# UK structural steelwork: 2050 decarbonisation roadmap

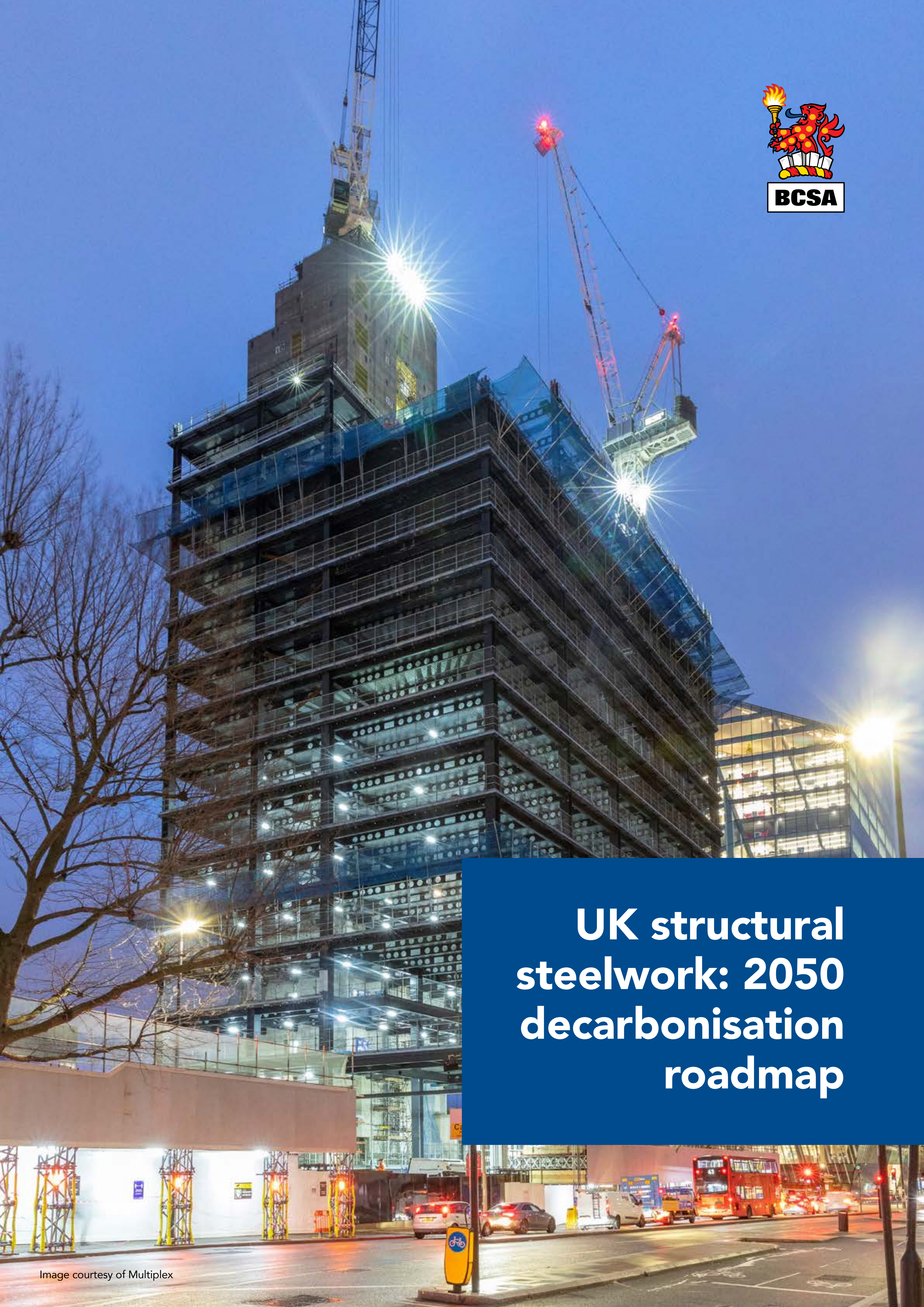


Image courtesy of Multiplex

# Contents

# Executive summary

**This roadmap sets out how the UK structural steelwork sector will decarbonise to meet the UK net-zero carbon target by 2050.**

While significant progress has been made over recent decades to reduce the energy and carbon intensity of steelmaking, more needs to be done and action is required by all parts of the supply chain; designers, steelwork contractors, steel producers and stockholders and demolition contractors all working closely together on both demand side and supply side reduction measures.

The scale of the challenge is recognised but given the right policies, incentives and financial support, the technologies outlined in this roadmap can deliver decarbonised steel structures by 2050. The breadth of available technologies and other measures is a major strength of the roadmap. It gives flexibility to respond and react to enabling policies as they are developed and implemented and as new technologies are commercialised at different timescales.

The prize is a big one; a truly circular and sustainable model in which steel structures are constructed, adapted and extended to prolong building lifetimes and ultimately, routinely deconstructed and reused. Where this isn't possible, the steel is recycled in electric arc furnaces powered using zero-carbon renewable energy, to be used again in the same or a new application.

# Introduction

**The need and urgency to address climate change is no longer challenged and the debate has moved on to how, and how quickly, we can decarbonise all aspects of our lives.**

Steel is the backbone of modern economies and underpins many industrial sectors, including construction which accounts for more than half of all steel use globally. Steel also has a vital role to play to facilitate the transition to a zero-carbon economy and the industrial and infrastructure revolution that is required to decarbonise the UK by 2050. Specific examples include wind turbines, solar harvesting and other renewable energy technologies including tidal, hydrogen production facilities and networks, nuclear power and biomass plants.

Steelmaking, using current, commercial technology, is carbon-intensive. Globally, steel production accounts for around 8% of all greenhouse gas (GHG) emissions [1]. But steel is the world's most recycled material with excellent circular economy credentials. By delivering this roadmap, steel construction can offer a net-zero, sustainable and truly circular future.

Significant progress has already been achieved in decarbonising steelmaking. For example, the carbon intensity of UK steel production has been reduced by around 60% since 1960 and 20% since 1990; the baseline for the UK's 2050 net-zero reduction targets [2].

More needs to be done however and this roadmap shows how the UK structural steelwork sector will substantially reduce emissions by 2030 and be net-zero by 2050 while continuing to deliver safe and sustainable buildings.

While climate change and reducing greenhouse gas emissions is a priority and the focus of this roadmap, the benefits of steel and steel construction systems within a broader sustainable context should not be forgotten. These include:

- Steel structures are lightweight and structurally efficient
- Steelwork is efficiently fabricated offsite offering quality assured, fully tested and traceable products
- Steelwork design and fabrication is BIM-led providing a digital-twin enabling future reuse
- On-site construction is safe and fast with minimal local adverse environmental impacts
- Structural steel is fully recyclable and many structural elements are reusable
- Steel-framed buildings are flexible to change of use and steel structures are easily adapted.

The roadmap has been developed by representatives from the following organisations:

ArcelorMittal
BCSA
BRITISH STEEL
HARE
Severfield
SCI
TATA STEEL

The roadmap has been supported by the following companies:

caunton ENGINEERING
Elland Steel

# The UK Constructional Steelwork Market

**The UK constructional steelwork market is worth approximately £1.6 billion per year and employs about 60,000 people (fabrication and erection). It represents a significant part of the UK economy and of manufacturing output.**

Steel's market share of UK buildings, compared to other constructional materials, has increased significantly since the 1980s and is now the highest in the world. Steel's market share of the single storey (shed type) building's market is 98% and it has approximately 65% of the multi-storey non-domestic buildings market. This has not happened by accident but is by a combined push in market development, new construction solutions and above all, improvements in efficiency and productivity.

The industry is now applying the same determination, innovation and expertise to the climate emergency and will meet the government's carbon challenge to be net-zero before the 2050 deadline.

# Roadmap scope

**The scope of this roadmap is the UK structural steelwork sector and therefore includes the major steelmakers who supply the UK construction market and the steelwork contractors who design, fabricate, transport and erect steel structures in the UK.**

The scope of products includes:
- Hot-rolled steel sections
- Steel plate
- Structural hollow sections

Although these products are globally traded, currently more than 90% are supplied to the UK market by UK and European producers. This is important because, underpinned by EU and national legislation, most UK and EU steelmakers have already committed to decarbonising steelmaking by 2050.

There is a range of technologies underpinning this roadmap, most of which are proven and many are already at the pilot and demonstration stage. For the examples presented, their technology readiness level (TRL) is provided as evidence that the sector is already engaged, committed and investing in the transition to net-zero by 2050.

The range and diversity of decarbonisation strategies and technologies available to steelmakers and steelwork contractors is a major strength of this roadmap and gives the sector options or 'levers' to implement different technologies at varying timescales depending on a range of factors including geography, local infrastructure and synergy with other industries, cost and available finance, national and international policy and commercial readiness.

But technologies are only part of the roadmap. It is vitally important that the right incentives, policy, infrastructure and funding are put in place so that the technologies outlined in this roadmap are commercially deployed to the required timescales. These are required both nationally and internationally so that there is a level playing field for decarbonising steelmaking.

# TRL - Technology Readiness Levels

**Technology Readiness Levels (TRLs) are a method for estimating the maturity level of a technology throughout its research, development and deployment phase progression. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology.**

Originally developed by NASA for space exploration technologies, TRLs have been normalised to enable their application to multiple industry sectors. The TRL definitions developed by the EU have been used in this roadmap. The EU defines the nine levels as follows:

| | | |
|---|---|---|
| DEPLOYMENT | 9 | **Actual system proven in operational environment** |
| | 8 | **System complete and qualified** |
| | 7 | **System prototype demonstration in operational environment** |
| DEVELOPMENT | 6 | **Technology demonstrated in relevant environment** |
| | 5 | **Technology validated in relevant environment** |
| | 4 | **Technology validated in lab** |
| RESEARCH | 3 | **Environmental proof of concept** |
| | 2 | **Technology concept formulated** |
| | 1 | **Basic principles observed** |

# The sector's vision for a circular, zero-carbon future for steel construction

**The role of structural steel in the circular economy is already proven, through a well-established scrap network that today recovers 99% of all UK structural sections; 86% for recycling and 13% for reuse.**

Fast forward to the end of the century. All the blast furnaces, equipped with carbon capture, use and storage (CCUS) technologies, have now been decommissioned and replaced with electric arc furnaces (EAFs) for primary steelmaking using hydrogen-DRI (direct reduced iron) where required.

Throughout this century, global scrap supply has steadily increased and reduced the demand for DRI and iron ore.

By 2100, the availability of scrap means that DRI is no longer required, and the industry now operates in a truly circular way based on 100% scrap feedstock using electric arc furnaces (EAF) powered by zero-carbon renewable energy.

But, that's only half of the story. In the second quarter of the century, designers and the supply chain capitalised on the inherent demountable attributes of steel structures to enable mainstream reuse of structural elements. Small changes were made in the choice of detailing to maximise bolting and minimise welding, demountable composite beam and slab systems employing bolted shear connectors were widely rolled out and adopted, platform based approaches and greater standardisation were embraced and BIM has facilitated the development of a national database of steel stock held within UK buildings. As buildings are deconstructed the industry has all the detailed information it needs to design and reuse elements into new infrastructure in a truly circular way.

Some may regard this as fantasy, but 37% of global steel today is made using scrap [3], a circular system. The only reason this can't go further is the limited availability of scrap. That is why the priority is to accelerate the decarbonisation of primary steelmaking to create the scrap to plug the gap to reach circularity.

In the case of reuse, UK research shows that this currently stands at 13% [4]. Technical barriers have been knocked down in the form of guidance from the SCI in P427 Structural Steel Reuse and also P428 Guidance on Demountable Composite Construction Systems for UK Practice. BIM, of course, will also play a key role in facilitating reuse.

All the parts of the jigsaw required to create a circular world are there. An efficient lean steel fabrication sector, high strength steels to reduce material use, inherent characteristics that encourage longevity and demountability and an efficient, established recycling network that creates new products from those that are no longer fit for purpose.

# Steelmaking today

**Global crude steel production was 1.88 billion tonnes in 2020 [3] and continues to rise, mainly as a consequence of industrialisation in developing economies and particularly, over recent years, growth in China which accounted for 57% of all steel production in 2020. UK steel production is currently around 7.1 million tonnes per annum; 0.4% of global production [5].**

Today steelmaking is dominated (99.5%) by two production processes [3]:

1. **Blast furnace-basic oxygen furnace (BF-BOF)** involving the reduction of iron ore in a blast furnace (BF) using coke. The liquid iron is then converted into steel in the basic oxygen furnace (BOF). The blast furnace accounts for around 70% of the greenhouse gas emissions associated with the BF-BOF steelmaking process and therefore is the priority for decarbonisation.
2. **Electric arc furnace (EAF)** production uses an electric arc to melt materials charged to the furnace. Most EAF production today uses scrap to produce secondary steel but direct reduced iron (DRI) is also used either on its own or mixed with scrap and alloys.

DRI is the process of reducing iron ore at a temperature lower than the melting point of iron. Today reducing gases used in DRI production are either derived from coal or more commonly (85% globally) natural gas.

DRI is used in both the BF, to optimise the mix, and more commonly, in EAF production generally, in addition to scrap, to maintain steel quality.

While global DRI production is only around 100Mt today, it has great potential as a low carbon technology using hydrogen as the reductant.

Globally BF-BOF accounts for 73% of all steelmaking and EAF 26% [3]. The dominance of BF-BOF production is driven mainly by the finite supply of scrap and growing global demand for steel particularly in developing economies. The UK production split (all steel) is currently 81:19 (BF-BOF:EAF) [3]. The European production split (EU-28) is currently (2020) 58:42.

**Summary:**

- Iron is made in two ways; in a blast furnace (BF) and by direct reduction (DRI)
- Steel is made in two ways; in a basic oxygen furnace (BOF) and in an electric arc furnace (EAF)
- There are two forms of EAF: DRI-EAF using a mix of solid DRI and scrap and scrap-based EAF using 100% scrap

# Steel construction products

All steel construction products can be produced using either of the two principle steelmaking routes, i.e. primary Blast Furnace-Basic Oxygen Furnace (BF-BOF) or the secondary, Electric Arc Furnace (EAF) route.

However, for various technical and economic reasons, some products are preferentially produced by one or other of these routes (see table on right).

In EAF steelmaking in the UK and Europe, the primary input is scrap steel and the type of the steel produced is heavily influenced by the blend of the input scrap. Globally, around 80% of EAF production [3] is directly from scrap steel (the remainder being from DRI-derived steel) – and this is certainly true of those EAF mills supplying structural steel sections to the UK.

Traditionally, it has been more difficult to make relatively thin, flat steel products (including plate and hollow sections) from scrap steel due to the variable nature of the input and this is why the majority of EAF steel is used for long products such as hot rolled sections and wire rod. Hot-rolled sections are produced, equally efficiently, via either production route, while plate and hollow sections used in the UK today tend to be produced via the BF-BOF route.

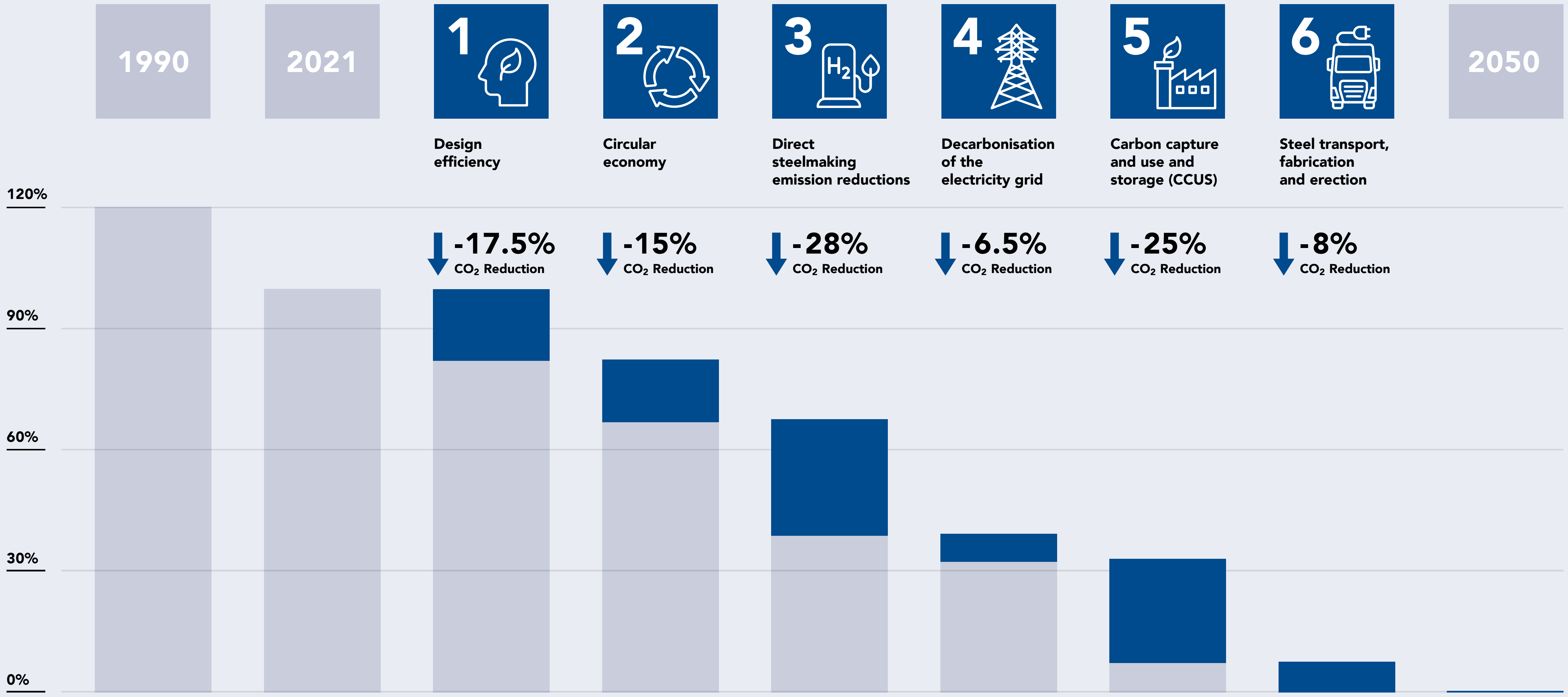
| Product Category | Manufacturing Route | List of Products |
|---|---|---|
| Long Products | Blast furnace route and electric arc furnace route | Sections<br>Rebar<br>Wire Rod |
| Flat products | Blast furnace route | Plate<br>Hot-rolled coil<br>Cold-rolled coil<br>Hot-dip galvanized<br>Organic coated flats |

From worldsteel LCA methodology report (2011)

# 2050 roadmap

The 2050 roadmap is based on six decarbonisation strategies or 'levers' that the sector will concurrently develop and deploy. Absolute carbon reductions attributable to each lever to 2050 are shown. While levers are presented as distinct steps, the transition to net-zero by 2050 will be a complex journey involving a diverse mix of the technologies described below.

The roadmap represents our most likely route as we see things in 2021 based on the current state of development of steelmaking technologies and the various pilot and demonstration studies already underway in the EU and the UK and other planned initiatives, for example relating to reuse. Some will be more successful than others and some will be commercialised sooner than others. Nevertheless, the range of technological options available coupled with their technology readiness (TRL) provides flexibility and multiple options to achieve our 2050 net-zero target.



# Main roadmap assumptions

1. Today's carbon footprint (2021) is based on the 2019 UK consumption tonnage of structural steelwork
2. The current UK BF-BOF:EAF consumption split and associated carbon emission factors are those used to derive the UK average consumption emissions factor [12]
3. Total UK construction demand and structural steel's market share are assumed to remain constant between 2021 and 2050. Demand reduction measures (Levers 1 and 2) are relative to this steady-state demand.
4. Of the many decarbonisation strategies reviewed in the development of this roadmap, those published by the UK Climate Change Committee, particularly the 6th carbon budget [13], the UK Industrial decarbonisation strategy [7] and Eurofer [14] have been most influential in predicting carbon reductions; these being the most likely to influence developing UK and EU decarbonisation policy. It is noted that many of the published steel decarbonisation strategies are global studies based on different scenarios that are not reflective of the scope of this roadmap.
5. In alignment with the UK's industrial decarbonisation strategy [7], two major decarbonisation options are available to UK steelmakers; CCUS (lever 5) and EAF production either with or without hydrogen DRI (lever 2). UK and other steel producers are considering both options, or a mix, and a clearer roadmap will evolve over time as the technologies mature.

   In the roadmap, a 50:50 split has been assumed between the carbon emissions abated via CCUS and hydrogen DRI-EAF. This is consistent with UK industrial decarbonisation strategy [7] which takes a technology-neutral approach and so does not rule out the use of coking coal in an integrated steelmaking process together with CCUS as a net-zero compliant option going forward.
6. The UK also has the option to electrify steelmaking by shifting from BF-BOF to scrap-based EAF production. It is assumed that by 2050, UK steel production, in alignment with the EU [3], is 60% scrap-based EAF. Carbon reductions are achieved through grid decarbonation (lever 4) and the displaced BF-BOF production (lever 3).

# Roadmap timescales

Decarbonisation timescales are uncertain and will depend on technological advances and enabling policies and support, both nationally and internationally. Indications of commercialisation timescales are however provided for all decarbonisation technologies and demand reduction measures included.

Demand side measures (Levers 1 and 2) yield the easiest, short-term reductions. In addition, many of the incremental, process improvements described under Lever 3, will deliver carbon reductions over the next decade. Decarbonisation of the UK electricity grid (Lever 4) is also well advanced with carbon intensity reductions of around 70% predicted by 2030.

The UK Climate Change Committee has recommended that ore-based steelmaking should be near-zero by 2035. This timescale has been modelled in the UK industrial decarbonisation strategy [7]. Although technically achievable, the supporting policies and funding necessary to facilitate this transition and timescale have not yet been agreed. Dialogue between UK Government and the Steel Council to decarbonise the UK steel industry is ongoing.

Many steel producers supplying structural steel to the UK construction market have committed to carbon reduction targets. For example, Tata Steel has committed to a 30% reduction in the UK by 2030 and similarly ArcelorMittal Europe has an emissions reduction target of 30% by 2030.

British Steel has recently committed to adopt Science Based Targets in line with the UK commitments to the Paris Agreement and to an 82% carbon emissions reduction target by 2035.

Although much uncertainty remains around decarbonisation timescales, in particular concerning the policies, funding and technologies relating to CCUS and hydrogen, this roadmap is aligned with the World Green Building Council target [16] to reduce building embodied carbon emissions by at least 40% by 2030. The sector is confident that the levers set out in this roadmap will achieve this interim target.

# Steel decarbonisation technologies and strategies

**The six decarbonisation strategies are described on the following pages. For each lever, measures are described along with their technology readiness levels (TRL) and likely deployment timescales.**

**Brief descriptions of a range of decarbonisation technologies currently underway in the EU and the UK are given in the Appendix.**

Image courtesy of British Steel

## 1 Design efficiency

Demand reduction through greater design efficiency is an important component of the roadmap both in terms of its contribution and timescale. In the short-term, while new steelmaking technologies are further developed and commercialised, material efficiency gains will deliver early, significant carbon reductions. Demand reduction does not mean fewer steel buildings rather it involves smarter, more efficient design; performing the same structural function but using less steel.

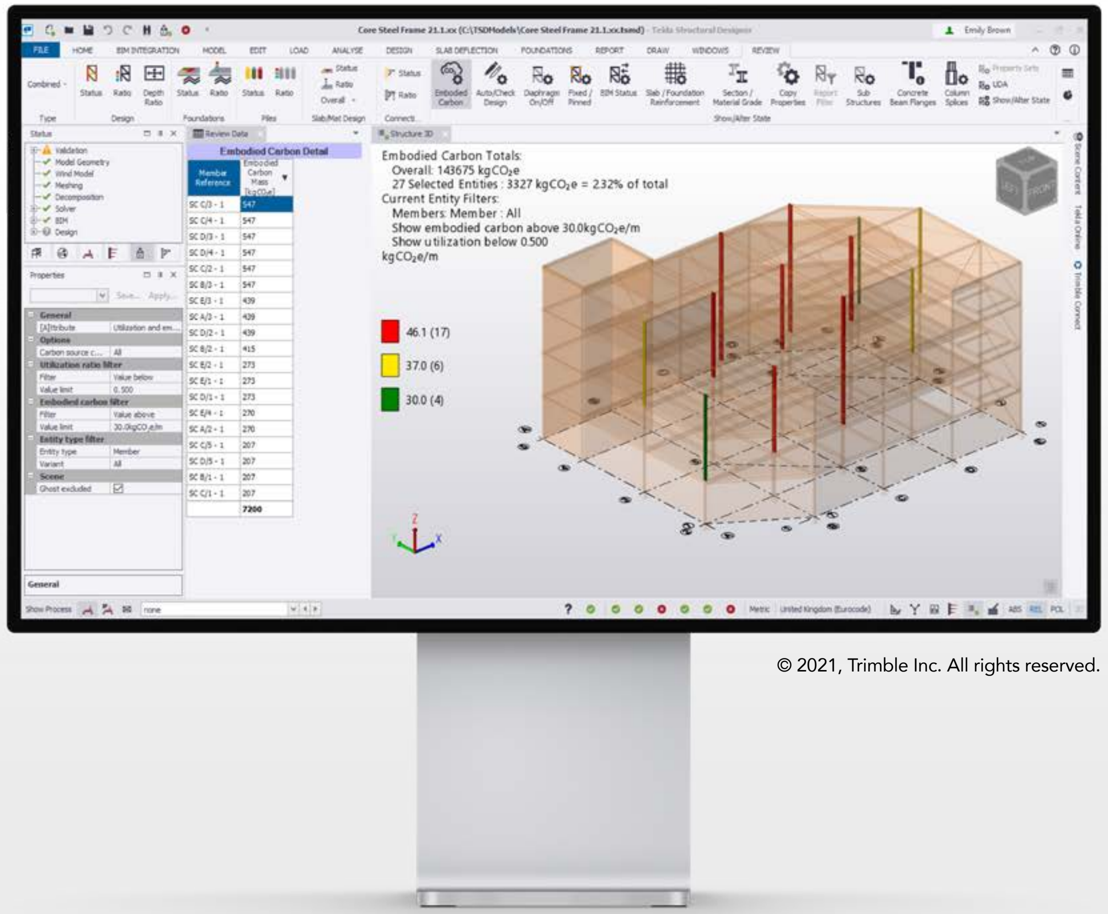
**Specific structural steel efficiency measures include:**

- Reducing over-specification of structural steel, e.g. more efficient and less conservative design
- Reducing over-specification of design loads
- Reduction of applied loads although it is noted that this may hamper future building flexibility
- Section and profile optimisation that tailors components to their required functionality
- Using higher-strength steel to facilitate the use of lighter members - For example, an S460 grade column weighs 32% less than a standard S355 grade column of the same length and thickness
- Extending building lifetimes, e.g. by designing for adaptability and designing for internal flexibility, for example, by using long spans.

**TRL**
9 Designers already have the skills to deliver greater material efficiencies but they need incentives, targets and in many cases, higher design fees to deliver more efficient designs.

**Timescale**
Ongoing to 2050 but with most efficiencies achieved by 2035 [1].

**Carbon reduction to 2050: -17.5%**



Embodied Carbon Detail

| Member Reference | Embodied Carbon Mass [kgCO₂e] |
|---|---|
| SC C/3 - 1 | 547 |
| SC C/4 - 1 | 547 |
| SC D/3 - 1 | 547 |
| SC D/4 - 1 | 547 |
| SC C/2 - 1 | 547 |
| SC B/3 - 1 | 547 |
| SC E/3 - 1 | 439 |
| SC A/3 - 1 | 439 |
| SC D/2 - 1 | 439 |
| SC B/2 - 1 | 415 |
| SC E/2 - 1 | 273 |
| SC E/1 - 1 | 273 |
| SC D/1 - 1 | 273 |
| SC E/4 - 1 | 270 |
| SC A/2 - 1 | 270 |
| SC C/5 - 1 | 207 |
| SC D/5 - 1 | 207 |
| SC B/1 - 1 | 207 |
| SC C/1 - 1 | 207 |
| | **7200** |

```
Embodied Carbon Totals:
  Overall: 143675 kgCO₂e
  27 Selected Entities : 3327 kgCO₂e = 2.32% of total
Current Entity Filters:
  Members: Member : All
  Show embodied carbon above 30.0kgCO₂e/m
  Show utilization below 0.500
kgCO₂e/m
```

🟥 46.1 (17)
🟨 37.0 (6)
🟩 30.0 (4)

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# 2 Circular economy

Steel in general, and structural steel specifically, is truly compatible with circular economic models. To drive optimum resource decision-making, it is important that we look at whole life impacts and the whole life benefits of our buildings and of the components used to construct them.

In the context of this roadmap, the circular economy delivers carbon emission reductions through demand reduction measures relating to extending building lifetimes and preserving the value of steel products through reuse and recycling.

**Whole life impacts:** delivering a low carbon building that requires significant maintenance during its lifetime or uses materials that cannot be reused or recycled can lead to future unintended consequences. Therefore, a Whole Life Cycle Assessment approach should be taken which considers all emissions produced over the entire life of the building, from sourcing through construction and use to disposal (cradle to grave).

**Whole life benefits:** steel structures give predictability to the reuse and recycling potential of buildings and construction products, therefore driving the circular economy. In terms of Life Cycle Assessment, the benefits of recycling and reuse are accounted for separately as beyond-life credits, technically referred to as Module D in CEN standards. For steel products, Module D generally gives a benefit by accounting for not having to manufacture virgin material in the future, although for some less-well recycled materials, the opposite could be true.

In the context of structural steelwork, there are other circular economy attributes that yield further whole life benefits. These include:

**Durability and resilience** - Steel construction products are inherently durable meaning not only that they will last a long time, beyond the conventional 60 year assessment timescale, but also that many steel construction products can be reused after their first life.

**Flexibility and adaptability** - Extending the life of buildings is a key aspect of the circular economy. This can be achieved by making buildings that are both flexible and adaptable to change so that they last longer and greater value is extracted from the materials and resources used to construct them.

The steel frame itself can be easily adapted, with parts added or taken away, and its light weight means that extra floors can often be added without overloading existing foundations. Steel's long-span capabilities provide flexible internal space.

Steel structures are commonly used to renovate buildings, for example behind retained façades. In this way the historic value, character and resources of the façade are retained and the building structure can be reconfigured to create open, flexible internal space that meets modern client requirements and maximises net lettable floor area.

**Versatility** - Steel is a versatile material both in terms of its metallurgy/chemistry and as a construction product and structural framing system.

**Reuse and remanufacture** - Structural steel sections are inherently reusable. Reuse, as opposed to the current, common practice of recycling structural steel by remelting, offers significant potential in terms of resource efficiency and carbon emission savings. Although proven to be technically viable, currently there are logistical and supply chain barriers to more widespread reuse that need to be addressed.

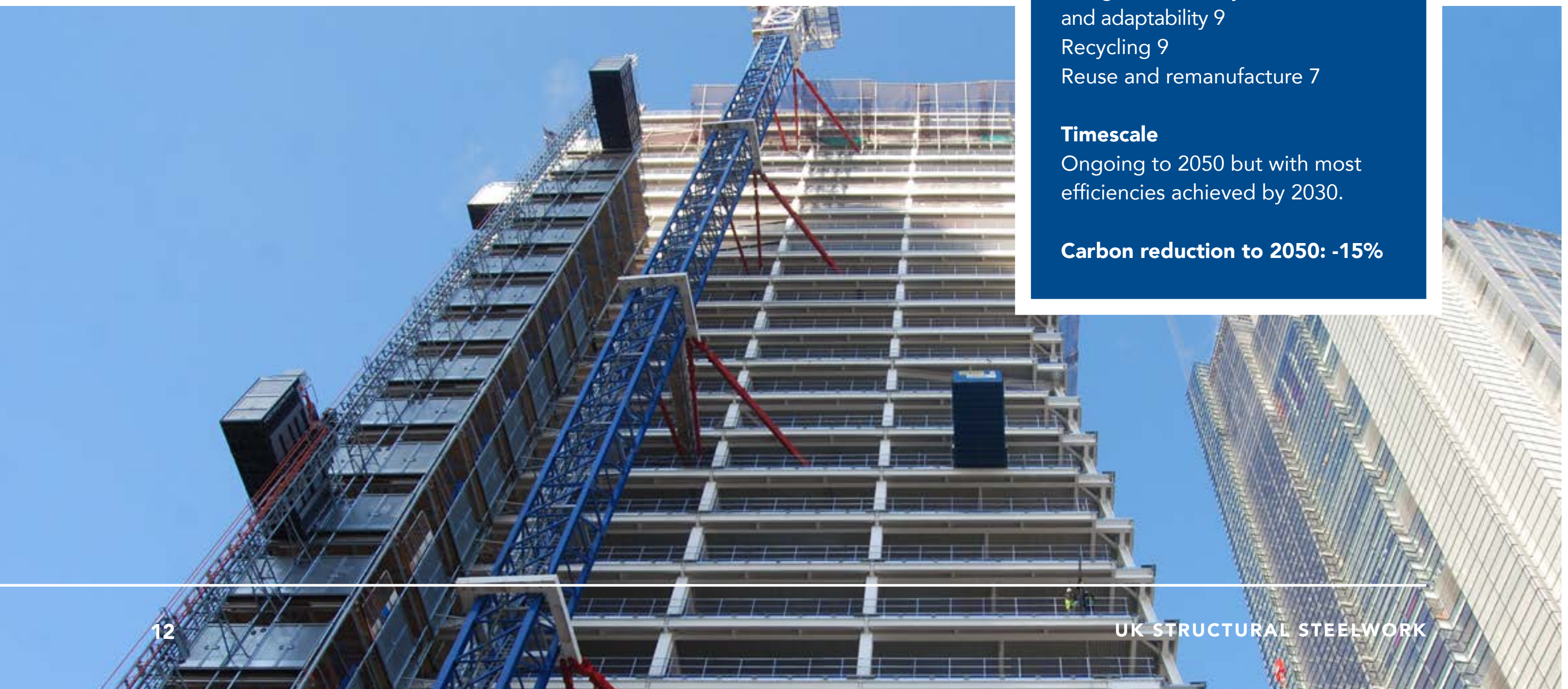
**Recycling** - Steel is 100% recyclable without loss of its inherent material properties and is the most recycled industrial material in the world, with over 650 Mt recycled annually.

Recycling steel is standard practice today and is intrinsic to future resource efficiency and carbon reduction. In the UK, 99% of structural steel is recovered from building demolition, mainly (86%) it is recycled by remelting. However structural steel elements are also inherently reusable. These inherent properties mean that beyond life cycle credits can be considered on a project-by-project basis if they are recorded separately along with an appropriate reuse / recovery recycling strategy being put in place.

**TRL**
Design for flexibility
and adaptability 9
Recycling 9
Reuse and remanufacture 7

**Timescale**
Ongoing to 2050 but with most efficiencies achieved by 2030.

**Carbon reduction to 2050: -15%**



# Module D – a metric for the circular economy

European (CEN) Standards relating to the sustainability assessment of construction works adopt a modular approach to assess and report environmental impacts over the life cycle of a building. These include:

- Module A - Covering the production of the construction products and their assembly into buildings
- Module B - Covering the use of the building over its design life
- Module C - Covering the end-of-life of the building including demolition and disposal of the demolition waste.

Module D is a supplementary module that reflects benefits and loads beyond the defined system boundary, i.e. the building lifetime, and includes reuse and recycling potentials of materials and products recovered from the end-of-life of buildings. BS EN 15804 [8] now mandates the reporting of Module D.

Module D benefits are calculated based on the avoided impacts of primary production. For example, if a product is recycled, the Module D benefit is the avoided impact, i.e. the impact avoided by not producing the product via the primary production route.

Where there is a loss of quality, for example crushing concrete into rubble, then a value-correction factor is applied to reflect the lower value of this type of recycling.

Whereas reducing Module A impacts may be a current priority for many, ignoring Module D effectively equates a material that is landfilled following demolition with one that is reused or recycled. To transition to a more circular economy, we have to start incentivising design for deconstruction and reuse and set Module D targets alongside those currently being proposed for Module A.

Juanan Barros Moreno – Shutterstock

# 3

# Direct steelmaking emission reductions

Steelmaking emission reduction technologies range from step-change technologies like hydrogen (see next page) to incremental performance improvements in energy/carbon intensity of specific BF-BOF or EAF processes and include a range of best available technologies, many of which can be retrofitted to existing steel mills.

Emission reduction technologies deployed in many UK and EU steel mills include:

**Waste heat recovery** systems in which heat is recirculated to preheat input streams and generate electricity, reducing the amount of energy consumed, or can be exported for use outside the steel mill for example, in district heating schemes.

**Coke dry quenching** recovers the latent heat from the hot coke output of coke ovens and uses it to generate electricity, and also reduces total coke oven fuel consumption. At the same time, a higher quality coke is produced, which can facilitate a reduction in the coke rate into the blast furnace.

**Top pressure recovery turbines** which use the pressure and heat of the blast furnace gas for electricity generation.

**Injection of natural gas or process gases,** such as coke oven gas, into the blast furnace in addition or in place of, pulverised coal injection (PCI). Natural gas and hydrogen can be used in place of works arising gases, this switch can yield $CO_2$ reductions but to a limited amount depending on BF specific constraints.

**Increased use of scrap in the BOF and EAF processes:** Use of scrap plays an important part in the BF-BOF route where scrap can displace the iron requirement in the integrated route. Short term reduction measures are possible by increasing the amount of scrap used, however the BF-BOF route is thermodynamically limited to the amount of scrap input used. This can be increased with preheating of the scrap at the BOF plant and adding scrap into the blast furnace. Similarly, EAF's can use a mix of scrap and ferro-alloys to produce the required steel grades. In both production routes maximising scrap reduces $CO_2$ emissions.

**Use of biomass and biowaste** materials, such as sustainable forestry and agriculture residues, to produce bioenergy for steelmaking. In addition, plastic waste can be used as the source of energy, in combination with carbon capture and use technology, the emitted $CO_2$ can be converted into hydrocarbon liquids (ethanol) or solids (plastics). This creates a carbon-neutral, circular carbon cycle while addressing society's waste challenge with plastics.

**Examples of pilot and demonstration projects include:**
ArcelorMittal has developed several district heating schemes in Europe in which residual heat from the steelmaking process is used to heat local businesses, schools, hospitals and homes. District heating schemes have been developed at the ArcelorMittal production facilities at Ghent (Belgium), Belval (Luxembourg) and Dunkirk (France).

Tata Steel has invested in BOS gas and BOS heat gas recovery systems which increased the local electricity generation on site at the Port Talbot steelworks reducing external grid requirements by 15%. This also reduced the $CO_2$ intensity on site by over 300,000 tonnes per year.

The heat generated by the Tata Steel's Port Talbot steelworks in south Wales is equivalent to the heating demand of 500,000 homes; capturing and reusing it would offset more than a million tonnes of $CO_2$ emissions each year. In 2020 funding was announced for a Mobile Energy Storage as Heat (MESH) project which will focus on a thermochemical heat storage material developed by Swansea University's SPECIFIC Innovation & Knowledge Centre. This work will examine technologies to capture, store and release waste heat from the Port Talbot steelworks and transport it to areas of need.

ArcelorMittal has introduced natural gas injection at its integrated mill at Ghent (2020); the same technology will be introduced in the blast furnaces at Bremen and Eisenhuttenstadht in 2021. Coke oven gas injection into the blast furnace has also been introduced at ArcelorMittal Gijon this year.

HIsarna, a radical new technology for making iron, has been in development since 2011, wherein the pre-processing of ores and coal into sinter and pellets can be skipped. Concentrated $CO_2$ off-gas from the process is ideally suited to carbon capture and storage (CCS). It has many other unique benefits, such as eliminating the emissions of other pollutants such as nitrogen oxides and sulphur dioxide from the processes it replaces. HIsarna is expected to be commercially available in 2030-35, when it could lead to blast furnace replacement. Combined with CCS, HIsarna can cut up to 100% of $CO_2$ emissions.

**TRL**
Varies by technology, but many are already implemented in some European steel plants while other technologies require development. What is critical, is that the implementation of 'best available current technologies' to deliver incremental decarbonisation gains complements future decarbonisation investment.

**Timescale**
Ongoing retrofitting to BF-BOF and EAF mills to 2050.

Green hydrogen-based steel production (DRI-EAF) commercialised and competitive with conventional steelmaking in mid-2030s.

**Carbon reduction to 2050: -28%**

# Hydrogen – the opportunity and the challenges

Hydrogen is chemically carbon-free and can be used for both heating (direct combustion) and reducing iron ore, replacing both coke and carbon monoxide. Hydrogen can be used in both the blast furnace (BF) and in DRI production.

**Hydrogen injection - $H_2$** is used as an auxiliary reducing gas to partly replace CO derived from coal or coke. There are chemical and operational limits to the amount of $H_2$ that can be used in conventional BFs, however partial substitution can reduce the carbon footprint by around 10%.

**Hydrogen DRI** – Hydrogen can be used in place of natural gas, to produce DRI which is then converted into steel in an electric arc furnace.

Although hydrogen is one of the most abundant elements on earth, in its pure form it is rare. Extracting hydrogen from its compounds requires a lot of energy and although these energy sources can be diverse, the most popular hydrogen production method today is carbon-intensive.

**There are three types of hydrogen that can be used:**
**Grey hydrogen** is hydrogen produced using fossil fuels such as natural gas, using a process called 'steam reforming'. The excess $CO_2$ is not captured. Today almost all hydrogen is produced using fossil fuels (so-called grey hydrogen).

**Blue hydrogen** - Hydrogen is considered 'blue' whenever the emissions generated from the steam reforming process are captured and stored underground via industrial carbon capture and storage.

**Green hydrogen** is hydrogen produced by splitting water by electrolysis using renewable energy. This produces only hydrogen and oxygen which is vented to the atmosphere with no negative impact.

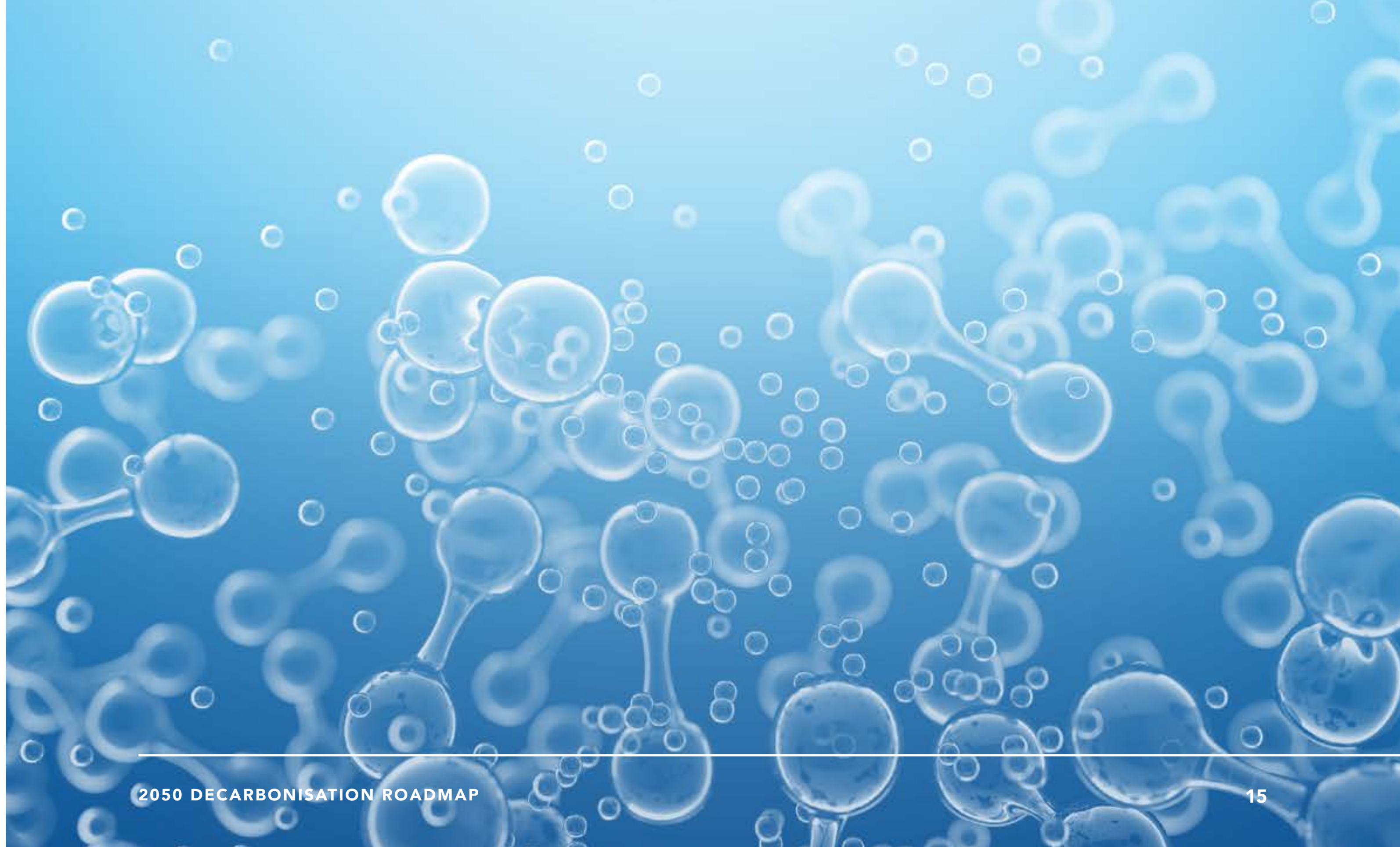
Electrolytic (green) hydrogen is expected to be available at commercial scale in mid 2030s.

Cost competitiveness of hydrogen-based steel production is a function of both the green hydrogen price and the cost of emitting $CO_2$. Green hydrogen prices are expected to halve over the next 10 years while simultaneously, carbon emissions costs, e.g. through the EU Emissions Trading Scheme (EU ETS), are expected to rise significantly. Hydrogen-based steel production is predicted to be competitive with conventional steel production between 2030 and 2040 in Europe [6].

Estimates of hydrogen demand by 2050 depend on a number of factors including the availability within and outside industrial cluster networks and whether the UK steel industry pursues hydrogen-based technologies. Consequently, hydrogen use by 2050 is expected to be between 24 and 86 TWh [6].

Industrial cluster networks are a cornerstone of the UK's industrial decarbonisation strategy [7].

Together with partners, Tata Steel is working to introduce hydrogen as a fuel source, to help create a hydrogen infrastructure, with the development of a 100MW green hydrogen pilot plant in South Wales. They are also executing engineering studies to explore viable routes to decarbonisation, including the use and production of a hydrogen supply, as a lead member of the South Wales Industrial Cluster.



## 4

## Decarbonisation of the electricity grid

Industrial decarbonisation, including steelmaking, requires clean electricity and so it is critical that the infrastructure is in place to deliver this. Decarbonisation of the UK electricity grid reduces the carbon intensity of both BF-BOF and EAF production. The impact of grid decarbonisation has a greater influence on scrap-based EAF production because electricity is the primary energy source and can contribute over 50% of the carbon footprint.

It is assumed that by 2050, and probably long before, the UK electricity grid will be almost decarbonised in line with national targets. For example, the UK National Grid [9] estimates that the grid carbon factor (or carbon intensity) will have fallen to 47 $gCO_2/kWh$ by 2030 (average of all four scenarios); a reduction of 72% compared to 2019 emissions intensity.

The impact of grid decarbonisation on UK steelmaking is also heavily dependent on whether there is a shift from BF-BOF to scrap-based EAF steel production. In the UK, where there is currently more scrap steel available (currently around 10 Mt pa [10]) than is used, then a shift from BF-BOF to scrap-based EAF production yields a greater benefit from grid decarbonisation.

To facilitate a large-scale shift to scrap-based EAF will require a supply of affordable renewable energy.

**TRL**
Diverse range of technologies with varying TRL.

**Timescale**
Significant UK grid decarbonisation by 2030.

**Carbon reduction to 2050**
A wide range depending on the electrification of UK steelmaking, i.e. the switch from predominantly BF-BOF production to scrap-based EAF production.
Current estimate **-6.5%**

## 5

## Carbon capture and use and storage (CCUS)

CCUS refers to a suite of technologies that involves the capture of $CO_2$ from large point sources, including power generation or industrial facilities that use either fossil fuels or biomass for fuel. If not being used on-site, the captured $CO_2$ is compressed and transported by pipeline, ship, rail or truck to be used in a range of applications, or injected into deep geological formations (including depleted oil and gas reservoirs or saline formations) which trap the $CO_2$ for permanent storage.

Both carbon capture and use (CCU) and capture and storage (CCS) will play an important part in the decarbonisation roadmap. Whereas CCS permanently stores captured carbon, CCU converts carbon into commercially viable products such as bio-oils, chemicals, plastics and fuels. These can be used in place of products made from fossil fuels, with the net effect of reducing greenhouse gas emissions.

A key attraction of CCUS technologies is that they can be retrofitted on existing BF-BOF steel plants without significant changes to existing equipment, which makes it easier and lower cost to deploy.

$CO_2$ utilisation or 'carbon recycling' technologies are also under development. These technologies use or convert $CO_2$ into new carbon-based products including fuels such as methanol and chemicals such as ethylene.

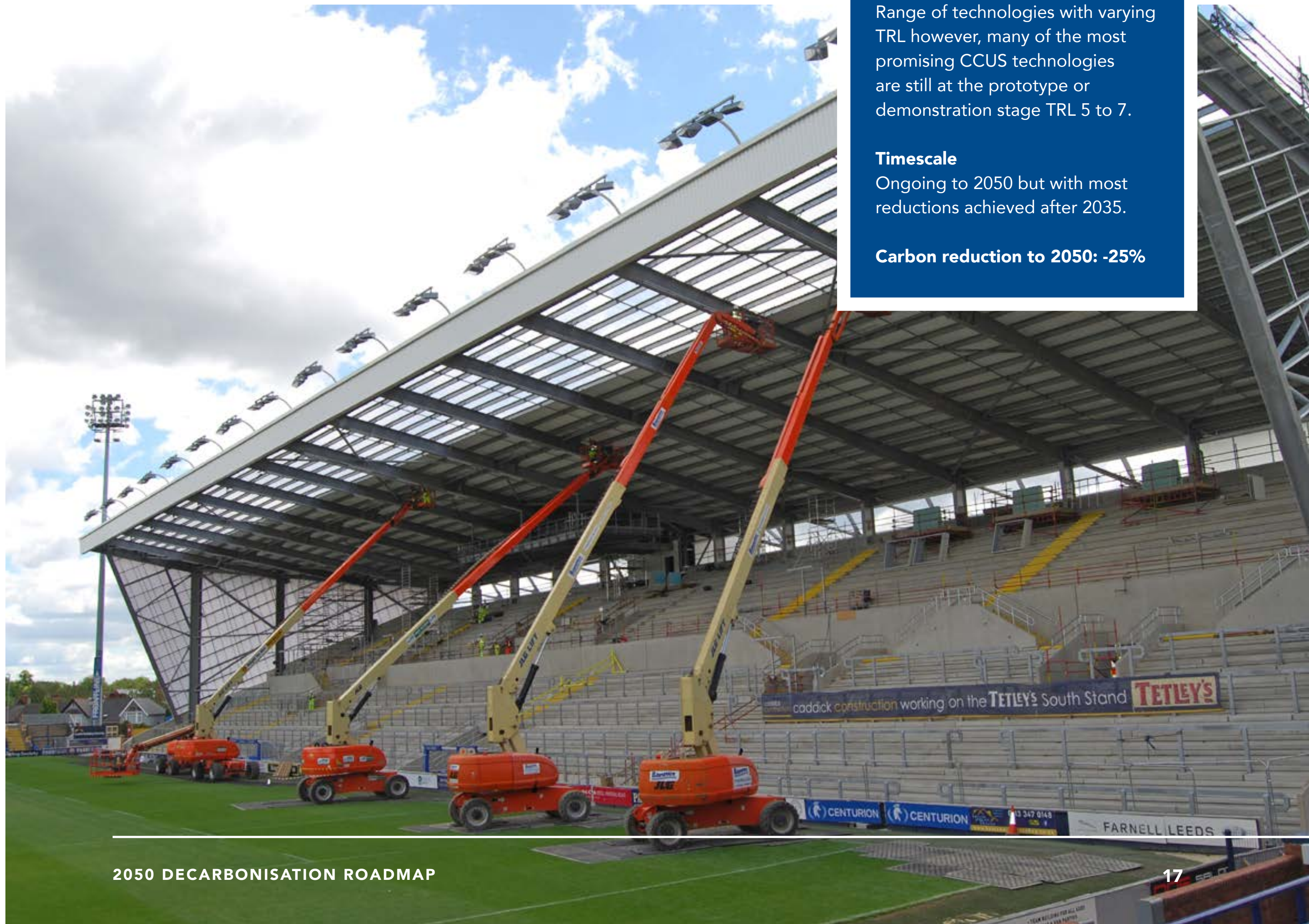
In the UK, CCUS hubs or clusters are being developed including the Zero Carbon Humber which includes British Steel. The principal benefit of the hub approach to CCUS deployment is the possibility of sharing $CO_2$ transport and storage infrastructure.

Tata Steel is a leading member of the South Wales Industrial Cluster (SWIC) which is working to examine decarbonisation schemes, and the infrastructure required for a hydrogen economy, in South Wales. Following successful completion of phase 1 assessments, phase 2 of the project has been granted £20m in government funding (March 2021) to execute engineering studies to explore the routes to decarbonisation, carbon capture usage and storage (CCUS) and $CO_2$ shipping from South Wales which would be the first $CO_2$ shipping industry in the UK.

**TRL**
Range of technologies with varying TRL however, many of the most promising CCUS technologies are still at the prototype or demonstration stage TRL 5 to 7.

**Timescale**
Ongoing to 2050 but with most reductions achieved after 2035.

**Carbon reduction to 2050: -25%**



# 6 Steel transport, fabrication and erection

BCSA steelwork contractor members have been measuring and managing their carbon footprint for many years as part of BCSA's sustainability drive and the introduction of the BCSA sustainability charter and carbon footprint tools in 2007. The Scope 1 and 2 [11] carbon emissions associated with the fabrication of constructional steelwork come mainly from the energy used in the fabrication shop and associated offices, together with transport of finished products to site, business travel and on-site erection activity. These emissions can be minimized through the increased use of renewable energy, best available fabrication technologies and the use of electric plant and vehicles where possible.

Some steelwork contractors are investing in renewable technologies such as wind turbines, biomass units which produce heat using locally sourced woodchips and anaerobic digestion plants. Some of the technologies used in the fabrication shop include simple ideas such as changing to LED lighting, the use of compressed air leak detection and efficiencies to reduce leaks in compressed air and gas systems, power optimization, inverters to control the speed of electrical drive motors so the speed is increased only when you need it and the use of new generation weld sets.

Many steelwork contractors are also investing in hybrid/electric company vehicles, maintenance vans and electric equipment on-site to reduce emissions.

Steel is a valuable material and consequently most steelwork contractors have systems in place to minimize waste. During procurement, steel sections are ordered by length to reduce the amount of scrap material, with any residual scrap being re-purposed or recycled. Nesting techniques are used when cutting steel plates to minimize waste and any temporary steelwork using during erection is recovered for reuse in future projects. Any material that cannot be reused is recycled.

Any unavoidable, residual carbon emissions are offset through verified carbon offsetting schemes that are aligned to the UN Sustainable Development Goals. Recently some steelwork contractors announced that all their UK facilities are carbon neutral and it is likely that the majority (by tonnage) of constructional steelwork fabricated in the UK and RoI will be carbon neutral by 2030. The fabrication industry's reliance on offsetting will reduce over time as new and better technologies are employed to further reduce the remaining emissions and with BCSA partners already looking to produce Road Maps with Science Based targets it is anticipated that the industry will achieve net-zero by or before 2050.

**Other supply chain efficiency measures include:**
Tata Steel and DB Cargo UK have successfully trialled the use of 100% renewable Hydro-treated Vegetable Oil (HVO) in a Class 60 locomotive transporting product from Wales to the West Midlands. The 'carbon-busting' locomotive carrying some 2,500 tonnes of steel coil was the first Class 60 powered purely by the environmentally-friendly fuel to travel on the mainline UK rail network earlier in 2021. The fossil-free, FAME-free fuel is synthetically made through the hydro-treatment process from vegetable oils or animal fats which can reduce $CO_2$ and nitrogen oxide (NOx) emissions by as much as 90%.

Tata Steel has a network of rail heads including at their Shotton site in North Wales where rail head investment has enabled the moving of steel substrate from road movements to rail.

**TRL**
8/9 Relevant renewable energy technologies are already available and commercial electric vehicles are likely to be widely available by 2035.

**Timescale**
Ongoing to 2050.

**Carbon reduction to 2050: -8%**

# Challenges and enablers

**The steel industry is committed to achieving net-zero steelmaking by 2050 and is investing significant sums in new technologies to decarbonise steelmaking. Technologies are however only part of the solution and a global framework is required to create the right market conditions to facilitate this transition.**

The steel industry is a low margin business, requiring long-term capital investment, and operating in a highly-competitive, global market in which not all steel is subject to the same carbon costs. This creates uneven incentives for decarbonising steelmaking between producers. This includes inequality between domestic production and imports, and between steel produced from primary and secondary sources. Without a level playing field, the UK and European steel industries will struggle to implement their decarbonisation strategies within the timescales required.

Steel decarbonisation will require the substitution of fossil fuels with low carbon electricity as an energy source. Where this is not the case and fossil fuels are required, for example in a blast furnace with CCUS applied, low carbon steel production is possible but will result in significant electricity consumption. CCUS requires electricity to clean, separate and compress the waste gas stream, creating a new electricity demand. A switch from blast furnaces to electric arc furnaces (EAFs) will increase the demand and use of electricity; EAFs require three times more grid electricity to produce the same volume of steel as a blast furnace.

A move from BF-BOF to conventional, scrap-based EAF and hydrogen DRI-EAF offers one of two main routes to decarbonise steelmaking by 2050. However, this will only be enabled in the UK with electricity prices at parity levels with European prices.

Power prices for UK steel producers are currently almost 90% higher than those available to their direct European competitors. Parity of electricity prices is essential to attract investment from multinational companies and addressing this imbalance must be the first step to decarbonisation, as well as being key to steel companies' short-term competitiveness.

A Carbon Border Adjustment (CBA) is a key policy mechanism needed to decarbonise, equalise the market and create a fair competitive landscape, by aligning the carbon costs of European domestic steel producers with those of imports. UK and EU steel producers are increasingly exposed to carbon costs through the UK and the EU Emissions Trading System (ETS), while imports are exempt yet continue to be responsible for a significant part of $CO_2$ emissions of steel used in the UK/Europe.

CCS offers an alternative and a way of retaining the installed UK production capacity. However, the CCS industrial clusters require sufficient support and funding to see them realised. Additionally, the operational costs of CCS including the associated gas cleaning and compression costs make this route potentially expensive. Carbon price support mechanisms could enable a fast uptake of industrial CCS as was the case for renewable energy subsidies.

Increased scrap utilisation in the current EAF and BF-BOF process and the electrification of BF-BOF route would yield considerable $CO_2$ reductions. The UK is currently a net exporter of scrap and therefore retaining more scrap in the UK is key to unlocking this decarbonisation lever. UK and EU countries have a legal duty to prevent export to countries with lower safety and environmental standards such as Turkey and Pakistan, two of the UK's biggest scrap export markets. Export markets could use these lower safety and environment standards to decrease operating costs and pay a higher price for high quality scrap, so depriving this valuable raw material from potential domestic users.

This roadmap depends on access to abundant and affordable clean energy in particular for scrap-based EAF production and for the production of green hydrogen: This is currently not available or economically viable in the UK or Europe.

Support is therefore needed from government and industry to enable the roll-out of low-emissions steelmaking.

# Conclusions

**The UK structural steelwork sector is committed to deliver structural steel and sustainable steel buildings in line with UK 'net-zero' 2050 targets.**

Decarbonising steelmaking, as for many industrial sectors, is a significant challenge. However this roadmap shows a credible pathway to transition to net-zero by 2050. Importantly, the roadmap demonstrates that the sector has multiple options, many of which are already at industrial pilot stage, for achieving net-zero.

Of all the 'harder to abate' industrial sectors, steel is the cheapest to decarbonise according to McKinsey [15] with an average abatement cost estimated to be around £90 per tonne of steel.

Technologies are only part of this transition. Policies and frameworks, both nationally and globally, are needed to ensure a 'level playing field' for steel producers and to provide the financing necessary to commercialise new, and adapt existing, steelmaking technologies. Integration and cooperation with other sectors, notably renewable energy, CCUS and hydrogen, will also be key.

The Sector is addressing the urgent need to reduce carbon emissions in line with national targets and in doing so will transition to a sector which is carbon-neutral, fully circular and truly sustainable.

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16. Bringing embodied carbon upfront. World Green Building Council.

# Steel decarbonisation studies

**The following studies have been reviewed to inform the development of this roadmap:**

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2. Decarbonization challenge for steel: hydrogen as a solution in Europe. McKinsey & Company.
3. Low carbon roadmap Pathways to a $CO_2$ - neutral European steel industry. Eurofer, November 2019.
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5. Key statistics guide July 2021. UK Steel.
6. A bright future of UK steel. University of Cambridge. April 2016.
7. Industrial decarbonisation & energy efficiency roadmaps to 2050 – Iron and steel. WSP, March 2015.
8. Steel arising; opportunities for the UK in a transforming global steel industry. University of Cambridge, April 2019.
9. Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century; sectoral focus steel. Energy transitions Commission, 2019.
10. Steel for the future: the transition to responsible, zero-carbon steel making. HSBC Centre for sustainable finance, November 2019.
11. Closing the gap: how competitive electricity prices can build a sustainable low-carbon steel sector. UK Steel, February 2021.
12. Industrial Decarbonisation Strategy. HM Government, March 2021.

# Steel company reports

1. ArcelorMittal Climate Action report May 2019
2. ArcelorMittal Climate action in Europe – Our carbon emissions reduction roadmap
3. Tata Steel Carbon neutral steelmaking | Tata Steel in Europe (tatasteeleurope.com)
4. Liberty – Greensteel initiative
5. British Steel Low-Carbon Roadmap and Q&A October 2021.

# Appendix

## Steelmaking decarbonisation pilot and demonstration projects

| Company | Name | Description | TRL | Timescale | Lever |
|---|---|---|---|---|---|
| Tata Steel | HIsarna | HIsarna is a new smelting technology that can produce iron without using coke ovens or agglomeration facilities. The process produces a $CO_2$ rich waste gas stream ideally suited to CCS.<br>The first test installation was built in 2010 and the fifth pilot study was concluded in 2019.<br>HIsarna consists of a reactor which maintains a temperature above the melting point of iron throughout, so that the injected iron ore immediately melts and is converted into liquid hot metal. The very high temperature of the process gases in the melting vessel is further increased in the cyclone at the top of the reactor by the addition of pure oxygen, which reacts with the carbon monoxide present. The turbulence in the cyclone helps the hot gas to melt the iron ore, which is injected at the top of the vessel. The iron ore then drips to the bottom of the vessel, where the powdered coal is injected, causing the oxygen in the iron ore (iron oxide) to bind to the carbon, creating liquid hot metal, which can then be drained off | 6 | Full scale in 2033 | 3 |
| ArcelorMittal | Carbalyst / Steelanol | Carbalyst® is a family of technologies that capture carbon from the steel-making process for use elsewhere, either a biofuel or biochemical for use by the plastics industry.<br>Steelanol uses gas-fermentation technology to transform carbon-rich industrial waste gases into advanced bioethanol for use in the transport sector and to make plastics.<br>In Ghent in Belgium, ArcelorMittal are building an industrial-scale demonstration plant to capture carbon off-gases from the blast furnace and convert it into 80 million litres of bio-ethanol a year. This €165 million project is expected to be completed in 2022. | 8 | The Steelanol demonstration project is expected to be complete in 2022. | 5 |
| Thyssenkrupp | H2morrow | H2morrow is feasibility study to capture and store $CO_2$ produced in the reforming process from natural gas imported from Norway.<br>Feasibility study to evaluate the supply of blue hydrogen, made from natural gas, to supply thyssenkrupp Steel's Duisburg. $CO_2$ from the production of hydrogen, will be permanently stored offshore. | 2-3 | Feasibility study concluded in 2021. Commercial implementation by 2027 | 2 & 5 |
| ArcelorMittal | IGAR | The IGAR project involves the conversion of waste $CO_2$ from the blast furnace into a synthetic gas that can be reinjected into the blast furnace in place of coal.<br>It will capture waste carbon monoxide and hydrogen from steel gases and reinject into the blast furnace as a reductant gas. Additionally, this technology increases the concentration of hydrogen in blast furnace off-gases, increasing the amount of carbon captured in Carbalyst processes by increasing the production of biofuels and biochemicals. This technology will also allow green hydrogen to be injected directly into the blast furnace, as and when it becomes available and commercially viable. | 6 | Currently under construction with completion expected in 2022 | 2 & 5 |
| Tata Steel SSAB | STEPWISE | STEPWISE is a novel technology for capturing $CO_2$ from blast furnace gas and simultaneously adsorbing the $CO_2$ and removing the acid gas. The decarbonised gas is then used to produce energy. | 4 | STEPWISE was a large EU project completed in 2019 | 5 |
| ArcelorMittal | Torero | Torero involves the use of wood waste in the blast furnace and the capture of CO from the blast furnace gas and its conversion into bioethanol.<br>• Torero: a EUR 50m large-scale demonstration plant to convert waste wood into bio-coal, partially replacing the coal currently injected into the blast furnace.<br>In the early stage, the Torero plant will be able to convert up to 60,000 tonnes of waste wood into around 40,000 tonnes of bio-coal every year. This volume will be doubled in a second stage of the project, after the start of the first Torero reactor. The new installation will create around 70 external jobs and will create around ten new permanent direct jobs for the operation of this installation. The plant, which is being developed in partnership with Torr-Coal, Renewi, Joanneum Research Centre, Graz University and Chalmers Technical University, is expected to be operational by the end of 2022. | 7 | The demonstration plant is being built in Ghent and is expected to be operational by the end of 2022 (reactor 1) and 2024 (reactor 2). | 2 |
| Multiple (SSAB / Tata Steel) | FReSMe | FReSMe involves the capture of $CO_2$ from the blast furnace and its conversion into methanol to be used by the shipping sector. | 7 | A pilot plant was commissioned in 2019 and testing and process optimisation is underway | 5 |
| Tata Steel | Everest | The Everest project will utilise carbon monoxide and hydrogen by-products from steel production for conversion into chemicals and also capture waste $CO_2$ for storage in North Sea gas fields. | 4 | 2027 CCS infrastructure in place | 5 |
| AME | Carbon2Value | Carbon2value is a demonstration project for capturing and separating $CO_2$ and CO from blast furnace gases. Conversion into ethanol and synthetic naptha are being explored. | 7 | A demonstration plant was installed in 2021 at the ArcelorMittal plant in Ghent | 5 |
| SSAB | HYBRIT | HYBRIT involves the development of green hydrogen, DRI-EAF steel production. The hydrogen is produced by the electrolysis of water. In addition, a pilot hydrogen storage facility is being planned.<br>SSAB will cut its $CO_2$ emissions in Sweden by 25% by as early as 2025, through the conversion of the blast furnaces in Oxelösund, Sweden, to an electric arc furnace. Between 2030-2040, the plan is to convert the blast furnaces in Luleå, Sweden and Raahe, Finland to eliminate most of the remaining $CO_2$ emissions | 5 | A demonstration plant is planned for completion in 2025 | 2 |
| Vargas | H2 Green Steel | Founded in 2020, H2 Green Steel is a Swedish initiative to develop green hydrogen, DRI-EAF steel production in North Sweden. | 3-4 | Production is planned to start in 2024 | 2 |
| Salzgitter | SALCOS | The SALCOS concept involves the use of hydrogen-based DRI-EAF, initially produced using natural gas.<br>Over time, Salzgitter plans replace its blast furnaces with DRI plants. SALCOS is linked to the GrInHy project, for production of green industrial hydrogen. | 3 | First SALCOS plant in operation in 2026 | 2 |
| Salzgitter | GrInHy2.0 | GrInHy is a demonstration plant to showcase the production of hydrogen via steam electrolysis using waste heat from the Salzgitter steel mill in Flachstahl. The hydrogen will be used for the steel annealing process. |  | The demonstration plant is expected to be in operation in 2022 | 2 |
| Dillinger and Saarstahl | ROGESA | Dillinger and Saarstahl has started using hydrogen-rich gas from coke ovens in its ROGESA blast furnace in Germany. Depending on the availability of green hydrogen, the blast furnaces may be converted to pure hydrogen in the future. | 5 | Implemented in 2020 | 2 |
| ArcelorMittal | SIDERWIN | SIDERWIN is a breakthrough technology using an electrolytic process, powered by renewable energy, to convert iron oxide into steel. | 6 (by 2023) | EU funded project running from 2017 to 2023 | 2 |
| Tata Steel | Athos partnership | This project is connected to Everest and HIsarna and examines the feasibility of carbon capture and storage under the North Sea as well as carbon usage. The project feasibility is now complete. The transport and storage system aspect of this project will build new infrastructure for the Amsterdam region, using existing infrastructure as much as possible. It will be owned and operated by a third party | 5 | 2027 | 5 |
| Tata Steel | H2ermes | Tata Steel, Nouryon and the Port of Amsterdam have started a feasibility study into building a 100MW green hydrogen plant in IJmuiden. This technology is likely to play an important role in hydrogen steelmaking solutions which will help us achieving our ambition. | 3 | Pilot commission in 2025 | 2 |
| Tata Steel | RICE | This aims to test and examine whether $CO_2$ produced from heavy industrial processes can be used to make high value products and chemicals, using a range of carbon capture and utilisation (CCU) techniques. | 3 | Energy Safety Research Institute (ESRI) at Swansea University research partnership project | 5 |
| ArcelorMittal | Hydrogen DRI | Construction of a hydrogen DRI-EAF facility at Dunkirk combined with carbon capture. ArcelorMittal JV with Air Liquide to provide low carbon hydrogen. | 9 | Commissioning planned for 2025 | 2 & 5 |
| ArcelorMittal | DRI-EAF | Construction of hydrogen ready DRI-EAF plant in Bremen. Initially to run on natural gas but transitioning to hydrogen from Germany's green hydrogen network. | 9 | Full-scale implementation in 2030 | 2 |
| ArcelorMittal | DRI-EAF | Construction of hydrogen ready DRI-EAF plant in Eissenhuttenstadht. Initially to run on natural gas but transitioning to hydrogen from Germany's green hydrogen network. | 9 | Full-scale implementation in 2030 | 2 |
| Tata Steel, British Steel | UK Industrial Clusters | Part of the UK Industrial Strategy, two industrial clusters are proposed centred on the Tata Steel site in Port Talbot (South Wales Industrial cluster) and British Steel's site in Scunthorpe (Zero Carbon Humber). These two sites account for 95% of the UK's iron and steel-making emissions. Decarbonisation options include: hydrogen direct reduced iron coupled with Electric Arc Furnace or CCUS. Scunthorpe would have access to CCUS infrastructure; however, Port Talbot would likely need shipping of carbon dioxide to utilise CCUS or Hydrogen | - | The goal is to create the world's first net zero industrial cluster by 2040 | 2 & 5 |
| ArcelorMittal | Hydrogen-DRI | ArcelorMittal has signed a MoU with the Spanish Government to develop hydrogen-DRI EAF mill at their Asturias plant in Gijon.<br>The plan is to construct a 2.3 million-tonne green hydrogen direct reduced iron (DRI) unit, complemented by a 1.1 million-tonne hybrid electric arc furnace (EAF). T |  | 2025 | 2 |

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