Towards Net Zero in UK manufacturing

Options and challenges for the biggest emitting sectors

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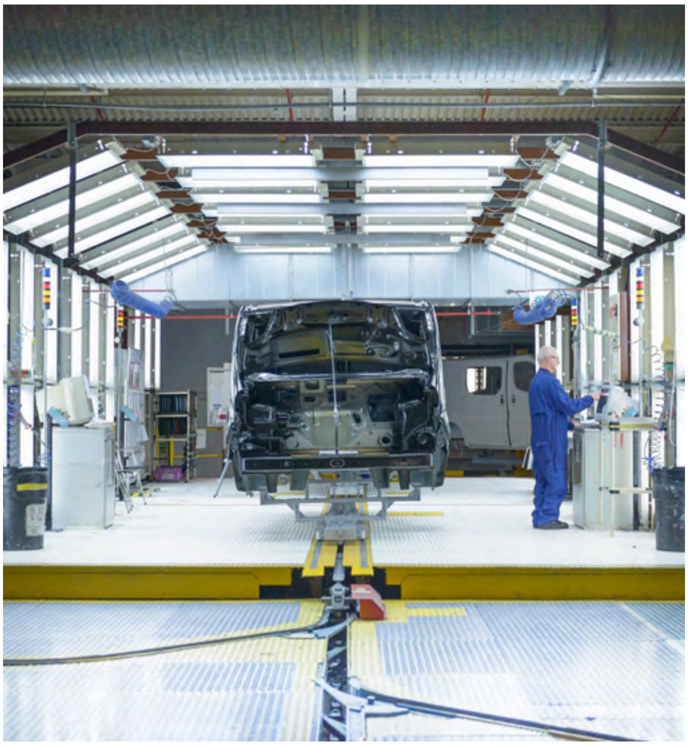

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Abbreviations

ADF	Advanced Disposal Fees
BCAM	Border Carbon Adjustment Mechanism
BEIS	The Department for Business, Energy and Industrial Strategy
BF	Blast Furnace
BNZP	Balanced Net Zero Pathway
BOF	Basic Oxygen Furnace
CCC	Climate Change Committee
CCUS	Carbon Capture Utilisation and Storage
CfD	Contracts for Difference
CO_2	Carbon Dioxide
CPS	Carbon Price Support
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EfW	Energy from Waste
EITE	Energy Intensive, Trade Exposed
EPR	Extended Producer Responsibility
EU ETS	European Union Emissions Trading Scheme
GGBS	Ground Granulated Blast-furnace Slag
GHG	Greenhouse Gas
GJ	Gigajoules
IEA	International Energy Agency
LNG	Liquified Natural Gas
MPA	Mineral Products Association
MTO	Methanol-to-olefins
OPC	Ordinary Portland Cement
R&D	Research and Development
SME	Small and Medium Enterprise
SRF	Solid Recovered Fuel
UK ETS	United Kingdom Emissions Trading Scheme
WTO	World Trade Organisation

Foreword from Professor Michael Grubb

Energy-intensive industries are vital to modern economies but are also a major source of greenhouse gases (GHG). In the UK, manufacturing accounts for 12% of our overall GHG emissions. Half of this arises from just three primary activities, namely steel, cement and chemicals manufacturing, which are the focus of this study.

To varying degrees these sectors are also facing strong economic pressure, with many more relying on older capital stock than their competitors abroad. New investment is needed, and it needs to be cleaner, and help these manufacturing sectors innovate towards thriving in a "Net Zero" GHG world. Given the UK's legal carbon budgets, the Climate Change Committee (CCC) projects that deep emission reductions need to be secured within 15 years.

This study presents three broadly-applicable findings. First, that deep emissions reductions are possible, but the options are mostly immature and the best routes remain to be tested at scale. Second, such reductions will not happen without strong, sustained and sophisticated government support. And third, the solutions in each of the three sectors differ, and require different approaches.

For steel, the big challenges are very specific: emissions are dominated (95%) by the blast furnace sites at Port Talbot and Scunthorpe. We suggest different approaches for each site, based upon their particular locations, to help UK industry gain experience and a stake in both carbon capture and storage (CCS), and hydrogen-based Direct Reduced Iron (DRI) technologies, the latter likely coupled directly with major clean hydrogen investments.

The cement sector needs innovation and investment throughout the supply chain, through to and including its key market – the construction industry. With smaller more dispersed sites, CCUS – utilising captured CO_2 – should be fostered where appropriate, along with development and standardisation of new construction materials, and removal of distortions that may inhibit use of renewable heating fuels.

The chemicals sector is the most diverse, and many of the opportunities for decarbonisation involve electrification. This is impeded by high UK electricity prices. Alongside targeted supports, including for integration in large industrial decarbonisation clusters, we point to a logic of policy reforms to spread the overall costs of the low carbon transition more fairly across fuels.

The transition in these sectors is unlikely to be effective without a meaningful carbon price. Border adjustments or other WTO-compatible consumption-based pricing may be required to avoid adverse competitive impacts. Echoing the findings of a major Carbon Trust report on carbon pricing in energy intensive industries a decade ago, this may require sector-specific solutions which match the sector characteristics, so as to best support sustained and efficient investment whilst minimising any trade distortions.[1]

At present, the UK risks an approach of 'muddling through' which is likely to raise the costs of the transition without building a strong stake in the manufacturing industries of a low carbon economy. This report outlines the changes in approach needed to 'Forge Ahead'.

This report, led by Matthew Winning with support from Catherine Willan, draws both on analysis of diverse national and international literatures, and interviews with key companies in each sector. It is one of four sectoral studies on decarbonising the UK economy conducted by the UCL Institute of Sustainable Resources with support from HSBC UK, for which we are most grateful.

Michael Grubb
Professor of Energy and Climate Change
and Deputy Director,
UCL Institute for Sustainable Resources

Executive summary

This report presents challenges and approaches of how the three largest emitting UK manufacturing sectors of steel, cement and chemicals can reduce their net emissions of greenhouse gases towards zero ('Net Zero') by 2050. These sectors currently account for about half of the emissions (almost all of it CO_2) arising from UK manufacturing and 6% of UK direct GHG emissions.

The economic and environmental significance of these three industries alone make them a vital part of any choices of pathways towards Net Zero in the UK. This requires strategic and committed decisions to be made in UK policymaking that will determine the future of these critical industries.

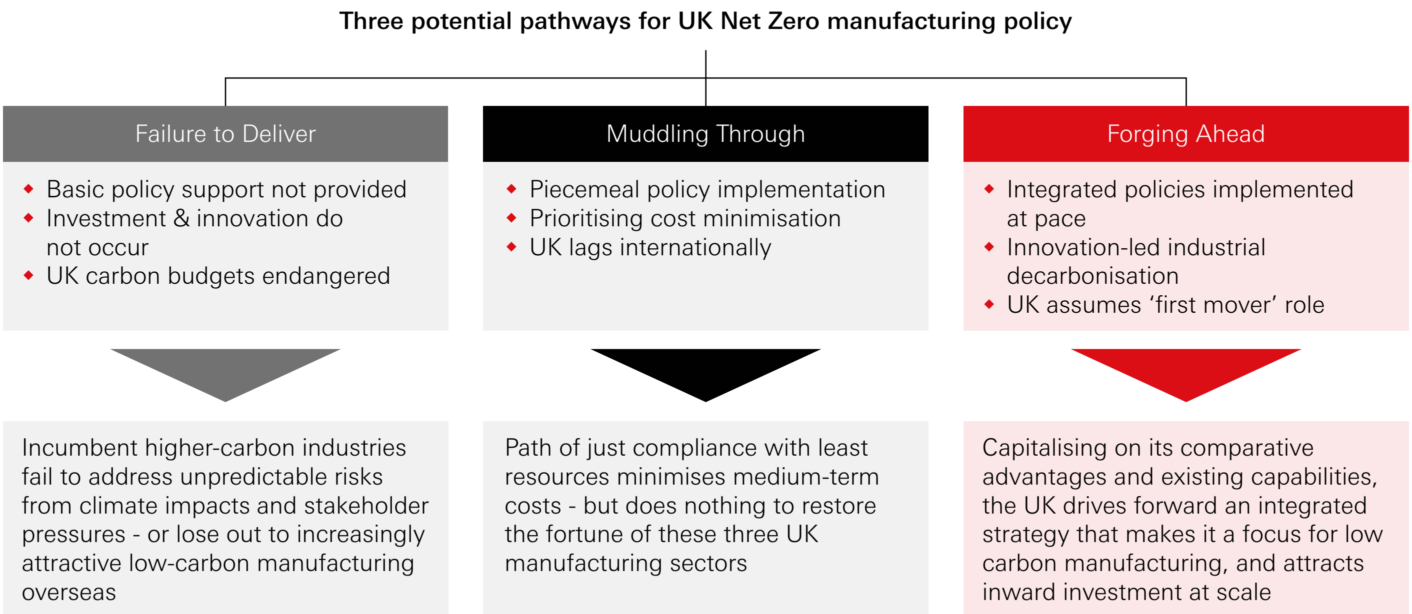
Three possible futures for UK manufacturing in a Net Zero UK

Manufacturing has a pivotal role in both the UK economy and in the delivery of 'Net Zero' including the UK's ambitious, legally binding carbon budgets to reduce GHG emissions by 68% by 2030 and 78% by 2035 (compared to 1990 levels). To date, UK manufacturing emissions have declined by an impressive 57% from 1990 levels, with direct CO_2 emissions falling over 25% in the decade from 2009 while output increased by 10%. Half of the change came from energy intensity improvements; the other half being divided equally between fuel switching and changes in the structure of UK industry. However, building upon this progress will require much more radical changes in technologies and structures over the coming decades.

Crucially, we find that strong policy intervention and clarity is essential for the coming decade if the UK is to both achieve its industrial decarbonisation goals and simultaneously benefit economically from the transition. We envisage three potential futures for UK manufacturing in this context. As shown in Figure 1.

- A **Failure to Deliver** occurs where the UK fails to introduce the minimal policy support needed to comply with its own carbon budgets. Lacking an adequate domestic market, low-carbon industry struggles to sell into international markets. Incumbent higher-carbon industries seek to maintain ageing capital, but face increasing challenges from unpredictable quarters – lawsuits, investor campaigns, consumer preferences or even boycotts, policy changes driven by extreme climate events or electoral swings – or just losing out to increasingly attractive foreign low-carbon manufacturing.
- Most akin to the current situation is **Muddling Through**. Where piecemeal policies are put in place and lack of a clear pathway and delayed implementation mean the UK lags behind the international cutting edge of industrial decarbonisation. Torn between the urgency and opportunities on the one hand, but fearful of the cost and hoping for cheaper 'second mover' advantages make for a hesitant, contested and cautious approach to industrial decarbonisation. This path of 'just enough' compliance with least resources minimises medium-term costs but does nothing to restore the fortune of these sectors.
- **Forging Ahead** involves a pro-active, sophisticated and timely industrial decarbonisation strategy to be put in place over the next year or two, with key measures quickly implemented. While there are real 'first mover' risks, it is

Figure 1 Policy choices for Net Zero manufacturing



Source: Authors own analysis

quite clear that hydrogen and Carbon Capture Usage and Storage (CCUS) will be essential. Drawing upon the UK's comparative advantages, in particular regarding large-scale renewables and potential storage, the clarity provided by our carbon budgets, combined with existing manufacturing and finance capabilities, integrated strategies can establish the necessary groundwork and support for these underpinning industries to help make the UK an attractive place for low carbon manufacturing.

Our sector studies draw upon scientific literature and industry and policy documents, supported by interviews with each of the three sectors. We present an overview of the current situation for each of the three industries in the UK, the options available for decarbonisation, and the factors that decision-makers will need to address. We conclude with recommendations and observations on policies for Forging Ahead.

2. Steel

Steel manufacturing in the UK

Two main processes produce most of the world's steel (and almost all in the UK and EU): (1) Blast Furnaces, with iron ore and coking coal as inputs, producing iron into Basic Oxygen Furnaces (BF-BOF); and (2) electric arc furnaces (EAF), using scrap steel and electricity as inputs. EAF dependence on scrap limits production, and some concerns about contamination in scrap limits markets for EAF steel.

The two BF-BOF integrated sites, at Port Talbot and Scunthorpe, dominate UK production of (81%) and emissions (over 90%) from steel, the remainder being at four smaller EAF facilities. The UK underutilises its potential to use its scrap steel supply and exports much of its scrap. Both forms in the UK have struggled competitively – the BF-BOF facilities due to competition from newer and lower-cost capacity abroad (especially China); and EAF, also from high UK electricity prices.

Globally, about 9% of steel production is from Direct Reduced Iron (DRI) technology, using various fossil fuels to convert iron ore directly into 'sponge iron' which is then processed through EAF, with emissions depending upon the fuel input.

Options for decarbonisation

Steel is an essential commodity with unique properties, unlikely to be displaced at scale in many applications. Emissions associated with scrap-based EAF plants are low and will decline further as electricity decarbonises, but whilst options exist for greater re-use and recycling, these cannot, globally, supplant the demand for new steel. The two main options are:

- Hydrogen from low-carbon sources can be used to produce sponge iron from ore via DRI for input to EAFs. The first hydrogen DRI trial run was produced in Sweden this year and several promising EU projects have been announced. However, current cost estimates are high, so cheap renewable sources at scale would be required; and producing the current level of BF-BOF using hydrogen would require 17% of UK renewables generation, or 6.5% of UK electricity generation, at present.
- Carbon Capture Usage and Storage (CCUS) for steel would capture the CO_2, with depleted oil & gas fields in the North Sea offering disposal sites. However, CCUS does involve extra costs and reduces overall efficiency, so CCUS for steel comes with some risk of stagnation in terms of global competitiveness.

Factors for decision-making

Relative to demand, UK production capacity is modest and maintaining production capability could plausibly be considered a strategic concern – simply importing steel instead would anyway not help tackle climate change. One or more sites with modest EAF capacity could be considered to trial DRI technology, ideally utilising renewables-derived hydrogen, complemented by research into addressing purity associated with scrap recycling.

However, unlike the other sectors we consider, in the short- to mid-term, the dominant challenges for UK steel boil down to two large, site-specific questions: the future of Port Talbot and Scunthorpe. The Climate Change Committee's balanced pathway scenario envisages the UK achieving a Net Zero steel sector as soon as 2035, implying that both must be either close to or fully transitioned to low- or zero- carbon production by then, an approach consistent with the need for major strategic choices about the future of these works anyway on grounds of age and competitiveness.

The general instruments for decarbonisation cannot supplant the need for strategic decisions on these two sites.

Whilst more detailed scrutiny is required, this should be set in the context of the need for experience in different options, potential for scale economies, and the specific contexts of the sites. One option may be to support a trial CCUS facility at Scunthorpe, being located near potential disposal sites, while Port Talbot may be more suited for conversion to an integrated DRI-EAF works (with hydrogen at scale potentially via construction of a tidal barrage, and/or initially methane reformation at nearby LNG terminals). Such investments would require some combination of direct state funding, carbon contracts-for-difference, significant infrastructure built and/or an extension of the UK ETS with carbon border adjustments as outlined below.

Takeaway

Any strategic decisions must consider the UK's two major steel sites at Scunthorpe and Port Talbot, which will both require significant support for investment, but potentially consideration of different technological solutions. Regardless of technological route, more competitive electricity prices are a must for the UK steel industry.

3. Cement

Cement manufacturing in the UK

Cement is a main input into concrete production. Producing the industry standard, Ordinary Portland Cement (OPC), is currently an emissions-intensive process due to two aspects – (1) from the fuels required to achieve the high temperatures that are necessary (30%), and (2) from the chemical calcination process (60%), with the remainder from transport, electrification etc. UK cement production is around 9 million tonnes per year with around 83% used for buildings and 17% for infrastructure.

Options for decarbonisation

The Climate Change Committee analysis suggests that the UK could achieve Net Zero cement as soon as 2040, and that several aspects have a role in decarbonisation.

- **Resource efficiency.** Using less cement in the design of buildings, lengthening building lifetimes, and improving end-of-life reuse of cement are cost-effective approaches compared to the decarbonisation of cement production. Working with the construction industry and architects will be important. There is considerable over-specification of cement in construction and therefore regulations and legislation related to design requirements may need to be updated in light of the Net Zero target.

- **Material substitution.** The substitution of clinker[i] with other materials can help further reduce emissions. It is also possible to grind up and reuse cement if it has not reacted with water, if it can be separated from other aggregates in concrete at the end of life of a building or other construction. There are also examples of novel low-carbon cements and concretes which have been developed, but many of these have characteristics which may not be suitable to directly replace OPC i.e., they lack strength, or may affect construction timescales because they take longer to set.

- **Fuel switching.** This is already an important aspect of cement decarbonisation, and significant action has been taken in regard to this, although further efforts are required. About 45.5% of thermal demand for UK cement production was met by waste-derived fuels which have lower CO_2 emissions. Just over half of fuel for cement currently comes from fossil fuels yet this was 94% back in 1998. It is also possible to switch over to green hydrogen for heating requirements. Testing of small amounts of hydrogen in cement kilns is taking place at UK sites.

- **CCUS.** For cement, CCUS is probably a necessity given the significant process emissions of current production methods, and despite carbonation, through which concrete naturally soaks up carbon during its lifetime which can help reduce emissions to a small extent.

Factors for decision-making

Geography is an important consideration for cement sites. Cement decarbonisation will be reliant upon a significant amount of CCUS. A main issue with CCUS relates to the transport of CO_2 to the storage site once it has been captured. Where cement sites are part of a cluster of industries, there may be communal pipelines created that can be used for this purpose. However, dispersed sites, that are not near clusters of other industries, may well require new pipelines, which are expensive if not shared, to transport captured emissions, thereby increasing costs of production.

Takeaway

To capture and store/use carbon from UK cement operations, answers must be found to the practical and financial challenges of linking up sites across the UK to new CCUS infrastructures.

4. Chemicals

Chemicals manufacturing in the UK

The UK chemicals industry is varied in terms of the products and the downstream demand sectors to which those products flow. Almost all manufacturing sectors in the economy utilise chemical products in one way or another. There are lots of small specialist chemical producers. 97% of chemicals businesses are small and medium enterprises (SMEs) of which there are around 2,500, and just over half of UK chemical companies employ less than five people.

The chemical sub-sectors with the largest emissions are petrochemicals, and ammonia for nitrogen fertilisers. A number of processes in the chemicals sector cause emissions in two ways:

(a) as a fuel requirement for energy (often heat), or

(b) as a chemical feedstock – where carbon is required to produce a specific chemical reaction, fossil fuels are currently used to this end.

Chemical production has the highest direct emissions among UK industrial sectors, accounting for 18% of total manufacturing emissions and 2.2% of total UK direct GHG emissions in 2019 of which petrochemicals[ii] was almost half.

Options for decarbonisation

The UK Climate Change Committee's Balanced Net Zero Pathway scenario has the majority of the chemical sector decarbonised by 2040, although there are still around 6% of chemical sector emissions which cannot be mitigated.

[i] Clinker is the main ingredient in cement production and is formed from heating limestone in a kiln to 1450oC. It is composed predominantly from four minerals: alite, belite, tricalcium aluminate, and tetracalcium alumino-ferrite.

[ii] Petrochemicals are a large group of chemicals (not fuels) derived from petroleum and natural gas, and are utilised for various chemical purposes e.g., plastic production.

- **UK recycling** of plastics could be increased by over three times by 2030 compared to 2019 levels. It is possible to undertake chemical recycling of plastics, breaking them down into basic components, and using them as a feedstock for the manufacturing of new plastics. Biomass feedstocks can also play a role in producing low-carbon chemicals. Carbon Capture and Usage could play a vital role where the captured emissions from production can be reused as a feedstock making production more circular.

- **Electrification** can play a significant role in the provision of low-temperature heat for the chemicals sector. However, the switch from gas to electricity for the sector is dependent upon their relative costs which, at present, are not conducive.

- **Green hydrogen** has the potential to play an important role in the production of olefins which are used in plastics production. The use of hydrogen[iii] is already significant in producing ammonia used for fertilisers. As such, greening this hydrogen energy carrier would be an excellent starting point, building up experience and supply chains, for the development of a larger use of hydrogen for low-carbon activities in chemicals and across UK manufacturing in general.

The chemicals sector has the potential to be an important manufacturer of a number of products for the Net Zero transition, including hydrogen, ammonia, methanol and other synthetic fuels. These solutions may be used in crucial sectors for decarbonisation such as aviation.

Takeaway

Greater electrification, chemical recycling of plastics to be reused as feedstocks, and green hydrogen can all play significant roles in the decarbonisation of this diverse sector in the UK.

5. Forging Ahead: Policy and recommendations

Choices on electricity pricing and strategic planning prevent Forging Ahead

The Climate Change Committee's balanced Net Zero pathway, consistent with our legislated carbon budgets, requires manufacturing and construction emissions to reduce by 70% by 2035 and 90% by 2040 (compared to 2018). Aside from specific policies, two underlying obstacles lie in the way of 'Forging Ahead' to deliver such reductions alongside the economic goals.

One concern is electricity. Whilst many solutions, particularly for chemicals and steel, involve electrification, UK industrial electricity prices are high by international standards, partly because the initial costs of what needs to be a whole energy-and-industry transformation are being carried almost entirely by the electricity sector, which itself puts more of the costs on industry compared to many countries. This is despite the UK having the best and potentially cheapest renewable electricity sources in Northern Europe at least. A separate report by our Institute (UCL Institute for Sustainable Resources) examines the reasons and offers seven policy solutions.[2]

The other is ideological and institutional: an aversion to integrated strategic planning. For example, the kinds of transformative investments required for e.g. South Wales industrial clusters, cannot be delivered by a host of disconnected companies with incremental infrastructure developments. In principle, BEIS has many, though not all the levers to coordinate a regional transition, but expenditure is controlled by the Treasury which not only prioritises minimising costs, but often assesses expenditure in piecemeal, not integrated ways.

Beyond these two fundamentals, our synthesis of the literature on innovation and transition emphasises the need to combine supply and demand forces, with more specific policy instruments as follows:

Demand-pull measures: carbon pricing, competitiveness and procurement

There are a number of key policies which can allow the manufacturing industry to transition to Net Zero in a way that does not dramatically effect competitiveness.

Carbon pricing is essential as a strong signal to business. But a lack of viable alternative, cost-effective technological options at present makes it difficult to switch away from current emissions-intensive technologies. Such pricing action alone may only serve to make UK industry uncompetitive where industry is open to international trade. The lose-lose outcome is if UK production moves to places with more emissions-intensive methods of production (so-called 'carbon leakage').

In the light of these issues of international competitiveness, carbon pricing in the steel, cement, chemicals and other energy-intensive sectors will need to be accompanied by a carbon border adjustment mechanism (CBAM) and product standards on imports. In light of the EU's proposed new CBAM, it would make sense for the UK to take a similar approach on a similar timescale. A shorter-term solution is public procurement, in particular for infrastructure projects, which can help establish demand and a domestic lead market for low-carbon products. It can also act as a test case for establishing product standards. Purchaser groups and clubs can also play a role in creating demand and lowering supply chain risks.

Supply-push policies: supporting infrastructure development

Direct funding can help initial research, development and testing for technologies which are at an early stage of development and cannot currently be directly substituted for

[iii] Current hydrogen production nearly all involves steam methane reforming (SMR) of fossil methane, with consequent carbon emissions. These could be captured by CCUS, or the SMR hydrogen replaced by green hydrogen from electrolysis of water.

incumbent technologies. Government support for CCUS and hydrogen business models (essentially contracts for difference (CfD) for these technologies) can provide certainty to get new markets created in the short term. CfDs were used with such success in the procurement of offshore wind. Hydrogen and CCUS are key components of the Government's 10 Point Plan.

The UK has committed to creating two industrial clusters by 2025, four low-carbon clusters by 2030, and at least one Net Zero cluster by 2040. Infrastructure for hydrogen and carbon capture in these clusters must be addressed soon, in order to allow for the near-term targets to be met. Yet addressing dispersed sites is also necessary as these will be trickier and require greater support in the long-term if they are to survive.

At an aggregate level jobs and skills are not viewed as an issue for the low-carbon transition – there will be many opportunities for retraining and to create low-carbon jobs in these sectors. The recent Green Jobs Taskforce report states that retooling and decarbonising existing industries is a preferable climate transition. There may be bottlenecks if many large infrastructure projects are undertaken in the UK in a short space of time. Therefore, a clear roadmap on specific large projects in the UK is needed.

Conclusions

We believe there is a clear direction of travel towards Net Zero and a commitment to achieve this goal from the steel, cement and chemicals industries. Avenues exist to decarbonise all three of the sectors we have studied, over the coming decades. However, the time frame within which to align heavy industry investment cycles with the climate goals is clearly tightening.

Of the archetypal futures we laid out for UK manufacturing, we noted that Failure to Deliver carries big risks, whilst Muddling Through could unnecessarily increase costs and miss potential opportunities. Forging Ahead offers the most responsible and promising way forward, but is not for the fainthearted: it would require multiple policies in the context of an integrated, strategic approach to supporting and coordinating industrial transitions in several regions of the UK. The UK Government must facilitate the regulatory framework now.

1. Introduction

The United Kingdom has committed to achieving Net Zero greenhouse gas (GHG) emissions by 2050 in order to contribute to the achievement of the Paris Agreement goals. Net Zero emissions requires near-100% emissions reductions, with any remaining emissions being balanced by GHG removals from the atmosphere and secure storage of the carbon. The Government has set legally binding interim targets to reduce GHG emissions by 68% by 2030 and 78% by 2035 compared to 1990 levels.[3]

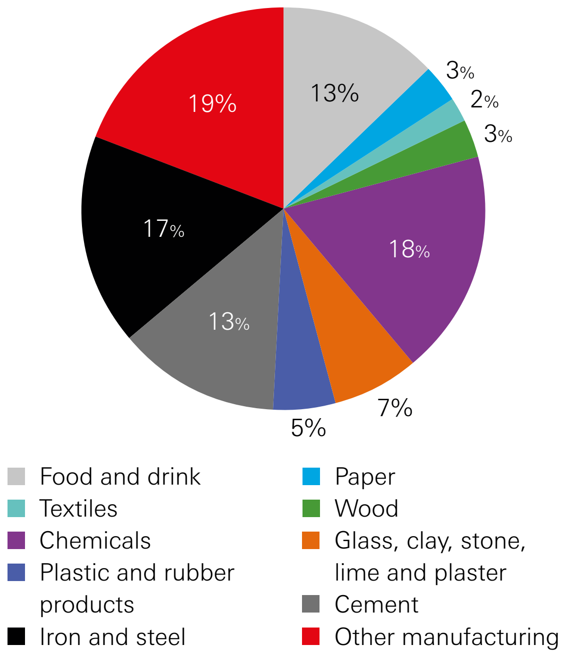
Therefore, even the hardest-to-abate economic sectors must now pursue the challenging transition to reduce their GHG emissions to as close to zero as is possible. It will take significant innovation, commitment, ingenuity and importantly, a considerable amount of new investment. The manufacturing sector, including heavy industry, is an area of the economy with significant GHG emissions that has so far proven difficult to decarbonise.[iv] While rapid progress has been made in the electricity sector, with major breakthroughs in renewables, many high-level heating and industrial processes have yet to achieve a low-carbon breakthrough at scale.

Value: Manufacturing is a key component of the UK economy. In 2019-20 it accounted for £191 billion in output, 2.7 million jobs, and represented over half of UK exports.[4] It is made up of a variety of sectors such as iron and steel, chemicals, cement, paper, glass, food and drink, and many more. In terms of gross value added, the largest manufacturing sectors, as a share of total manufacturing, are food and drink (17%), transport (14%), chemicals (14%) and metals (10%). For exports, it is transport (22%), chemicals (15%), machinery (11%), and electronics (8%).[4]

Emissions: While manufacturing sectors are quite heterogenous, many have the same requirement for fossil-fuel-intensive combustion processes and process emissions from chemical interactions. The most emissions-intensive sectors often involve the conversion of materials into processed products and therefore have a requirement for both low- and high-grade heat for industrial processes. Current standard practice satisfies this requirement through the burning of fossil fuels, resulting in significant direct, indirect and process GHG emissions. These manufacturing sectors combined currently represent around 12% of the UK's direct GHG emissions in 2019, with almost all (98.6%) of these emissions coming from CO_2.[5,6] Of that 12%, just under half of the emissions come from three sectors as shown in Figure 2: chemicals (18%), iron and steel (17%), and cement (13%). And the majority of manufacturing emissions are from fuel combustion (86%) with the remaining amount (14%) coming from process emissions.[6] The UK manufacturing sector's historical GHG emissions trend appears promising – having declined by 57% since 1990, although this obviously differs by sector and structural change plays a role.[5] However, this masks the fact that most of the low-hanging fruit, in terms of efficiency improvements, have now been achieved and further abatement is not possible without significant disruption to technological production routes.

This emissions reduction is sometimes attributed to 'de-industrialisation', with heavy manufacturing moving abroad. This has certainly played a part since 1990, but has not been the dominant factor, at least in recent years. The UK independent advisory body the Climate Change Committee (CCC) undertook a decomposition analysis of the 25% emissions reduction in the whole industry sector between 2009 and 2017. Output increased by 10% over that time period, and they found that half of the reductions came from reduced energy intensity, while a quarter of the reduction was due to changes in the fuel mix, so that just a quarter came from structural change in industrial output (which would include trade effects).[6]

Figure 2 Direct GHG emissions from UK manufacturing 2019 as % of total manufacturing



Source: ONS (2021)[5]

Note: The chart refers to direct emissions only, including process emissions, but not those associated with scopes 2 (electricity) or 3 (material inputs to manufacturing or emissions from the use of the product).

Options: Despite progress to date, reducing industrial emissions to Net Zero from manufacturing in thirty years or less poses many substantial challenges. There are several approaches to tackling the stubborn emissions from manufacturing.

- Demand - resource efficiency refers to methods which allow for less raw material input into the production process, and this can be achieved through greater recycling, longer

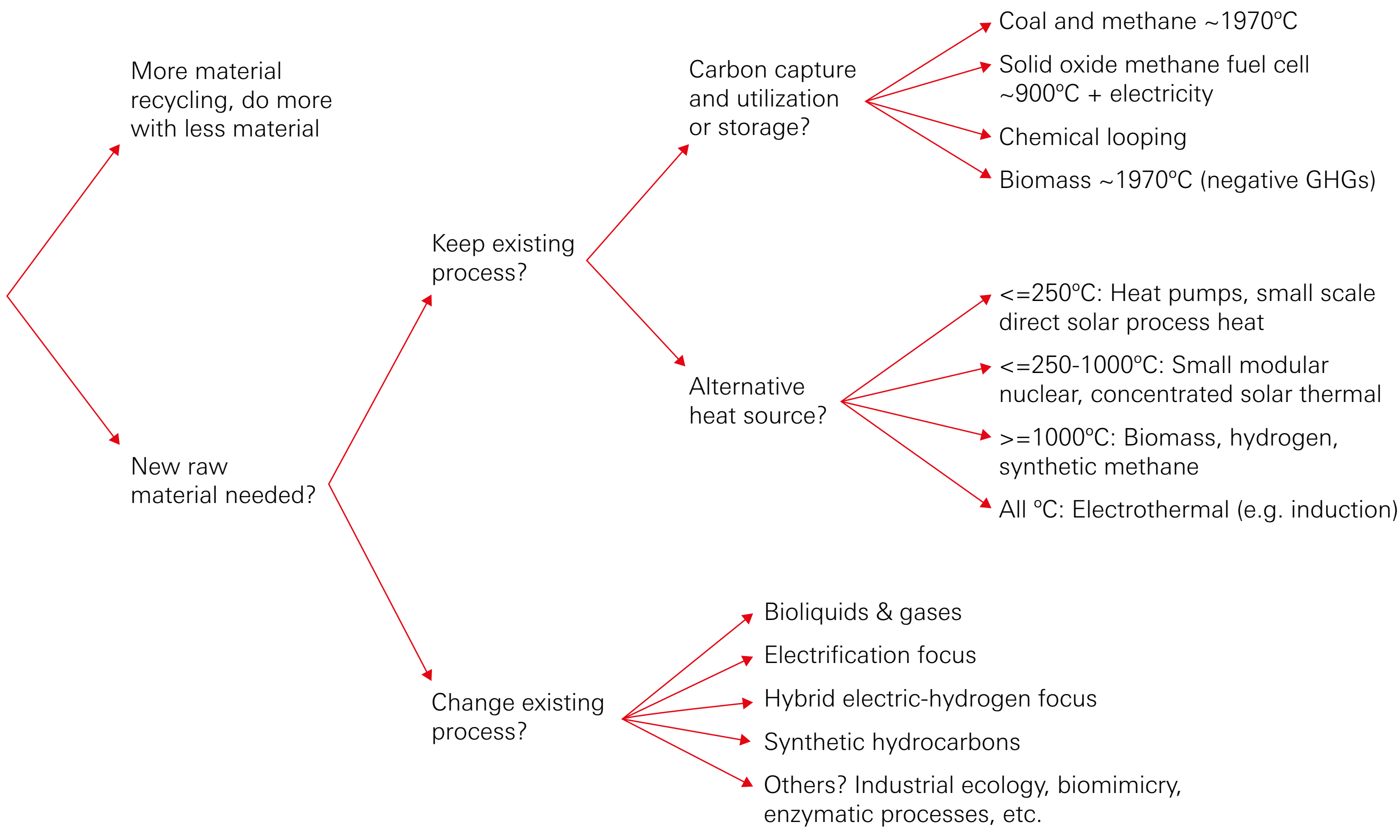
[iv] Here we define manufacturing as a sub-sector of industry. Manufacturing does not include oil and gas extraction or refineries and does not include direct emissions from the construction sector.

use and more efficient use of products, which are all components of a more circular economy. These can be on the consumer or producer side. Material switching may also allow for lower-carbon materials to replace higher-carbon ones in production such as replacements for clinker in cement, or alternative construction materials. Energy efficiency improvements are also possible and may be achieved through upgrading equipment, heat recovery systems and clustering industries together to use their waste heat and by-products.

- Supply - Where these approaches are not possible, or not sufficiently effective for decarbonisation, the question arises whether it is possible to change to a different low-carbon process, e.g. is electrification or another novel approach feasible? Often new processes are not possible due to specific requirements and so the final step becomes a distinct choice between whether to use an alternative energy source or to capture the emissions from existing fuels. The former could involve replacement of fossil fuels with green hydrogen (see Box 1) or bioenergy. With the latter, CO_2 can either be stored via Carbon Capture and Storage (CCS) or used as an input into other manufacturing processes (CCU). Some of the possibilities require further research but most of them are already understood today, but need to be scaled-up dramatically. However, this deployment requires having the right polices and regulations in place. See Figure 3 for an overview of options.

UK pathways. The Climate Change Committee's Sixth Carbon Budget (CCC CB6) details their estimation of how the UK manufacturing sector's emissions need to be reduced to achieve the legislated Net Zero target. They find that a balanced Net Zero pathway (BNZP) requires an overall reduction in manufacturing and construction emissions of 70% by 2035 and 90% by 2040 compared to 2018.[6] In their analysis, decarbonisation is initially through improvements in resource and energy efficiency that occur in the early 2020s. From 2025 Carbon Capture, Utilisation and Storage (CCUS) and fuel switching begin to be deployed at scale and infrastructure for hydrogen production and distribution

Figure 3 Generalised decision tree for industry sectors



Source: Bataille et al., 2018

Box 1 Hydrogen

Hydrogen (H) is not an energy source: it is an energy carrier, whilst also, a very reactive chemical agent. Therefore, hydrogen, like electricity, can be considered to have various levels of carbon dioxide intensity depending upon how it is produced i.e., via fossil fuel reforming or via electrolysis. The UK currently produces around 27TWh of hydrogen a year mostly from steam methane reforming (SMR) with an intensity of 285 gCO_2/KWh. The Government's Clean Growth Strategy suggested the amount of H production could increase to 700 TWh by 2050.

is put in place, CCUS clusters and electrification begin at scale and substantially increase in the 2030s. Such changes will not come about without strong policies, with policy measures cost-effective for both business and society as well as accounting for non-financial barriers e.g, local public acceptability of CCUS.

Finance. Mobilisation of capital in the coming five years is of fundamental importance to achieve the substantial changes within industries over the required timeframe. The CCC CB6 report states that the amount of investment required to achieve Net Zero across the entire economy must increase by around five times in the next ten years, from around £10 billion in 2020 to £50 billion in 2030.[6,v] It is critical to immediately put in place the policy framework and conditions, and a clear pathway of government regulation, to allow capital investments to take place on the short timescale required. The decision-making processes within financial services will also require adjustment to Net Zero. For instance, under traditional forward-looking analysis, using historical data, then investment in more expensive CCUS would not occur. Understanding and incorporating risks of both climate impacts and low-carbon investments are essential, and pooling risks across investors may be required. However, further analysis of the financial services sector is beyond the scope of this study.

Sectoral roadmaps. In 2015 the UK Government published eight industrial decarbonisation and energy efficiency sector pathways for Iron and Steel, Cement, Chemicals, Oil refining, Food & Drink, Pulp & Paper, Glass, and Ceramics. These were returned to and updated in 2017. Greater ambition has been established more recently in the government's Energy White Paper, published in December 2020.[8] Building upon the White Paper, a more detailed Industrial Decarbonisation Strategy was published in March 2021 which aims for the world's first low-carbon industrial cluster and to cut UK industrial emissions by two thirds in the next fifteen years.[9] A wider point should also be noted about winding-down dirtier production techniques – while being replaced with more efficient or new production methods – and whether and how support for such contributions towards Net Zero are considered.

International dimensions. The UK manufacturing sector operates within an interconnected global economic system which trades and competes with many other countries in what are often highly competitive markets with low profit margins. In addition, many manufacturing companies are international. Therefore, any actions and government regulation by the UK to reduce elements of its manufacturing emissions must consider and take fully into account industry-specific competition aspects, otherwise the UK will be disadvantaged in comparison to regions with lower environmental standards.

The remainder of this report focuses in detail on the three manufacturing sectors which between them contribute almost half of the UK's industrial greenhouse gas emissions: iron and steel, cement, and chemicals, which are covered in Sections 2, 3 and 4, respectively. We discuss the current conditions of each sector, what has been achieved already and the demand and supply-side options for deep decarbonisation.

In Section 5 we then examine cross-cutting and policy issues. These include carbon pricing, competitiveness impacts including carbon border adjustments, funding mechanisms, clusters, and jobs and skills. Finally, in Section 6 we conclude and draw broader conclusions.

[v] No breakdown is supplied for investment specifically in manufacturing.

2. Steel

2.1 Background

Steel is considered one of the hardest-to-abate economic sectors in relation to climate change and is responsible for about 7% of global greenhouse gas emissions.[10] Worldwide, steel is one of the largest consumers of resources, in particular, iron ore and metallurgical coal and half of steel production now occurs in China. Downstream in the economy, steel is used for construction (53%), industrial equipment (20%), consumer products (18%), and vehicles (10%) in terms of volume.[11] Steel remains in use for an average of 13 years in vehicles, 15 years in consumer products, 30 years in machinery, and 50 years in construction, after which the steel may become available for recycling.[12]

In the manufacturing process, steel can be produced using primary production from iron ore or from secondary production using scrap steel. Most UK steel [81%, see Figure 4] is produced using the primary Blast Furnace and Basic Oxygen Furnace (BF-BOF) method which tends to occur in large integrated mills using significant inputs of coking coal and iron ore. In the first step, the oxygen in the iron ore is removed ("reducing") in the Blast Furnace when mixed with coking coal and other materials to produce pig iron. The coke acts as a reducing agent as well as an energy source for the BF-BOF. The iron is then turned into steel. Here the molten iron is combined with other materials such as scrap steel to give the required carbon content, and then blasted with pure oxygen. This ore-based production process is carbon-intensive due to the chemical reactions in the reduction process and the significant heat required.

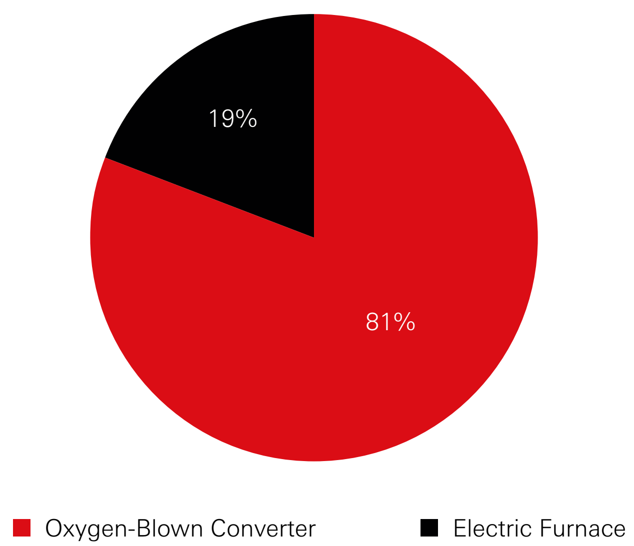
The remainder of UK steel [19%] is produced using the less emissions-intensive secondary production method. This uses an electric arc furnace (EAF) which utilises scrap steel and electricity as its main inputs. Compared to primary production, every tonne of steel made from scrap through the secondary route, avoids the need for 1,400 kg of iron ore, 740 kg of coking coal, and 120 kg of limestone, and requires 40% less energy and 60% less CO_2 emissions.[13]

In 2019 there was an estimated 865 Mt of scrap steel available for use globally.[10] At present about half of the scrap used in secondary production comes from offcuts from the production process itself rather than end-of-life products. In particular, 20% comes from ‘home scrap’ which occurs from initial steel production, 30% from ‘prompt scrap’ which are offcuts returned by metal fabrication industries, and 50% end-of-life scrap which is situated in products and buildings. Also, the fact that electricity can be decarbonised leaves significant scope for further emissions reductions. This secondary production EAF method is used more extensively in certain countries such as Spain, Italy, Turkey and the USA: the UK is a significant exporter of scrap to such countries.

A third method, the Direct Reduction route is used to produce Direct Reduced Iron (DRI), also known as Sponge Iron, using a combination of hydrogen and methane or syngas, to reduce the iron ore. This method is less emissions-intensive but also less efficient than the BF-BOF route. It is not currently utilised in the UK but is used in Middle Eastern and South American countries with large gas reserves as well as in India with coal reserves, and accounts for around 9% of global production. Due to large quantities of natural gas often used during the DRI process, these facilities tend to be close to areas with plentiful supply. Logistics/transportation is another issue as DRI needs to be transported to steel mills in an efficient and cost-effective manner for processing. The DRI route is often directly situated next to EAF production.

Beyond the creation of liquid steel there are activities of casting, forging, rolling and drawing. However, it is the basic production of steel that accounts for most of the CO_2 emissions.

Figure 4 Percentage of UK steel production by type 2020



Around the turn of the century the UK went from being a net exporter of steel to a net importer. In 2020 the UK produced around 7.1 million tonnes of steel, about 0.4% of global production,[14] significantly less than UK consumption (11.9 Mt in 2018).[15] However, a large proportion of UK produced steel is exported abroad, mostly to EU countries. Only about a sixth of final consumed steel goods in the country come from UK-produced steel.[16]

The UK steel industry employs around 31,900 people.[17] Output and employment (Table 1) are dominated by the two Blast Furnace integrated sites, operated by Tata Steel (Port Talbot) and British Steel (Scunthorpe) (the other companies on different sites are Celsa, Outokumpu, Liberty, and Forgemasters). These two primary production sites imported 8.7 million tonnes of iron ore and 2.4 million tonnes of coking coal in 2018. In total that year there was 2.7 million tonnes of recycled steel used in the UK, of which 1 million was utilised in primary production while 1.7 million was used in electric arc furnaces in the other sites.[18]

Table 1 Main UK steel producers

Steel Producer name	Type	Capacity (tonnes)	Total UK employment No.
Tata Steel	BF-BOF	3,000,000[(1)]	8,500
British Steel	BF-BOF	2,800,000[(1)]	4,600
Celsa	EAF	1,100,000+	2,000
Liberty	EAF	212,000	2,100
OutoKumpu	EAF	350,000+	570
Forgemasters	EAF	40,000	640

Source: UK Steel (2018)[19] and interviews

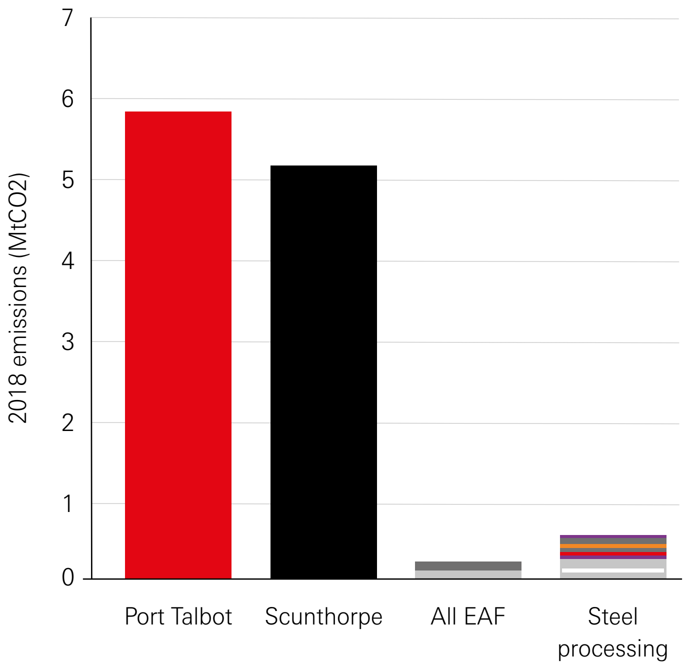
Notes: For Tata Steel and British Steel, this refers to output rather than capacity

The difficulties involved in decarbonising UK steel must be considered in the context of international trade given how highly traded the product is. These are discussed further in Section 5.

The UK steel industry has suffered a difficult period over the last decade or so. It struggled to regain profitability after the financial crisis and then in 2015 global steel prices crashed due to overcapacity in China creating a surplus of supply on the market, which in turn made UK-produced steel appear relatively expensive and resulted in the closing of sites, lost international orders and job losses, estimated at 7,000 that year. Recently UK steel companies have changed hands. The British Steel plant in Scunthorpe was purchased by the Chinese-owned Jingye Group in March 2020, after it entered compulsory liquidation in 2019 having previously been bought by Greybull Capital in 2016. Also, in July 2021 it was announced that the Forgemasters site will be purchased by the Ministry of Defence.

Overall, steel manufacturing emissions in the UK have reduced by about 56% since 1990, largely due to energy efficiency improvements as well as a reduction in output.[5] Nevertheless steel production still accounts for 2% of overall UK emissions, making it the second largest emitting manufacturing sector.[5] As per Figure 5, over 90% of emissions from the UK iron and steel industry come from the Port Talbot and Scunthorpe plants.

Figure 5 UK CO_2 emissions from steel by site 2018



Source: Ember (2020)[20] Steel Production Dataset

Globally steel demand is expected to remain strong over the coming decades but the mix of how it is produced will require significant alteration in relation to meeting climate change targets.[21] In this respect, the UK's dependence on ageing blast-furnaces is both a challenge, and an opportunity. If these expensive assets require investment anyway to improve competitiveness globally, then seizing the opportunity can potentially bring about benefits on both fronts – the economy and environment. However, there is likely only one investment cycle for incumbent primary steel production during that time period. The CCC suggests the UK's steel sector can lead the way and quickly decarbonise to become a Net Zero emissions steel industry by 2035. This will require immediate government action to put in place the conditions in which the required investment will take place.

2.2 The future of Net Zero steel

According to the IEA's Steel Roadmap the global end use demand for steel will be almost 40% higher in 2050 compared to 2019.[10] The need to decarbonise, and wide-spread national goals for 'Net Zero' covering almost two-thirds of global emissions,[22] imply a rapid move for this growth, and much of existing demand, to be met by low-carbon steel. Therefore, the difficult choice in decarbonising for UK steel companies, with

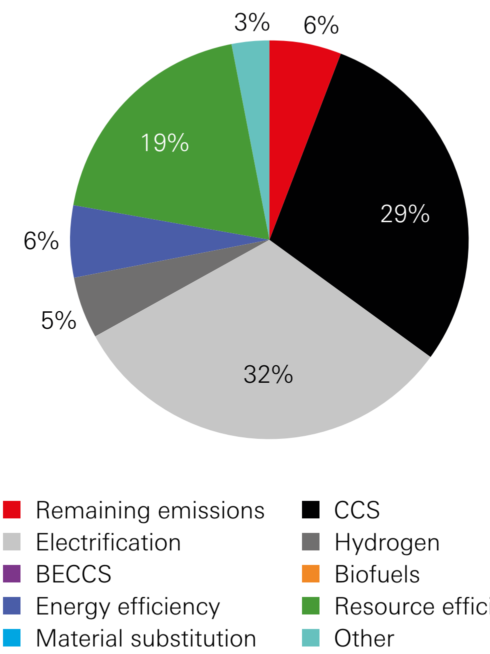
Box 2.1 UK Steel

> "It's the complexity of the trade market and the global economy around steel that makes this so much harder than many other options of many other decarbonisation routes."

fairly low margins, is between being an early mover, which is risky given the highly competitive international nature of the steel industry, and being a late-mover where the demand for low-carbon steel, and the expertise in producing it, has already been captured by early movers. Government policy is a key input into the choices these companies will make.

The CCC's Balanced Net Zero Pathway (BNZP) scenario has the steel industry's emissions achieving Net Zero by 2035.[6] When compared to the baseline emissions of 11.5 $MtCO_2e$ in 2050, the BNZP achieves emissions reductions for steel mainly via electrification (32%), CCS (29%) and resource efficiency (19%) with energy efficiency and hydrogen playing smaller roles, and 6% residual emissions, amounting to 690,000 tonnes of CO_2 which must be removed from the atmosphere by other means (see Figure 6).[vi]

Figure 6 Contribution to UK iron and steel emissions reductions in CCC Balanced Net Zero Pathway scenario



Source: CCC (2020)[6]

In terms of the routes to decarbonise the steel industry in the UK the main options identified are listed in Table 2.

Resource efficiency and reducing demand are necessary, but not sufficient, methods to lower emissions associated with the steel industry. Smaller vehicle size, for instance, may use less steel in the production. It is also possible to move towards other materials e.g., the Arrival van which uses an aluminium frame and thermoplastic-composite panels.[vii] Extending the lifetime of products and designing for increased reuse and repairability are also simple solutions. Steel bars in construction can become smaller as the height of the building increases but often, for ease, the same size is used throughout the building, resulting in 2-3 times overspecification.[11]

Table 2 Main options for steel sector decarbonisation

Technology	Role in decarbonising steel
Resource efficiency	Achieves the same level of steel output with less inputs. A more effective approach to employing resources and greater use of recycled materials. Can help minimise primary material production that uses carbon-intensive methods.
Electrification	Requires low-carbon electricity and is essential for EAF production and for creating electrolysis to produce hydrogen. This route requires an expansion of electricity generation from renewables and reduced electricity costs to industry.
Hydrogen	Hydrogen can be a replacement reducing agent for coke in bigger steel plants that may face significant challenges in adapting to EAF production using scrap. In the long run, the aim should be to produce as much hydrogen as possible through electrolysis, avoiding the need for the steam methane reforming (SMR) fossil methane gas (and associated emissions), and could be used to produce direct reduced iron that can be utilised in EAFs.
Carbon capture and storage (CCUS)	CCUS can be retrofitted to existing BF-BOF steel production sites, or to the SMR production of hydrogen, to capture emissions, which can then be removed to be stored or used as an input for another process. Both usage and storage options will likely require extra transportation and infrastructure.

Source: Adapted from IPPR (2021)[23]

Much of the same issues with regards to steel products and applications also apply to cement i.e., in construction, and we provide more detail of issues there (see Section 3.2.1).

One significant potential method of UK steel decarbonisation is through greater secondary production via EAF which is already an established technology route in the UK with low emissions. This is possible given the significant supply of domestic scrap steel. The other two main options to ensure a continuing steel sector in the UK, with Net Zero emissions, are to continue using fossil fuels as a reducing agent while dealing with their emissions post-combustion, or to avoid using fossil fuels in the process in the first place. In practice, this likely means either employing carbon capture technologies, or using other techniques, such as 'green' hydrogen as a feedstock instead of coking coal, or a combination of the two. Neither of these technology pathways are as developed with regard to

[vi] However, it must be stated that this was one of five scenarios with wide variations for iron and steel decarbonisation between the scenarios. Detail on the other scenarios at the level of iron and steel is not publicly available.
[vii] https://arrival.com/

steel production as EAF, and neither are deployed on steel at scale in the UK. The Materials Processing Institute highlights four aspects that make rolling out these new solutions quickly a challenge:[24]

- High energy prices (mostly electricity) for EAF and hydrogen DRI;
- Access to imported raw materials i.e., iron ore;
- Uncertainties in the provision of green hydrogen; and
- Insufficient R&D.

There is currently a £35m research project on low-carbon steel, Sustain, run out of Swansea University[viii] and a new circular economy centre on metals, CircularMetals.[ix] Both are UKRI funded.

Overall, there are a number of factors that mean the route to decarbonisation for steel will differ by company and by region. Factors such as geography, the demands for different types of steel, the policy context, and the history of steel companies themselves, will all play a role in determining whether a company goes down one route or another, be that CCUS, green hydrogen, EAF, or a combination. When you factor all these in, this adds up to different economic choices for different companies.

2.2.1 Secondary steel

Steel stocks in developed countries are fairly saturated, whereas the extra net demand occurs where stocks of steel in (mainly developing) economies are still growing.[25] About 70% of steel in-use stock is in construction, and much of this will become available over the coming decades as end-of-life scrap.[10] This means that globally it will be possible to meet much of the increased demand over the next few decades with greater secondary production using scrap steel. China is expected to increase its EAF from around 10% of production today, to around 45% of production by 2050.[10] Although, if demand-side reductions are implemented for steel, then this will lower future supply.

With a mature steel economy there is plentiful supply of scrap steel in the UK of around 11.3 million tonnes a year.[26,x] Domestically only 2.7 Mt of scrap is used at present.[18] The remainder is exported at little value-added, mostly to places like Turkey that use significant amounts of scrap in their own electric arc production. 8.7 Mt of scrap was exported by the UK in 2018.[15] However, when viewed in the context of a low-carbon transition to a Net Zero economy, this scrap can be considered a much more valuable resource. Better segregation and retention of scrap would assist the low-carbon transition and the Government could place restrictions on the amount of scrap that is exported by the UK.[27]

If the UK was to retain this resource rather than export to abroad, then its impact on global emissions would be complex and dependent upon a number of factors. These include whether it replaces UK BF-BOF production or is additional to UK production, whether it reduces UK steel imports and where these are from, and how it effects steel production for the previous scrap purchaser i.e., does Turkey get its scrap from elsewhere or is production reduced and demand met from elsewhere. However, increased UK EAF production would certainly benefit the UK economy.

The fact the UK has a relatively large share (37% in 2019) of renewables in electricity generation (and over 50% when including all low-carbon sources including hydropower and nuclear) means that the EAF steel from scrap is considerably lower carbon than many other countries e.g., China and EU average. Therefore, the UK already has a potential comparative advantage producing lower-carbon steel from scrap. This potential could increase further with the goals now set for renewables, especially offshore wind.

At present around 2.7 Mt of scrap is employed, but this underutilises UK steel-making capacity (Table 3). If all existing EAF and BOF plants ran at full capacity of scrap use, then it would be possible to have 6.1 Mt of scrap steel utilised in the UK but would require investment in downstream processes e.g., rolling capacity, and also greater export of semi-finished products in order for the plants to be operating at full capacity.[26] Therefore, to meet the level of the UK's annual steel consumption, of 11.9 Mt, by fully using scrap, significant investment in new EAF capacity would be required and in practice it would need to be accompanied by a reduction in comparative electricity prices. A new EAF facility requires capital expenditure in the region of $2 billion for a plant 3 Mt of steel capacity per year.[26]

Box 2.2 UK Steel

"Electricity prices are immensely important; it cannot be overstated really the importance for the electric-arc furnaces. The reason why we don't produce more steel with the electric-arc furnace, is because their capacity is underutilised at the moment."

[viii] https://www.sustainsteel.ac.uk/
[ix] https://www.circularmetal.co.uk/
[x] The earlier (Allwood et al, 2019)16 report suggest that around 10Mt was collected in UK each year. Regardless, the level is almost the same as the UK's annual total consumption of steel.

Table 3 UK scrap steel recycling

UK Steelmaker	Current scrap steel consumption (tonnes per annum)
Tata Steel	500,000
British Steel	300,000
Celsa	1,100,000
Liberty Steel	300,000
Others	400,000

Source: Hall et al. (2021)[26]

The uptake will depend upon the relative price between ore-based and scrap-based steel and, also, on the substitutability between these two types in products. Primary steel, iron ore and scrap steel are all traded internationally, therefore prices are set by global supply and demand. One challenge is that steel produced at present using secondary methods can result in impurities which can limit its technical application in certain products. This is less of an issue with the pre-consumer "home scrap" which occurs from initial steel production, and "prompt scrap" offcuts returned by metal fabrication industries, which are both able to be utilised in a wider variety of products. These are therefore more valuable as their quality is known with more certainty. Therefore, arrangements are often made for the purchase of home and prompt scrap by secondary production facilities and prices are fairly stable.

However, the "obsolete" scrap, i.e., the end-of-life post-consumer scrap where steel is collected and recycled from its end use e.g. buildings and vehicles, often results in contamination from other sources e.g. copper, which can make recycling more expensive and limit its future application. It is easier to use contaminated scrap as an input into the BF-BOF production route as an alternative to iron ore, but only up to around 30%,[11] whereas EAF requires higher grades of scrap with less impurity. While demand for steel from vehicles is less than say for construction, if the amount of secondary steel production is to increase, then improving the ability to use scrap in such sectors is necessary.

Developing new methods to remove contaminating elements would allow for greater substitutability and improve the recyclability of the abundant supply of end-of-life scrap steel. In a low-carbon future this may add significant value to the resource being underutilised in the UK. For instance, the copper contamination in scrap steel from cars comes about because the method of recycling cars is by shredding together all the other components and materials together with the steel. Options for generating better quality recycled steel could include better disassembly before shredding, using copper substitutes in car production, such as aluminium, which is more easily dealt with in the recycling process, and developing purifying technologies for liquid metal from scrap. On the latter, the high energy requirement and cost for current known purification techniques means there is little economic incentive either to pursue them, or to research other potential routes for purification. However, the economic incentive may change in the future. Globally, as low-grade scrap steel can only be used in certain products e.g. construction, eventually recycled steel will fully satisfy these demands, and there will be an excess of unused scrap which will drive down the scrap price.

Recycled steel from scrap in the UK is currently utilised for products for which relatively low-quality steel is tolerable, but innovation in improving the quality/purity of scrap would allow it to be recycled in greater quantities for more products. If the government is keen on creating a new low-carbon British industrial sector for the future, then a focus on secondary steel production seems like a strong approach given relative UK advantages in supply and in researching and developing new technologies related to metallurgical process innovation.[xi] A number of policies could facilitate a switch to secondary production including carbon pricing, subsidies for scrap, and research and development of metals recycling. These are discussed further in Section 5.

2.2.2 Carbon capture for steel

Carbon Capture Usage and Storage (CCUS) could play a significant role in helping the UK steel industry achieve its Net Zero target. Here, the carbon dioxide emissions that occur during the production process are essentially collected, compressed using additional technology, and then treated in one of two ways. The first option is injection of the captured carbon underground, where it is stored (CCS). This requires transportation to a suitable geological storage site. In the UK this would most likely be under the North Sea or other unused oil and gas sites. The second option is to use the captured carbon (CCU) as a commercial input into other processes such as fertilisers and chemicals. This can be a source of revenue to steel producers if there is significant demand, if the CO_2 is of sufficient quality, and there are nearby users, perhaps in an industrial cluster, which can reduce transport costs. However, it raises questions of whether steel companies essentially want to become chemical companies.

Identified barriers to CCUS deployment include high infrastructure costs, lack of incentives because of lack of return on the investment, and safety concerns.[24] The main obstacles are that CCUS is energy- and capital-intensive, and the required infrastructure for storage is expensive. Interviewees suggest this may make steel produced with CCUS around an estimated 30% more expensive than without. Without a guaranteed market for this more expensive steel, investment to produce it is unlikely to be forthcoming. Given the limited time available before 2050 in terms of investment decisions, it is likely that CCUS would require to be operational during the 2030s and so scaling up during the 2020s is essential. While there are no examples of CCU related to steel production, the CARBON2CHEM project by Thyssenkrupp uses flue gases from steel production to create low-carbon chemicals.[28]This is discussed further in Section 4 on chemicals.

[xi] https://www.circularmetal.co.uk/

CCUS technologies can be retrofitted on to existing plants, and thus do not require brand new installations to be built. CCS has been pursued for some decades and there are diverse types in various stages of development, but globally there is only one steel CCS site, the Abu Dhabi CCS Project by Emirates Steel Industries. The International Energy Agency (IEA) assumes that 16% of the global iron and steel sector's cumulative emissions reductions in their Sustainable Development Scenario will come from CCUS between 2020 and 2050.[10]

The two large integrated sites at Port Talbot and Scunthorpe would be the main contenders for CCUS in the UK. The Scunthorpe site's proximity to the North Sea would make it better suited for storage, whereas the Port Talbot site is part of a South Wales cluster that allows for usage in many industries. The required investment would require significant public support, especially as the UK's plants are already struggling to remain competitive, and these sites will anyway have to invest in relining some of their blast furnaces, or even rebuilding them, if they wish to continue using the current BF-BOF process.[24] The only semi-firm commitment from a steel producer in the UK is the British Steel announcement that it is part of the Humber zero carbon cluster, yet it does not go as far as saying how the steel will be produced.[29] Development of CCUS for steel needs a clear direction and support from Government. Essentially, either Government guarantees to purchase the steel produced or pays for the investment and the operating costs of CCUS. The Materials Processing Institute states that in any case there is a risk of this route to low-carbon steel locking the UK industry into existing technology, thereby reducing incentives to invest in new low-carbon technologies, foregoing gains in productivity and capability, and losing competitiveness.[24]

2.2.3 Hydrogen for steel

Hydrogen-based steel production using iron ore could instead replace the traditional carbon-based Blast Furnace route, in several ways:

- One approach is injecting hydrogen into the Blast Furnace as an auxiliary reducing agent.
- Another approach would see hydrogen entirely replace reduction agents such as coking coal using electrolysis, with a by-product of the chemical reaction then being water rather than CO_2. This would produce direct reduced iron (DRI), otherwise known as sponge iron, which would then be turned into steel using the EAF route.
- Another hydrogen-based option is directly using hydrogen in an electrolytic process and plasma smelting.

To be low carbon, the hydrogen in these options would have to be produced either 'green' (using low-carbon electricity – presumed renewables), or 'blue' hydrogen from natural gas with CCUS, most likely from steam reforming.

It is estimated that producing 6Mt of steel through hydrogen DRI, about the same as the current level of steel produced via BF-BOF in the UK, would require an extra 20 TWh of electricity demand annually.[30] This is equivalent to about 23% of all electricity supplied to UK industry at present and about 17% of all current renewable generation.[24] The Materials Processing Institute also states that to be competitive it would require a renewable price of less than £25/MWh and a carbon price of £50, and reports that a 600 MW electrolyser may cost around £600 million and allow a reduction of 2 $MtCO_2e$.[24]

In Sweden this direct reduction using the green hydrogen route is being trialled at the HYBRIT plant (LKAB, SSAB and Vattenfall) and aims to bring green steel to market by 2026. Vehicle manufacturer Volvo has committed to using this steel for their cars within the same year.[xii] A test run was completed in summer 2021 which claims to be the world's first ever green steel. LKAB are planning on investing $46 billion. However, even they do not anticipate having the technology on all of their steel plants until 2040.

There is also the WindH2 project (Salzgitter, Avacon, and Linde) using wind turbines and electrolyser units. German company Thyssenkrupp have also committed to changing their production to a green hydrogen process by 2050. It is estimated this H-DRI-EAF route would break even with BF-BOF at a carbon price of 34-68 €/tCO_2e and an electricity price of 40 €/MWh. A recent Green Steel Tracker database has been set up to keep track of the various green steel projects that have been announced and provide details on them.[31] A list of current EU projects compiled are provided in Table 4 and Table 5. The former refers to projects where hydrogen is injected straight into the Blast Furnace and the latter refers to specific DRI projects where hydrogen will be used.

The UK already risks falling behind in terms of hydrogen-based low-carbon steelmaking as across Europe there have been over twenty such projects announced recently, yet none in the UK.[30] The Materials Processing Institute has stated that hydrogen-based DRI steel production could be best for the UK as it has less technological risk compared to a CCUS route as it could be developed in tranches as the technology improves rather than the all-or-nothing approach of CCUS.[24] The Tata Steel integrated site in Wales, close to the Swansea Bay, could make use of the significant resources of the tidal barrage, with the second highest tidal range in the world, to produce significant amounts of electricity required for green hydrogen-based steel production. However, this would obviously require significant amounts of coordinated strategic investment. The previous barrage plan which was turned down by the Government would have had about 320 MW of installed capacity. In the short-term, DRI production in Wales could be supplied via LNG imports at nearby terminals.

[xii] https://www.media.volvocars.com/global/en-gb/media/pressreleases/282789/volvo-cars-is-first-car-maker-to-explore-fossil-free-steel-with-ssab

Table 4 European hydrogen BF projects

Company	Location	Notes
ArcelorMittal	Bremen, Germany	DRI plant online from 2026, output 3.5 Mt per year
ArcelorMittal	Dunkirk, France	Direct H2 injection project with CCS
ArcelorMittal	Asturias, Spain	Direct injection of H2 into blast furnace
ArcelorMittal	Fos-sur-Mer, France	Carbalyst project with direct H2 injection
Voestalpine	Linz, Austria	Pilot project already running
Thyssenkrupp	Duisberg, Germany	Already injecting H2 into blast furnace. DRI plant online 2025, collocated with electrolyser
TATA	Ijmuiden, Netherlands	Pilot online since 2017, electrolyser to be completed in 2024
Dilinger/Saarstahl	Dilingen, Germany	Direct injection of H2 into blast furnace, in operation since 2020

Source: taken from ECIU (2021)[30]

Table 5 European DRI projects

Company	Location	Notes
ArcelorMittal	Hamburg, Germany	Demonstration plant by 2023, target for commercial operation 2025
ArcelorMittal	Dunkirk, France	Feasibility study taking place
ArcelorMittal	Taranto, Italy	Planning stage
ArcelorMittal	Eisenhuttenstadt, Germany	Pilot plant online in 2026
ArcelorMittal	Bremen, Germany	Large scale plant online in 2026
Voestalpine	Leoben, Austria	Commissioning Q2 2021
Salzgitter AG	Salzgitter, Germany	Demonstration project scheduled to go online 2022
Salzgitter AG	Wilhelmshaven, Germany	Feasibility study
SSAB	Gallivare- Oxelosund, Sweden	Pilot plant, market production by 2026
LKAB	Kiruna-Malmberget-Svappavaara, Sweden	DRI plant by 2029
Thyssenkrupp	Duisberg, Germany	Production by 2025
Liberty	Galati, Romania	DRI plant to be installed 2023-25
Liberty	Dunkirk, France	Feasibility study taking place
H2 Green Steel	Boden-Lulea, Sweden	Large scale production by 2024

Source: taken from ECIU (2021)[30]

There are also other approaches which can reduce emissions from steelmaking. Whilst they would not be able to reduce emissions to near-zero themselves. However, when combined with CCUS, they could. One such option is the HIsarna project from Tata Steel which was developed out of the ULCOS project for ultra-low carbon steelmaking.[32] The fifth pilot was completed in 2019 and it reduces CO_2 emissions by at least 20%. The next is attempting to upscale and commercialise the project, and this can be expected in the next five to ten years.[32]

3. Cement

3.1 Background

Cement is a main input into producing concrete and is predominantly used in construction and infrastructure. It is used to build our homes, offices and schools and is utilised in constructing railways, bridges, paving slabs and many other applications. Cement is therefore ubiquitous and is an integral part of the UK economy. Globally, around 4.1 Gt of cement was produced in 2019 most of which is the industry standard Ordinary Portland Cement (OPC).[33] Due to various production characteristics, cement is a high emitting industry which accounts for around 6% of global CO_2 emissions and 1.5% of UK GHG emissions.[33,34]

In the initial part of the cement-making process (figure 7), calcium carbonate, typically in the form of limestone, is ground together with clay or shale and heated to 1450°C in a kiln to produce clinker. Then in the second part of the process the clinker is cooled and ground together with other minerals including gypsum, to make cement. When mixed with water and aggregates such as sand, stone, gravel and recycled concrete, cement hardens to create the strong concrete used by the construction industry for structures. Different products and strengths of concrete are made depending upon the ingredients and type of demand.

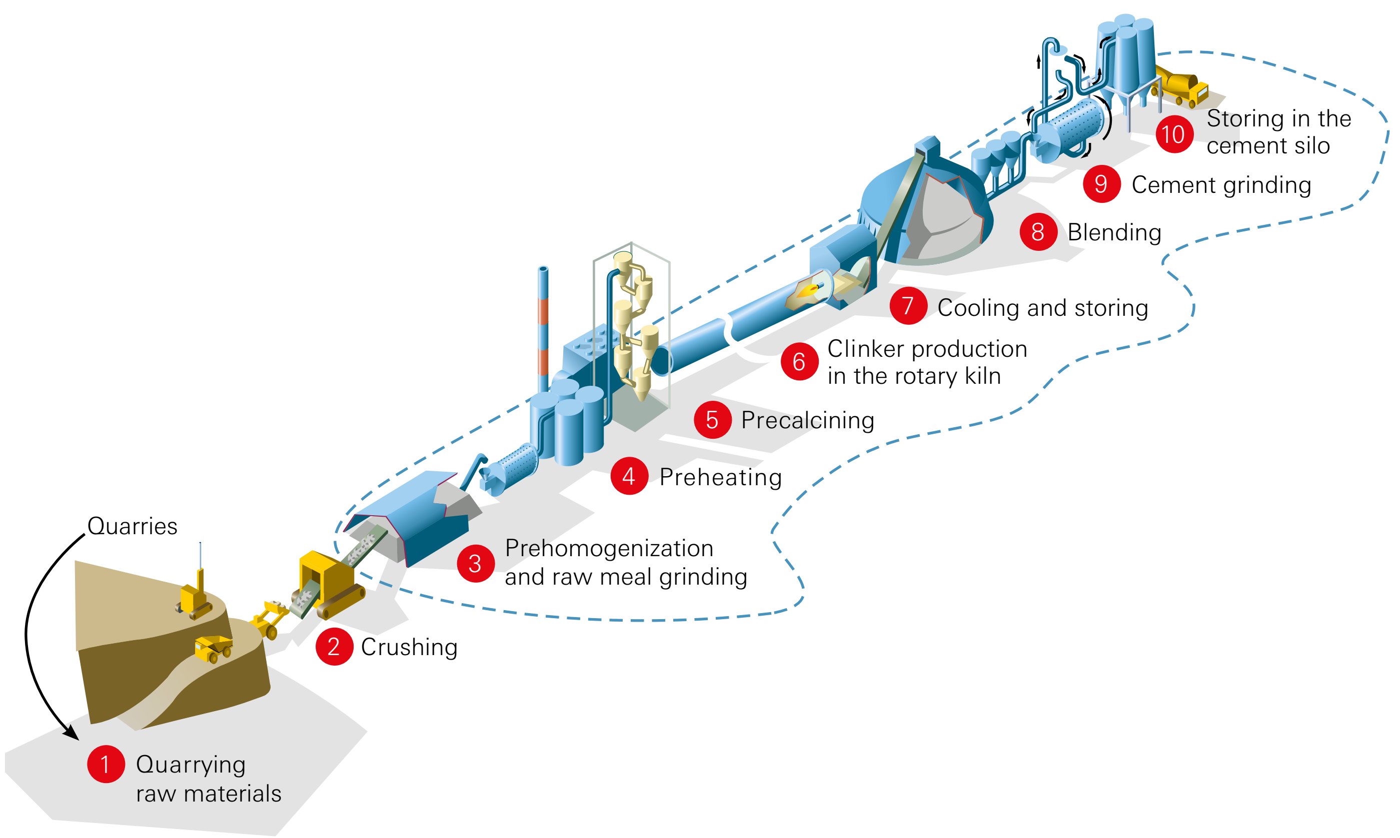
The majority of the CO_2 emissions in the production of cement come from two aspects.

(1) The energy required to heat the cement kiln to such a high temperature, by combustion of fuels, accounts for around 30-40% of cement's CO_2 emissions. While various fuels can be used to heat the kiln, it has predominantly been coal but other fuels that allow such high temperatures can be used.

(2) The chemical calcination process from the transformation of the limestone feedstock into clinker. This occurs in the precalciner and in the kiln. When the limestone is heated it splits into calcium oxide and carbon dioxide. These process emissions account for roughly 60% of CO_2.

There are some minimal other CO_2 emissions which occur

Figure 7 Cement manufacturing process



Source: Taken from IEA (2020)[35]

throughout the whole production process from the mining extraction of raw materials, electricity requirements for grinding at various stages, as well as emissions from transportation. Already the cement industry has made significant energy efficiency improvements from the transition to dry kilns with preheaters.

The UK produces around 9 million tonnes of cement and 90 million tonnes of concrete per year, with 95% of concrete used in the UK produced here, and with 83% of UK cement used for buildings and 17% for infrastructure.[34,36]

The five main cement companies in the UK which form the Cement Mineral Products Association are:[xiii]

- Cemex – Kiln sites in Rugby and South Ferriby (recently mothballed) and a grinding site in Tilbury.
- Hanson (part of HeidelbergCement) – Kiln sites in Ketton, Padeswood and Ribblesdale.
- Breedon – Kiln site in Hope as well as blending sites in Dagenham, Dewsbury, Theale and Walsall.
- Lafarge – Kiln sites in Cauldon and Cookstown.
- Tarmac – Kiln sites in Aberthaw, Dunbar, and Tunstead. Grinding site in Barnstone. Blending sites in Celtic Ash, Northfleet, Seaham, Scotash and West Thurrock.

The UK cement sector employs around 2,000 people although this is just cement production and not concrete plants etc. More broadly, the mineral products sector employs 81,000 people in the UK and supports a further 3.5m jobs in the supply chain.[37]

In 2019 the UK's direct greenhouse gas emissions from manufacturing cement were 7.7 $MtCO_2e$, about 1.4% of total GHG emissions.[5] Of the total CO_2 emissions in the sector, 60% were process emissions from limestone calcination, 30% was from fuel combustion, and the remaining 10% from electricity and transport.[34] Overall, UK CO_2 emissions from cement have decreased by 43% compared to 1990 levels.[5] However, around half of this absolute reduction is as a result of declining production, with the remainder resulting from decarbonisation and energy efficiency improvements. There have been significant improvements in the UK by moving the fuel combustion mix in cement production away from fossil fuels and towards waste and biomass as fuel. In 2019, 45.5% of the thermal demand was provided by waste derived fuels, meaning that fossil fuels account for just over half of combustion fuel use now, compared with 94% back in 1998.

There has also been increased import volume for cement, which is becoming more of an important issue for UK manufacturing companies. It has increased from a fairly low number by around a percentage point a year, from 8% in 2003 to 17% in 2020.[38]

3.2 The future of Net Zero cement

Global production of cement is set to grow by 12 to 23% by 2050 above the 2014 level, mostly driven by urbanisation in Asia.[35] Demand for cement in the UK over the coming decades will depend upon domestic demand for new construction, including new homes and government buildings and infrastructure projects, as well as on regulations related to construction and climate. The main areas which can help tackle emissions in cement production are resource and material efficiency, material substitution, fuel switching, and carbon capture.

The Climate Change Committee (CCC) estimate the UK can achieve a zero-emissions cement sector by 2040. In their central BNZP scenario, emissions from cement reduce by 51% by 2030 compared to 2019 levels. For cement and lime the CCC's scenario (see Figure 8) provides the following breakdown of how the reduction is met. Increased resource efficiency accounts for 40% of the reduction. The remainder is achieved through CCS, BECCS and material substitution representing 23%, 22% and 13%, respectively. Overall, CCS would be involved in 45% of cement's emissions reductions in this scenario.

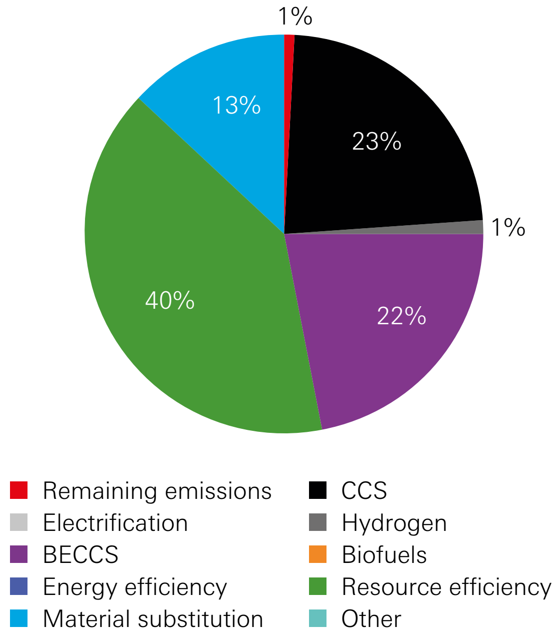
Cement companies have also made their own commitments to emissions reduction. Cemex is committed to reducing emissions by 35% by 2030 compared to 1990 levels, and to Net Zero by 2050. Hanson UK have a commitment to reduce emissions per tonne of cementitious material by 30% by 2025 and to provide Net Zero cement by 2050 at the latest.[xiv]

Box 3.1 Cemex

> "People seem to think that it [cement] can't be transported over large distances. That's on land. By sea, it's something that can be transported very easily and in bulk and the UK is particularly vulnerable given that we're such a small country surrounded by water, import and access points are literally all around us and it makes it an easy target going forward."

[xiii] There is also the 'Inerys' site in Purfleet which has a much smaller kiln that produces calcium aluminate cement, which is different from standard OPC, and as a specialist cement does not serve the same bulk market.
[xiv] https://www.heidelbergcement.com/en/energy-and-climate-protection

Figure 8 Contribution to UK cement emissions reductions in CCC Balanced Net Zero Pathway scenario



Source: CCC (2020)[6]

3.2.1 Resource efficiency and material substitution

There is significant potential for the reduction of CO_2 emissions from cement through resource and material efficiency.[36] This can be achieved through reduced consumption i.e., using less concrete in building, as well as improving resource efficiency in the production process. Future demand reduction does not need to be at the expense of building fewer structures, simply of using less concrete per square metre to make them. This requires changes in the design and construction stages. The design of structures is frequently over-specified with materials as standard practice. There are few incentives for change given how cheap and abundant cement is in the building process. Using less concrete would be possible if the industry had a reason to spend more time considering the materials it uses. Increasing the lifetime of buildings is another option to reduce demand for new cement, and may involve repurposing commercial buildings, which would otherwise be demolished, for residential purposes.

Achieving the benefits of material efficiency will likely require several integrated strategies. Architects and the wider construction industry have a direct role in driving demand for Ordinary Portland Cement. The carbon implications of construction should be considered in the education, training and regulations for all those in the supply chain, i.e. architects, designers, transport and civil engineers, construction workers, manufacturing companies, material and parts suppliers, and demolition companies.[11]

There are also potential options for reuse and recycling. If designs allowed for slabs to be transported for repurpose and reuse at end-of-life, this could reduce further demand. Also, if the clinker can be separated from the aggregates, when the cement is ground up, then it should be possible to reuse it. This is being undertaken in the new Smartcrusher project in the Netherlands.[xv]

Substitution with different end-use materials may also lower emissions. Moving towards the use of timber in construction may be possible in certain instances, although it would be limited for infrastructure. The production of timber uses about 30% less energy, and produces 15% less emissions, than cement.[39] Timber is effectively a carbon sink which stores carbon during its growth and holds it while intact. However, timber has different characteristics to concrete, such as being less durable, and it is important what happens to timber at end of life. Replanting the trees can then remove more carbon from the atmosphere. However, land availability and time to forest maturity are major issues for large-scale substitution. It would require forests 1.5 times the area of India in order to provide timber to replace 25% of the cubic meters of concrete used each year, and if planted now these forests would not be available for harvest until around 2050.[39]

Switching of inputs in the production process can also play a substantial role in reducing emissions. One option is to reduce the clinker to cement ratio. This requires the substitution of materials that can be used instead of clinker such as fly ash and ground granulated blast-furnace slag (GGBS). Fly ash is a waste product of coal plants, and blast-furnace slag is a by-product of steel production by the BF-BOF route. This is already occurring with CEM II type cements.[xvi] In the UK these secondary cementitious materials can be added at the cement plant or at the concrete plant helping to reduce the clinker content of the overall mix. In the UK on average just 65% of the total cementitious material in concrete is clinker, making it comparably resource efficient.

In the future, however, the supply of fly ash and blast-furnace slag is tied up with the future of the UK and global coal power and steel sectors. With their decarbonisation, these clinker substitutes may not be available in the future. They may therefore play only a short-term role in helping decarbonise cement, unless coal power and steel production shifts to CCUS long term. To address this the Mineral Products Association industry body has embarked on a research and development programme part funded by The Department for Business, Energy and Industrial Strategy (BEIS). The research under the Industrial Energy Efficiency Accelerator programme has developed and tested ‘low carbon multicomponent cements’ which have three components: clinker + limestone + either GGBS or fly ash. The lowest carbon option of these cements is 60% lower than the current market-leading cement, CEM I.

Clinker could also be substituted (up to about 45%) with other lower CO_2 materials such as limestone (15%), which is abundant in the UK, and calcined clays (30%).

A Material Flow Analysis found that UK cement emissions could be reduced by 51% through combined material

[xv] https://www.slimbreker.nl/smartcrusher.html
[xvi] The CEM I category is 100% cement, whereas CEM II is a minimum of 65% cement, with CEM III being over 45% cement.

efficiency improvements alone.[36] The six techniques required are calcinated clay and lime (27.2%), reducing cement content (10%), reducing overdesign (7.3%), precast (3%), post-tensioning (2.6%) and construction waste (0.8%).

There is also the possibility of developing novel low-carbon cements and concretes to replace the use of Ordinary Portland Cement. There are already some low carbon cements and concretes available in the UK market. Cemex offers a range of Vertua low-carbon concretes which, depending on the specific product, reduces emissions anywhere between 30-70% compared to typical products using CEM I cement.[xvii] Although the product has lower emissions, fewer applications are possible with it. Vertua is being used in the construction of HS2.[xviii] There have been several products which have been developed over the years as green cements that have not come to fruition, such as the UK-based Novacem. The scaling of such novel cements, and their necessary supply chains, will likely be difficult in the timeframe envisioned for Net Zero by 2050, without significant market intervention, not least because regulations and codes are all based around the assumption of continued use of Ordinary Portland Cement.[40] There is also the possibility of removing cement completely from concrete as has been done with Greenbloc in the UK, which uses Cemfree.[xix] This claims to reduce concrete emissions by 73% and is just as strong a concrete material as those produced by cement. However, it is not ready-mix and so only meets some of the concrete market.

Table 6 Novel cements with new chemistries

Type	Notes
Belite clinker	Available, however, emissions reductions only 10%
Calcium sulphoaliminate (CSA) or carbonisation of calcium silicates (CACS)	Emissions reductions are 20-30% but minerals less available
Magnesium-silicate-based cement	No emissions but much less availability of minerals
Alkali/Geo-polymer-based-cements	More than 70% reduction and pozzolan (volcanic rock) is likely good availability

Source: Adapted from Energy Transitions Commission (2019)[39]

Box 3.2 Cemex

"Whilst you may be able to design [novel cements] to have similar end qualities to more traditional cements, you may end up with significantly slower strength gain for example, which can have significant impacts on building project schedules… Whilst this may not be a roadblock, it is certainly a consideration when you look at the overall picture of a project."

Box 3.3 Hanson UK

"Things like [GGBS] they change the durability of the concrete, and it also changes the setting time. So, if you want to build something quickly then you don't want something that takes longer to develop its strength and set. So, there's that tension between, "Yes, you can have low carbon but the build programme might be a little bit longer."

xvii They provide the use carbon offsets to remove the residual emissions (around 30-40%) from using the product.
xviii https://mediacentre.hs2.org.uk/news/hs2-uses-new-pioneering-low-carbon-concrete-to-reduce-carbon-emissions-in-construction
xix https://dbgholdings.com/uks-first-cement-free-ultra-low-carbon-concrete-block-launched-greenbloc/

3.2.2 Fuel switching

As mentioned above, fuel switching has been underway for some time within the cement industry. The alternative fuel used in place of fossil inputs is dependent upon on several factors, including local availability and quality of alternatives.[40] These are outside the control of cement producers.

The UK cement industry has made significant investments over recent decades towards using waste and bio-fuels to replace fossil fuels as fuel for heat. Working with waste companies has been a major success in reducing cement's emissions as the specific content of the fuel source is important. For instance, the Cemex plant in Rugby uses an adjacent Solid Recovered Fuel (SRF) plant run by Suez to power a significant part of its kiln.[41] This sort of industrial symbiosis can help reduce emissions in the industry. In 2019 Hanson derived 55% of their kiln energy from alternative fuels, of which 20% was biomass.[xx] Increasing the percentage of waste and biomass in the fuel mix is certainly possible but requires quite large changes at plant level. Interviewees stated that it wasn't possible to simply use any form of waste. For the kiln it requires a specification for both the calorific value and also the chemical profile that ensures that the cement or the clinker is produced correctly, and the cement will work properly.

In the medium to long term, there would need to be a significant uptake in alternative zero-carbon fuel sources to meet targets. It may be possible to increase the percentage of biomass-based fuel sources from low levels, but this change becomes more difficult at higher percentages, and it is unlikely that the entire fuel source could be biomass. Therefore, biomass is likely to be combined with carbon capture and storage (BECCS), which would be an option for sites where there are already good storage or usage infrastructure in place for the process emissions as well. Obviously, this would require support, given the additional costs it would entail.

There is also the possibility of using hydrogen (green or blue) as a fuel as well as some electrification for heating cement kilns. Availability and transport are key considerations for hydrogen use in cement. These would depend on the UK infrastructure being built for hydrogen and its availability as a fuel source for plants not located near pipelines – see section 5.5 on clusters and dispersed sites. Funding from BEIS of £3.2 million has been given to the MPA for fuel-switching trials on two cement kilns operated by Tarmac and Hanson.[42] One plant will test hydrogen and biomass in the main burner while the other plant will trial electrical plasma energy and biomass in the calciner. An earlier feasibility study suggested that 70% fuel could be from biomass, 20% from hydrogen, and 10% from electrically-generated plasma.

3.2.3 Carbon capture for cement

Carbon capture will be essential to reduce emissions from the significant unavoidable process emissions from Ordinary Portland Cement, which is the majority of current production. It is possible to directly retrofit kilns with CCUS technology without significant modifications. While there is not yet a full-scale CCS cement plant, the technology is well understood but also challenging. The current lack of uptake is far more to do with cost and lack of incentives than technological barriers. Once captured, CO_2 may then be (a) transported and stored in a geological location, or (b) used for a specific purpose either in cement production or another industry.

In essence there would be one capture plant on a site capturing all emissions, but technically it could be a combination of both CCS and BECCS at the same time if part of the fuel comes from biomass. However, in cement manufacturing the emissions in the flue gas arise from a range of fuels – fossil, waste fossil and waste biomass and the process emissions from the breakdown of the raw materials. Therefore, the capture of emissions from the combustion of waste biomass is the BECCS part.

In terms of specific examples, there is a CCS demonstration plant for cement at the LEILAC plant in Belgium hosted by HeidelbergCement (owners of Hanson in the UK) and also involving Cemex.[43] Heidelberg have also announced plans for the world's first carbon-neutral cement plant in Gotland in Sweden which will operate from 2030 and capture 1.8m tonnes of CO_2 annually.[44] In the UK the Heidelberg Group are partners in the HyNet cluster in North West England which will include the Hanson UK Padeswood site which will save around 800,000 tonnes of CO_2.[45] It is intended that this cluster can combine CCS and hydrogen for industrial and other use and

Box 3.4 Cemex

> "We've been investing in alternative fuels for the last 15 years. And we've just reinvested, we've put a whole new processing line in because, as things develop, the alternative fuels have developed right up to 50 or 60%. … to be able to get up to the high 80, 90% alternative fuels, we need to be able to turn the coal feed right down and this is all a huge cost just to eke those extra few percent out of alternative fuel."

[xx] https://www.hanson-sustainability.co.uk/en/carbon

provide the necessary infrastructure for both.[xxi] The cluster site is situated with good port links for storage in the Liverpool Bay oil and gas fields.

However, while clustering can be beneficial for certain plants already in a prime location, there are also many dispersed cement sites across the country without plausible CCS options. Building pipelines or transport links in and out of existing sites may not be possible or economical. Carbon capture and usage would be a preferable option if there are local users of CO_2.

Related to the idea of capture and storage is the concept of 'carbonation'. This refers to the fact that concrete naturally absorbs CO_2 throughout its lifetime when exposed to air. The MPA believes carbonation can play a role in contributing towards cement's Net Zero emissions target, about 12% of the necessary reduction, and that this could even be accelerated with innovation through techniques to improve carbonation. It is also possible to directly inject CO_2 during the concrete production process. An example of this is being undertaken by the CarbonCure technology development which Bill Gates' Breakthrough Energy Ventures has invested in.[xxii]

Box 3.5 Hanson UK

> "The problem is that [fuel switching for cement] only deals with about a third of the carbon emissions. The other two thirds is from the limestone. So, it's an interim measure really. It's something we can do before we get to CCS.
>
> So, ultimately, I think we always end up back at carbon capture and storage as the long-term solution. Changes in the use of concrete, recycled aggregates or recycling cement paste will not get us to Net Zero. I think it always leaves a residual big-ticket CCS."

[xxi] https://hynet.co.uk/
[xxii] https://www.carboncure.com/

4. Chemicals

4.1 Background

The chemicals sector is diverse with a wide range of processes and products of different scales and sizes across the entire economy. The sector uses fossil fuel hydrocarbons for energy and as a feedstock in the production of numerous chemicals. Globally the industry produces about 1.5 $GtCO_2$ per year which is about 18% of global manufacturing emissions and represents 6% of global GHG emissions.[46,47]

In terms of global emissions from the chemical industry, roughly 85% come from energy use while 15% are process emissions.[46] Chemical products are used in a variety of sectors across the economy such as agriculture, pharmaceuticals, manufacturing, and in households. The main uses of chemical products are as inputs into fertilisers, and in consumer products such as paints, detergents and soaps. Others are used as intermediates in the manufacture of rubbers and plastics, which are used for packaging, motor vehicles and construction. In the UK, 96% of manufactured goods contain chemical industry content.[48]

There are a number of processes in the chemicals sector that require fuels for energy or as a feedstock. In relation to energy provision, the transfer of materials, chemical reactions, separation, and recycling all require energy inputs to drive equipment and facilities, usually in the form of heat and electricity. Heat is needed to provide the high temperatures necessary for many chemical reactions and separations (e.g. distillation) to occur. Electricity is also used to drive pump motors, compressors, chillers etc. throughout the production process, where there can often be many sequential stages. Some chemical reactions generate excess heat, a by-product which can be captured through heat recovery and used elsewhere in the process.

Then there is the requirement for fuel inputs as a feedstock in many chemical processes. Here, the requirement is for elements of carbon and hydrogen in order to make a product. Therefore, fuels are used, and their atoms rearranged to constitute the new product in question, such as polymers for plastics. Cutting down on feedstock use is difficult due to the nature of the chemistry required. More than half of the chemical sector's global energy requirements are for use as a feedstock. Oil and natural gas together make up 99% of this feedstock demand.[46] Given the feedstock requirement, chemical industries are often situated in countries with plentiful local oil and gas supplies such as the Middle East and, more recently, the USA, with its shale gas industry. Within countries it often means chemical plants are located close to where they can access feedstocks.

There are far too many chemical processes to be described in detail in this report (see Figure 9). Some of the main sources of GHG emissions are ammonia and urea, olefins, methanol and hydrogen, and chlorine. These can roughly be split into two main chemical sub-sectors which cause the most emissions:

(1) Basic Inorganics, and

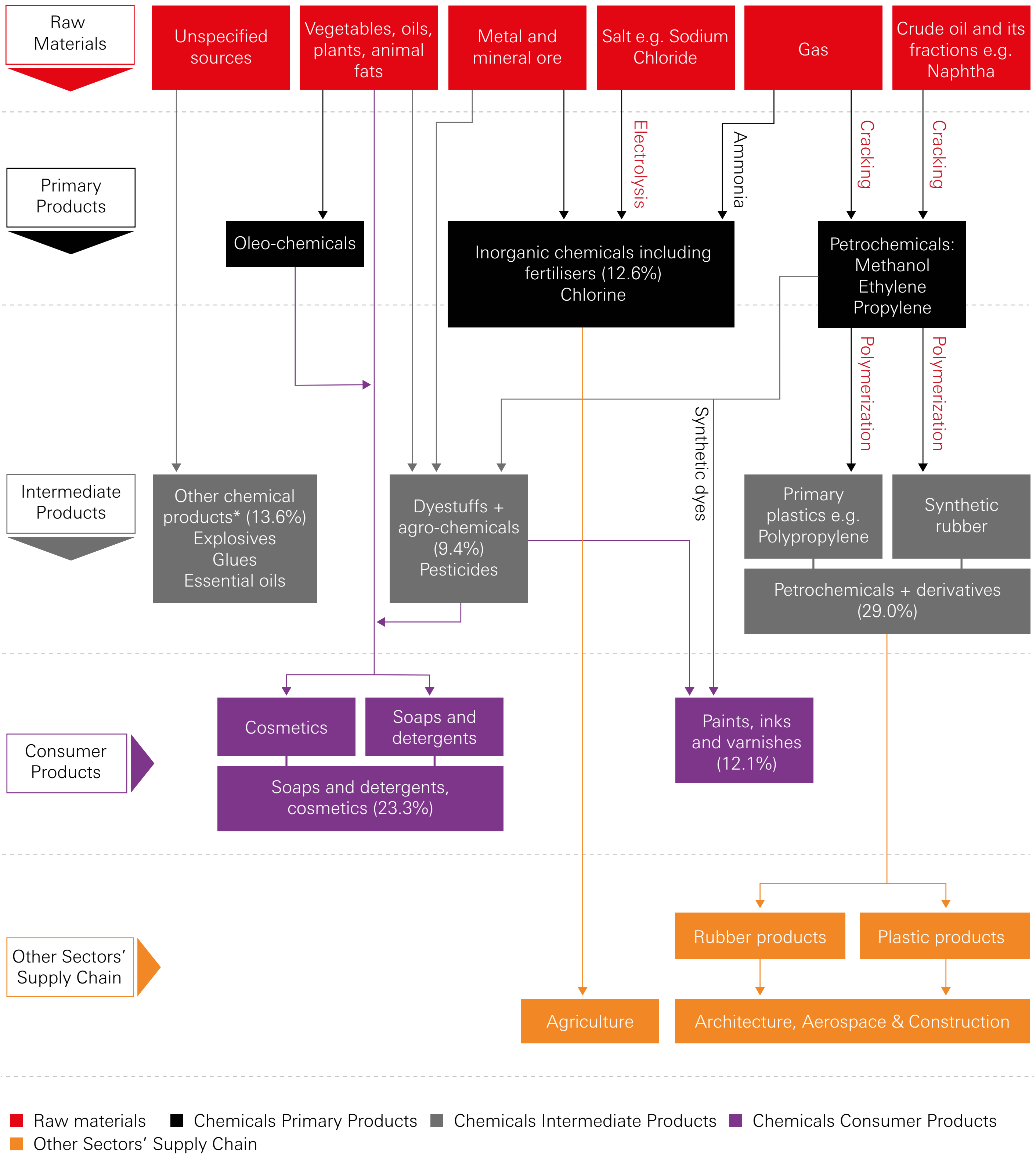
(2) Petrochemicals.

There are, however, other sub-sectors such as polymers and consumer chemicals supplied to high-value downstream sectors such as aerospace and pharmaceuticals.

Box 4.1 HCS Group

"If you look around your office today, the paint on the wall, the PC, the desk, your phone are all manufactured with chemicals and solvents. The supply chains are often diverse and complex before the finished material arrives at the consumer. Many chemicals and solvents are used within industrial applications as part of the manufacturing process. HCS supply into the industrial market to downstream users and to chemical traders but not directly to consumers."

Figure 9 Structure of the chemicals sector



* Given the diverse nature of products categorised under "other chemical products", it is difficult to quantify, as well as articulate, an exact source or destination for these products. Therefore, for the purpose of this diagram, we have simplified the illustration to solely show that the vast majority of "other chemical products" are intermediate goods which enter into other sectors' value chains.

N.B numbers in brackets refer to % of total chemicals GVA

Source: Taken from Make UK (2020)[49]

4.1.1 Inorganics

The basic inorganics sub-sector produces ammonia, chlorine and soda ash. Ammonia is primarily produced for use in nitrogen fertilisers for the agriculture sector. Ammonia is mostly produced by synthesised hydrogen, usually from the steam reforming of methane from a natural gas feedstock.[50] The hydrogen from methane is then combined with nitrogen from within the air to create ammonia, with CO_2 as a by-product. In some chemical plants the hydrogen input is taken from the by-products of other chemical processes such as acetic acid production. It is also used to make fibres, as a refrigerant, and by the mining and petroleum, rubber, paper and metal industries.

4.1.2 Petrochemicals

The petrochemicals sub-sector produces olefins (ethylene, propylene, butylene) and other intermediates from feedstocks derived from oil and gas, such as naphtha and ethane. Steam cracking is the main process in the production of these products. Furnaces are used in the cracking stage of olefin production where extremely high temperatures are needed. Using the best available technology for steam cracking at temperatures of around 750-950°C, about 13.6 GJ of thermal energy per tonne of product is required, and it is possible to recover about 1.4 GJ/t as process steam.[51] The types of products produced using ethylene and ethylene polymers are wide ranging and include: fibres, bins, pails, crates, bottles, piping, food packaging films, bin liners, bags, wire and cable sheathing, insulation, surface coatings for paper and cardboard, as well as tiles and flooring for building and construction. Ethylene is also used to manufacture other chemicals that are used as antifreeze, solvents, surfactants and detergents. Butylene is used in making tyres, wetsuits, rubber hoses, plastic gloves, and other latexes and plastics. Olefins production in the UK is by far the largest energy-consuming sub-sector in the chemical industry in terms of both fuels and feedstock.[50]

4.1.3 Chemicals industry and emissions

The UK chemicals sector accounts for £18 billion in Gross Value Added, employs around 150,000 people and also is responsible for around a fifth of UK research and development spending.[48] Much of UK chemical production goes into other sectors with about 45% used as intermediate inputs into the rest of the economy, with 24% sold directly to end users and 31% exported.[49] The largest intermediate consumer was the chemicals sector itself with 39% of total intermediate production, followed by the manufacturing of rubber and plastic products and manufacturing of motor vehicles sectors, with 11% and 5%, respectively. Within the chemicals sector, the largest self-consuming sub-sector was petrochemicals with over half being utilised there.[49]

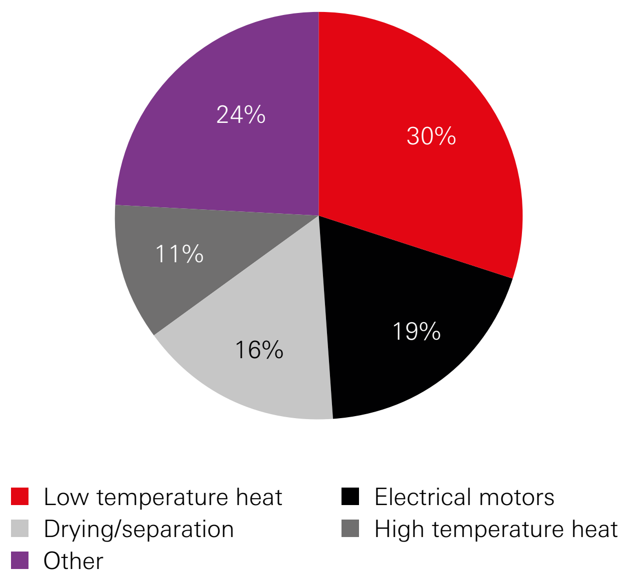
A significant proportion of chemical production in the UK is concentrated in four parts of the country, with around half of the sector's employment occurring in these clusters – Hull, Teesside, Runcorn and Grangemouth.[52] Companies vary by size and by product. They can range from small companies that produce batches of a hundred tonnes a year to large ones that produce in bulk thousands or millions of tonnes per year.[50]

Some further statistics on the economic aspects of the UK chemicals sector include:

- 97% of chemicals businesses are small and medium enterprises of which there are around 2,500, and just over half of UK chemical companies employ less than five people.[52]
- There are also about 75 large companies.[53]
- Estimates suggest around 31% of UK chemical production is exported.[49] Around half of exports are to the EU and around a fifth to the United States.
- The value added by the chemicals sector is particularly high, at 82% that of the average value added created across the UK manufacturing sector as a whole.[54]
- 10.7% of UK chemical companies are foreign owned.[49]

Figure 10 shows that energy consumption from the UK chemicals sector consists of low temperature heat (30%), electrical motors (19%), drying/separation (16%) and high temperature heat (11%). Combined Heat and Power (CHP) is already used extensively in the chemicals industry and generates a significant proportion of the energy used in the sector, with 53 chemical sites in the UK using CHP as of 2019.[55]

Figure 10 UK Chemicals energy consumption by process



Source: Griffin et al. (2017)[50]

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- Direct UK GHG emissions from the chemicals sector have already reduced dramatically, by about 79% from 1990 levels.[5] A significant proportion of the initial reduction appears to be from an abatement unit being installed at the UK's main adipic acid plant in 1998.[56]

- In terms of UK GHG emissions, chemicals is the largest direct emitting sector accounting for 18% of total manufacturing emissions and 2.2% of total UK direct GHG emissions in 2019, of which petrochemicals was almost half.[5]

- In 2018, 53% of UK chemicals emissions were from energy and 47% from feedstocks.[57]

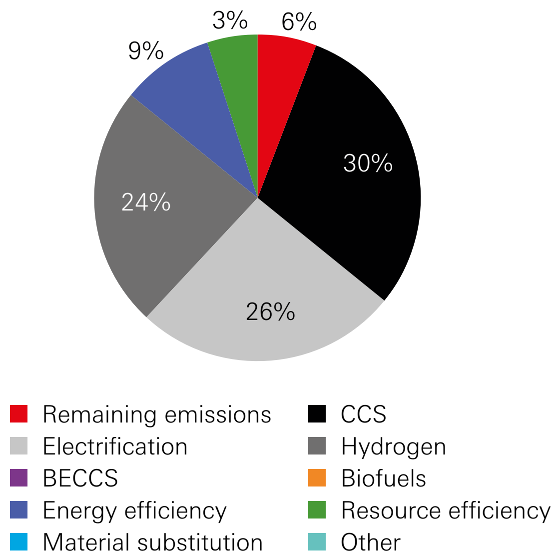
- The CCC's CB6 report has UK ethylene and ammonia production as 3 $MtCO_2e$ and 1.3 $MtCO_2e$, respectively in 2018, with the remainder of the chemicals sector processes producing a total of 8.2 $MtCO_2e$. [6]

4.2 Net Zero chemicals

Demand for chemicals is strong at a global and UK level. Even in its Clean Technology Scenario the IEA foresees growth in global chemicals demand of 30% by 2030 and 40% by 2050.[46] Due to the complex structure of the chemicals sector, future demand is tied to the outlook of a variety of different products both domestically and abroad. Plastics production is linked to a number of factors but may well face public acceptability issues in the coming years. Future ammonia consumption will depend on food production and consumption patterns as well as food waste. Aviation sector demand for new, cleaner fuels may also provide new demand opportunities. Despite the variety in the chemicals sector, and therefore of the approaches to reduce its emissions, a few of these will produce the majority of emissions reduction on the path towards Net Zero. And if the supply of oil and gas disappears to tackle climate change, then this also reduces the availability of these as feedstock inputs.

The UK Climate Change Committee's BNZP scenario has the majority of the chemical sector decarbonised by 2040, although from 2040 onwards there are still around 6% of chemical sector emissions which cannot be abated.[6] The main contributions in this scenario to emissions reductions comes from CCS (30%), electrification (26%) and hydrogen (24%), while there are smaller contributions from energy efficiency (9%) and resource efficiency (5%) (Figure 11). Of course, other pathways are possible.

Figure 11 Contribution to UK chemicals emissions reductions in CCC Balanced Net Zero Pathway scenario



Source: CCC (2020)[6]

Box 4.2 HCS Group

"If a company is reliant on fossil feedstocks and those feedstocks are no longer available because the upstream demand characteristics have changed there is a clear imperative for downstream change."

Box 4.3 Chemical Industries Association

"The chemical industry makes advanced materials that will be necessary for a Net Zero economy. So, for an example, e-fuels – like biofuels, synthetic kerosene or methanol – are chemical products. Other examples would be ammonia and hydrogen. These are all touted as fuels of the future. These are chemical products but, at the moment, there is no business case to manufacture them without government support, because the demand is not there."

There is already a considerable amount of electricity use in the chemicals sector to operate various mechanical processes and machinery. However, there is also scope for further electrification, in particular for low-temperature heat requirements that are currently met mainly through natural gas as well as electrification of compression, steam and cooling. The Climate Change Committee considers that more competitive industry electricity prices will be required to bring this about.[6] Energy efficiency may also play a role in reducing emissions. However, in the UK most energy efficiency options have already been undertaken as cost-saving measures.

4.2.1 Plastics and other petrochemicals

The production of a tonne of plastic results in about 2.6 tonnes of CO_2 emissions, with a further 2.7 tonnes embedded in the product which can be released if incinerated.[58]

An important means of reducing emissions is to make the chemicals sector more circular (for example, through re-use, remanufacture and recycling), thereby lowering the requirements for new production. While greater circularity may reduce the virgin output of certain sub-sectors, it can also reduce production costs, create new opportunities in, for example, recycling businesses, in addition to reducing environmental impacts including carbon emissions.

Increased material efficiency is also possible through reducing over-use of packaging and better design. Longer lifetimes of products can reduce demand and be achieved through higher quality polymers as well as a right to repair plastic-containing products e.g., washing machines. And demand could also be reduced through sharing products, for instance, car sharing would reduce overall demand for both metals and plastics. Material substitution of plastics in packaging by other fibre-based materials could be applicable in up to 25% of instances. Overall, material efficiency and sharing business models could reduce EU plastic demand by 13 million tonnes by the mid-century.[58]

A major challenge at present is the recyclability of different plastics and attempting to reduce the amount that is incinerated as energy from waste (EfW), landfilled or sent overseas. In 2017, UK households bought products which resulted in 2.26 million tonnes of plastic packaging, of which about 43% was recovered or recycled.[59] The main barrier for increased recycling is the ability to sort and decompose many polymers into their components.[60] The British Plastics Association's recent roadmap suggests that UK recycling could be more than tripled by 2030 compared to 2019 levels.[61] Investment in mechanical recycling facilities with sensor-based state-of-the-art-facilities can boost collection rates. This will be difficult to achieve without a significant innovation push, with scaled up operations, and design adaptation throughout the plastics value chain. About 30% of plastics demand could come from mechanical recycling and reuse.[58]

Chemical recycling is another possible, though more expensive, strategy that if made to work economically, could provide game-changing benefits. By breaking plastics down into their component molecules, this allows for recycling without quality degradation.[60] It also has the benefit of being able to recycle plastics that the mechanical route cannot such as mixed polymers. One way of reusing such recycled plastics is as a feedstock into the manufacturing of new plastics. A recent UKRI Industrial Strategy Challenge fund is supporting four innovative recycling plants.[62] ReNew ELP and Recycling Technologies are two of these UKRI projects which will undertake chemical recycling methods to turn end-of-life plastics into chemicals that can be used to produce virgin grade plastics as well as bitumen-type residues for laying roads. Chemical recycling combined with low-carbon energy inputs e.g., via hydrogen can reduce emissions of a tonne of plastic by 91% compared to current fossil production. Taken together, mechanical and chemical recycling process could lead to plastic recirculation rates of 62%, not far off steel (85%) and aluminium (70%).[58]

Not all production can be met through recycling options as there will be both losses and increased demand. Therefore, new techniques are required, and these techniques can also be applied to wider petrochemical production. It is possible to replace the chemical feedstocks that predominantly come from natural gas, oil and coal, with alternative sources. These sources can either be renewable, and therefore do not have a CO_2 impact, or can be materials that would otherwise be unutilised e.g., CO_2 waste from other processes. As described above, recycled plastics can be one option.

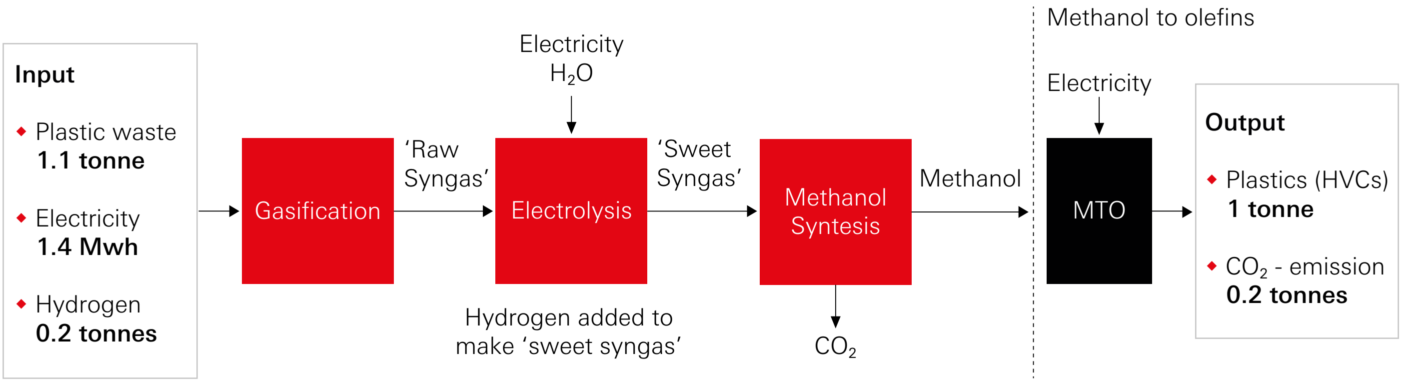
Bioenergy is another as it is a source of both carbon and hydrogen.[46] Biomass feedstocks can be turned into bioethanol, biomethanol, biogas and bio-naptha which can then be utilised to produce plastics.[63,64] Bioethanol which comes from sugar canes and other bioenergy crops can be used to produce ethylene. Half of the world's bioethylene capacity is in Brazil where the availability of the raw materials is plentiful.[60] However, how these are sourced are, of course, important and must not lead to further destruction of rainforests. In Sweden, the world's first commercial biomethanol plant is operating.[65]

There are options for bio-based polymers too, and the UK is well placed to start producing biopolymers for materials such as polystyrene, polyester, and PVC.[50] There are obviously issues with an overreliance on biomass which competes with food production for limited land resources. However, given limited other options in the chemicals industry, it may make sense to prioritise this use of biomass over other uses such as biomass for power. But there will not be enough bio-based plastic to swap directly one-for-one with current fossil-based practice. Other approaches to emissions reduction will also be required.

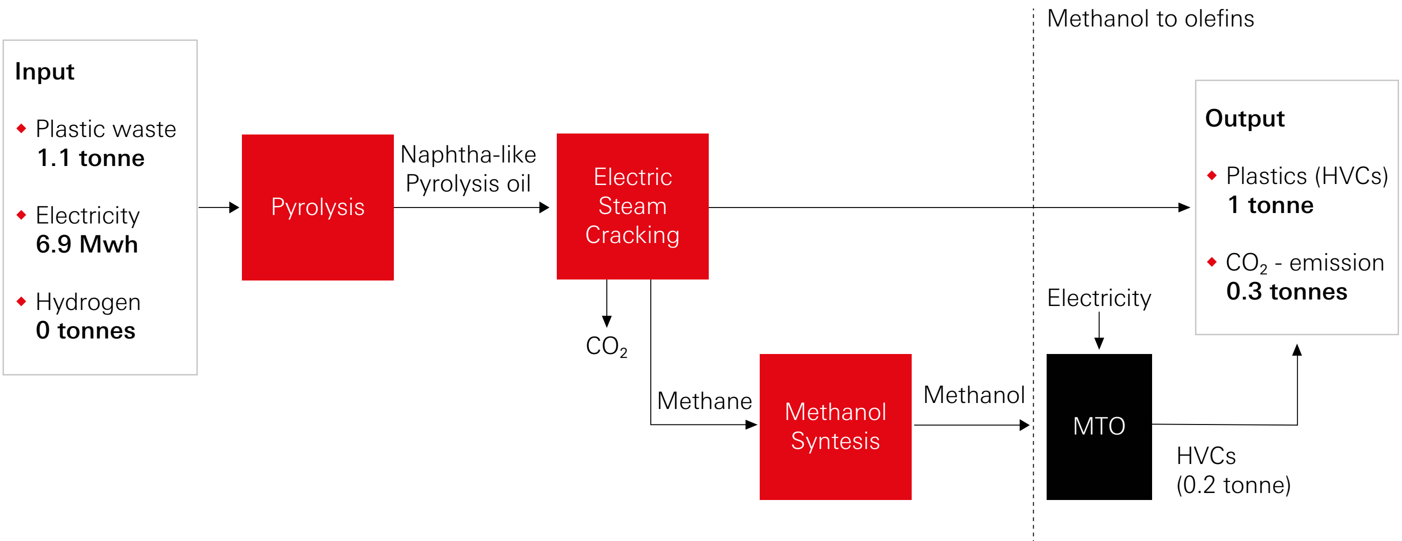
An option to decarbonise the production of olefins, is via the methanol-to-olefins (MTO) route (see Figure 12) which is currently undertaken using natural gas via methanol. It is possible to get methanol from low-carbon feedstocks such as biomass with captured CO_2 or green hydrogen. However, at present the lack of availability of these low-carbon inputs is a barrier.[66] In principle, however, green hydrogen could play an important role if electricity prices were low enough and there was plentiful low-carbon electricity, as the electricity requirements are considerable.

Figure 12 Chemical recycling of plastics through two routes

Gasification



Pyrolysis & steam cracking



Notes: The methane stream is the main by-product from steam cracking. Electricity for production of 0.2 kg hydrogen requires around 8 Mwh of additional electricity. The pathways use a combined route with a 50/50 share between the gasification and the pyrolysis & steam cracking routes.

Source: Taken from Material Economics (2019)[58]

Box 4.4 HCS Group

"Using wastes or residues to generate an alcohol that can then be turned into something that we can use in a fuel with a biogenic component that effectively comes out at carbon zero, even if we start putting that in only in small percentages into our hydrocarbon mixtures, then we're starting to look at something that the customer might like. The trouble with these materials at the moment, is that they are three, four, five times the price of the carbon equivalent and in very limited supply."

Studies have suggested a case to prioritise deploying hydrogen in the chemicals sector over other sectors, because of efficiency characteristics that lead to the greatest carbon savings over the medium term as well as the most efficient use of electricity.[67,68]

In Germany the CARBON2CHEM project uses smelter gas emissions from blast furnace steel manufacturing as inputs into chemical production of ammonia, methanol and others.[28] The first phase has now completed. The second continues until 2026 and may take 15 years for the process to be applicable on an industrial scale. The Carbon4PUR project funded by EU Horizon 2020 uses captured CO_2 from industrial waste streams, instead of oil, to produce polyurethane which can make products such as foam and insulation board.[xxiii]

4.2.2 Fertilisers

Beyond plastics, there are other options, in particular for ammonia. Ammonia is already commercially produced using hydrogen as an input into the Haber-Bosch process, where it is combined with nitrogen at high temperature and pressure (Figure 13). At present, 44% of global hydrogen use is for the production of ammonia. Around 90% of emissions come from the hydrogen production which is derived from natural gas via steam reformation and is about 1.8% of global emissions.[69] The remainder of emissions are from energy provision for heat and power. In the EU, production of a tonne of ammonia currently emits about 2.5 tonnes of CO_2.[58] Nitrous oxide (also a GHG) emissions are also a side-effect from nitrogen used as fertiliser with a larger global warming potential than CO_2.[70] More efficient fertiliser use and switching to organic fertilisers can help reduce emissions from agriculture. However, as mentioned before, hydrogen can be produced through different methods, including through electrolysis of water, and if the electricity comes from renewable sources, then emissions are essentially zero for this route. Improving the ability to store hydrogen will allow for hydrogen to be produced from renewables that would otherwise be wasted i.e., on excessively windy and sunny days. Green ammonia produced in this way could play a role in the Net Zero transition. The main challenges are not technological but financial and the availability of low-cost, low-carbon electricity.

4.2.3 Carbon capture for chemicals

Capturing the emissions from chemical production can be implemented where it is cost-effective compared to other options for meeting the Net Zero requirement. It is possible to retrofit post-combustion carbon capture technologies on to steam crackers for the production of high-value chemicals, and also to steam reformers for the production of hydrogen, and to refining and incineration of waste.

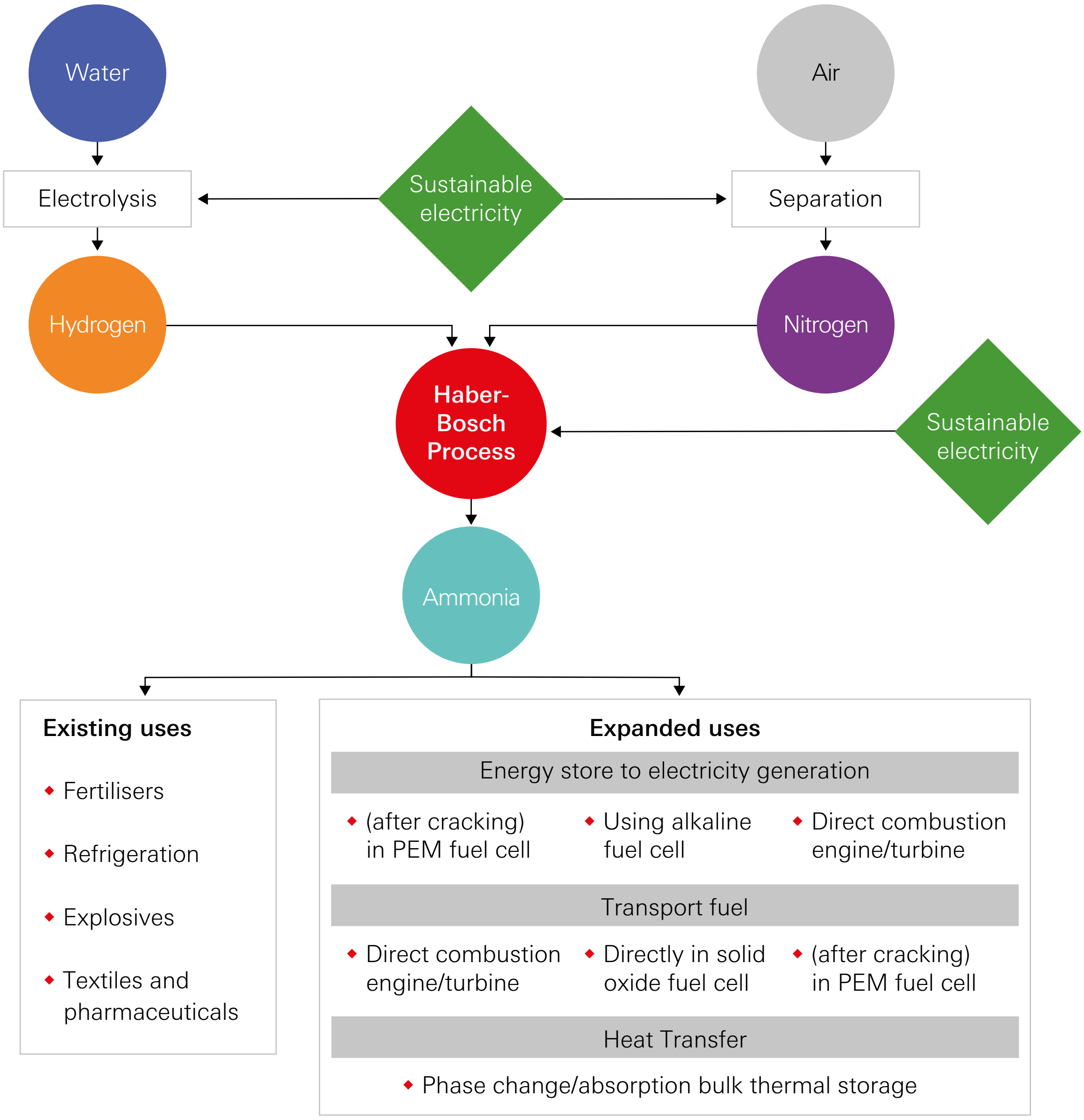
While CCUS adds cost to any process, it may well be appropriate in certain situations. The cost of capturing CO_2 from the production of ‘blue’ ammonia is comparatively low because of the purity of the CO_2 stream which can be utilised for other purposes without much extra effort and the size of production allows for good economies of scale. Given that carbon is an input into chemical production, the chemical industry therefore has a high potential for inter-sector carbon capture and usage.[71] Tata Chemicals Europe are introducing CCU in 2021 at their Winnington site in Cheshire to make sodium bicarbonate and sodium carbonate with a low carbon footprint.[72] The Klemetsrud waste-to-energy plant in Oslo successfully tested carbon capture technology for its production in 2020.[73] Carbon captured from breweries is being mixed with potato waste by Walkers crisps to be used as fertiliser.[xxiv]

Box 4.5 Chemical Industries Association

> “The vast bulk of emission cuts to get us to Net Zero will come from one of three routes: fuel-switching to either hydrogen or to electricity, or retrofitting of carbon capture technology. The majority of our sites, those with low heat processes, will most likely switch to electricity from gas for their heat. The high heat processes will need to switch to hydrogen, or remain with natural gas but capture their emissions.
>
> But these three routes to decarbonisation are heavily reliant on infrastructure. What we need is access to competitively priced and reliable infrastructure, in other words hydrogen networks, clean electricity networks and CCS networks. And if you have those then you’re in a really solid position to attract inward investment to the UK.”

[xxiii] https://www.carbon4pur.eu/
[xxiv] Developed by https://ccmtechnologies.co.uk/

Figure 13 Green ammonia production and use



Source: taken from The Royal Society (2020)[69]

In terms of undertaking CCUS, one benefit of the current UK geography is that all ammonia and steam cracker plants are located in cluster regions and therefore will have good connections to other industries for carbon usage in other industrial processes and also the necessary connections to any transport and pipeline requirements for storage, as well as for inputs such as hydrogen. The UK's first low-carbon hydrogen plant is being developed as part of the HyNet project in the North West cluster.[74] Having the necessary infrastructure in place is essential for chemical companies as no single plant could afford to implement the required connections alone. Therefore, if the UK can successfully create CCUS infrastructure, it can play a role across a number of low-carbon industries including chemicals.

5. Facilitating a Net Zero future for UK manufacturing: regulatory drivers and business models

Manufacturing, in particular, will find it difficult to decarbonise without incentives and support. The production of steel, cement and chemicals is highly capital and energy-intensive and competitive, with, in the case of steel and cement, low profit margins. Transitioning to the various technological and efficiency routes discussed previously to achieve Net Zero GHG emissions, would incur higher production costs than at present. Taking these low-carbon options from where they are today and making them cost-competitive within the short timescale required, when these heavy industries tend to operate with long investment lead times and slow capital turnover, will be an enormous undertaking.

This transition must occur in an international context, where carbon leakage - the lose-lose of reduced UK manufacturing activity and increased global emissions from industries relocating or investing in less efficient plant in other countries - is possible.[xxv] Many UK firms are also part of multinational companies, where decisions on capital investments and R&D spending are decided through comparing policy frameworks across the countries in which they operate. A number of interviewees in this report were from UK parts of international companies and stated that the large capital investment decisions would be made at a high level, comparing the UK's policy framework with that in competitor countries.

Various UK Government industry roadmaps have previously listed some of the barriers to decarbonisation across these sectors as the following:

- International competition from low-cost producers
- Lack of capital availability
- Slow capital stock turnover
- Short-term return-on-investment requirements
- High electricity and gas prices
- Uncertainty about regulation
- Uncertainty about commercialisation of new and unproven technology

And on the flip side, they have listed the following as enablers of decarbonisation:

- Access to growing markets
- Improved and stable policy framework
- Strong business case with clear payback
- Carbon pricing
- Location near CCS
- Increased demand for material in renewable energy
- Link between climate and risk in investment projects

It is clear that a Net Zero transition for the UK manufacturing industry is entirely dependent upon the regulatory context in which companies in these sectors find themselves. If UK steel and cement are to follow the CCC's pathway of Net Zero by 2035 and 2040, then the 2020s require a clear roadmap and all the necessary regulatory pieces to be put in place, to allow for the large changes in production to occur in the 2030s.

The Climate Change Committee has set out the following requirements for industrial decarbonisation in contrast to current policy:[6]

(a) **An overarching strategy.** Current policy on decarbonising manufacturing is piecemeal and needs an overarching strategy.

(b) **Supporting green jobs and the recovery.** Government should support and create jobs through its industrial decarbonisation policies.

(c) **A plan for competitiveness consistent with Net Zero.** Free allowance allocation may not be the most efficient way to achieve the combined goals of deep decarbonisation and avoiding carbon leakage, in future.

(d) **Carbon and electricity pricing for decarbonisation.** Existing carbon pricing is too weak and not applied across all manufacturers i.e., depending on size, and electricity prices do not reflect costs appropriately.

(e) **Addressing manufacturers' appetite for risk.** UK manufacturers typically require investments to pay back within at least three to five years.

[xxv] Carbon leakage is where a business transfers its production from a region with high carbon cost/regulation to another region with lower costs/standards. Thereby causing an increase in emissions outside the original region. And a well-intended climate policy may well cause an overall increase in global emissions.

(f) **Funding mechanisms for deep decarbonisation.** Policy lacks support for electrification and is too limited to upfront rather than ongoing costs.

(g) **Support for innovation and demonstration.** A range of key technologies still require development.

(h) **Policy to improve resource efficiency, energy efficiency and material substitution.** There are gaps in policy to support more resource-efficient products and construction.

(i) **Off-road mobile machinery.** This area appears to have fallen through the gaps between Government Departments and planned strategies.

(j) **Infrastructure development.** Electricity, hydrogen and CO_2 networks will all require development or upgrade.

(k) **Target dates.** Current ambition on manufacturing decarbonisation is insufficient.

(l) **Skills.** Appropriate skills and supply chain capacities need to be increased.

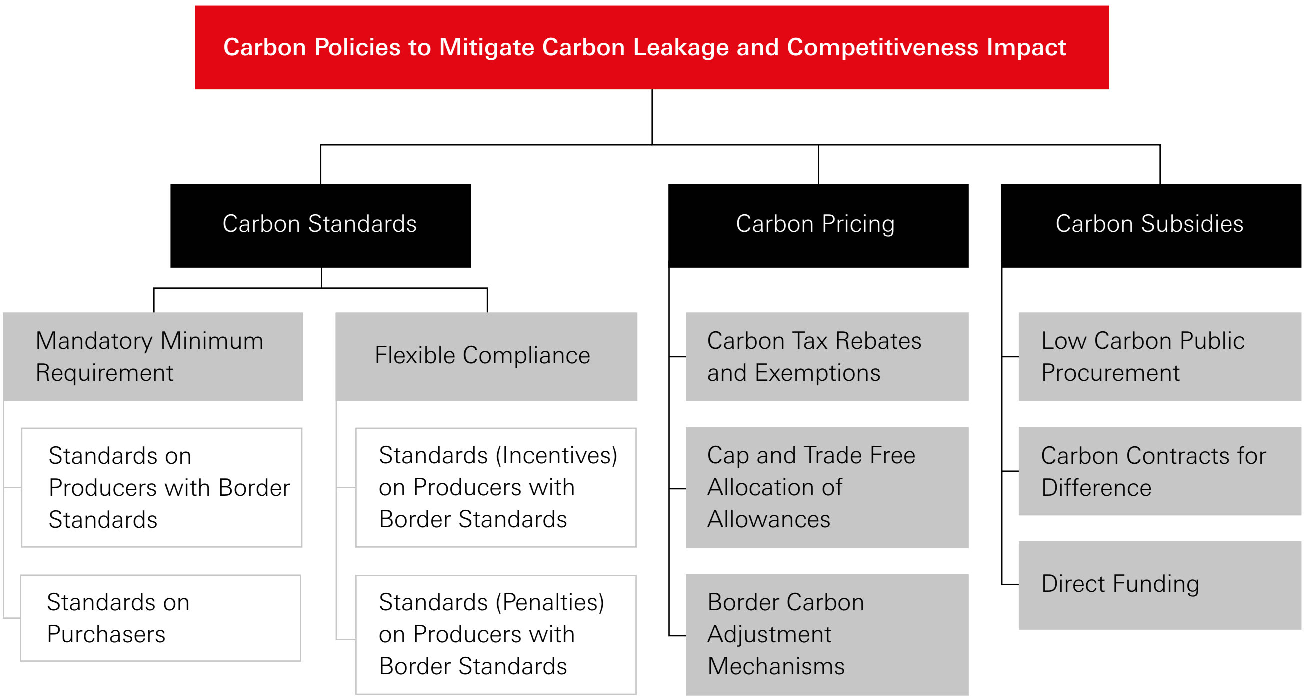
The first point, on having an overarching strategy and roadmap, was a point that came up time and again from interviewees as being the starting point for moving forward.

The previous attempt at detailed sectoral roadmaps in 2015 was useful but did not come to fruition due to a lack of Government commitment to new policies. The hope is that a direction of travel can be decided upon quickly, as there appears to be a stand-off between Government working out what polices to implement to influence industries and companies needing clarity of policies before being able to choose a path to decarbonise.

An initial attempt to address many of these issues has begun with the recent Industrial Decarbonisation Strategy, which was published in March 2021 and highlights three key levers to pull through the funding necessary: (1) a carbon price, (2) funding, and (3) carbon leakage mitigation.[9] There are a number of announced polices and schemes that are discussed in more detail below, such as the new UK Emissions Trading Scheme (UK ETS), a Net Zero cluster by 2040, and separate funds for clean steel, Net Zero hydrogen, CCUS infrastructure and industrial energy transformation.

On top of these levers, there are a number of other policies (see Figure 14) to tackle decarbonisation that can also help to mitigate carbon leakage and the competitiveness impacts. It is likely that many of these policies will require to be employed at various times throughout the journey to Net Zero and we discuss them further below.

Figure 14 Carbon policies to mitigate carbon leakage and competitiveness impacts



Source: taken from Sturge (2020)[75]

5.1 Carbon pricing

A strong carbon pricing signal through a tax or cap and trade system can enhance carbon efficiency throughout the supply chain and the development and deployment of low-carbon options. The theoretical assumption of such approaches is that higher initial costs for producers will incentivise higher production efficiency and a move towards low carbon production, whilst passing through the carbon costs to products will also encourage consumers to use products more efficiently or make lower carbon choices (Figure 15).

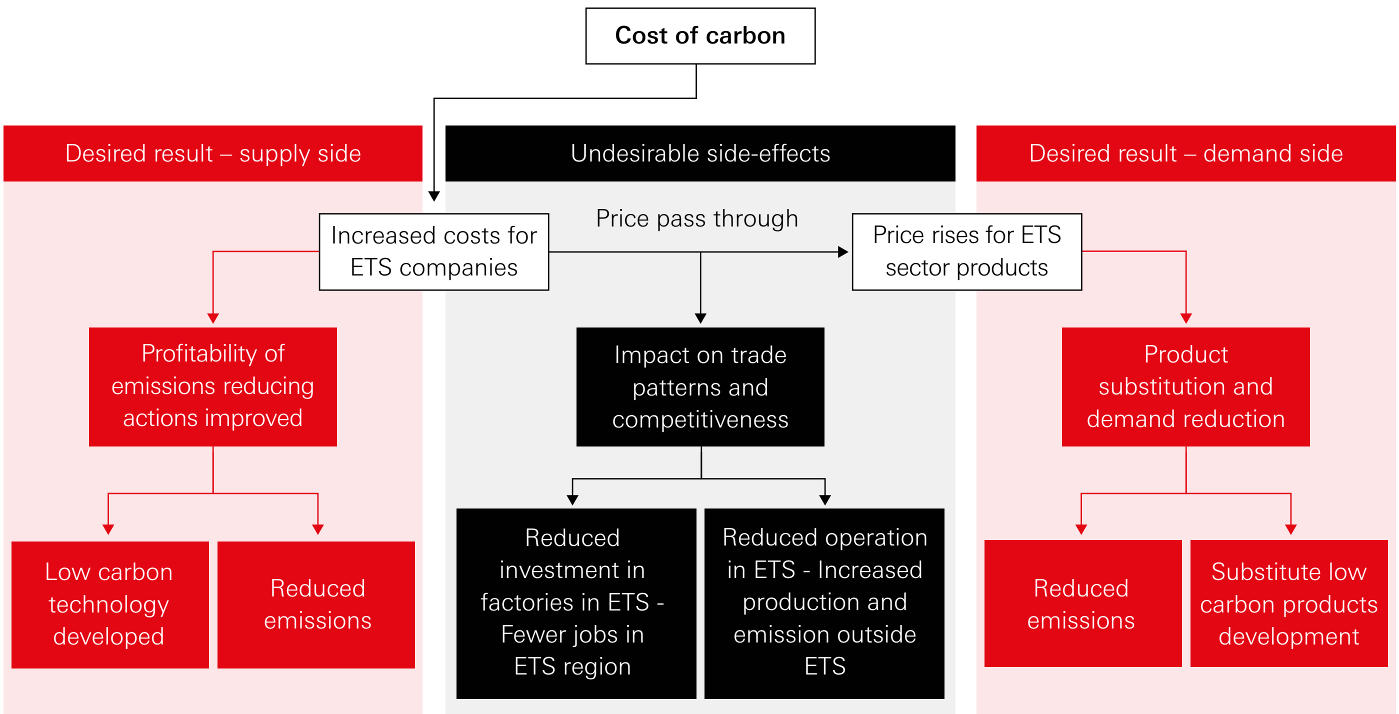
In practice, given the highly competitive international nature of steel, cement and chemical manufacturing, this cost pass-through is not a given. And, at present, the ability for industry to simply deploy decarbonisation technologies to mitigate against this is limited, e.g. inadequately developed technologies, or lack of hydrogen availability and CCUS transport and storage. These sectors then face the unenviable choice of trying to absorb higher costs, reducing their profitability and capacity to invest, or passing them through and losing market share to foreign producers who do not face the same costs.

Consequently, to date, emission trading systems have mostly allocated allowances for direct industrial emissions free, specifically to mitigate the perceived risk of leakage. This free allocation of permits means that the full carbon price is not fully faced and this tends to dampen the incentive effects.[76] How the free allocation is undertaken, in practice, can have different impacts. Allocations can be based on grandfathering i.e. historical emissions, or current production, and in tandem with sector benchmarks.

UK manufacturing has been part of the EU Emissions Trading Scheme since its inception in 2005. This implemented a single carbon price across the EU for energy and carbon-intensive industrial sectors, covering most manufacturing. Free allocation for less energy-and-trade intensive sectors was largely phased down during the ETS' third phase (the proportion allocated for free reducing from 80% in 2013 to 30% in 2020), whilst the Energy Intensive, Trade Exposed (EITE) sectors, including those covered in this report, almost all received nominally "100%" relative to the sector benchmark, although cross-sectoral adjustments added further complications.[xxvi]

In 2013, due to the very low carbon price in the EU Emissions Trading System (ETS), the UK introduced an additional carbon price support (CPS) for the power sector. Initially intended as a price floor to create a price both more meaningful and more predictable for investment, essentially a top-up on the EU ETS, this was soon changed to a fixed addition. The higher UK price helped push coal to the margin of power production, but as

Figure 15 Desirable and undesirable effects of carbon prices



Source: Carbon Trust (2010)[1]

[xxvi] Sectoral benchmarks are based on the average of the top 10% plants in the sector, so as to give a clear incentive for improvement. However, cross-sectoral adjustments, to bring overall allocation within limits for the manufacturing sectors overall, reduced allowance allocation for the cement sector in 2015 to 91% and by 2020 to received 82%.

the EU ETS price rose, the fixed top-up meant the CO_2 price in the power sector rose even higher, contributing to exceptionally high electricity prices.[xxvii]

With the UK leaving the European Union, a replacement carbon pricing mechanism was required to provide a strong incentive for UK industrial decarbonisation. A carbon tax was considered but – as with EU experience in the 1990s – despite theoretical potential to 'recycle revenue' for various purposes, the revenue transfers and potential competitiveness impacts made it politically untenable.[75, xxviii] The UK ETS, which largely mirrors the design of the EU ETS (Phase IV), is now up and running and the first auction took place in May 2021. For energy-intensive sectors it introduces a new "activity level change" regulation which adjusts free allocation levels but only when production changes by more than 15% (up or down). The principle of using ETS revenues to support transformative industrial investment, and potentially to help with other dimensions of transitions, has been much more extensively integrated into EU ETS Phase IV, but remains more strongly resisted by the UK Treasury.

Linking the EU and UK ETS schemes together would improve liquidity and likely price stability of the UK system, and in the manufacturing industry should help to ensure convergence of carbon prices, reducing competitiveness concerns on both sides so long as free allocation rules do not diverge too much. Obviously, a globally agreed trading scheme would improve the situation even further but is unlikely to happen in practice.

The UK ETS and CPS go alongside other overt price-related mechanisms. Notably, the Climate Change Levy is a downstream tax on industrial electricity consumption, partially alleviated for companies which are part of sectoral Climate Change Agreements which focus mainly on more efficient electricity use, and with some exemptions for metallurgical and mineralogical businesses introduced in 2014.

Policies may also be targeted at the use of specific inputs associated with emissions i.e., electricity or heat. Heat is a major input to, and often a significant emitting aspect of, manufacturing processes. The Renewable Heat Incentive (RHI) compensates for higher costs of renewable heat, the capital investment and other barriers. However, the limited eligibility for industry creates a potentially perverse incentive that takes renewable heating sources (notably, limited biomass supplies) away from industrial applications.

5.1.1 Competitiveness issues

One solution to the issue around balancing competitiveness and decarbonisation goals, and thus circumventing unwanted carbon leakage, is a carbon border adjustment mechanism (CBAM). Here, imports are required to be taxed based upon their carbon content and thereby treated with the same climate policy as domestic production. Higher prices are therefore passed on to consumers regardless of where goods are produced. There are challenging issues with implementing a CBAM. Determination of carbon content is dependent upon an understanding of how products in other countries are produced. Also, inherent carbon in products with many components and lengthy supply chains will be difficult to determine. Therefore, monitoring and verification of a product's carbon content will be important, otherwise a scheme will simply be relying on rule of thumb. CBAMs must also be compliant with World Trade Organisation (WTO) competition rules and an even playing field between domestic and imported products must be maintained. CBAMs have the advantage of potentially raising significant government revenue and being a strong incentive to reduce emissions in line with Net Zero.

The issue arises because there are asymmetric climate policies between countries or regions. The more similar climate policies are between two countries, the less of an issue there would be with imports/exports having differing carbon content. Agreeing

Box 5.1 Mineral Products Association

> "You can't make cement in Europe these days without CO_2 being a huge factor. Whether you are in EU or the UK, energy-intensive industrial processes are part of a trading system, and therefore CO_2 is a major factor in investment… we've probably got to see a carbon border adjustment mechanism to help the Net Zero transition, because any hint of additional cost of production in the UK encourages more imports. Imports undermine the UK's economic, environmental and social goals because we lose the GVA, the jobs and export our environmental responsibility."

[xxvii] For wider comparative discussion of UK electricity prices see Drummond, Grubb and Barazza (September 2021).[2] Price-setting in the UK and EU wholesale electricity markets is a complex function of gas, coal and carbon prices; an empirical study finds "fossil fuels are still the main power plants 'at the margin', determining power prices in Europe nearly 66% of the time whilst generating only 37% of electricity in 2019. Renewable energy transitions in Europe, combined with rising carbon prices since 2017, has shifted dependency from coal to natural gas as electricity price setter, making European electricity prices dependent on natural gas (and carbon prices) more than any other fuel." (Zakeri et al, IIASA / UCL research paper, submitted manuscript available on request to zakeri@iiasa.ac.at).

[xxviii] Some recycling of revenues from a putative carbon tax were proposed by the UK Treasury, but the rebate would only have partially covered the cost of the tax in the first place so remained strongly opposed by potentially vulnerable EITE sectors.

to implement similar CBAMs across a number of nations could be beneficial to implementation, help initiate product carbon measurement standards as well as facilitate faster innovation whereby producers across the world aim to make products compliant, otherwise, they are cut off from markets. Proposals are for an EU-wide CBAM to begin at the end of 2023 and for full application to begin by 2026. It will apply to iron and steel, aluminium, cement, ammonia, some fertilisers and electricity. Some European industries are concerned that this will coincide with the end to free allowances under the EU ETS and are therefore calling for extra policy in the form of export rebates.[77]

Analysis for the CCC's CB6 suggests that, in the UK, a CBAM in place from 2025 until 2040 and linked to the UK ETS could be used as a method to protect industry over the medium term before carbon standards are put in place.[75] The UK government appears to be considering this approach but at present has made no announcement. Keeping alignment with an EU CBAM will be necessary if UK industries such as steel and chemicals, that export a significant part of their production to the European Union, want to compete on an even playing field, and for the UK to avoid becoming a dumping ground for high-carbon steel that is uncompetitive in the EU market.[78] The introduction of an EU CBAM will also help stimulate demand for low-carbon steel and help drive investment in the UK since the majority of UK steel is exported there.

Carbon standards are another policy option for ensuring long-term competitiveness, whereby steel, cement and chemical products must adhere to a requirement for carbon content.[79] These could be through either enforced mandatory minimum standards or a flexible scheme. Mandatory standards would require a product to have a specific maximum carbon content and could also involve numerous other standards including minimum recycled content. A flexible scheme would involve setting a benchmark e.g., top-quartile emissions performance, and those with emissions exceeding that benchmark have to pay a government buyout, thereby raising revenue which can be used for supporting low-carbon R&D or to lower other distortive taxes e.g. corporation tax.

Alternatively, a tradable flexible scheme could be introduced where those companies who produce less emissions than the benchmark can sell on excess credits to those who exceed the benchmark, incentivising emissions reductions. A difficulty of carbon standards are that they are reliant on life-cycle assessments that need to be verified and compared across products, preferably across the world.[75] This difficulty may make a carbon standards approach unfeasible. The requirement may also be placed upon purchasers, this is discussed further below on public procurement. It has been suggested that product standards should be the long-term policy put in place to achieve the UK manufacturing sector's Net Zero roadmap, being introduced from 2035 in order to overcome technical, legal and political challenges, and applied to both domestic and imports.[75]

5.2 Funding, subsidies and market pull

There are a number of novel low-carbon technology options such as green hydrogen, post-combustion air capture, electric virgin steel, new cement chemistries and renewable ammonia which are at an early stage of development and cannot be directly substituted in the short term for incumbent technologies.[7] These require successful commercialisation first. And while a carbon price signal can help provide certainty and shift towards these in the longer term, there is no way of making sure they are available on the timescales required by carbon budgets and the 2050 Net Zero target.

These technology options require several steps to bring them to market before they are able to compete directly with incumbent technologies. Once they are developed enough then it is possible to raise carbon prices or apply carbon standards to generalise these technologies.[7] Whilst there is internal research and development in the chemicals sector, there tends to be less research and innovation activity in UK steel and cement. To support the uptake of nascent technologies it is necessary to make available funding for specific research and test cases.

There are a number of announced funding pots available for manufacturing sector decarbonisation (see Table 7). The largest ones are the Industrial Energy Transformation Fund of £315m, the Clean Steel fund of £250m, and the Industrial Decarbonisation Challenge of £170m. The Industrial Strategy Challenge Fund has £2.6 billion of public funding matched with £3 billion of private sector, and it has also funded the new research centre on Industrial Decarbonisation (IDRIC).[xxix] There has also been funding for low-carbon multi-component cements through the Industrial Energy Efficiency Accelerator, and £1 billion available for CCS which is discussed further

Box 5.2 Robinson Brothers

> "Now, we're not considered part of the energy intensive user's group, we're just below that, which really frustrates me – because we are a high energy user but we're outside the bracket of energy intensive, which means a lot of support is not there for us. We're also not in any cluster – so that's also a difficulty for us."

[xxix] https://idric.org/

below. While these are good starting points, strong near-term support needs to be made available for specific pilot project(s). There are already 23 hydrogen-based steel projects in various European countries and the UK faces being left behind.[30]

Contracts for Difference (CfD) are an additional policy tool that can help provide a more certain price for investment in new projects which have high upfront costs and long lifetimes. CfDs work whereby any difference between the strike price (a price for investing in a specific low-carbon technology) and the market price (the average market price in the UK/GB market) is compensated by the government. Over time these strike prices should reduce for new projects as competition rounds are often used to determine who can undertake the project at lowest cost via auctions. These have been used successfully in the power sector, in particular for offshore wind.

For steel, there could be a guaranteed strike price for a tonne of steel, and the difference between that and the market price for steel, which would be influenced by carbon price in other countries, would be paid by Government. Carbon Contracts for Difference were found to be the most effective policy method to achieve green steel in the EU.[80] However, this approach would result in an unequal distribution of transitional costs where steel sites that are not in prime locations e.g., close to cheap renewable electricity, are at a disadvantage in competing for contracts. Therefore, consideration and support for these sites may be required.

CfDs may also be applied to CCUS and green hydrogen. A major planned policy is the Government's Industrial Carbon Capture (ICC) business models for CCUS which will consist of: (1) a contract of up to 15 years to provide payment per tonne of CO_2 captured to cover expenditure, and (2) capital grant co-funding for a portion of capital costs for initial projects only via the Carbon Capture and Storage Infrastructure Fund, for which there is £1 billion earmarked. This is intended to unlock greater levels of private sector investment in the long run. However, the ICC business model is aimed at initial projects only and as such these will occur in clusters. Support for dispersed sites will have to come afterwards, more on these issues are discussed below.

The UK Infrastructure Bank can also co-invest with the private sector. It is hoped that the UK will be capturing and storing 3 $MtCO_2$ per year by 2030. There is also a Net Zero Hydrogen Fund of £240 million which is intended to assist capital co-investment in low-carbon production projects for hydrogen, and a low-carbon hydrogen business model, similar to that for CCUS, is being developed. The Hydrogen Strategy which is due late summer 2021 will provide more specific details on policies for industrial hydrogen production and will likely include similar CfDs for hydrogen.

Another way of driving a market for low-carbon goods is through the government procurement process. If minimum carbon standards are attached to the procurement process, then this can help establish a lead market for low-carbon materials, in particular steel and cement used in infrastructure projects. Creating the initial demand in this way can provide certainty that there is a market for the low-carbon product. Public procurement can be used as a test case for establishing carbon standards which could eventually be applied more widely and help to establish early learning and iron out issues.[75] The HS2 project utilised low-carbon concrete supplied by Cemex with 42% lower emissions than traditional concrete.[81] Additionally, it was a requirement for Crossrail that, for their concrete specification, there is a minimum of 50% cement replacement for poured in-situ concrete.[82] The UK Government announced in June 2021 that any companies bidding for tenders above £5 million must have set a Net Zero 2050 target and have published credible plans on how to achieve this.[83] Demand-side market creation can help reduce the subsidies required for new technologies and help global diffusion of low-carbon production methods.[80] The UK Government expects to require 3 Mt of steel over the coming decade with a value of £0.5 billion.[26] However, procurement can help speed up the industrial transition but not get to Net

Table 7 Main capital funds for UK manufacturing decarbonisation

Scheme	Scope	Public funding	Timeline
Industrial Energy Transformation Fund	Manufacturing decarbonisation	£315m	Announced 2018. Spent by firms by 2024
Clean Steel Fund	Steel decarbonisation	£250m	Announced 2019. Spent by Government by 2024
Industrial Decarbonisation Challenge	CCS and fuel switching sites within clusters	£170m	Announced 2018. £10m awarded. Spent by firms by 2024
Industrial Fuel Switching (Energy Innovation Fund)	Fuel switching pilots	£20m	Announced 2018. All awarded
Transforming Foundation Industries Challenge	Energy and resource efficiency	£66m	Announced 2018. £5m awarded. Spent by firms by 2024

Source: CCC (2020)[6]

Zero by itself. Interviewees noted that procurement is only about 10-15% of the UK steel market, so companies will not necessarily switch over their entire production method for this.

In a similar vein, downstream users of products can help drive a market for low-carbon products by establishing whole supply chain procurement initiatives such as Steel Zero run by Responsible Steel and The Climate Group.[84] This initiative commits companies to purchase 100% Net Zero steel by 2050 and includes renewable company Ørsted, construction company Lendlease, and UK fabricator Severfield PLC. While the overall target is distant, there is also an interim commitment to meet 50% Net Zero steel by 2030 which will create short-term demand. And the commitment of Volvo to purchase low-carbon steel from the HYBRIT plant has already been noted.

Many interviewees mentioned that there had been a recent uptick in interest from both public and private sector customers about low-carbon products and the carbon footprint of the products they buy, as these sectors get to grips with their own climate impact. The extent to which downstream customers had enquired varied greatly but there has been a noticeable increase in overall interest in the last couple of years and a general expectation this will increase further in the future. As such, Cemex have introduced a carbon footprint tracker to allow their customers to better understand the carbon involved in producing different building materials.[85]

However, there are also potential detrimental impacts to the UK if there is both domestic demand for low-carbon products but without the ability to meet these demands domestically and faster decarbonisation elsewhere due to interventionalist policy. Almost the opposite of carbon leakage would take place, in that the UK will become inundated with low-carbon imports from the EU.

5.3 Energy prices

Heavy industry is energy-intensive by nature and therefore the price of energy, in its various forms, both today and projected for the future, plays a significant factor in company decision-making and investment processes.

Electricity prices are an important cost for steel, cement and chemical companies, both at present and also in projections of future decarbonisation. A number of key innovations including electrification of heat, CCS, electric arc and green hydrogen all depend significantly on increased low-carbon electricity availability. If hydrogen-based steel replaced Blast Furnaces in the UK it could increase electricity demand for these sites by 800%, while shifting them to 100% electric arc would raise it by 300%.[17] Carbon capture for cement and chemical production would require increased power consumption too. An interviewee noted that initial work suggests power demand in cement production may double with deployment of CCUS. Therefore, the policy treatment of electricity costs is a crucial concern for manufacturing companies, as is the comparison of electricity prices in other countries.

A major disadvantage for the UK manufacturing sector has been the high industrial electricity prices compared to its main competitors in EU countries such as Germany and France. The UK electricity price in 2016 was 33% higher than it was back in 2008 and higher, by the same amount, than the EU average in 2016, which essentially remained flat.[86,xxx] Figure 16 illustrates this situation. There are several reasons why UK electricity prices have been higher, including: differentials between gas and coal prices; new investment in upgrades for ageing transmissions networks, including how these are recovered from consumers; exchange rates; and how policy costs and their recovery are designed.[86] This higher price has made profit margins tight for those UK

Box 5.3 Cemex

> "Procurement policy could really help if it specified that cement and concrete that are going into projects are being supplied by companies that are making the right sort of investments and commitments."

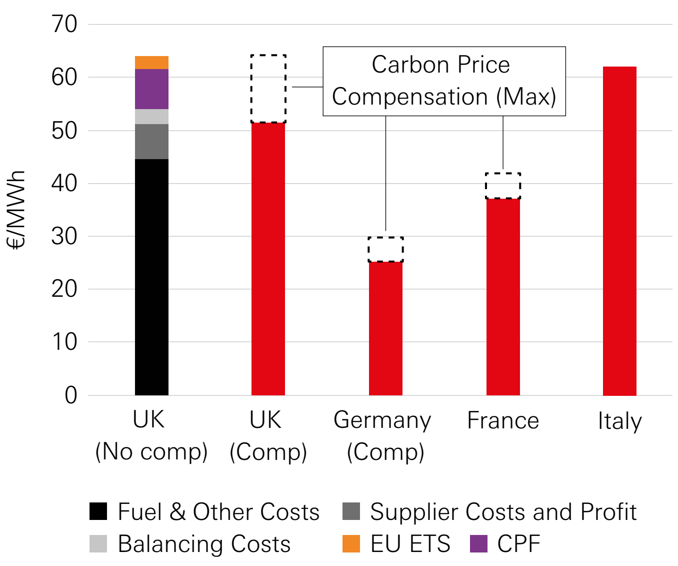
Box 5.4 Cemex

> "It's a huge thorn in our side in the UK… that the UK energy-intensive industries were quite significantly disadvantaged by the high cost of electricity."

[xxx] This analysis is being updated by UCL colleagues but is yet to be published at time of release. Findings suggest that in 2019 the UK prices reached 44% above the EU average.[2] However, due to concerns about double counting of carbon prices in UK accounting methods, we suggest waiting until this can be confirmed.

heavy industries that are open to international competition. According to UK Steel, producers of steel in the UK faced electricity prices 86% higher than Germany and 68% higher than France in 2020/21.[17]

Figure 16 Industrial price energy and supply components 2016



Source: Grubb and Drummond (2018)[86]

Some companies believe that this leads to a lack of investment in the UK, which in turn erodes competitiveness. In particular many steel, cement and chemical companies are international, and therefore decisions about where to make company investments are partly determined by comparing countries, and current electricity pricing means the UK is seen less favourably than others. For instance, the average cost per year to UK steel production over the last five years has been £51 million higher than in Germany, compared to the average capital investment in the UK of £200 million.[17] High prices also do not, at the moment, incentivise the shift towards electrification of low-heat processes in manufacturing.

Until 2014 the UK did not differentiate between electricity consumer groups while many other countries placed more of an emphasis on protecting industries by making sure the costs for industrial consumers were lower.[xxxi] Germany has had a higher level of industrial network and policy costs compared to the UK but has implemented substantial exemptions for specific industries. In France, a consortium of industrial companies struck a long-term contract at favourable rates directly with the state electricity company EDF. Establishing more of these types of direct long-term contracting between industry and electricity generators and suppliers could be significantly beneficial to all. Also, countries on the continent have benefitted from greater interconnection between each other which allows for greater flexibility. Essentially, the UK made the political choice to shield households rather than industry from electricity costs (e.g. through the 5% rate of VAT), while other countries have had a more protectionist attitude towards industry. However, while UK industrial electricity prices have been higher, the compensation paid to industry has also been considerably higher to offset the impacts. Also, recent changes have moved UK electricity towards using Contracts for Difference with compensation measures which have been effective at reducing prices.

The future of UK policy in relation to electricity pricing for industry is of upmost importance for a manufacturing Net Zero transition, and clarity about the policy will determine industry's willingness to innovate and invest. An advantage for the UK in making low-carbon chemicals, cement and steel is the substantial low-carbon electricity resource that is

Box 5.5 UK Steel

"If you go down switchover from the integrated process over to electric arc furnaces, about two to three times as much electricity is being consumed from the Grid. If you're switching over to hydrogen, and you go through the electrolysis route, it's probably six to eight times as much electricity being consumed. And for CCUS, if you capture the emissions there, you also have a significant energy penalty because you have to use energy and electricity on capturing the emissions as well. Effectively there's no way around it, if the two integrated sites are to decarbonise, they will have to increase their electricity consumption significantly. And that is very difficult. If you have substantially higher prices than your competitors abroad that is one of your key barriers to switching over, because the business case doesn't really exist in that way."

[xxxi] However, energy-intensive industries did receive an 80% (from 2001) and then 90% from around 2011) discount on the Climate Change Levy in return for Climate Change Agreements

beginning to be exploited, in particular offshore wind. Other policy approaches that would help the low-carbon industrial transition include: a more integrated approach to network development, pricing and funding; greater interconnection and cross-border contracts for electricity; supporting industrial involvement in the capacity market; and establishment of a long-term Net Zero electricity contracts market.[86]

A seemingly obvious solution to high electricity prices would be to switch policy costs from electricity over to gas, in order to incentivise a switch towards greater electrification, while maintaining, or even improving, overall competitiveness. UK gas prices for medium industrial users were the fourth lowest in EU15 in 2019.[9] While the costs of policies for a cleaner energy system generally fall on electricity consumers, increasing the price of electricity relative to those of fossil fuels runs directly counter to the aim of such policies. Therefore, it can be argued that such a shift would provide a more equitable distribution of costs of the energy transition.

However, shifting policy costs to gas raises its own issues. Wholesale UK electricity prices are now set by gas generation, coal having dropped almost entirely out of the system. Gas is also used extensively in current chemical production, so higher gas prices would bring about significant cost increases in this sector, where gas is used as a feedstock and substitutes are currently significantly more expensive. Therefore, raising gas prices may encourage some substitution towards electricity, but with others the consequences are not clear. It will be necessary to ensure such businesses using processes currently heavily reliant on gas consumption are not disadvantaged in the short-term. Policy solutions may be time-limited or declining rates of compensation, or a phased shift in policy costs. Further research into, and exploring options for, switching policy costs from electricity towards gas should be investigated by UK Government.

5.4 Clusters and dispersed sites

The distribution of industrial sites around the UK is an important factor that must be considered when designing a Net Zero industrial policy, especially in light of various UK Government strategies such as the Clean Growth Strategy and the levelling up agenda. Planning where Net Zero industries are to be situated is bound to consider the availability of skilled workforces and materials, the proximity of customers, good access to transport links and the existence of oil and gas fields for CCS, but there are also political, geographical and historical considerations to be taken into account, which can make the transition harder.

The distinction is often made between clusters – an area where a number of industrial firms operate – and dispersed sites – where sites are stand-alone and not situated near other companies. Just over half of UK industrial emissions occur in areas that can be considered an industrial cluster, and of the cluster emissions, 32% come from iron and steel. The remaining emissions come from dispersed sites, and for these, 12.5% of emissions come from cement plants.[9]

The benefit of clusters is that there are economies of scale for new, shared infrastructure as well as improving resource efficiency, including through industrial symbiosis where by-products can be utilised by neighbouring companies,

Box 5.6 HCS Group

"HCS has purchased electricity, by agreement with our electricity supplier, and has specified that we take electricity generated by local turbines – we've paid a bit more, but effectively, we're buying renewable – and it's local. And that's something that we would like to continue in the sense that we'd like to help put something back into the community, if we can, in terms of a more social, responsible way of doing business"

Box 5.7 Robinson Brothers

"We burn quite a lot of gas to raise steam for our operations. It would be easy just to switch to electricity thereby reducing our emissions significantly, however, it would shut the business down, given the immense cost differential between gas and electricity as a source of energy for manufacturers. This presents a real conundrum and it is something government must consider and offer a real solution to."

helping companies spread risks, share costs and learn from each other. Dispersed sites do not have these advantages. Transferring hydrogen in, or post-capture carbon out, will be difficult and even if achieved, will make costs of decarbonisation higher at these sites. How dispersed sites are treated vis-à-vis clusters will be important to the long-term survival of many companies.

Electrification, CCUS and green hydrogen – the main Net Zero solutions for steel, cement and chemicals – all require new infrastructure. While there is already significant grid infrastructure for electricity, new local additions and strengthening will be required due to increased industrial demand, renewables integration, and battery storage. The other two solutions – CCUS and hydrogen – are both starting more or less from scratch. The UK benefits from its offshore oil and gas fields which can be utilised for storage of carbon captured from industrial processes. Abundant low-carbon electricity from offshore wind can be utilised for hydrogen, although long-term contracts need to make this available and cheaper for industrial users. Government investment in infrastructure is required because of its shared-good characteristics. Funding and facilitating the provision of this infrastructure in consultation with industry is crucial.

The Government's Industrial Decarbonisation Strategy intends to create two industrial clusters by the mid-2020s, four low-carbon clusters by 2030 and have at least one net- zero cluster by 2040. This will significantly benefit those companies situated within such clusters, including the two large integrated steel sites and many large cement and chemical companies in the UK. It is envisaged that throughout the 2020s there will be infrastructure introduced to clusters and then expanded to dispersed sites throughout the 2030s.

There are many cluster projects forming:

- **HyNet North West.** At present the area has 1.35 $MtCO_2e$ and 0.55 $MtCO_2e$ of chemicals and cement emissions, respectively. The project on Merseyside involves both CO_2 and hydrogen pipelines and is expected to begin CO_2 capture by 2025 and be capturing 10 million tonnes of CO_2 per year by 2030. A blue hydrogen production plant (i.e. emissions captured by CCS) will be located at Stanlow Refinery, with the hydrogen stored in salt caverns to help manage energy demand.

- **Zero Carbon Humber Partnership.** This was established by Drax, Equinor and National Grid in 2019. At present this cluster emits 30% more total emissions than the next largest cluster, and produces 5.09 $MtCO_2e$ from iron and steel, with 0.5 and 0.3 $MtCO_2e$ from chemicals and cement, respectively. It will involve a hydrogen demonstrator by mid-2020s, CCUS pipelines potentially passing Cemex and British Steel sites, and carbon capture applied to the Drax biomass power station.

- **Net Zero Teesside.** The NZT consortium consists of BP, Shell, Equinor, ENI and Total. At present, industrial emissions from Teesside are predominantly chemicals production with 3.66 $MtCO_2e$. The cluster aims to capture emissions from industry and power to a total of 10 $MtCO_2e$ and will have access to the southern North Sea with considerable storage potential.

Box 5.8 Chemical Industries Association

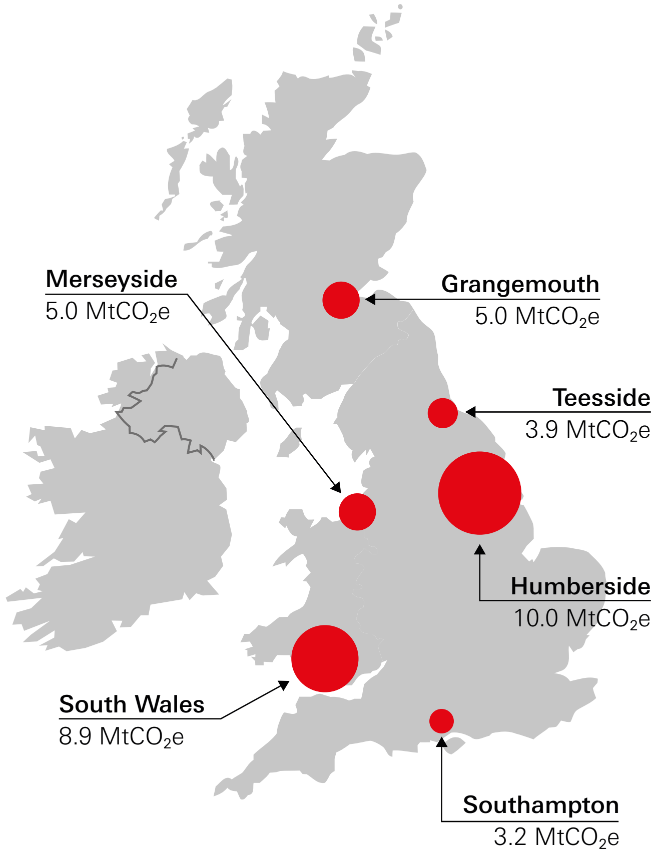
> "If we want manufacturing in the UK, then investment in clean infrastructure is a sensible thing to do because it gives us long-term control over our own production emissions. It gives us manufacturing security too. The alternative is that we just say, "We don't want manufacturing", we let it go to production locations that are cheaper because they don't put a price on pollution. But then we lose all control over our consumption emissions because our goods are manufactured overseas, and we have no lever left to pull to change how they are produced."

Box 5.9 Hanson UK

> "Take something like CCS – that's going to be driven by where is the most attractive place to do it. So you end up with a lifetime of the plant: how much reserves are available, where is it located? Is there a suitable storage nearby? So there needs to be some additional support."

- **South Wales Industrial Cluster (SWIC).** Current emissions are around 6 $MtCO_2$ from iron and steel at Port Talbot and 0.34 $MtCO_2$ from cement production. The SWIC consists of a number of partners including Tata Steel, Liberty Steel and Celsa. It may be possible to link up SWIC with HyNet via sea to form a West Coast industrial cluster.

Figure 17 Potential UK locations for clusters and CCUS transport and storage



Source: HM Government, Industrial Decarbonisation Strategy (2021)[9]

Grangemouth in Scotland is another potentially relevant place for a cluster with a significant chemicals industry presence and access to the North Sea oil and gas sites. Southampton is another cluster site but is predominantly oil refining and so not relevant to this study.

These clusters are important for the surrounding economies, often in deprived areas where industrial jobs pay more than median wages. The average steel wage in 2020 was 50% higher than the average wage in Wales, Yorkshire and also Humber, where the cluster provides 55,000 jobs and almost a quarter of the region's GVA.[9]

Away from clusters the picture is potentially quite different for sites where a lack of viable options for transport by pipeline, road or ship may, in a Net Zero future, cause stranded assets. A BEIS research paper for dispersed sites finds that there are 36 such sites in the UK that are suitable for CCS.[87, xxii] These emit 20.7 $MtCO_2e$ with 87% of these emissions coming from iron and steel, cement and refining. They also identify that high risks around obtaining permits to operate CCUS for such sites can be off-putting for investors, as there is no certainty that licenses required to transport carbon off-site would be granted. Interviewees mention that the issues are not only about funding and carbon prices but planning policy and regulation.

The 36 sites are split into four categories depending on location, and costs of transportation. The first group, with the lowest costs, are for those sites situated in the South Wales industrial cluster but with limited storage nearby, and they face costs at £18-21/tCO_2 for transporting to a storage site. This includes Tata Steel. The next group, with access to large ports, include chemicals in Dalry and Maydown, and face transport costs of £23-40/tCO_2, via pipeline and shipping. The third group consists of five sites near each other, in and around the Peak District National Park. Two of the five are cement sites, including Breedon's Hope cement works. These sites would face costs of £15/tCO_2 via pipeline but more than double that for road and rail. The last group, comprising the remaining sites which are truly isolated, were at the high end of the

Table 8 Main CCS transport risks

Onshore pipeline	Shipping	Road/rail
• Permit requirements for the construction of onshore pipelines. These permits vary by length	• Exposure to different international regulatory frameworks	• Route may be constrained due to CO_2 considered a dangerous substance
• CO_2 classified as if transporting a dangerous substance until government introduces required legislation	• Some ports are unable to accommodate CO_2 ships	• CO_2 trucks currently operate with only 20 tonne capacity
• One-off construction impact to local environment and population	• Lack of experience and business models in CO_2 shipping	• Local impact from constant operation in and out of site
		• Additional storage capacity required at capture site

Source: BEIS (2020)[87]

[xxii] Sites were only considered if annual emissions exceeded 50 $ktCO_2$/year.

spectrum by facing costs of around £31-£44/tCO_2. Pipeline and rail tended to be the best option for these though they differ by site. These included six cement sites, the largest of which is Cemex in Rugby, as well as two small chemicals plants.

Other options for these dispersed sites are CCU, fuel-switching and electrification. However, it was found that for those that had high process emissions such as cement, CCS was a more cost-effective option because other options such as hydrogen were also problematic from a transportation perspective. A number of issues with CCS transport are shown in Table 8 on the previous page.

5.5 Other regulation and circular business models

A reassessment of design regulations for products and buildings in light of Net Zero could help to reduce steel and cement use, and low-carbon building design standards may need to become mandatory.[11] New UK requirements could refer to minimum lifetime of materials, ability to disassemble for reuse, and separability of components for recycling. Therefore, a thorough review of education on design and construction as well as legislation and regulations pertaining to materials use from a climate perspective is necessary.

Extended Producer Responsibility (EPR) policies would also help producers plan better for the end of life and return of their products.[88] Enforcing producers to be accountable for the whole lifetime of their products incentivises them to consider lengthening lifetimes and encourage remanufacturing. Advanced Disposal Fees (ADFs) could be implemented and paid to a collective producer organisation, with the pooling of fees allowing collective organisation of logistics for collection etc.[89] For example, if the car manufacturing industry were producing electric vehicles together with EPR, the steel and plastics in their long-lived products could be designed to be recycled and used again.

However, there are also significant potential improvements to be made in current downstream practices. For instance, because of the difference between what final users want (car doors) and what is provided by intermediates (strip steel coils), a quarter of all finished steel produced each year does not end up in end-use products, it is cut off and recycled.[16] A lack of material efficiency on such a scale can only come from the fact that steel is so cheap in comparison to other costs e.g. labour. There are other areas where steel and cement are overused such as in commercial buildings, where safety codes stipulate minimum requirements, yet are still over-specified by a factor of two. Again, these instances occur because it saves on labour costs. Light-weighting i.e., using less material in construction could contribute emission savings of 6.3 MtCO_2e to the UK's 6th carbon budget.[90]

Currently, products using steel are not specifically designed with recycling in mind and supply chains can often be opaque both within and between firms.[15] Better product design can help minimise the types of materials that contaminate the ability to recycle e.g. copper use in car manufacturing that contaminates scrap steel. This requires greater cooperation between scrap suppliers, steel producers, original equipment manufacturers, and final demand customers.

There are a number of issues with the current market set-up. At present, there is a short-term month-by-month purchasing of scrap on a cost-effective basis, mostly from a few large scrap recycling companies who have access to 70% of UK-generated scrap.[15] There is also no standardisation of scrap quality in place. The price differential between high- and low-quality scrap is small, so that the incentive to improve recycling techniques for higher quality scrap is not strong. Advanced recycling techniques are available but without improved financial incentives, either through policy intervention or improved business models, these will not be implemented at speed. Overall, the current scrap market is not

Box 5.9 Hanson UK

"I think the other thing that does cause us problems is just the geography of where the sites are. The production plants are remote from industrial clusters where the focus of CCS is at the moment."

Box 5.10 Cemex

"The discussion we're in at the moment is trying to ensure that the government understand that and what they come up with, it's flexible enough, not just to address the clusters but also key dispersed assets which we still need the products from."

conducive to greater use in UK products of recycled steel, and therefore greater EAF production.

In the longer term, improving scrap sorting in the UK can help with Net Zero goals. There is the potential for selling steel as a service. Here, steel would be leased to sectors e.g., vehicle manufacturing, and returned to producers at products' end of life, which would provide known quality and stable scrap supply while allowing for development of innovative business models and technologies. The move from a product to a service-based approach could provide the UK with a competitive advantage by shifting to high-value products and away from undifferentiated over-supplied commodity markets.[15] Overall, renting rather than owning products could save the UK 39 $MtCO_2e$ over the time period to 2050, much of which comes from renting vehicles and chemical leasing.[90]

There is also scope for a more circular cement manufacturing process. Specific policies to incentivise the recycling of concrete and concrete components could be mandated at appropriate spatial levels.[11] Regulatory limits on the substitution of low-GHG cementitious materials for clinker should be reassessed in light of Net Zero targets in situations depending on usage and function.

To achieve a circular chemicals sector is perhaps more difficult given the lower rates of present recycling of products such as plastics. A plastic packaging tax will be introduced from April 2022 for any packaging that does not have more than 30% recycled plastic, at a rate of £200 a tonne.[91] Hopefully the percentage of recycled content can be increased over time and can be extended to other plastic products where using recycled plastics is possible. At the same time, policies could encourage business models for products that utilise high rates of recycled plastics and also those which move towards more service-orientated plastic use e.g. the toy subscription service Whirli which provides child's toys that can be returned as they grow out of them, thereby reducing the amount sent to landfill. [xxxiii]

More targeted policies which facilitate the use of biomass, preferably with CCUS, could be utilised in both the cement and chemicals sectors. However, given biomass supply limitations it may be preferable to focus on use in chemicals.

5.6 Skills and jobs

One aspect that was not considered a significant barrier for industrial decarbonisation during our industry interviews was skills. The businesses we spoke with were all reasonably confident that while there may be some retraining and movement of jobs required, it would not be on a large scale and therefore would not have a large effect at an aggregate level. Certainly, a lack of skills was not an issue that these sectors were expecting to experience, and these sectors are not explicitly mentioned as having problems in this regard in the recent report from the Green Jobs Taskforce.[92] The report states that for sectors like steel, decarbonisation and retooling of pre-existing workplaces would deliver a more beneficial climate transition. It also states that highly skilled jobs in the chemicals sector may come from greater battery production in the UK.

If anything, the main concern amongst industry interviewees was potential bottle necks in skills. These may occur where there are not enough skilled workers available to undertake the necessary work in the required time frame. The size of many of the one-off transitional infrastructure projects will be large and take significant time to implement. Therefore, planning construction projects well in advance and in conjunction with each other may be required. There is also an issue with the fact that skills expertise in newer areas such as CCUS and

Box 5.11 UK Steel

"It is not like the oil and gas sector for example where you virtually have to close down the sector and kind of find a new way of – or a new market or job market for those employees. If you change the production method you largely retain the existing employees and they would need some retraining."

Box 5.12 Mineral Products Association

"I think in terms of skills, that is not so much skills, as availability of contractors and engineers… I think that you could end up with an issue with availability of the plant technology, and the people to install it. So, I think that might be a possible barrier that's heading our way."

[xxxiii] https://whirli.com/

hydrogen have yet to be built up because there is no market for them at present. However, it is likely that funding and policy clarity will create these jobs going forward once the lack of economic motivation is overcome.

Within these industries there appears to be a significant shift in focus towards sustainability at board level and in day-to-day activities. While the businesses have been undertaking decarbonisation for many years, it has clearly now become more of a concern for their operating activities. We spoke with employees who used to have a wider role on ESG issues but are now focussed more exclusively on climate as it becomes more prominent in the core business. There were also privately owned companies that had committed to Net Zero too.

Of far more concern was how loss of competitiveness could lead to shutting down the businesses entirely which would obviously have massive employment impacts on local communities. What is required is adequate policy support for these sectors while they decarbonise until such time as low-carbon production in major competitor countries becomes the norm globally, with government funding underpinning the provision of new infrastructure and helping with training and skills provision where this is necessary, inside or outside the sectors concerned, perhaps through a just transition fund.[23]

Of course, particular areas with industrial clusters are likely to benefit greatly from infrastructure investment – by one estimate creating the necessary infrastructure for CCUS could create 50,000 new jobs in the UK by 2030.[93] This infrastructure could then attract inward investment from other companies desiring to move towards clean manufacturing. And, if the global direction of travel in these sectors is towards Net Zero, then early UK decarbonisation of heavy industry through CCUS, hydrogen and low-carbon circular steel, cement and chemicals could lead to investment elsewhere and the utilisation of UK experience and expertise abroad.

Box 5.13 Cemex

> "There is a very deep understanding and commitment at a company level to the concept of Net Zero … right from the Chief Executive, every Executive in the company has built into their performance and appraisal, meeting our sustainability targets, including our climate targets."

6. Conclusions and future steps

For industrial businesses already covered by EU or UK ETS (Emissions Trading Scheme), carbon (or energy costs more broadly including carbon) is a Board-level issue which impacts on the overall business operation. For instance, Cemex staff have sustainability as part of their performance metrics, and for Hanson the Science-Based Targets filter down through the organisation. They have been active in this area for a long time and substantial emission reductions have already been made in the UK market. Therefore, decarbonisation is not new for these sectors.

However, the Net Zero target has fundamentally altered what is required in terms of the scale and pace of change. And those working in these industries have noticed an increasing emphasis on carbon – especially from the public and investors as well as policy makers. Carbon disclosure and targets are now increasingly being linked to the provision of capital and are the subject of questions of primary manufacturers by other businesses.

The Net Zero target means that pressure is increasing on these sectors to decarbonise fully. The three sectors have all seen decreases in emissions over the years, as has been seen, some from emissions reduction and some from production moving out of the UK. Further potential for energy efficiency improvements is limited due to already well-established and optimised processes. This is a significant strategic issue for the UK as to whether it keeps these industries alive by persuading the parent companies of UK steel, cement, and chemicals plants to invest in their decarbonisation.

In terms of whether there is demand for low-carbon products from these sectors, it is clear there is considerable appetite from downstream sectors for low-carbon steel, cement and chemical products. This is fairly recent as previously emissions in these sectors were of little interest from elsewhere in supply chain or end users. However, cost is still the most important factor. Other factors such as usability and impact on construction schedules are also relevant and can provide obstacles to use of low carbon products, but these also feed into costs, which remain the over-riding consideration.

Increasingly there are questions from the other businesses on carbon content – e.g. construction companies wanting to reduce their own emissions in the supply chain, where concrete and steel would be major contributors. However, while questions might be asked about CO_2 at a general level by media or customers, few understand the issues in detail. Public procurement policies could do much more to support investment in low-carbon UK production through creating near-term demand for the products. The market for large-scale adoption of low-carbon industrial products is completely untested, meaning that the UK's competitive advantage in moving first is highly uncertain. There is also the consideration that changing the production route to reduce emissions may change the nature of the products produced (e.g. for steel or cement) and therefore what these materials can be used for.

The Net Zero target will require the UK manufacturing sector to undergo significant structural change over the coming three decades. While the overall target is for 2050, achieving it requires policy action and a clear roadmap from today onwards, in order to provide time for research, innovation, most importantly align with investment cycles for capital assets, and investment in essential infrastructure to take place in line with the industries' investment cycles for capital assets.

This is especially true for the UK steel sector, which according to the Climate Change Committee should decarbonise earliest of all the manufacturing sectors, by 2035 in fact. The majority of current emissions from this sector come from two integrated steel sites – Port Talbot and Scunthorpe. The strategic investment decisions to decarbonise these sites, whether through green hydrogen, CCUS, EAFs or a combination of these will need to be made soon, and are clearly dependent on the scale and nature of the available policy support. More competitive industrial electricity prices have a crucial role to play, as have improved policy for more domestic scrap steel recycling and production and decisions on infrastructure. Mixed messages from the Government about whether to back a new coking coal mine in Cumbria are not helpful.

For cement there is a dual task of tackling both fuel and process emissions. Reducing emissions from fuel has been going for some time such as using waste materials as a fuel source (e.g. tyres) and projects are still being initiated (e.g. the Hanson fuel- switching demonstration using hydrogen). There is also the overlap with the steel sector, whereby blast furnace slag from steelmaking is used in cement production to replace clinker and lower emissions. However, this may only be available as an option for a few more years, unless CCUS is applied to the UK's steel BF-BOF plants. Cement production in the UK is probably the most dependent upon CCUS as a long-term solution to decarbonisation given the prevalence of process emissions in the sector. Although there is a multitude of potential sinks for CO_2 from cement in the UK, it is the most dispersed of the three sectors in terms of geography, which makes the installation of the necessary pipelines for transport more difficult. Issues around safety of transport and storage as well as public acceptability will also have to be addressed.

A portion of emissions in the chemicals industry could be reduced through greater electrification of heat processes. However, this is dependent upon making the switch from gas to electricity affordable. Also, like the other sectors, significant reliance on either green hydrogen or CCUS to help reduce emissions from high-temperature heat. Circular economy policies can play an important role in reducing emissions from plastic and other chemical production. Improved product design and building standards can have a significant impact in all three sectors. Given the wide variety of chemical products across the entire economy, there are many potential solutions to what can be done to achieve a Net Zero chemicals industry and the risk for the chemical companies is summarised well in the following quote in box 6.1 overleaf.

It is possible to foresee a number of industrial futures for the UK steel, cement and chemicals sectors which are entirely dependent upon how pro-active UK policymaking is over the coming years. Three possible outcomes for UK industrial decarbonisation may be envisaged.

(1) **Failure to Deliver.** Achieving Net Zero is perceived to be too difficult by Government, which fails to deliver the required policy support. If decarbonisation proceeds elsewhere, the UK would find it increasingly difficult to sell its steel, cement and chemicals into low-carbon markets.

(2) **Muddling Through.** With global momentum behind decarbonisation, the UK Government does just enough to be able to sell into low-carbon markets but not enough to establish a leadership position and become attractive for low-carbon inward investment. Torn between the urgency and opportunities on one hand, but fearful of the cost and hoping for cheaper 'second mover' makes for a hesitant, contested and cautious approach.

(3) **Forge Ahead.** A UK industrial roadmap within the next two years combined with policy implementation over the coming five years makes the UK a magnet for low-carbon investment and innovation in a context where this is recognised globally as the essential direction of travel, a situation that could lead to a revival of UK heavy manufacturing. Drawing upon the UK's comparative advantage in particular regarding large-scale renewables and potential storage, the clarity provided by our carbon budgets, combined with existing manufacturing and finance capabilities, integrated strategies can establish the necessary groundwork and support for these underpinning industries and help to make the UK an attractive place for low carbon manufacturing.

It is too early to say which outcome is most likely for the UK. 'Failure to deliver' is still very much on the cards, as shown by the repeated warnings from the Climate Change Committee that the UK is not yet even on track for the fourth and fifth carbon budgets, put in place when the target was for an 80% GHG emission reduction by 2050, let alone the sixth carbon budget that is in line with Net Zero.

However, the UK Industrial Decarbonisation Strategy provides grounds for hope for one of the more positive decarbonisation outcomes, especially through the investments and industry involvement in the industrial clusters. But there are broader decisions to be taken beyond these clusters: whether the UK ETS should be linked to the European scheme; whether to introduce a carbon border adjustment mechanism which companies appear to broadly support; what to do about electricity prices; how to make CCUS and hydrogen available outside the clusters; how to use public procurement to kickstart the market for low-carbon steel; how to make sure that planning regulations and public opinion are supportive of the required infrastructure developments. Answers to all these questions will need to be forthcoming in the next two years if the required decarbonisation investment is to be forthcoming.

A Net Zero UK will still require steel, cement and chemicals. The challenge is to put in place the policy support that allows these industries in the UK to make the transition to Net Zero in a highly competitive global context, so that they are not undercut by high-carbon competitors before Net Zero industry is established as the new global norm. The interviews conducted with the sectors have shown clearly that they are up for the challenge, but they need policy support and they need it soon if emission targets are to be met.

Box 6.1 HCS Group

"The challenge for HCS is that we've got probably 10 or 15 different projects looking at new feed stocks, new processes, for instance, sustainable aviation fuel, gas to liquids, plastic to liquids, – the challenge for us is deciding on the correct path. If we pick the wrong one, and we invest considerable sums in plant and equipment on this site, the risk is that, on account of the long lead time, customers may eventually no longer require our solution and want something different because the market and global economics have changed."

Box 6.2 Chemical Industries Association

"If we have low-carbon infrastructure in the UK then we can attract clean manufacturing and then that's jobs, that's R&D and our sector is one of the biggest funders of R&D in the UK at the moment. This net- zero transition is a real opportunity for an innovative sector in the market for advanced materials."

7. ANNEX: Businesses and interviewees' information

British Steel is a leading European steel manufacturer with facilities across the UK and Europe, supplying a wide range of high-quality long steel products to markets around the world. British Steel operates an integrated 2,000-acre site at its headquarters in Scunthorpe with four blast furnaces, where it has been producing steel for more than 130 years, as well as processing and distribution services around the UK and Ireland. In March 2020, British Steel was bought by Jingye Group, a Chinese multi-industrial company specialising in iron and steel manufacturing.

We interviewed Lee Adcock, Environment and Sustainability Director, British Steel Ltd.

CEMEX is a building solutions company and leading supplier of cement, ready-mixed concrete and aggregates, as well as other building materials, to the construction industry. The company has a long history in the UK, where it now generates around £775m in annual sales and employs around 2,200 people. CEMEX UK is part of the global CEMEX group, headquartered in Mexico, and which operates across more than 50 countries.

We interviewed Martin Hills, Head of Carbon, Legacy Landfill and Special Projects, and Martin Casey, Director of Public Affairs Europe, CEMEX UK Operations Ltd.

The **Chemical Industries Association (CIA)** is the organisation representing and advising the many and diverse chemical and pharmaceutical companies operating across the UK. Their representation includes lobbying legislators, policymakers and stakeholders on the issues that affect member companies at UK, European and international level. The CIA provides advice and guidance to its members on policy, business support, technology and good practice. It has published extensively around Net Zero, energy and climate, including in 2020 "Accelerating Britain's Net Zero Economy", and in 2021 is collaborating with ITN Productions Industry News on "The Chemical Industry – Our Route to Net Zero".

We interviewed Rich Woolley, Head of Energy and Climate Change, and Pete Walters, Head of Environment and Sustainability, Chemical Industries Association.

Haltermann Carless is a leading international supplier of high-value hydrocarbon-based speciality products and solvents. Its customers range from the automotive, aerospace, oil and gas, agrochemical and pharmaceutical industries. Its Harwich Manufacturing Centre employs 100 people and is capable of producing large or small scale quantities of products to precise specifications, tailor-made to customer requirements. The company can trace its origins in the UK back to 1859. Today, it is a key brand of the HCS Group with 450 employees based in Germany, UK, France, and the USA. The company is looking forward and is developing sustainable product options for its customers.

We interviewed Keith Mead, Sustainability Manager, Haltermann Carless UK Ltd.

Hanson are a leading supplier of heavy building materials to the construction industry, producing aggregates (crushed rock, sand and gravel), ready-mixed concrete, asphalt, cement and cement related materials. The UK company is part of the HeidelbergCement Group, which has leading global positions in aggregates, cement and concrete. Hanson UK is split into four business lines – aggregates, concrete, asphalt and contracting and cement – which together operate around 300 manufacturing sites and employ over 3,500 people.

We interviewed Iain Walpole, Environmental Sustainability Manager, Hanson UK.

The **Mineral Products Association (MPA)** is the industry trade association for the aggregates, asphalt, cement, concrete, dimension stone, lime, mortar and silica sand industries. Within this, it represents 100% of UK cement and lime production. MPA represents members' interests on policy, planning and technical matters with government departments, local authorities, professional trade bodies and other key audiences at European, national and local levels. MPA is currently undertaking innovative fuel switching demonstrations in cement and lime production, and has launched a roadmap for the UK concrete and cement industry to become net negative by 2050, removing more carbon dioxide from the atmosphere than it emits each year.

We interviewed Richard Leese, Director, MPA Cement, Industrial Policy, Energy & Climate Change, and Diana Casey, Director, Energy and Climate Change, Mineral Products Association.

Robinson Brothers is one of the UK's largest independent manufacturers of speciality and fine chemicals, high impact aroma chemicals and rubber accelerators. They are well-respected as a consistent and quality manufacturer to the pharmaceutical, agrochemical, life science, personal care, photographic and general chemical industry, with highly-skilled chemists able to support all stages of chemical product life cycle development. Founded in 1869, Robinson Brothers has successfully adapted and diversified its business over its 150 year history, and continues to manufacture at its site in the West Midlands.

We interviewed Adrian Hanrahan, Managing Director, Robinson Brothers Ltd.

UK Steel champions and celebrates the UK steel industry as important, innovative, progressive and environmentally responsible. UK Steel is the voice of the steel industry, interfacing with government and parliament – in both London and Brussels – to influence policy so that it underpins the long-term success of the sector, in addition to a range of policy and industry insights, including sector specific expert analysis on the steel industry.

UK Steel is part of Make UK which represents 20,000 manufacturers in the UK. They enable manufacturers to connect, share, solve problems and create opportunities through regional and national meetings, groups, events and advisory boards. Make UK has recently published its paper, "Demystifying Net Zero".

We interviewed Frank Aaskov, Senior Energy and Climate Change Policy Manager, UK Steel.

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