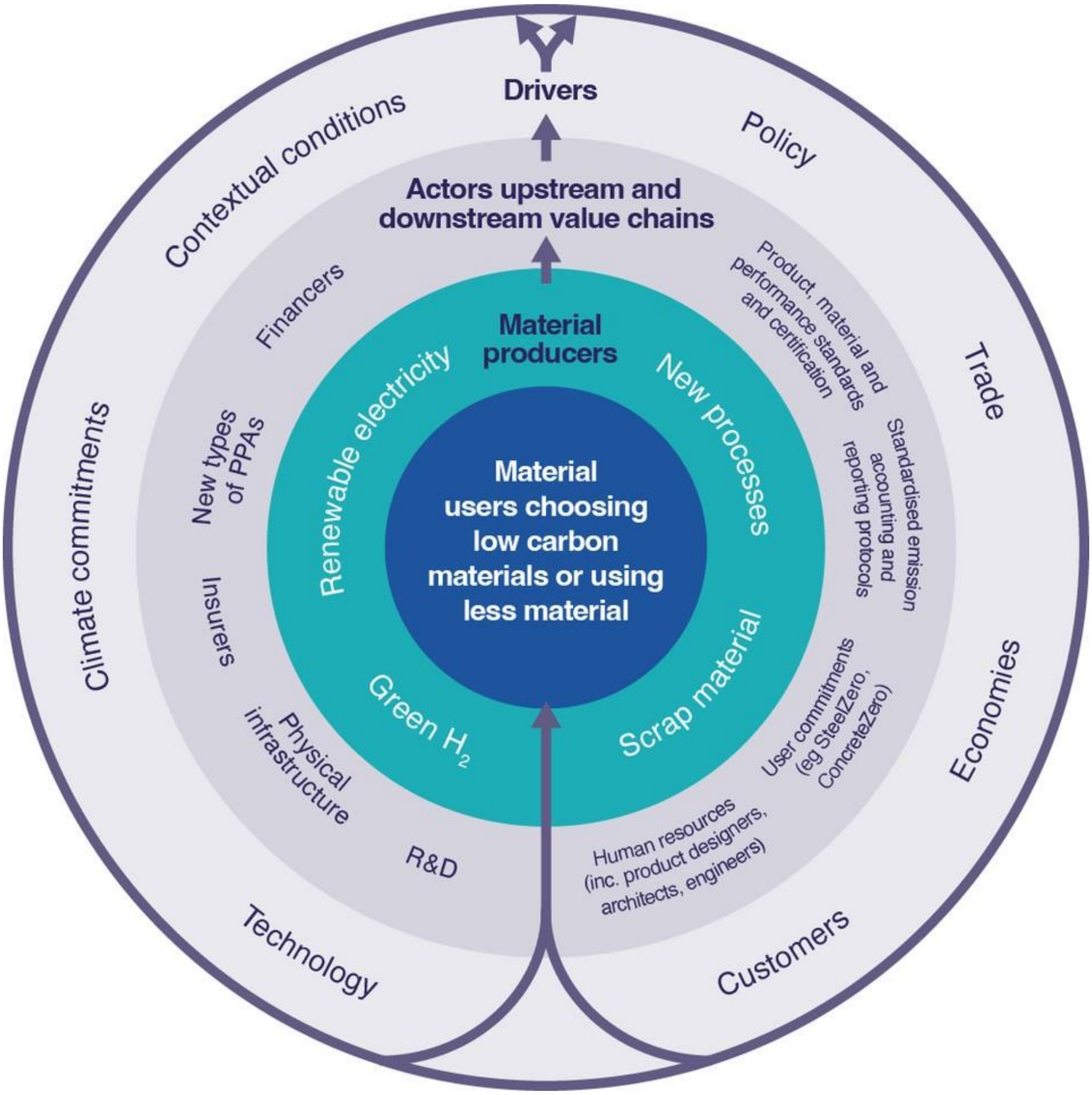
Table 3: Policy measures to support the development of demand for low carbon materials and create enabling conditions for an effective supply-side response



	Key actions the UK government could undertake		
Type of policy intervention	**Policies to create demand and support the scaling up of demand**	**Policies to establish supportive contextual conditions for effective supply-side response**	**International collaboration**
Regulatory reforms	Mandatory product standards on embodied carbon content (across value chains) or recycled material content (Aldersgate Group, 2022), supported by clear emissions accounting protocols and standards Regulation mandating (and creating a framework) for whole life-cycle carbon assessments for material-intensive products (Cannon et al., 2020) Regulatory processes that make it easier and faster to update product and material standards in response to the emergence of new, innovative, solutions Ban on sales of products from emission-intensive processes (Gerres et al., 2021)	Electricity market reform such as green power pools (Grubb et al., 2022) Cap on industrial electricity prices or increased indirect cost compensation for companies that use electricity or green hydrogen to provide long-term certainty that using cleaner energy (ie renewable electricity or green hydrogen) will always be more cost-effective than using fossil fuels Mandatory embodied carbon data collection and disclosure (McKinsey & Co, 2020b) Regulatory sandboxes to test new ideas / materials (German Federal Ministry for Economic Affairs and Climate Change, 2019)	Collaborate with trade partners and other major economies to develop and implement a shared embodied carbon emissions accounting and reporting rules for basic materials and intermediate products, such as the Clean Energy Ministerial Industrial Deep Decarbonisation Initiative (United Nations Industrial Development Organisation, 2023) Support initiatives that are led by the private sector and non-governmental organisations, such as the Carbon Call initiative (The Carbon Call, 2023) Collaborate with major trade partners to implement policies, such as the Carbon Border Adjustment Mechanism (CBAM) or 'climate clubs' (Financial Times, 2023; Markkanen 2021; OMFIF, 2023)
Financial support and fiscal incentives	Tax deductions / exemptions for user companies who commit to buying 'low carbon' (for incrementally growing share of material demand, assuming available supply) Fiscal incentives for companies further down the value chain (ie foundation industry material users) to invest in new product designs to make products more recyclable	Carbon tax or Emissions Trading System (ETS) Capital subsidies, grants and subsidised loans that cover a considerable share of the capital cost of investing in newly emerging experimental technologies as soon as they reach the market, but incur a considerable cost premium Tax exemptions for certain investments (eg deployment of transformational technology) Tax deductions or exemptions if revenue is recycled for certain purposes, such as R&D or investment in low carbon production technology Fiscal incentives to support investment in innovative solutions, including experimental new technologies and new business models Fiscal incentives for companies expanding their operations to cover recycling during the early stages of the transition to a more circular economy (including quality testing operations for recycled and reusable materials, components and products)	
Risk sharing and risk mitigation mechanisms	Government-backed insurance schemes for new products, recycling businesses, and recycled products and materials	Incentives for insurance providers to create new products for low carbon markets (eg providers and users of experimental / novel technologies) Carbon Contracts for Difference (CfD) for foundation industry materials (Chiappinelli & Neuhoff, 2020) Government-backed insurance schemes for new products, recycling businesses, and recycled products and materials	
Public sector investment	Revision of public sector procurement rules (embodied carbon limits and recycled content requirements) (Grubb et al., 2020) Allocation of government contracts to first movers (OECD, 2016) Operations that receive government subsidies could be subject to minimum requirements on low carbon material use / maximum levels of embodied emissions	Public sector infrastructure investment (eg waste management and recycling, electricity grids, hydrogen supply and distribution) Grants and low-cost loans for the private sector for transformational technologies Allocation of government funding to support convening activities and funding programmes by non-departmental government bodies to support knowledge generation and collaboration between academic institutions and the private sector to facilitate the emergence of new insights, best practices and innovative solutions	

The interrelationship between policies, contextual factors, decarbonisation pathways and companies across the foundation industry value chains is illustrated in Figure 6 below. The purpose of this figure is to depict how demand, driven and enabled by complex factors, could flow across the ecosystem to enable companies across the foundation industry value chains to decarbonise their operations, resulting in low carbon materials and products.

Figure 6: Demand-driven ecosystem to facilitate decarbonisation in foundation industry value chains



Source: Created by authors

6.1 Regulatory reforms

Regulation can play a hugely important role in driving demand for low carbon materials and products, as well as affecting the ability of the supply to respond to demand-side signals.

Although many of the policy measures mentioned in Table 3 are well known and widely used, some ideas are novel or have not yet been applied in foundation industry decarbonisation. For example, regulatory sandboxes (German Federal Ministry for Economic Affairs and Climate Action, 2019), which provide a real-life environment for testing innovative technologies, products, services or approaches that are not compliant with the existing legal and regulatory frameworks, have previously been used predominantly in the finance industry (Glossop, 2021). However, they could potentially be used to create the opportunity for companies in manufacturing sectors to test products that have been made using new technologies or novel production practices, to assess their suitability and fitness for purpose in real-life conditions, and for policymakers to identify if regulatory changes should be made to enable these products to access the market. Regulatory sandboxes could also be used to explore the regulatory and legislative frameworks that need to be created to support data collection and sharing on embodied carbon emissions.

Product standards can mandate a minimum level of environmental performance and incentivise producers to adopt low carbon technologies and production methods, leading to innovation and overall sustainability improvements. Product standards can also support the reduction of embodied carbon emissions associated with the entire life cycle of products. **Product standards that set limits on embodied carbon content could nudge consumers towards more sustainable products and disincentivise the sale of higher carbon products, thus stimulating investment and innovation in low carbon materials by creating confidence about future demand.** To be effective, these standards would need to be well designed, mandatory and tightened over time (Frontier Economics, 2022).

By implementing mandatory product standards, the UK government could ensure that industry is competing on a level playing field, and companies pushing further on reducing emissions are not put at a competitive disadvantage (Frontier Economics, 2022). To remain effective, product standards could be made dynamic and adaptable through increased digitisation efforts, reducing implementation costs. Stakeholder engagement could also be incorporated to determine the validity periods of assessments and certifications.

However, to avoid hindering innovation, emissions intensity standards should be technology neutral and focus on performance instead of using specific technology or material inputs (CISL & Agora Energiewende, 2021). It is important for product standards to be influenced more by the performance of products than by the material inputs or the use of specific production technologies. Updating and revising these standards should also be responsive to the emergence of new, innovative, solutions. For example, the current standards for cement and concrete are based on incumbent technologies that are emission intensive by design, although performance-based standards would be more neutral, incentivising innovation and making it more feasible for downstream companies (such as the construction industry) to switch to new low carbon alternatives.

Some countries are already moving in this direction. For example, the PERFDUB project in France aims to establish a performance-based methodology to ensure the durability of concrete and to create an operational and practical performance-based approach that can be adopted by all stakeholders in the construction industry. This will involve defining the ‘absolute’ and ‘comparative’ methods for justifying durability through gathering input and feedback from all stakeholders to identify and address gaps in the current framework. The goal is to create an operational and practical performance-based approach that can be adopted by all stakeholders in the construction industry (PERFDUB, 2015; Linger & Cussigh, 2018). The results of the PERFDUB project have been incorporated into the new concrete standard published at the end of 2022, creating opportunities for the use of innovative formulations within the new standard.

Labelling schemes are another tool that can be implemented independently or alongside product standards and other policy measures. **Labelling schemes can support decarbonisation by providing clear information about the carbon emissions of cement products, incentivising sustainable production, empowering consumers to make informed choices and driving innovation in low carbon technologies.** Such schemes have already been effectively applied in relation to the operational emissions of various products, such as white goods. However, labelling schemes must balance accuracy and accessibility to avoid confusion during the purchasing process. Colour codes or scales can simplify messaging but may sacrifice scientific precision. Additionally, business-to-business transactions may require support to bridge knowledge gaps between purchasers and suppliers, such as Japan’s Act on Promoting Green Purchasing (Ministry of the Environment, Japan, 2016) and the Buy Clean California Act (California Department of General Services, 2023).

Although there are currently no limits in place for embedded CO_2 in final products that are material intensive, these emissions will eventually need to be regulated to keep global warming below 1.5 degrees centigrade. Pressure is already growing on the construction and consumer product manufacturing sectors to provide information on the embodied emissions of their products, and to minimise them where possible. Demand for low carbon materials from downstream production processes is growing, albeit slowly. Automotive companies such as Polestar that make products using low carbon processes are looking to procure carbon-neutral parts, which are often made from specialised metals. Technology companies such as Apple have also announced plans to buy carbon-free aluminium for its products. Although metals are not currently priced based on their carbon footprint, this could change in the future, especially with the introduction of carbon passports and labelling schemes (McKinsey & Co 2020).

Regulatory frameworks and standardised emissions accounting and reporting methodologies will need to be used by all suppliers to enable companies further down the value chain to make informed choices about how best to reduce their scope 3 emissions. Attempts and plans to design reporting protocols and mechanisms for specific sectors or product categories are already in place in the UK (WRAP, 2022) and the EU (Simon, 2022). For example, France's RE2020 programme seeks to enhance the energy efficiency and environmental performance of all new buildings through regulation that requires all new buildings that are built in the country after 2020 to have very low operational and embodied emissions. The RE2020 guidelines cover the complete lifespan of the building and gradually decrease the acceptable emissions limit for new constructions over time (RTE, 2020). However, it is not only up to governments to push for progress here: some progressive companies and non-governmental organisations are already collaborating to design systems for embodied carbon data accounting and sharing, independent of government support, for example under the Carbon Call initiative (The Carbon Call, 2023).

It is important for the UK government to collaborate internationally to ensure that carbon content accounting and reporting mechanisms in the UK are aligned internationally and across sectors, to make it easier to compare the carbon content of materials and intermediate products in multiple countries. The EU has already announced plans to implement the DPP as a mechanism for information sharing; however, as previously mentioned, this is not yet complemented by a shared standard for embodied carbon accounting and reporting (CISL & Wuppertal Institute, 2022). It is in the UK's best interests to collaborate with trusted trade partners that have similarly ambitious climate targets (for example, the EU, the USA and Japan) to design regulatory frameworks on embodied emissions accounting and reporting. Shared accounting and reporting mechanisms are necessary for implementing many other regulatory tools, such as standards that set maximum acceptable embodied carbon content for products (Aldersgate Group, 2022) and bans on the sale of materials that are manufactured using emission-intensive processes (Gerres et al., 2021). Such sale bans could effectively set near-zero emission requirements for certain products and materials, accelerating the phase-out of carbon-intensive production processes. Most importantly, the announcement plans for a future sales ban would send a strong signal to producers, financing institutions and other stakeholders, incentivising them to invest in the shift to a carbon-neutral society.

The downside of embedded emissions accounting and reporting standards is that they may attract vocal opposition from companies that either do not wish to share these data or find the task of implementing these methodologies economically unviable (Bolton et al., 2021). For example, the development of specific methods for embodied carbon accounting in the cement industry has proven challenging: the most accurate measure – which calculates CO_2 emissions based on the weight and composition of carbonates in raw materials and fuel sources, the emissions factor of carbonates and the proportion of calcination achieved – is also the most data intensive, and therefore may be difficult to implement in practice (Liao et al., 2022).

Case study 12: Scottish Power – Regulatory and policy challenges for green hydrogen

Green hydrogen, produced using 100 per cent renewable electricity, can make a significant contribution to the government's decarbonisation goals, particularly in sectors that are hard to electrify, such as heavy industry and heavy transport. However, developers of green hydrogen production projects, including Scottish Power, face several regulatory and policy barriers. These barriers, some of which are outlined below, need to be addressed if the hydrogen sector is going to realise its potential.

Smaller-scale green hydrogen production can be co-located with renewable assets such as onshore wind or solar PV, reducing (but not necessarily eliminating) the demand for grid-imported electricity to power the process. However, larger-scale green hydrogen production is likely to be reliant on grid-imported power. To make this type of production financially viable, the non-energy-related costs associated with electricity access for green hydrogen production (such as the network access and policy costs) must be cost-reflective, proportionate and support the development of the green hydrogen projects in the UK.

In terms of **network access costs**, it is appropriate for green hydrogen producers to pay any cost-reflective charges associated with delivering power through the grid. However, if hydrogen production is linked directly to a renewable asset (even if this is through the grid) and producing hydrogen only when that renewable asset is generating, it may not be appropriate to apply the standard balancing system charges because the hydrogen project is effectively helping to balance the system. The same applies to the Capacity Market Levy, as the hydrogen production plant will not need the security of supply assurance provided by the Capacity Market.

In terms of **policy costs**, green hydrogen production could be justifiably exempt from paying the Climate Change Levy (CCL), given that it would be using 100 per cent renewable energy to produce a zero carbon product. Moreover, hydrogen production plants that are directly linked to renewable energy assets should also be exempt from the policy costs of supporting renewables, such as through the Renewables Obligation[1], Contracts for Difference (CfD) and small-scale Feed-in Tariffs (FITs). With this is mind, Scottish Power welcomes the Department for Business, Energy and Industrial Strategy (BEIS) proposal (BEIS et al., 2022) to increase the exemption for energy-intensive industries from 85 per cent to 100 per cent.

The **regulatory framework around metering needs to be amended** to facilitate renewable hydrogen projects that need access to grid-connected renewables. Hydrogen production can play a valuable role in **system balancing** and alleviate **system constraints** by turning down at times of high demand on the system and using renewable electricity that could not otherwise be distributed to consumers through the grid to produce hydrogen. This could facilitate higher uptake of renewable electricity, and reduce the need for load shedding, especially if the hydrogen production was sited appropriately and had the right signals to operate. However, the elements of the **network charging arrangements** that are dependent on location and **the current system of constraint payments** (ie how renewable generators are paid when they are required to turn down their generation as a result of excess supply) would need to be reviewed to ensure that hydrogen production can contribute to the overall economic efficiency of the electricity system. It is essential that the design of the ancillary services market allows hydrogen producers to contribute and be properly rewarded for the services they provide.

Scottish Power welcomes the introduction of mechanisms to support the production of low carbon hydrogen, including both the BEIS Hydrogen Business Model (HBM) and the Renewable Transport Fuel Obligation (RTFO). These mechanisms, which provide a top-up payment to low carbon hydrogen producers, will play a vital role in reducing the price of hydrogen to a level that makes it attractive for consumers to make the switch to hydrogen technologies. It is vital, however, for the complexity of these mechanisms to be reduced, wherever possible. Government foresight around the extent of support and the timing of allocation rounds is likewise needed to allow developers to plan their investments with confidence.

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[1] An obligation on licensed electricity suppliers in the UK to source a proportion of their supply to customers from eligible renewable sources.

6.2 Financial support and fiscal incentives

Financial support (such as grants and subsidies) and fiscal incentives (such as favourable tax treatment) have been widely used to nudge individuals, households and companies to make more sustainable choices, particularly in relation to energy use, energy efficiency and transport choices. Thus, they have been effective in increasing the adoption rates of solar PV by business and households, and the sale of electric vehicles, among other things. Financial support and fiscal subsidies, with long-term sustainability objectives, feature prominently in the 2022 US Inflation Reduction Act (IRS, 2023).

In relation to the foundation industry decarbonisation challenge, **grants, subsidies, subsidised loans and fiscal incentives can take many different forms and be deployed to influence the behaviour of actors across the value chains**. For example, the UK government can support the very early stages of innovation and demonstration of new technologies and production processes by issuing grants and low-cost loans to universities and the private sector for R&D into developing and testing transformational technologies and new approaches. However, it may also choose to make some financial incentives available for companies to purchase, or commit to the purchasing of, low carbon materials (such as SteelZero and ConcreteZero featured in this report), companies that invest in new product designs to improve recyclability, or companies that either expand their existing operations, or emerge, to improve the recycling of materials within the UK. Some examples of ongoing initiatives from other countries include the Netherland's CO_2 performance ladder, which assists organisations, companies and projects to reduce their carbon emissions. By obtaining a certificate on the Ladder, organisations can gain a competitive advantage in their bids for tenders (OECD, 2016).

6.3 Risk sharing and risk mitigation mechanisms

Multiple policy solutions could be implemented to incentivise innovation by de-risking investment by guaranteeing demand and revenues. The de-risking of investment can be achieved through conventional methods to guarantee revenues, such as regulations or product standards (eg electric vehicle innovations are de-risked by banning the sale of internal combustion engine vehicles in the long term), or through the use of financing instruments (eg capital subsidies or subsidised loans) to subsidise innovative products and processes through.

De-risking can also be achieved by directly guaranteeing revenues up to a given level. Examples include feed-in-tariff (FiT) and Contract-for-Difference (CfD) systems, whereby governments make advance commitments to pay a fixed CO_2 price to investors. CfDs have previously been used in the energy sector, but could also be applied to the foundation industries (Chiappinelli & Neuhoff, 2020). In the power sector, a combination of carbon pricing and CfD worked effectively to incentivise the development and uptake of renewable electricity technologies, while also mitigating the investment risk. The increased uptake of low carbon technologies then further reduced their risk profile and capital costs as a result of greater technical and construction experience. Consequently, the Levelized Cost of Electricity (LCOE) from renewable sources has declined rapidly (BEIS, 2020), below the cost of electricity produced from fossil-fuel sources.

One increasingly important de-risking mechanism as industries develop innovative solutions – which may affect the material composition of products – is the need for innovative products and technologies to be insurable. **Taking out an insurance is a standard risk-mitigation mechanism that is chosen, but in many cases is also legally mandated, in various situations.** The inability to insure 'novel' or less well-known products or technologies, or excessively high insurance premiums, presents a major disincentive to innovation and the upscaling of innovation.

6.4 Public sector investment

Public sector investment will need to play a key role in accelerating demand for low carbon materials and products, as well as creating enabling conditions for effective supply-side response to demand signals. Some of these, such as grants, loans, subsidised loans, subsidies and fiscal incentives, have already been mentioned above.

As a significant consumer of many foundation industry materials, including steel, cement and glass, the UK government, devolved administrations (Northern Ireland, Scotland, Wales and England) and local **authorities can accelerate demand for low carbon materials and products by adopting public sector procurement rules that are aligned with the net zero target**. The scale of public sector spending is substantial: in 2019–20, a total of £295.5 billion was spent by over 10,000 public sector authorities and organisations in private sector procurement of various goods and services, accounting for about a third of public sector spending (32 per cent) (UK Parliament, 2022b). Public sector procurement rules aligned to net zero could set embodied carbon limits or recycled content requirements on all materials used in public sector infrastructure projects (Neuhoff et al., 2021). Suppliers could be informed of the policy through official channels, with compliance being monitored through inspections or audits.

Such public sector procurement rules could encourage low carbon cement production and support sustainable development. However, to effectively implement such policies, staff training and investment in R&D would be necessary. The US Federal Buy Clean Initiative (United States Office of the Federal Chief Sustainability Officer, 2023) is a good example of gradually introducing policies and encouraging reporting to set appropriate benchmarks. Flexible and accessible product standards, digitisation and industry engagement can also help to reduce implementation costs and increase compliance. Another, less frequently mentioned option, would be to allocate government contracts to first movers.

The government, at all levels of governance, needs to invest both urgently and heavily in developing the infrastructure required to facilitate foundation industry decarbonisation along the pathways described in Section 4 of this report. To enable all efficient supply-side response to any demand signals, this would need to encompass waste management and recycling, electricity grids, and hydrogen supply and distribution.

6.5 Demand-side policies in action: using the steel sector as an illustrative example

As mentioned in Section 5, strong demand-side signals are needed to support the effective and efficient decarbonisation of the UK steel industry. These signals must flow through the entire value chain and all sectors that use large quantities of steel (such as construction, transport, appliances and the intermediate products going into the manufacturing processes). This, in turn, will support the development of low carbon, resource-efficient steel markets. To cultivate and sustain a reinforcing loop between value chain actors who push for sectorial decarbonisation, strategic innovation and policy mechanisms are needed. In this section, we focus on a few specific demand-side policy instruments that substantially improve the financial viability of low carbon steel production in the UK.

Targeted procurement policies. The vast quantities of steel-containing products purchased by downstream sectors must meet the demands of private and public sector clients, including the embodied carbon value. The UK government, which funds most of the infrastructure projects that consume large quantities of steel, should lead the way in mandating low CO_2 steel, measured by emission factor and/or recycled content. Procurement policies may also mandate a minimum amount of UK-produced steel to protect local industry against cheap imports, alongside anti-dumping polices. The struggle to compete against cheap steel imports is not a challenge unique to the UK (United States Department of Commerce, 2018) – it is also felt by the US and EU steel sectors. We must provide steel manufacturers with the assurance of demand to invest in decarbonised technology and practices.

Consistent, cross-border carbon pricing. A consistent and effective carbon price for all steel producers is necessary to level the playing field. Peculiarly, the current effective carbon price (levied carbon price minus compensation) paid by BF-BOF steel producers in the UK is less than that paid by EAF steel producers (Allwood et al., 2019). Given the global nature of steel markets, domestic climate policies must take into consideration the policies that are in place in trade partner countries to: (i) assure market competitiveness, and (ii) reduce the risk of carbon leakage. One carbon policy solution would be to impose comparable penalties to the UK carbon price on imported products based on their embodied carbon content through a UK carbon border adjustment mechanism (CBAM). It has been argued that a CBAM would benefit the UK steel sector by increasing steel import prices (UK Steel, 2022). Positively, for consumers of steel further down the value chain, the added costs burdens of a CBAM would likely be minor; at

£100/tCO_2, the average car could cost an extra £150–200 to produce, which is 2 per cent of the selling price. However, because of the necessary phasing out of free ETS allowances, a CBAM would decrease the competitiveness of UK exports of steel and steel-containing products in jurisdictions where the carbon price is not as high as in the UK, or where steel manufacturers are eligible for free allowances for the domestic steel industry. Revenue from carbon pricing schemes should be fed into industrial decarbonisation support.

Fair and visible life-cycle emissions accounting. To support carbon pricing, strong industrial regulations must be enforced for embodied carbon certification within steel products, and a standard global emissions accounting method agreed upon that covers the entire product life cycle. Life-cycle analysis methodologies and inventories must be consistent across the global market, especially regarding the boundary definition and input data for emissions accounting tools. Alongside transparent embodied carbon declarations, publicly available supply chain information should be mandated and normalised in annual company reports.

A stable renewable power supply and a fair price for electricity are required to support the electrification and decarbonisation of steel manufacturing. To achieve this, the national electricity grid capacity needs to increase. Energy sources switched to renewables and/or captive, islanded, renewable energy systems need to be developed specifically for high-demand uses, such as the steel industry. As an EAF works in a flexible batch mode, it can be integrated with variable renewable energy to optimise available resources as a demand–response management technique to balance the power grid. Current industrial electricity tariffs in the UK (£137/MWh, including taxes) are 40 per cent higher than the EU median and 120 per cent above US prices (DESNZ, 2022). Globally, electricity accounts for ~12 per cent of EAF steel production costs (Steel On The Net, 2020). This percentage would be much larger in the UK. A fair price on electricity is required to enable today's scrap-based EAF steelmaking facilities to regain market competitiveness, and future electricity-intense steel production to obtain an investable business case.

Electricity market reform will be required to appropriately reflect the growing share of cheap renewables: electricity auctions for UK offshore wind are reaching £48/MWh (in today's money) (Carbon Brief, 2022) for production in 2026–27, which is more than 60 per cent below the current industrial electricity tariffs. Nearly half of the UK's delivered power in 2020 was zero carbon, with renewables accounting for 43 per cent and nuclear for 16 per cent (National Grid, 2023a), and the UK government has committed to complete decarbonisation of the power grid by 2035. Novel renewable electricity contracts such as long-term power purchase agreements (already in place) and green power pools (recently proposed) (Grubb et al., 2022) may be successful in supporting low carbon electricity generation and consumption, and maintaining efficient supply–demand market dynamics. The recent subsidies available to UK steel producers under the Energy Bill Relief Scheme, which capped electricity prices at £211/MWh for businesses for 6 months up until March 2023 (Lawson, 2022), were insufficient in effectively addressing the high electricity costs and providing long-term certainty for industry.

7. The macroeconomic benefits of demand-led approaches to support innovation

This modelling exercise illustrates the impacts that demand-led innovation can induce in the UK economy. Demand-led innovation is innovation that happens to meet the requirements of consumers or buyers, in a process often also described as market pull innovation. Supply-led or technology push innovation, on the other hand, describes a situation where a given technology improves because of process innovation as more of a certain good or service is supplied to the market, to the extent that it is able to compete for, and capture, market share (Brem, 2008).

This analysis focuses on innovations towards low carbon solutions in the so-called non-metallic mineral products (NMMP) sector. This sector includes industries with substantial carbon emissions and abatement potential, such as cement, glass and ceramics production. The analysis compares the effects of two modes of innovation on the UK economy by establishing two deliberately extreme scenarios: **in the supply-led scenario, innovation is led by the**

price of the technology; in the demand-led scenario, new innovation is adopted to meet consumer demand for low carbon goods. Ways of decarbonisation and potential solutions were considered based on discussions with SMART group members, sectoral plans and research publications by industry organisations (British Glass, 2021; Czigler et al., 2020; MPA UK Concrete, 2020), firm-level decarbonisation plans and also the academic literature (Ahmad et al., 2022; Faber et al., 2022; Gardarsdottir et al., 2019; Habert et al., 2020; Zier et al., 2021).

The modelling exercise was carried out using the E3ME macroeconomic model (Cambridge Econometrics, 2022). This is a detailed and complex model, integrating economy–energy–environment modelling with the aim of understanding impacts and interactions across these areas. The E3ME model is built on post-Keynesian economic thought, understanding the economy as a demand-led system. It differs from general equilibrium-based economic modelling in the sense that it assumes that there could be unused capacities in the economic system (eg involuntary unemployment is possible), that there is path-dependency in the economy without full optimisation across the agents (no central planner) and that money in the economic system is endogenous (as in created by financial institutions through loans). This approach is largely beneficial for the current analysis in practical terms: the endogenous money approach allows money supply to increase as innovations are being implemented, path-dependency means that (in line with empirical observations) if a technology is implemented on a larger scale its costs decrease faster (eg as happened in the case of solar PV technology), and the notion of unused resource allows the economic and labour system to react positively to new investments that arise from government policy.

Based on this framework, **the modelling results show that guaranteed downstream demand for low carbon goods could drive the upscaling of low carbon technologies within the studied sectors, which in turn could lead to a quicker cost decrease through learning-by-doing and market competition effects**. In other words: in a world where demand for low carbon goods is guaranteed, the economy will find solutions to supply those goods. As those solutions are found, their cost will decrease not only because suppliers will see economies-of-scale effects, but also because competition will drive prices down as more firms enter the ‘green goods’ market.

7.1 Modelling demand-led low carbon innovation in the cement sector

Cement, lime and concrete production in the UK

Statistics about cement, lime and concrete are available with varying degrees of detail. In 2018, these industries were responsible for 0.18 per cent of UK GVA (gross value added) and 0.23 per cent of UK total output, equivalent to ~£3.4 billion in GVA and £8.6 billion output (ONS, 2022a). Emissions related to energy consumption and employment are available at the level of the whole non-metallic minerals sector. Employment figures indicate that employment has decreased significantly since the start of the 2000s, and in the last five years have stagnated at ~80,000–90,000 people or 0.27 per cent of total UK employment (ONS, 2022b) (see Annex 2 for details). The NMMP sector is responsible for ~0.8 per cent of total energy emissions in the UK (EEA, 2021). Other indicators are available with a higher granularity: for example, data on process emissions shows that cement, lime and concrete production are responsible for ~23 per cent of the total process CO_2 emissions in the UK (EEA, 2021).

Based on these statistics, we note that the sector makes a substantial contribution to employment and the economy in the UK. Looking at the NMMP sector, it has a slightly higher proportion of UK GVA than employment, which indicates higher-than-average productivity. However, the energy intensity and the emissions intensity of the industry are also clear. The share of energy-related CO_2 emissions in total UK emissions is higher than the industry’s output share, which demonstrates the higher-than-average energy intensity of production. Moreover, the contribution of the industry to process emissions is rather high, given that 7 per cent of total emissions in the UK are process emissions. As a result, cement, lime and concrete production, through process emissions alone, are responsible for ~1.6 per cent of total UK emissions.

Low carbon innovations in the cement sector

Decarbonising cement and concrete production, especially focusing on process emissions, could be a substantial contributor to overall decarbonisation, and a step towards achieving a net zero economy. Based on desktop research, industry association documents, the academic literature, company documents and stakeholder discussions, we identified several solutions relevant for decarbonisation of the sector. We categorised these solutions into different groups for the purposes of modelling:

(1) Energy-use emission reductions
    a. Fuel switching in auxiliary processes (ie transport)
    b. Fuel switching in direct production processes (eg biomass use)
(2) Process-related emission reductions
    a. Clinker substitution, use of supplementary cementitious materials (SCMs)
    b. Carbon capture, utilisation and storage (CCUS)

The costs, maturity and potential impact of these solutions differ widely. Nevertheless, they are the cornerstones of decarbonisation strategies across the industry. This fact is supported by a review of the sustainability and net zero strategies across a sample of UK firms that are active in the industry (see section 7) and the review of MPA UK Cement's net zero strategy (MPA UK Concrete, 2020).

Three solutions: SCMs and clinker substitution, fuel switching to biomass and CCUS, are expected to be responsible for ~89 per cent of the emissions reductions on the path to net zero emissions. Therefore, in the scenario design we focused on these solutions. To better understand the potential and implementation of these solutions, we conducted stakeholder interviews and data collection. However, it is worth noting that additional emissions reductions could be achieved by reducing the use of concrete through improved circularity and material efficiency (see Case study 6).

Scenario design

The two scenarios that are modelled (demand-led and technology cost led) focus on the innovations listed in the previous section. The modelling focuses on the introduction of these solutions to the cement sector. It applies changes to the input–output (IO) structure, representing supply chains, to the energy use of the sector and also to the costs (and hence prices) of the sector.

Both scenarios employ the same methods for decarbonisation; however, the timing and magnitude of these measures are different across the scenarios.

In the **technology cost led scenario**, the decision rule for introducing the solutions is: if the cost of the implementation (including both capital investment, or CAPEX, and operating costs, or OPEX) per tonnes of emitted carbon (c_t) (with $_t$ indicating time) is less than the relevant carbon price (p_t) in the given year, then the solution will be implemented in a given share (μ) of the market. The share of the market implementing the solution is calculated simply as:

$$\mu_t = \frac{c_t}{p_t}$$

In practice, this means that the technology is not implemented until it is more expensive to pay the carbon price (UK ETS price) than to implement the given technology. However, once the technology is cheaper, its take up will accelerate as the difference between the carbon price and the cost of the solution increases.

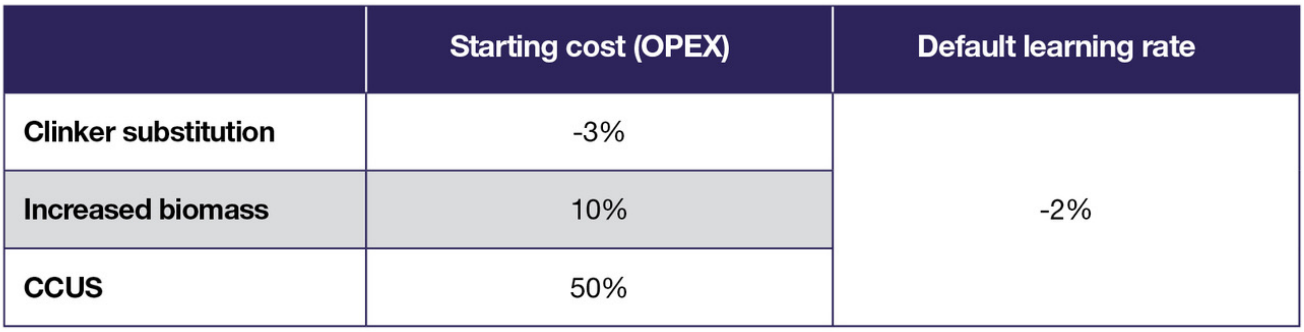
In the **demand-led innovation scenario**, we assume that there is market demand ('market pull') for low carbon technologies. To estimate demand for low carbon goods, we analysed the scope 3 commitments and targets of industries that are purchasers of goods produced by the cement and limestone sector. We found that the main buying industry is the construction industry, and we therefore focused on commitments by this sector.

We reviewed sustainability reports, net zero plans and other materials from 15 construction companies that are active in the UK, with aggregated revenues totalling ~£50 billion. We then constructed a scenario that meets industry-level plans, and is also in line with 'consumer demand' for scope 3 emission reductions.

For each of the solutions introduced, we used increased (or decreased) operating expenses (OPEX), which are passed on to industry prices; introduced required capital expenditures (CAPEX) as appropriate; changed both the IO structure and the energy consumption structure; and decreased process emissions where relevant.

Based on the data collection and assumptions about how technologies will mature, we used the cost curves shown in Figure 2 to represent costs in the industry. These cost curves are based on the starting assumed costs, annual learning rates and a decrease in costs due to increasing capacity ('learning by doing') over time. See Table 4 below.

Table 4: Starting costs and learning rate – cement



	Starting cost (OPEX)	Default learning rate
Clinker substitution	-3%	-2%
Increased biomass	10%	
CCUS	50%	

CAPEX is modelled for CCUS capacities only (as it is not applicable for the clinker substitution or increased use of biomass), with the assumption that ~40 per cent of total costs are capital costs (United Nations Climate Technology Centre & Network, 2022).

The decarbonisation actions drive changes to the supply chain structures of the industry. To capture this, we dynamically changed the IO structure used in the modelling. In the cement industry scenarios, this meant increasing the demand for intermediate goods from other sectors: agriculture (biomass), transport, mining and electricity (CCUS), and basic metals (clinker substitution, eg ground granulated blast-furnace slag). See Annex 2 for details about the assumed IO changes that are gradually introduced over time.

The energy mix (ie the fuels used in production) is changed for the sector to increase the share of biomass, in line with the assumptions made for the scenarios. Because of the nature of the E3ME model, a change in the mix of the energy consumed will also have follow-on induced effects; as the cost of inputs changes, so too will the prices charged by the industry, while emissions will change based on the type of fuel used.

In this case, we simulate fuel switching in such a way that reductions occur in the consumption of oil and coal first. Once these are depleted (ie are no longer used in the sector), then natural gas use will be decreased, while biomass use is increased.

Process emissions are reduced in line with the implemented measures. While fuel switching does not lead to a direct reduction in process emissions, clinker substitution and CCUS implementation do reduce these emissions. Clinker substitution and SCMs are assumed to be able to reduce process emissions by 30 per cent, while the rest need to be eliminated by the use of CCUS, putting the maximum reduction from CCUS at 70 per cent of sectoral emissions. It is important to note that within the broader non-metallics sector, cement and limestone production are responsible for ~94 per cent of all process emissions (EEA, 2021). Therefore, process emissions first and foremost need to be mitigated within this sector.

Results

Our results focus on two main areas: economic and emission abatement outcomes. The analysis covers both the sectoral impacts and the economy-wide impacts. It should be noted that results are presented at the level of the non-metallic minerals sector – about 54 per cent of that sector is the cement, limestone and concrete production industry in economic terms, while 94 per cent of process emissions accounted for the sector belong to the cement industry.

Figure 7 provides an overview of the main sectoral results. As panel (a) at the top-left corner shows, output of the sector, compared with the baseline where there is no sectoral decarbonisation, increases in both scenarios. This is driven by decreasing prices, seen in panel (c), which induce higher domestic consumption and displace some international competition (ie imports).

In this case, decreasing prices are connected to the falling process emissions from the sector. As process (and energy-related) emissions are decreased, so is the carbon price component of the price (which otherwise increases further). Therefore, even though there is a price increase due to the implementation of the abatement measures, this is offset by what is gained by having to pay much lower carbon prices in total.

This boosts consumption and production in the sector as well as employment (panel (b)). Output increases by as much as 20 per cent by 2050, while employment increases even more, by close to an additional 30,000 jobs in the same year. Nevertheless, wages might not grow proportionally (as GVA is somewhat lower than baseline), which can lead to lower real incomes, even though the number of people employed is increased.

Comparing the two scenarios, we see that the demand-led innovation scenario, because of its more ambitious nature and earlier start, brings down prices faster, and therefore leads to higher output and employment in aggregate, with minimal trade-offs (until 2030, the scenario has a slightly negative impact on output, due to increased prices).

In terms of emission abatement, much of the reduced emissions are process emissions, which are a major source of emissions in this industry. **By 2050, the scenario reduces total emissions by 80 per cent in the demand-led case and by 69 per cent in the technology cost case**. Note that total emissions in the NMMP sector, of which cement is responsible for ~81 per cent, reach the net zero target in the demand-led case, but not in the technology cost case.

Figure 7: Overview of sectoral results of the cement sector scenarios, non-metallic minerals sector

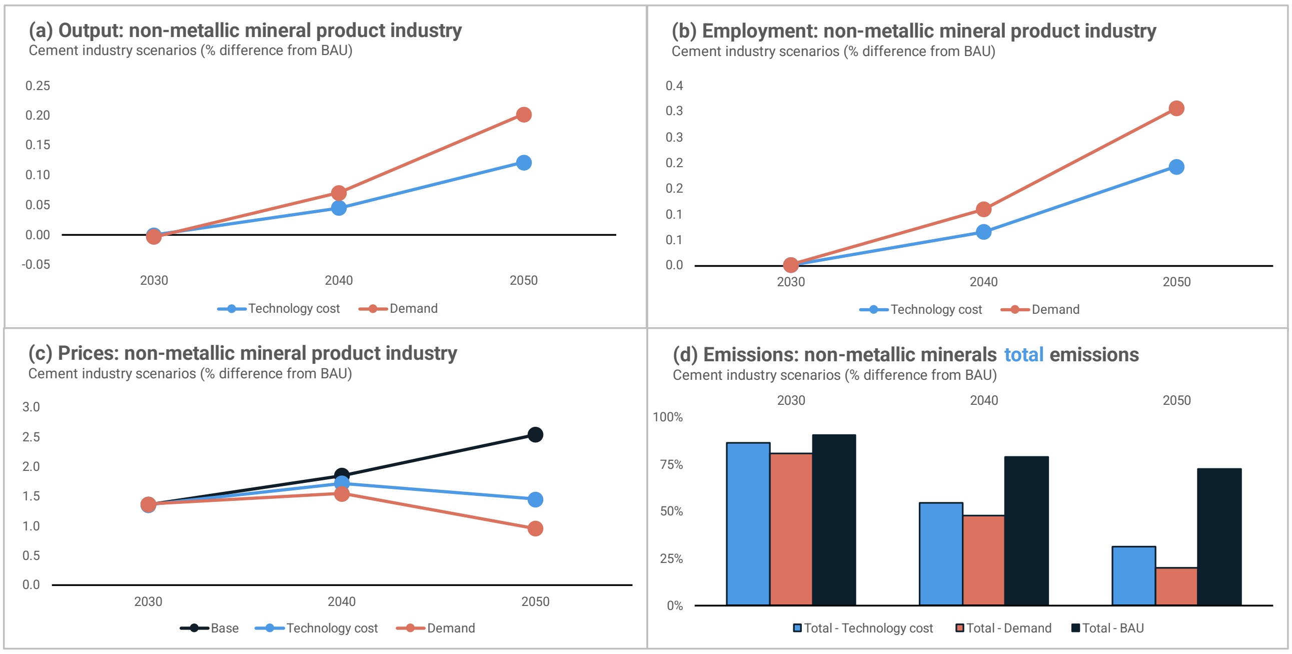
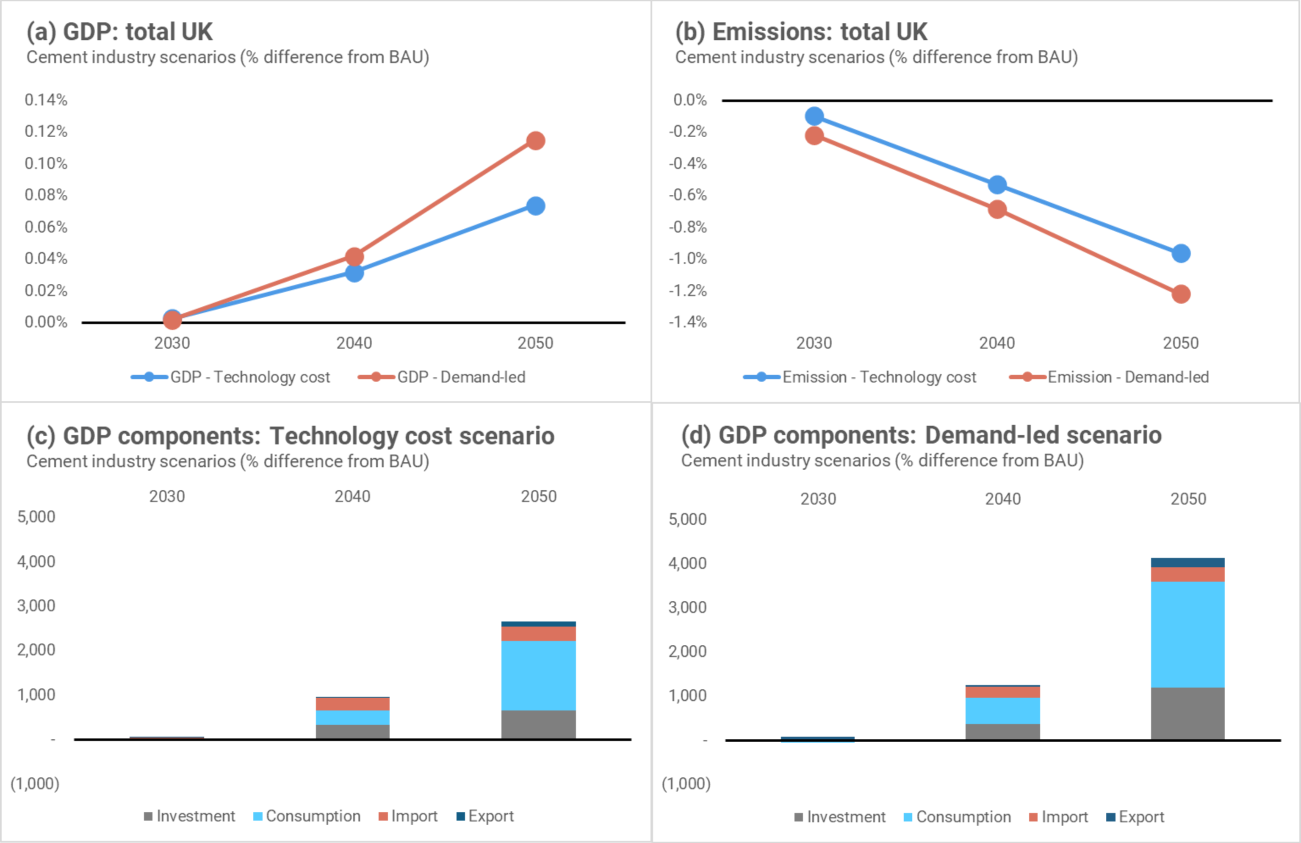


Figure 8 presents the economy-wide results of the scenarios. In panel (a), GDP results are shown to be positive, with a growing trend towards 2050 in both scenarios. Although a similar trend across the scenarios can be detected in the sectoral results, the divergence between the two scenarios, in relative terms, is higher here indicating a greater multiplier effect for the demand-led innovation scenario.

Panels (c) and (d) give more insight into these developments: in both cases, consumption is the strongest driver of the GDP increase, with investments providing a substantial contribution as well. The role of investments is a result of the capital investments that are assumed to happen in order to decarbonise the sector. Increased consumption, on the other hand, is explained by two factors: investment and the decreasing prices in the NMMP sector lead to increased demand, and therefore generate new jobs. These new jobs, in turn, increase aggregate disposable income in the economy, which leads to higher consumption.

Although the GDP impacts of 0.07 per cent and 0.11 per cent are not substantial, they signal how much impact the decarbonisation of a single industry could have on the economy as a whole.

Figure 8: Overview of regional results of the cement sector scenarios, UK



7.2 Modelling demand-led low carbon innovation in the glass and ceramics sectors

Glass and ceramics production in the UK

As for the cement, lime and concrete sector, indicators with various granularity are available for glass and ceramics production. Some statistics are unfortunately available only at the level of broad industry (non-metallic minerals).

The more narrowly defined sector (glass and ceramics) is responsible for ~2 per cent of total UK process emissions, or ~10 per cent of process emissions from the broader NMMP sector (EEA, 2021). The narrowly defined sector also contributes ~40 per cent of total NMMP GVA and ~44 per cent of total NMMP output (ONS, 2022a).

Although there is no indicator for the disaggregated energy-related CO_2 emissions of the sector, these statistics show that the glass and ceramics 'subsector' is responsible for a much lower share of the broad NMMP sector's emissions than cement and concrete production, while its economic share is about half of that for the total industry. Therefore, although decreasing energy-related emissions from glass and ceramics production could substantially reduce NMMP emissions, decreasing process emissions would contribute less than in the case of cement and concrete production. (As explained in the Glass sector deep dive, the main sources of CO2 emissions from glass manufacturing are from fuel combustion (58%) and energy consumption (24%) while process-related emissions only contribute a small amount)

Low carbon innovations in the glass and ceramics sector

Innovations that could decrease the embedded carbon content of these products should therefore focus on fuel switching and electrification within the sector, rather than on eliminating process emissions. Relevant current innovations mostly fall into this category, although some innovations decrease process emissions as well:

(1) Energy-use emission reduction
    a. Electrification
    b. Carbon capture, utilisation and storage (CCUS)
(2) Process-related emission reduction
    a. Increased use of recycled raw materials

As in the case of cement production costs, the potential and impact of these solutions vary, particularly across different product categories (flat glass, container glass, standard ceramics or advanced ceramics). However, there are some commonalities within the broader sector, which were identified both from stakeholder consultations and from industry documents (eg British Glass, 2021).

In the modelling, we focused on three main decarbonisation solutions: electrification, CCUS and raw material recycling. Hydrogen, although mentioned as a solution across the industries, is not currently considered because of the multiple uncertainties about the availability and supply chain of low carbon hydrogen.

Scenario design

Initially, the scenario design followed that described earlier for cement and concrete production (see Section 7.1). Two scenarios and a business-as-usual (BAU) case were defined, and the two scenarios follow either a **technology cost led approach** to implementing decarbonisation solutions or a **demand-led approach**.

The demand-led approach is influenced by the scope 3 commitments of companies that are potential buyers of glass and cement, and are active in the UK. Based on ONS IO data, 63 per cent of the products of the glass and ceramics industry are purchased by the construction industry, 9 per cent by beverages manufacturers, 6 per cent by households directly, and the remainder distributed across other economic sectors. Therefore, in the demand-led innovation scenario, commitments from construction companies and from leading beverage producers were taken into account (see Annex 2).

Costs are considered using the same approach as in the cement and concrete production case (see Section 7.1), but obviously the costs differ. As shown in Table 4, for CCUS, 40 per cent of the total costs are considered to be capital costs (United Nations Climate Technology Centre & Network, 2022), while capital costs for electrification could be up to £12 million per site in the glass industry (British Glass, 2021).

Table 5: Starting costs and learning rate – glass

	Starting cost	Default learning rate
Raw material recycling	-24%	-2%
Electrification	44%	
CCUS	56%	

Notes: based on IEA (2021); Zier et al. (2021)

The shift towards low carbon innovations could cause supply chain changes in glass and ceramics production, just as in cement production. We considered changes similar to those assumed for the cement sector for CCUS implementation: an increased demand for transport, mining and electricity. At the same time, raw material recycling decreases demand for mining and increases demand for goods from the recycling / waste management sector. Detailed IO changes are presented in Annex 2.

The changes in energy mix (ie the fuels used in production) occur as a result of electrification. Gas usage is decreased as electricity usage increases, which leads to increased electricity generation to meet demand.

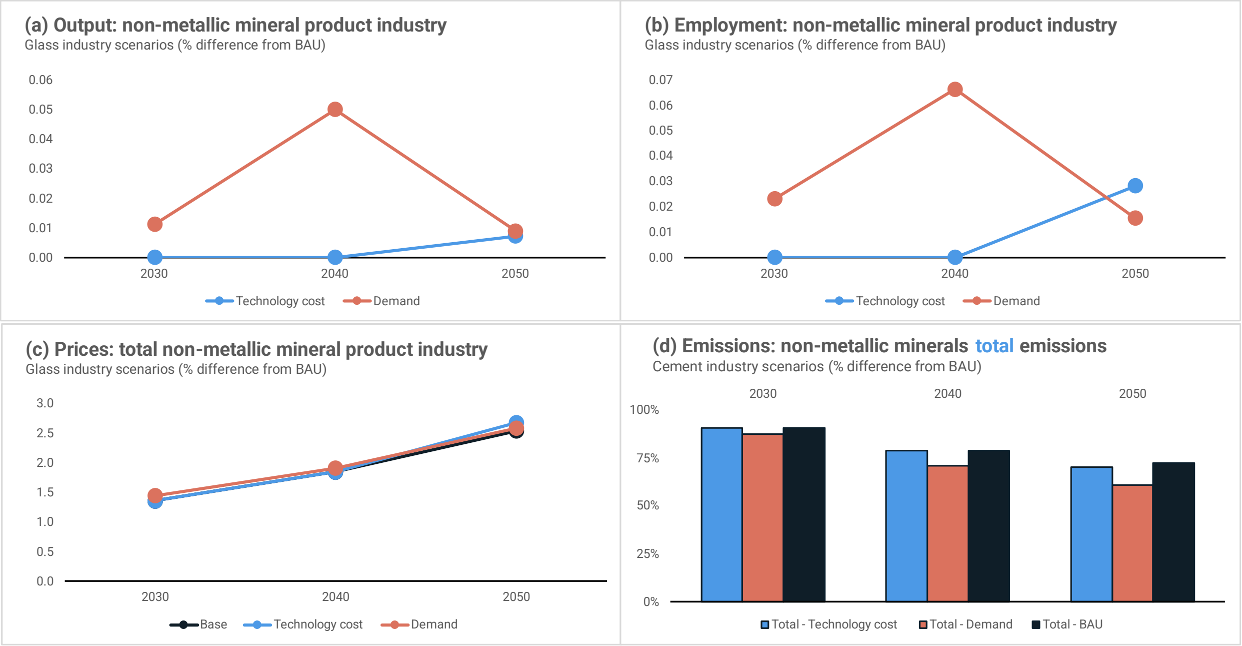
Results

This section presents results of the modelling exercise for the glass and ceramics sector scenarios. Our results focus on two main areas: economic and emission abatement outcomes. The analysis covers both the sectoral impacts (ie the impact within the NMMP sector due to the accelerated decarbonisation of glass and ceramics production) and the economy-wide impacts, including induced supply chain impacts. In economic terms, glass and ceramics production represents ~46 per cent of the overall NMMP sector; however, as discussed earlier, in terms of emissions, glass and ceramics production represents a much lower share.

Figure 9 provides an overview of the main results for the broader NMMP sector. Panel (a) at the top-left corner shows economic output of the sector compared with the baseline (which has no sectoral decarbonisation). The scale of the impacts is about one-tenth of what was seen in the cement sector scenarios. This is largely due to the lower emissions reductions needed in the sector compared with cement production, which reduces the scale of the investment and change within the industry that is required. The time profile of the two scenarios is also rather different; impacts are not substantial in the technology cost scenario until after 2040, whereas in the demand-led scenario they start as soon as 2030. This is because, given the sector's relatively (compared with cement) lower emissions profile and higher technology costs, it is not cost-efficient to start implementing the solutions earlier – even if this leads to higher emissions and smaller gains compared with the demand-led scenario. These impacts are mirrored in the employment figures (panel b).

A relatively limited impact can be seen in the changes to prices as well (panel c). Prices are somewhat higher by 2030 in the demand-led scenario, as a result of the early costs of the implementation of low carbon solutions, but by 2050, due to learning-by-doing effects and avoided carbon costs, the price is lower in the demand-led scenario.

Figure 9: Overview of sectoral results of the glass and ceramics sector scenarios, non-metallic minerals sector



Emissions are presented in panel (d), which shows that at the broad NMMP sectoral level, the emission abatement contribution of the glass and ceramics sector is relatively limited. Again, the reason behind this is that glass and ceramics production is responsible for only ~18 per cent of total (process and energy-related) emissions in the broader NMMP sector. Therefore, the 12 percentage point emission reduction (compared with BAU), together with the BAU's circa 6 percentage point reduction in the sector, means that the demand-led scenario achieves net zero emissions for the glass and ceramics sector by 2050.

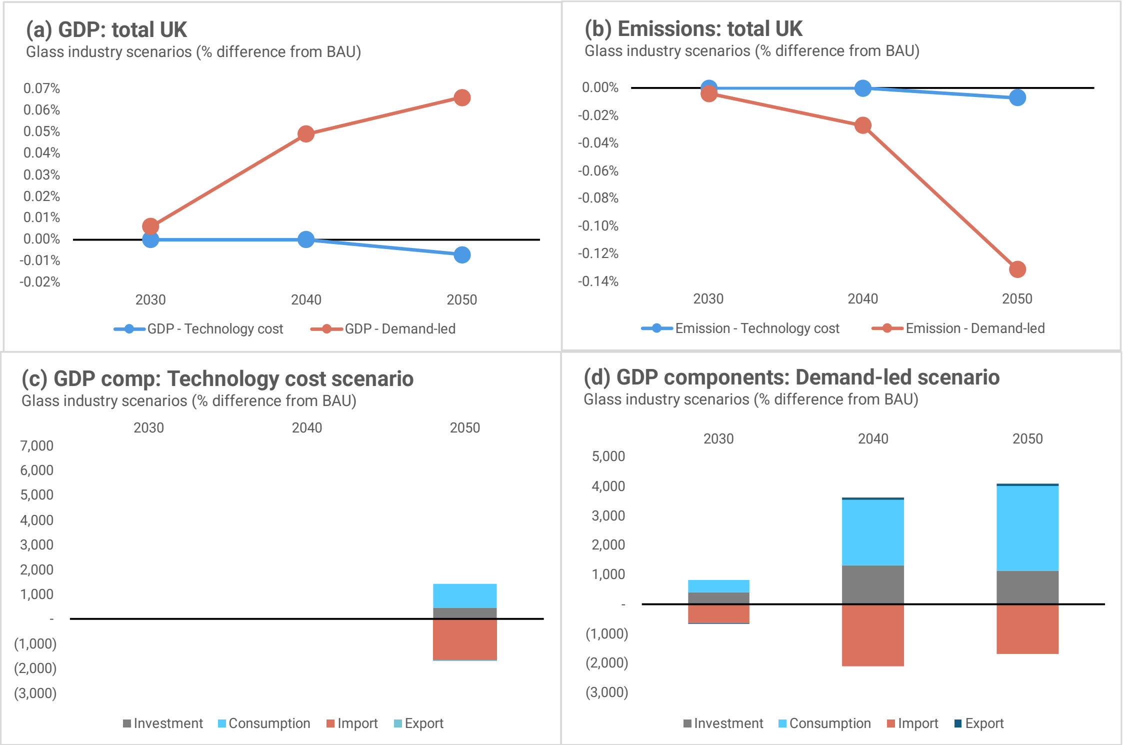
The pathway of the impacts is also relevant; an initial small output increase (0.01 per cent) by 2030 increases to 0.05 per cent in 2040, before falling back later. This is due to the profile of investments in the scenario (which also boost output of NMMP) – they are mostly concentrated to the middle of the period (around 2040). In order to achieve these emissions reductions, firms need to increase investments, which in turn increases demand for investment goods (such as NMMP products).

Figure 10 shows the economy-wide results of the scenarios. In panel (a), despite the sectoral output effect being positive in both scenarios, the overall GDP effect is negative in the technology cost led scenario, while it is positive in the demand-led scenario. The impact on the economy as a whole is negligible.

Panel (b) shows how the scenarios contribute to economy-wide emission reductions; in the demand-led scenario, we see a reduction of 0.14 per cent, which is around one-tenth of the effect in the cement scenarios, and again something that can be explained by the initial lower emission level of glass and ceramics production.

Finally, panels (c) and (d) provide deeper insight into what is driving the GDP outcomes. In the technology cost scenario, a positive consumption effect (due to lower prices) is offset by increasing imports.

Figure 10: Overview of regional results of the glass and ceramics sector scenarios, UK



In the demand-led scenario, total imports are lower compared with the baseline because of decreasing demand for fossil fuels, NMMP and gas imports, although imports of chemicals and mining products increase. The increase in mining is linked to greater demand for CCUS activities. In the demand-led scenario, however, GDP increases slightly, because of investment and consumption effects balancing out the impact of increased imports.

7.3 Conclusions from the modelling exercise

Several policy-relevant conclusions can be drawn from this scenario modelling exercise. These can be split into what can be taken from the scenario design (informed by the literature and stakeholder views) and the results of the modelling exercise itself.

First, basing the implementation of technological solutions solely on the price competitiveness of the technology can lead to long delays in the technology emerging and being adopted by industries. Industries are waiting for the cost of the technology to come down, while what could really bring down the cost of the technology is if firms begin to adopt it.

A solution to this issue is guaranteeing the demand for specific products, ie products with a lower embedded carbon content, which then incentivises decarbonisation – with this, and with an increasing role for low carbon products in the market, firms that choose to implement large-scale decarbonisation measures will not fall behind, but can instead be market leaders. These firms can obtain cost advantages as carbon costs increase, bringing down the competitive industry price and – as the modelling shows – increasing output and domestic production as well as employment, all while reducing emissions.

This exercise, using the multisectoral E3ME model, also highlights that the decarbonisation of industries will not just create jobs and economic gains in the sectors where it is happening, but also in other parts of the economy that: (i) produce the investment goods needed to decarbonise in the first place, and (ii) come to be part of the new ‘green’ supply chains servicing the decarbonised industries. Adopting low carbon technologies within industrial sectors can therefore provide a clear double dividend, by reducing emissions, boosting industrial competitiveness and driving economic growth.

8. Concluding remarks and policy implications

This report outlines the challenges and potential solutions to achieving net zero emissions in foundation industries and their value chains through fostering demand-led innovation. Evidence from macroeconomic modelling demonstrates an economic benefit could be gained from decarbonising through a demand-led approach that goes beyond just delivering emissions reductions in alignment with climate ambitions. Real-life industry case studies illustrate how demand from the downstream value chain plays a crucial role in enabling not only foundation industry decarbonisation, but also the delivery of a less wasteful and more circular economy, and the development of a robust green hydrogen industry.

As we have demonstrated, there is value to be gained from investment in decarbonisation in the long term. However, the **current challenges of the high capital cost of production technologies, supply–demand catch-22, exposure to trade-related competitive risks, lack of standardised data on embodied emissions and lack of familiarity with new materials** slow down innovation and upscaling of low carbon technologies. Moreover, regulatory frameworks do not always adequately incentivise innovation or the early adoption of low carbon technologies. Given these challenges, the ability of private sector actors is constrained by conditions that either prevent large-scale demand from emerging or make it difficult for the supply side to respond effectively to demand-side signals. In this context, intervention from the government through appropriate policy measures could play an important role in driving the innovation and uptake of low carbon technologies, processes and practices across the foundation industry value chains.

In collaboration with industry partners, the research informing this report and the policy briefing **identified four key decarbonisation pathways: electrification, circularity, novel technologies and innovative processes**, highlighting the key role that demand across the value chains plays in driving progress along these pathways. To address the key barriers to low carbon innovation and upscaling, the research developed a policy framework that could support demand creation and establish enabling conditions to facilitate success. Some policies are needed to create demand locally and globally, while others are required to create contextual conditions to enable innovation and scale-up demand.

Although the UK government has written strategies and plans to support industrial decarbonisation in recent years, the UK's industrial strategy needs to be further developed and better connected to the net zero strategy. Many challenges and potential solutions are similar across several foundation industries, but some are sector-specific and require targeted action. It is also important for the government to design and implement a comprehensive policy framework that details how the various targets outlined in the industrial strategy are to be achieved and how the government intends to support demand creation for low carbon materials and products.

However, in addition to government action, non-governmental organisations and non-departmental government bodies facilitate these processes by bringing companies together, facilitating dialogue and information sharing, and encouraging higher ambition. Moreover, grants and loans to support knowledge generation and collaboration between academic institutions and the private sector to address specific challenges can facilitate the emergence of new insights, best practices and innovative solutions.

We are now only one industrial investment cycle away from 2050, by which time the UK foundation industries should have reduced their emissions by at least 90 per cent. To support the transition required to meet the target, new policies to create markets for low carbon basic materials are urgently needed to incentivise innovation and to remove barriers to scaling up new, innovative solutions that are currently being piloted. To be effective, these policies will need to address all stages of the industrial production value chain.

As highlighted in Section 2.1 of this report, developing the necessary technologies to decarbonise the basic materials production presents an enormous opportunity for UK industry. Large economies such as the USA and the EU have acknowledged both the substantial economic benefits and the competitive advantage that early investment in low carbon innovation and adoption can deliver. These commitments are reflected in the US Inflation Reduction Act (IRA) and the EU's Green Deal Industrial Plan (GDIP) and Net-Zero Industry Act, which seek to support the scaling up of the manufacturing of clean technologies in these jurisdictions.

In the race to net zero, failing to address the industrial decarbonisation challenge can result in carbon leakage, growing import dependency and loss of revenue. This is a race that the UK cannot afford to lose. Therefore, we would encourage the UK government to be wary of relying heavily on CCUS and hydrogen to deliver on its industrial decarbonisation targets without a more comprehensive policy framework. Considering the multiple benefits that demand-led approaches could deliver, as outlined in this report, we would invite the government to undertake urgent action to:

1) Design and implement **policies to create demand for low carbon products and materials.**
2) Design and implement **policies that support contextual conditions to encourage innovation or support the scaling up demand for innovative technologies and approaches** by businesses across the foundation industry value chains.
3) Establish **international collaboration to accelerate demand for low carbon materials and products globally.**

Annex 1: The research process

Project summary

Project focus: Accelerating the transition to the net zero economy through demand-led innovation

Start date: May 2022

End date: May 2023

Deliverables/outputs:

- Research report
- Policy Briefing
- Sectoral deep dive: steel
- Sectoral deep dive: cement
- Sectoral deep dive: glass

Launch event: 24 May 2023, Innovation Zero conference, Olympia, London

Dissemination: The dissemination of outputs will be shared and promoted via CLG UK, as well as CISL's wider network of civil society and businesses and policymakers.

Project structure

Work package 1

Convening a Sustainable Markets Advisory Roundtable (SMART) Group

Work package 2

Research into policies to support and incentivise innovation for future markets

Work package 3

Discussion and illustration of the macroeconomic benefits of investing in innovation

Primary output: Research report

Additional outputs:

- Sectoral deep dives: steel
- Sectoral deep dives: cement
- Sectoral deep dives: glass

Work package 4

Convening industrial stakeholders to support interventions around demand led innovation

Output: Policy briefing

Project team

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SMART group members

ALDERSGATE GROUP Leaders for a sustainable economy
JLL
encirc
KraftHeinz
LIBERTY
CATAPULT High Value Manufacturing
SCOTTISHPOWER
TATA STEEL
NSG GROUP
ROLLS ROYCE
Responsible Steel standards & certification
SKANSKA
green alliance...
ecocem
LUCIDEON
SCHAEFFLER

During the project, five SMART group meetings took place as follows:

Meeting 1: 13 July 2022 (online)

This meeting focused on introducing the project to the SMART group members and discussing the timeline and expectations.

Meeting 2: 22 September 2022 (online)

In this meeting, the SMART group members were told about the opportunity to provide case studies for the report, and were invited to actively input into the research report structure. They were also asked to share their thoughts on five key topics:

1) What are the key points in foundation industry value chains where new innovation is needed?
2) What kinds of new innovation are still needed? How could this be supported or incentivised?
3) What innovation needs to be scaled up? How could the scaling up be facilitated?
4) What role can policy play in driving demand-led innovation? What would good policies look like?

5) What role could progressive industry play in supporting demand-led innovation and the scaling up of new innovation?

Meeting 3: 2 November 2022 (online)

In this meeting, the SMART group members were invited to provide feedback on the research questions and the draft outline for the research report.

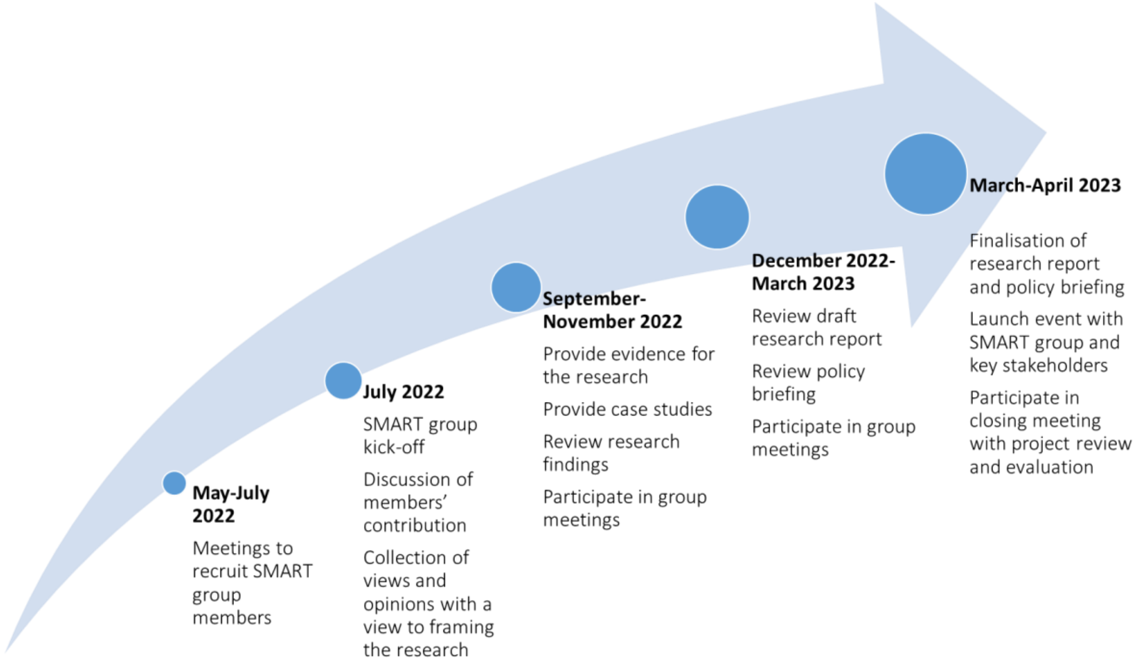
Meeting 4: 23 January 2023 (hybrid)

In this meeting, the SMART group members were invited to provide feedback on the first draft of the research report. There was also a presentation and Q&A session on the modelling exercise, which forms Section 7 of this report.

Meeting 5: 22 March 2023 (online)

In this meeting, the SMART group members were invited to discuss and provide feedback on the proposed conclusions and the content to be covered in the policy briefing.

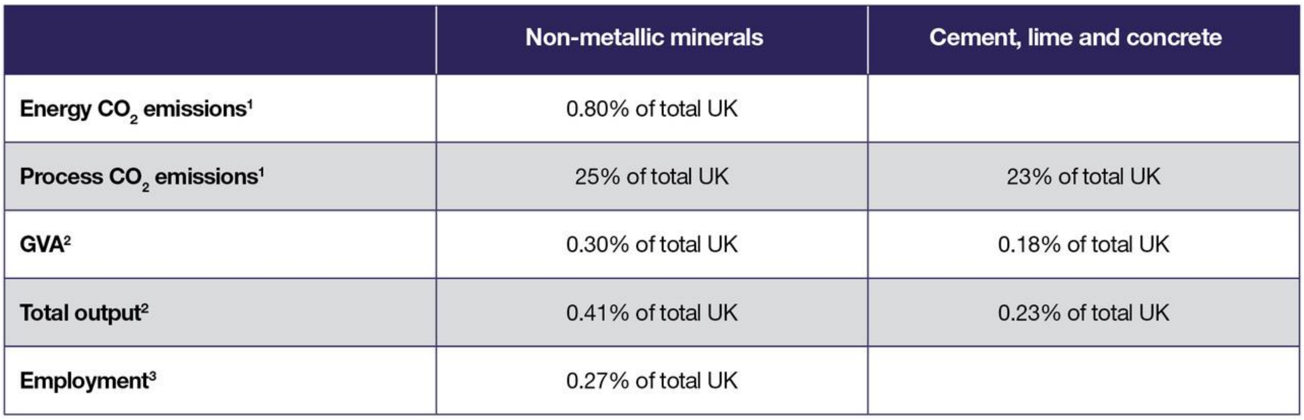
Project timeline



Annex 2: Further details on the macroeconomic modelling

Cement and concrete

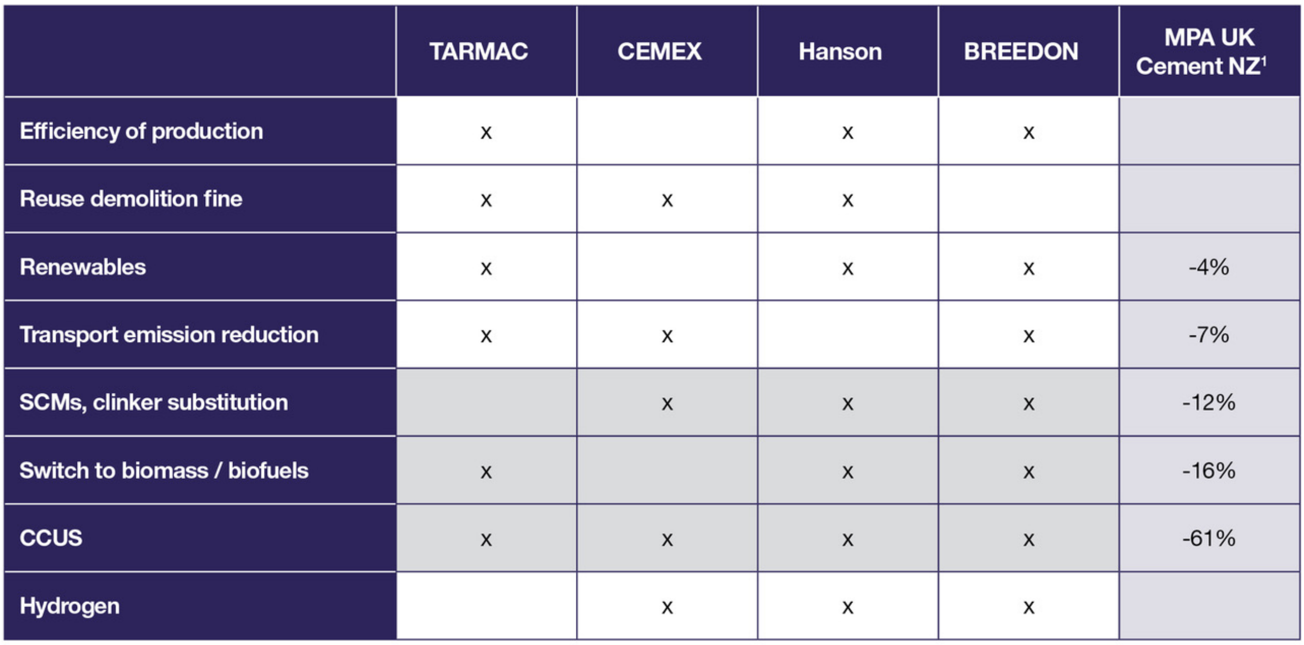
Table 6: Summary statistics on the cement, lime and concrete, and NMMP sectors



	Non-metallic minerals	Cement, lime and concrete
Energy CO_2 emissions[1]	0.80% of total UK	
Process CO_2 emissions[1]	25% of total UK	23% of total UK
GVA[2]	0.30% of total UK	0.18% of total UK
Total output[2]	0.41% of total UK	0.23% of total UK
Employment[3]	0.27% of total UK	

Notes: 1 – 2020 data, 2 – 2018 data, 3 – 2022 data

Table 7: Sample of solutions in decarbonisation strategies across the UK cement industry



	TARMAC	CEMEX	Hanson	BREEDON	MPA UK Cement NZ[1]
Efficiency of production	x		x	x	
Reuse demolition fine	x	x	x		
Renewables	x		x	x	-4%
Transport emission reduction	x	x		x	-7%
SCMs, clinker substitution		x	x	x	-12%
Switch to biomass / biofuels	x		x	x	-16%
CCUS	x	x	x	x	-61%
Hydrogen		x	x	x	

Notes: 1 – expected contribution of the solution to total emission reductions in the sector, based on sustainability reports of the companies (Breedon, n.d.; Cemex, 2021; Hanson, n.d.; Tarmac, 2021) and MPA (2020)

Figure 11: Assumed cost curves in the scenarios for the decarbonisation solutions for the cement industry

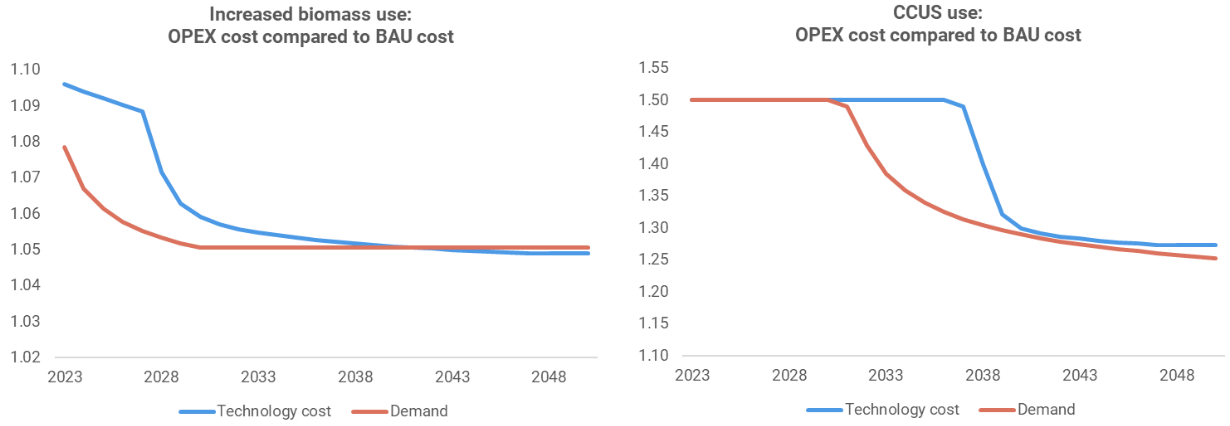
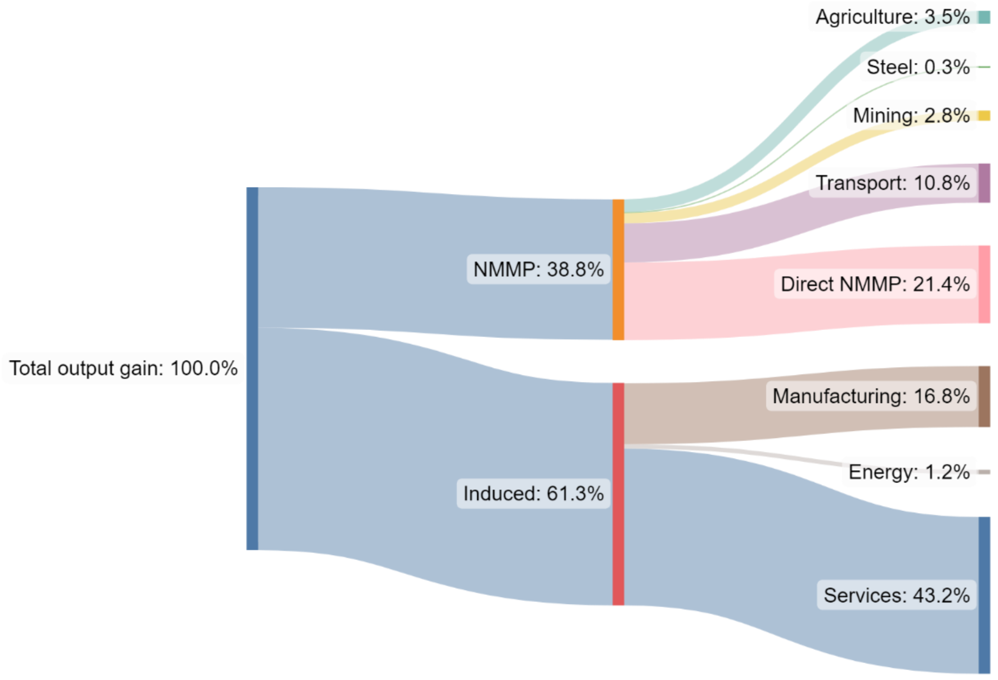


Figure 12: Output gains in the cement scenarios[1]



Notes: The figure above shows results for the technology cost scenario in 2050; however, the distribution of the sectoral effects is very similar in the demand-led innovation scenario, but the timing and the magnitude differ substantially

Figure 12 presents the distribution of output gains across industry sectors. Output gains here are understood as excess economic activity in the named sectors, which results from the impacts of the scenario. In other words: in this case, the scenario generates additional economic activity, and ~10.8 per cent of that extra economic activity is expected to happen in the transport sector.

The distribution of the impact is similar across the scenarios (demand-led and technology cost), but the magnitude and the timing are different (as seen in Figure 8 in Section 7.1 of the report). About 40 per cent of the output impact is directly related to the NMMP sector; half of this impact is a direct effect of higher production in the sector and the other half is related to supply chain changes induced by low carbon technologies: transport, mining (CCS), agriculture and forestry (biomass), and steel (SCMs).

The other 60 per cent of the impact is due to indirect effects, as it can be seen on the GDP level as well (as seen in Figure 8 in Section 7.1 of the report); increased consumption boosts the output of both services and manufacturing.

Glass and ceramics

Table 8: Summary statistics on the glass and ceramics, and NMMP sectors

	Non-metallic minerals	Glass and ceramics
Energy CO_2 emissions[1]	0.80% of total UK	
Process CO_2 emissions[1]	25% of total UK	2% of total UK
GVA[2]	0.30% of total UK	0.12% of total UK
Total output[2]	0.41% of total UK	0.18% of total UK
Employment[3]	0.27% of total UK	

Notes: 1 – 2020 data, 2 – 2018 data, 3 – 2022 data

Table 9: Sample of solutions in decarbonisation strategies across the UK industry

	Flat glass	Container glass	Ceramics	Advanced ceramics	British Glass NZ[1]
Electrification	x	x		x	56%
Hydrogen	x	x	x	x	9%
CCUS	x	x	Passive, innovation required		7%
Biomass	Commercially not viable				
New production technology[2]				x	
Raw material recycling	x	x			3%

Notes: 1 – expected contribution of the solution to total emission reduction in the sector, based on British Glass (2021); 2 – for example, applying pressure to lower the heating temperature required in ceramics production

Figure 13 and Figure 14 present the distribution of direct and induced economic output effects across the economy by 2050. In both cases, the induced impacts are higher than the direct impacts; in the technology cost scenario, ~25 per cent of the output gains are directly related to NMMP, whereas in the demand-led scenario the equivalent figure is 36 per cent. In both cases, the direct output increase in the NMMP sector is relatively small, because of the lack of strong price reductions in the sector. However, the supply chain changes do have substantial impacts; 14 per cent of the total output gains in the *technology cost case* and ~22 per cent in the *demand-led case* are in the transport sector, while the waste management and mining sectors also gain. Both impacts are due to decarbonisation activities; increasing CCUS use boosts transport and mining demand, while recycled raw materials boost consumption in the waste management sector.

Figure 13: Output gains in the glass and ceramics sectors – demand-led innovation scenario

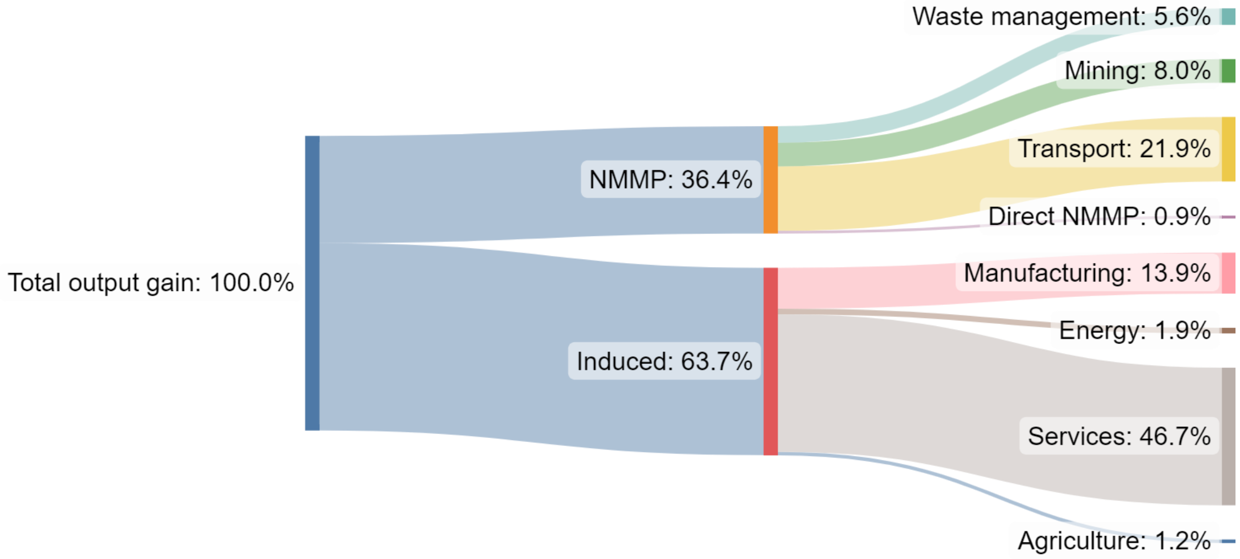
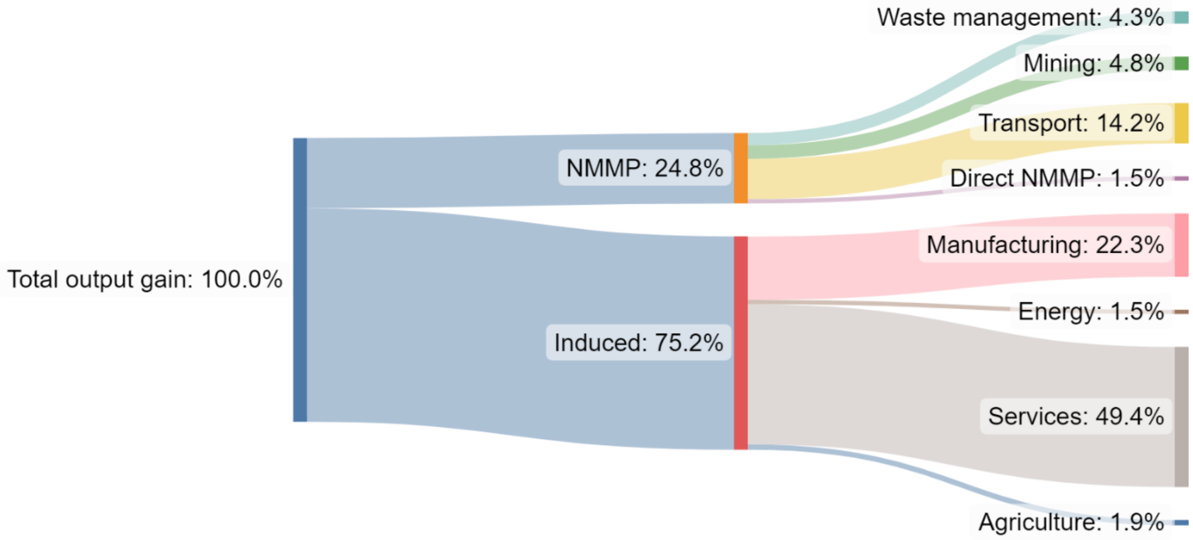


Figure 14: Output gains in the glass and ceramics sectors – technology cost scenario



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1.A.2.f - Non-metallic minerals
2.A.1 - Cement Production
2.A.2 - Lime Production
2.A.3 - Glass production
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