UKRI Interdisciplinary Centre for Circular Metals | Brunel University London | BCAST | Loughborough University | WMG The University of Warwick | UCL The Bartlett Institute for Sustainable Resources | NICER Programme | UK Research and Innovation

2050
Circular Metal Visions

About this progress report

This progress report presents some initial findings of the WP3 'Circular Business' of the UKRI Interdisciplinary Centre for the Circular Metals. The aim of the centre is to transform the metals industry and make the UK the first country in the world to have a fully circular metals system.
The purpose of this progress report is to present a set of visions of how circular economy can transform the metal value chain in the long term. The progress report presents 12 visions for 2050 and discusses the most significant challenges and opportunities that might respectively hinder and support the shift to those visions.
The progress report is the result of research activities that brought together leading experts from academia, industry, and government to explore how the UK could transition to a circular metal economy.

For environmental reasons, this progress report should not be printed because it contains numerous photographs and was originally meant to be a digital edition.

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List of key terms

Circular Economy (CE): Refers to an economic system where waste and pollution are designed out, and resources are kept in use for as long as possible.
Closed-loop system (CLS): Refers to a system in which unused or recaptured value is reused for the same or similar business purposes.
Carbon capture, utilisation and storage (CCUS) refers to a suite of technologies that can play an important and diverse role in meeting global energy and climate goals. CCUS involves the capture of CO2 from large point sources, including power generation or industrial facilities that use either fossil fuels or biomass for fuel.
Electric arc furnace (EAF): Refers to specialised furnaces used to heat scrap metal to produce steel, using an electric current to create an arc between the scrap and the furnace lining. The high temperatures generated by the arc melt the scrap, which is then poured into a ladle to be cast into ingots.
Electrolysis: Refers to the process of decomposing water into oxygen and hydrogen by passing an electric current through it. The hydrogen can then be used as a fuel in a metal manufacturing process.
Electrodeposition: In this report, refers to a process that involves depositing a thin layer of sensor material onto the metal surface using an electric current. The sensors can then be wired together and connected to a data logger or other device for monitoring and data collection.
Ecosystem: Refers to a network of organisations and individuals that interact with each other to create value.
Life cycle data (LCD): Refers to information about a product or material from its creation to its disposal. This includes data on the raw secondary materials used to create the product, data on the manufacturing process, data on the use and disposal of the product, and data on the recycling or reuse of the product. In the context of CE, life cycle data can be used to assess the environmental impact of a product or material throughout its entire life cycle. This information can then be used to improve the design of products and materials to reduce their environmental impact.
Net-zero emission: Refers to a situation where the total amount of greenhouse gas emissions released into the atmosphere is balanced by the amount that is removed. This can be achieved through a variety of means, including planting trees, which absorb carbon dioxide from the atmosphere, and using technology to capture and store carbon dioxide emissions.
Open-loop system: Refers to a system in which the value created by one business is reused by other businesses to generate new value.
Original equipment manufacturer (OEM): Refers to a company that produces parts and equipment that may be marketed by another manufacturer.
Product Life Cycle: Refers to a series of stages that a product goes through during its lifetime. The cycle begins when a product is first introduced and ends when the product is recycled. Between the first and final life cycles, a product may undergo multiple life cycles in which it is reused, refurbished, or remanufactured.
Product lifetime Refers to the length of time that a product remains on the market across several product life cycles.
Pure metal flow: Refers to a notion in which the metal flow is optimised to such an extent that the materials remain pure even after multiple recycling cycles. This process is also known as Industrial Upcycling.
Small and Medium Enterprise (SME): Refers to businesses that employ fewer than 500 people. These businesses make up the vast majority of businesses in the UK and play a vital role in economic development.
Snapshot from the future: Refers to a brief glimpse of what the future may hold, it is based on current trends and future projections. It is a way of seeing the future through the lens of the present, and can be used to help decision makers plan for the future.
United Kingdom (UK): Refers to the country that this report is built on. All the visions and snapshots from the future are implemented for this country and may or may not apply to other countries.

Foreword by Baroness Brown of Cambridge

The UK has a long history of steel and aluminium production. These essential materials are used extensively in buildings, cars, machines, packaging, and other commodities on which society and economic growth rely. This reliance comes at a cost to the environment. Steel and aluminium production is one of the world's largest industrial sources of carbon dioxide emissions, driven largely by the energy required to produce the metal and subsequent downstream processing. In June 2019, the UK Government legislated to reduce greenhouse gas emissions to zero by 2050. To achieve this goal, we need a radical rethink of our linear 'take, make, dispose' relationship with the products made from steel and aluminium. We need to develop a more circular relationship, in which products are maintained in their highest possible value state, through reuse, repair and remanufacture, with recycling only as the option of last resort.

Full 'metal circularity' by 2050 is an important way in which the UK metals industry could support the UK in meeting the Net Zero goal. It is a bold ambition, requiring the metals and manufacturing industries to work together. Whilst the goal may be common, there are different routes by which it can be achieved. This report brings together insights from over 30 experts across the metals industry and circular economy, to create 12 compelling visions of the bold steps industry could take towards full metal circularity by 2050. These visions provide a direction with which those in the metals and manufacturing sectors can align, enabling collaboration to overcome the technical, social, economic, and environmental challenges and turn visions into reality.

Achieving full metal circularity is a journey. To take the first steps, we need to know where we are heading. This report provides the direction. Addressing climate change cannot wait; it is time to start.

The Baroness Brown of Cambridge


2050

Executive summary

This progress report has been produced as part of Work Package 3 'Circular Business' of the UKRI Interdisciplinary Centre for Circular Metals. Its main goal is to propose **preferable future visions for the circularity of steel and aluminium** (from now on, referred to as metals) in the UK by 2050. This progress report outlines **12 visions** of how the UK may move to a more sustainable and effective circular metal economy (CME). Each vision includes distinct **'snapshots from the future'** that exemplify how the vision might look like in practice. In addition, each vision is accompanied by a set of barriers and opportunities that might respectively hinder and support the vision.

A CME is one in which reuse, repair, refurbishing, and remanufacturing are prioritised over the recycling of metals. Metal recycling is essential for recovering the value of metals in a CME, but it should not be the primary focus. Instead, products and materials should be designed so that they can be reused with minimal value loss and without generating hazardous emissions. The 12 visions presented in this progress report are based on research involving a wide range of stakeholders, including businesses, governmental organisations, NGOs, policymakers, and scholars from several academic fields.

A CME would result in a number of benefits for the UK, including:

1. Reduced reliance on imported metals: A CME would mean that the UK would need to import less metal from other countries, as it would be able to reuse and eventually recycle the metals available in the country.

2. Reduced environmental impact: A CME would result in a reduction in the environmental impact of metal production as reuse and recycling require less energy and produce fewer emissions than mining and refining new metal.

3. Improved economic security and resilience: A CME would generate value through maximising resource utilisation. This involves the provision of superior, specialised, and tailored goods and services. This can generate more employment opportunities due to the increasing demand for service workers.

4. Improved resource efficiency: A CME would optimise the utilisation of what already exists through improved resource flow design and management. This would eliminate the need to mine new metals, reducing greenhouse gas emissions and other negative environmental impacts.

5. Boost innovation through cooperation: A CME would create joint ownership, and spread the investment risks over a larger group of actors. This would facilitate innovation and knowledge sharing across social and professional networks.

All these benefits are highlighted throughout the 12 visions:

NET ZERO EMISSION METAL PRODUCTION: In 2050, all processes related to metal production will release no greenhouse emissions. This has been made possible by advances in renewable energy, energy storage, and process efficiency.

CIRCULAR ALLOYS AND MANUFACTURING: In 2050, the UK has one of the most efficient metal closed loop systems worldwide. This has been made feasible by the implementation of rationalisation of usable alloys regulations, a new generation of more "circular" alloys, innovative fabrication processes, and improved metal application. Technology innovation has also been critical in improving efficiency and productivity compared to the past.

DISTRIBUTED METAL MANUFACTURING: In 2050, the UK has a CE in which factories are more diverse and distributed than those of the past. Numerous small and medium-sized businesses manufacture, repair, and distribute their goods in both urban and rural locations. These new local economies are supported by Fablabs and smart manufacturing systems, which provide innovative and tailored services for their customers.

END-TO-END SUPPLY CHAIN: With the use of intelligent assets, the circular supply chain has radically altered the traditional constrained and silos system. The modern end-to-end supply chain encompasses all the aspects of a product lifetime. This is a fully integrated and automated system that allows for real-time monitoring and execution of all supply chain processes.

METAL AS A SERVICE: In 2050, the UK is a world leader in providing metal solutions as a service. The government has a 'Department for Metal Services' that leases metal molecules from metals and mining corporations to UK materials industries. Businesses have adopted different business models such as offering metal components and products as-a-service. Product sharing has become widely adopted by businesses, particularly for B2C, due to tracking technologies and product automation.

METAL LIFE CYCLE DATA: In the 2020s, the UK government built an open metal data infrastructure to make data available to companies along the supply chain in order to maximise metals' circularity. This was made possible by the spread of asset-monitoring technologies such as digital passports on Metal Blockchain. These technologies have increased openness and data transparency among all stakeholders.

FULL METAL PACKAGING: Metal packaging is recognised as an excellent material for preserving food quality and prolonging shelf life. Today, the majority of packaging is intended to be reused numerous times before being recycled. In this new paradigm, companies and/or customers keep ownership of and responsibility for the packaging life cycle.

STOP RECYCLING START REPAIRING: Today's economy is built on the principle of repair. Specialised companies provide new services for the maintenance/repair of metal products and components, such as the Metal Health Service (MHS). This includes services such as component rejuvenation, structure rejuvenation and 'metal day hospital'. Due to research and technology, metals are more durable and can self-heal cracks and extend their life.

REPAIR-IT-YOURSELF (RIY): People nowadays own fewer but higher-quality products. Reuse and repair have replaced the throwaway culture. Thanks to courses provided in schools, maintaining and repairing products have become common knowledge. People can also learn and share practices in repair community centres. In addition repair kits and new technologies are available to enable users and small entrepreneurs to repair products.

THE LOGIC OF SUFFICIENCY: In 2050, individuals are more aware of the ethical implications of overconsumption and embrace a more sustainable attitude. Owning fewer and higher-quality products saves material usage and can be passed down generations. The trend towards sustainable consumption is being pushed by initiatives such as MyMetal, which limits the amount of metal any individual can own, and open libraries of things, which let users borrow items instead of buying them.

REUSING, REMANUFACTURING, AND REPURPOSING: In 2050, the UK is a world leader in reusing, remanufacturing, and repurposing products. The UK government has supported a radical shift in pace, encouraging the reuse of goods rather than the production of raw resources through a vast infrastructure adjustment. Consumers are educated on the benefits of buying products that are made to last or be repurposed.

BETTER METAL RECOVERY, SORTING, UPCYCLING AND RECYCLING: The reuse of products, components, and materials lies at the heart of today's most successful businesses. Open or closed distributed disassembly are common and cost-effective industrial practices used by most businesses to disassemble components to be reused. Recovery of all kinds of valuable material resources becomes essential if the product itself and its components cannot be reused. Industrial upcycling, smart waste management systems and landfill scavenging are only some of the many ways material value is recovered.

Introduction to the circular economy

The concept of circular economy (CE) has been gaining traction in recent years as a more sustainable alternative to the traditional linear economy (EMF, 2013; Patwa et al., 2021). In the linear economy, we take raw materials from the earth, make products from them, use them for a period of time, and then dispose of them when they are no longer useful. This 'take, make, dispose' model is not sustainable in the long term, as it relies on a constant supply of new raw materials and generates waste. A CE is an alternative to a traditional linear economy in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life. Achieving a CE will require a fundamental re-think of how we design, make, use and reuse products and materials. It will require us to move away from the 'take, make, dispose' linear model of production and consumption, which is currently the norm, to a more sustainable 'closed-loop' system in which we keep materials and products in use for as long as possible, then recover and regenerate them at the end of each life cycle. There are many benefits to moving to a CE, including reducing environmental impacts, creating jobs and boosting the economy. A CE is also more resilient to shocks, such as resource shortages and economic downturns (Stahel, 2016).

Circular metal economy in the UK

Metals are a valuable resource that can last for very long periods of time, can be reused and recycled indefinitely, and are utilised by a wide range of industries (Cullen et al., 2013). CE may be able to help assure long-term use of steel and aluminium, two critical commodities for the UK economy. However, transitioning to a circular metal economy (CME) isn't easy. Industrial recycling is still the primary focus of most metal-related circularity approaches today, with a heavy emphasis on logistics and the technical and thermodynamic limits of metals recycling (Dominish et al., 2018). The recycling process is also energy-intensive because it requires energy to collect, sort, and process the materials. While recycling is crucial to recover the value of the materials, this shouldn't be the main focus of a CME.
Some of the main evidences brought through this progress report are that servitisation, reuse, repair, refurbishing and remanufacturing should be the main focus of the CE for the future, thus, replacing the idea of a CE based only on recycling with one based on extending the life of products (e.g. through better design, manufacturing, distribution, sales and maintenance) and reducing the amount of products (e.g. by sharing or servitising products).
Clearly, this demands structural and systemic changes that involve not only the metal industry, but all stakeholders, including manufacturers, retailers, logistic providers, citizens, governmental organisations and NGOs. This is why this research focuses on a long-term vision for the CME in line with the UK's ambitious zero net targets for 2050.

Visions for 2050

Looking to the future, what will the CME of 2050 look like? What are the key drivers of change that will shape the CME of the future? What are the challenges and opportunities that will need to be addressed? What are the possible pathways that could be taken to achieve a CME? This progress report gives insights into these questions based on an in-depth investigation using a number of research methods better explained in the next paragraph.
This progress report aims at stimulating a conversation on how a future metal CE would look, and how various socio-economic stakeholders can act now to move towards that vision. This will allow them to better understand the transitional potential and adjust the standpoint to accommodate a new modus operandi. Having such a standpoint is a privileged position to anticipate, redirect and take the lead in the transition. Visions presented in this study, however, are not meant to be taken literally but as understandable and appealing alternatives that can inspire more creative solutions. When reading this progress report, readers need to be prepared to question even our findings and look for different or even better answers.

Types of futures

There are several ways to categorise thoughts about the future, and one of the most useful is the Future Cones (see Figure 1). Hancock, et al., (1993) described four futures as wider and narrower cones:

- A **possible future** describes all kinds of possible futures. They are often used in planning and decision-making to define dystopian futures that are sometimes far from reality. These can help in identifying and even preparing for future unforeseen events.

- A **plausible future** is a future scenario that is based on a logical and coherent extrapolation of current trends. It is one possible outcome of the future and is used as a tool for exploring the implications of different decisions. Plausible futures are not predictions, but rather a way of thinking about the future that allows for different possibilities.

- A **probable future** is a potential future that is likely to occur, based on current knowledge and trends. Probable futures are used in future studies to explore different possible outcomes of current trends and to develop plans and strategies for dealing with them.

- A **preferable future** is a tool used in future studies to help individuals, groups, and organisations articulate their desired future state. It is a process that helps people identify and describe their ideal future, and then develop a plan to achieve it. This process can be used to develop long-term plans, short-term goals, or both.

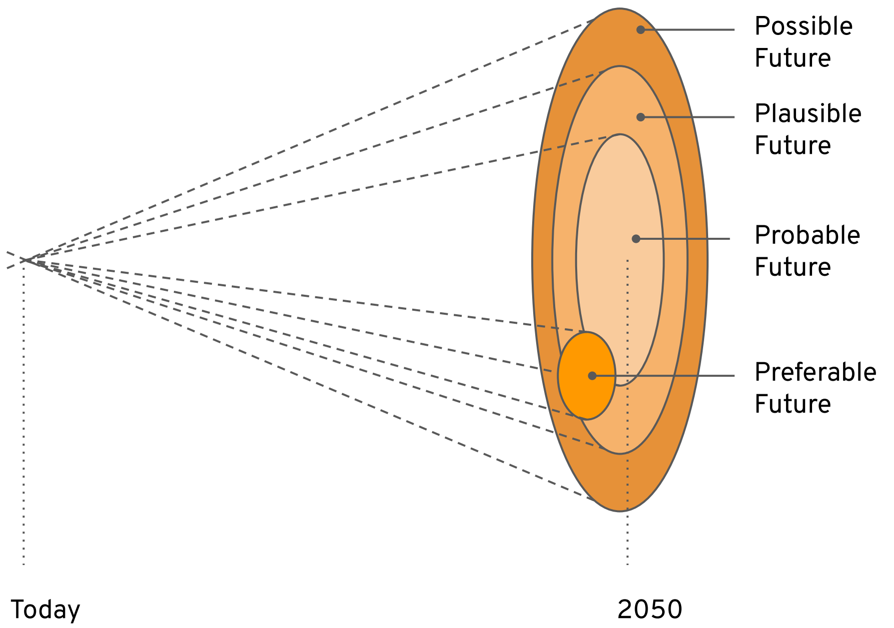


Figure 1. Future cones (readapted from Hancock, et al., 1993).

Research approach

Futures research is an approach that can be used to anticipate future trends and developments, and to make decisions in the present that will shape the future. It is based on the understanding that the future is not predetermined, but is shaped by the decisions we make today. For the purpose of this study, we adopted a 'preferable future' approach to envision how a CME in the UK would look in 2050. This is encapsulated in the depiction of a scenario, a set of visions and a set of 'snapshots from the future'. In more detail:

- A **scenario** describes a preferred future situation, such as how full metal circulation can be reached by 2050. A scenario may contain multiple visions. Visions are more elaborate but short descriptions of a desired future. Visions answer the basic question: "What would the world be like if...?", and does so by proposing a short story of a desired future state. In the CircularMetal project we developed multiple visions which could be related to specific parts of the metal value chain and/or technologies and/or business models.
- A **vision** can be exemplified with a set of snapshots from the future, and multiple visions may be used to articulate a scenario.
- A **snapshot from the future** is the most specific component of a vision and can provide 'depth' and 'substance' to it. It answers the basic question: "How would the vision look in practice?". And it does so by providing practical and visual examples of the implications that a certain vision could have on our lives.

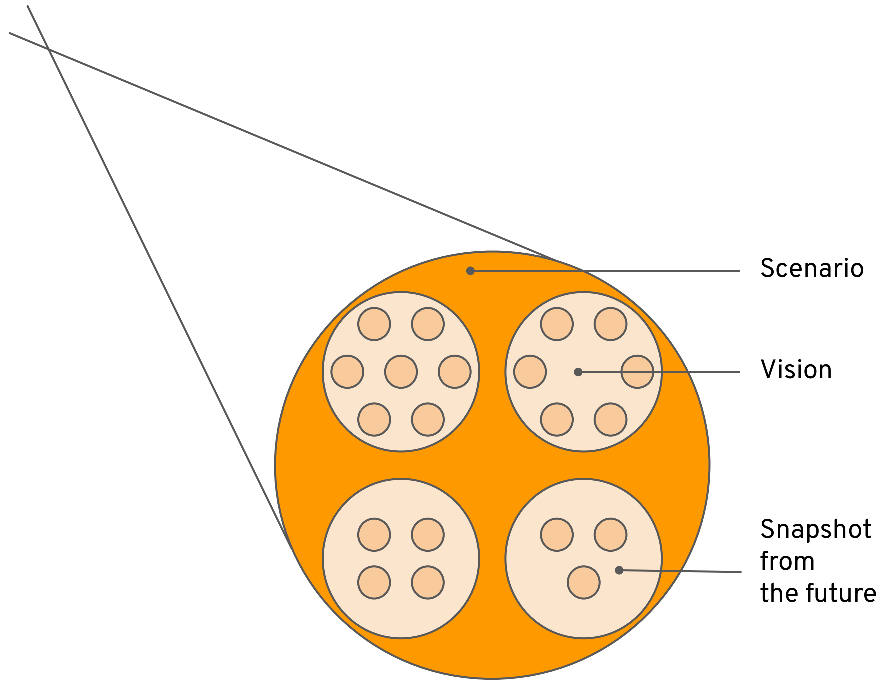


Figure 2. This illustration shows how these different future descriptions used in this study are related to each other.

The research approach we adopted is visualised in Figure 4 and summarised in seven phases as follows:

1. We interviewed 30 experts from academia, business, and government, whose experience ranged from metallurgy, metal manufacturing, and product development to policymaking, logistics, and others. This was intended to define the initial singular visions of each expert or organisation interviewed.

2. We analysed the collected data and identified and clustered common themes and areas of agreement and disagreement among the experts.

3. Building upon the identified themes we then identified a first set of eight visions and 36 'snapshots from the future'.

4. On the basis of this initial set of visions, we held an internal workshop with eight academics from various fields. The aim was to discuss the findings of the interview data synthesis and validate/refine identified visions and ‘snapshots from the future’, and develop new ones. This resulted in a set of 12 visions and 64 snapshots.

5. Following the internal workshop, we conducted an initial survey with 25 experts in order to validate/refine the results, which were then better redefined through a co-design workshop (step 6).

6. The co-design workshop took place online and lasted three hours. Experts were divided into four groups, each of them focusing on three visions. In the first part of the workshop, participants had the opportunity to critically assess the visions and propose changes. In the second part participants worked on defining, for each vision, barriers and opportunities against five lenses (social, technological, ecological, economic and political, see Figure 3). By looking at the future through multiple lenses, we were able to identify potential problems and opportunities that we may not have considered otherwise. In the last part of the workshop, each group presented their findings followed by a plenary discussion.

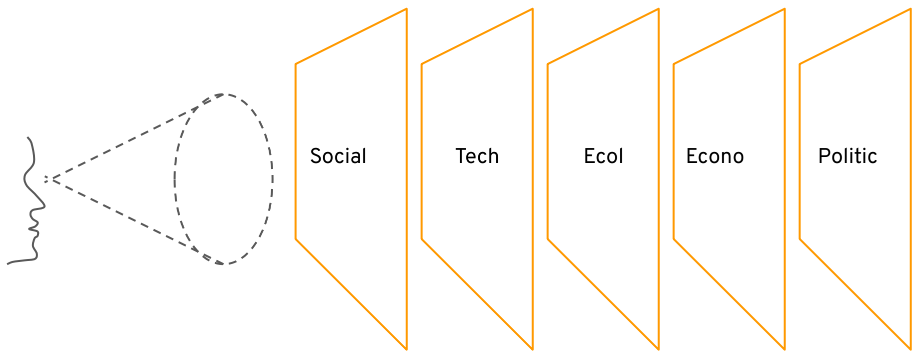


Figure 3. An illustration of the five lenses used during the co-design workshop do define barriers and opportunities.

7. After the workshop we analysed its outcomes and the video recordings of each session. This enabled us to refine the visions and snapshots (e.g. some visions were better articulated, some snapshots were integrated/removed) and identify barriers and opportunities for each vision. Barriers and opportunities were also explored through a literature review, to enhance and complement the workshop outcomes.

Research Approach

PHASE 1
Semi-structured interviews with 30 leading experts from industries and academia on the future of the circular metal economy.

PHASE 2
The interview data has been broken down into smaller, more manageable topics in order to identify patterns and trends.

PHASE 3
The main topics were narratively characterised in visions, and subtopics have been organised and narratively and visually characterised inside each vision to create the first cohesive output (8 Visions + 36 Snapshots).

PHASE 4
Internal workshop with eight academics from various fields to generate creatively related and novel future visions and snapshots.

PHASE 5
The data from the internal workshop was reorganised in conformity with the prior organisation of future visions and snapshots (12 Visions + 64 Snapshots).

PHASE 6
A 25-expert online survey was conducted to validate and provide significant insights for visions and snapshots.

PHASE 7
A three-hour co-design session with 29 experts from various disciplines to implement and validate visions and snapshots.

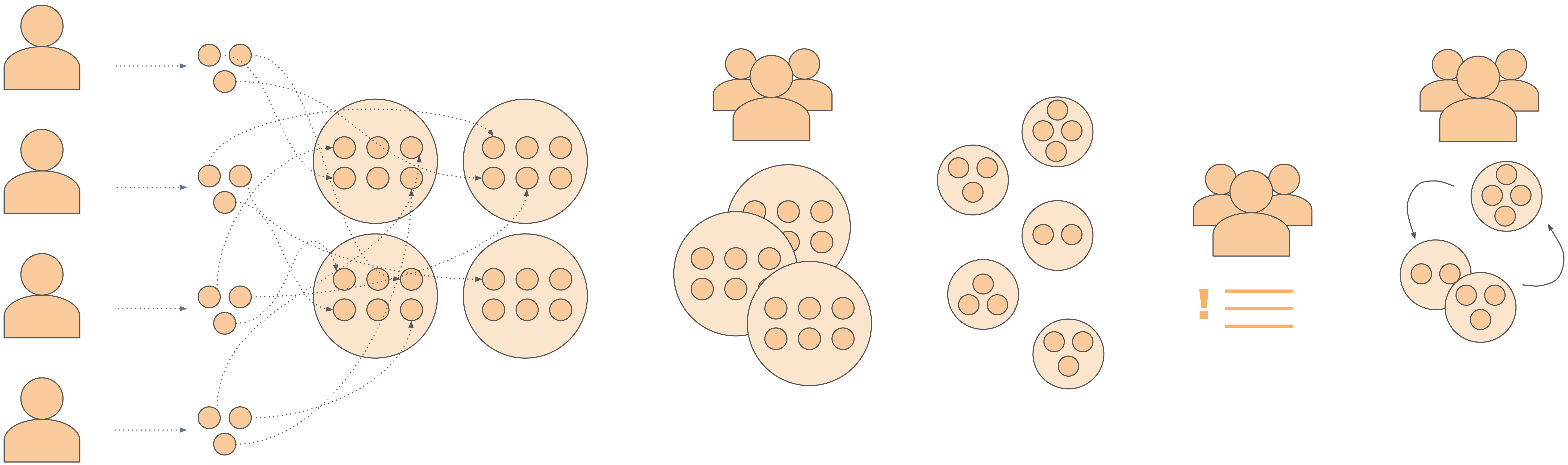


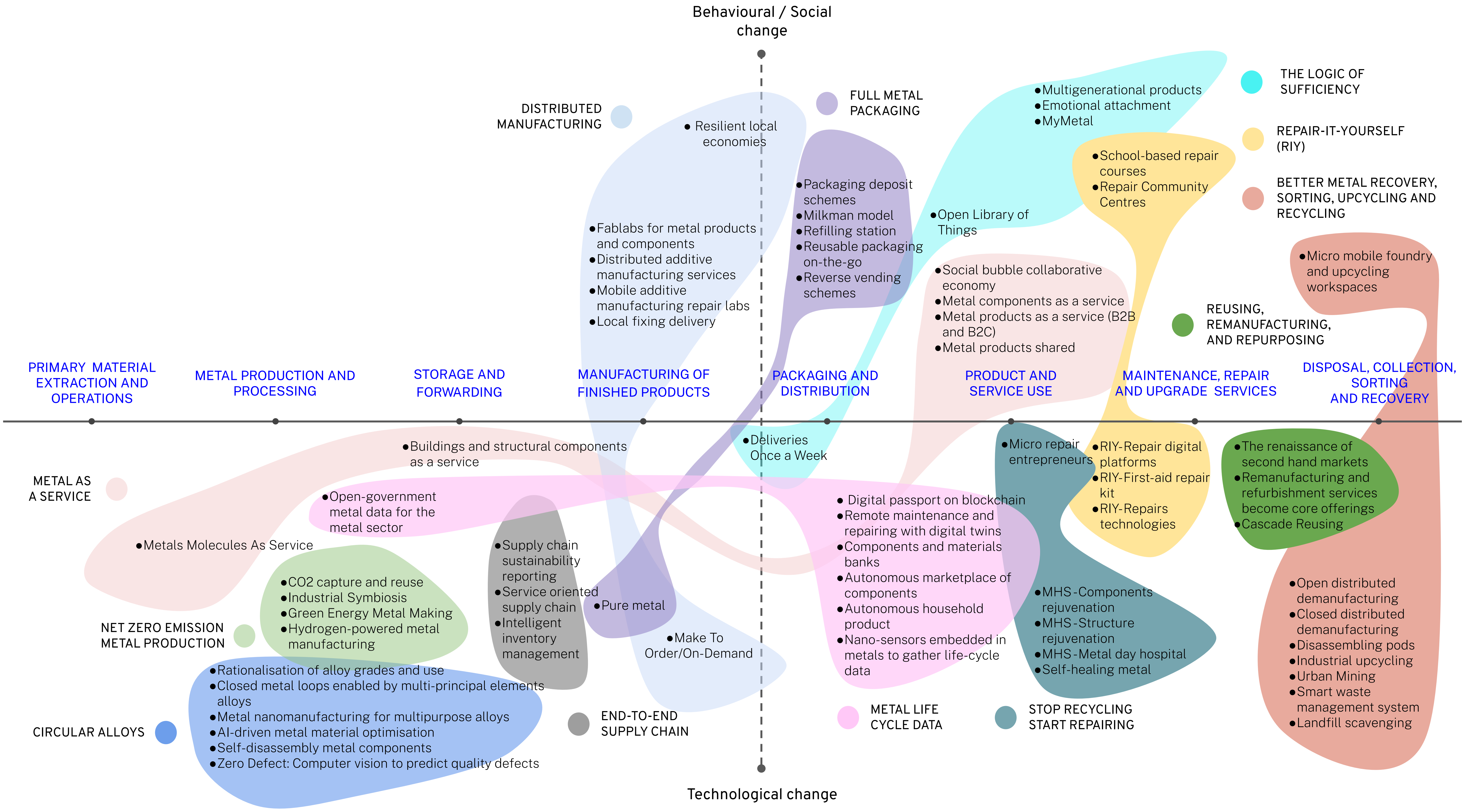
Figure 4. A visualisation of the main research phases of this study.

The UK’s circular metal economy in 2050

Today, in 2050, the UK is at the forefront of a global shift towards a net zero and circular economy. The current economy is regenerative, resilient and local and the **recovery, reuse, sorting and recycling** of products takes place almost entirely within the UK. **Net zero metal production** is no longer a Utopian dream, thanks to significant investments in both renewable energy transition and manufacturing infrastructure. For enterprises, closing the metal flow has never been more profitable due to the widespread use of **circular alloys**. This, however, would not have been achievable without a shift towards circular businesses, supply chains, and designs. Businesses have made a significant change, shifting from selling metal materials, components and products to selling **metal as a service**, becoming in this way responsible for their products' entire cycle. This wasn't straightforward, but major technological improvements and the utilisation of **data applied to the metal life cycle** made it possible. This boosted **distributed metal manufacturing** as well as an **end-to-end supply chain**. Superior product design and cutting-edge technology have made **industrial and self-repairing** a thriving industry. In addition, changes to consumption habits have led to widespread **sufficiency**, with people aiming at reducing their overall consumption levels by owning fewer and higher quality products and reducing product ownership towards a consumption based on more access and sharing.

PREFERABLE VISIONS:

- Net zero emission metal production
- Circular Alloys and Manufacturing
- Distributed metal manufacturing
- End-to-end supply chain
- Metal as a service
- Metal life cycle data
- Full Metal Packaging
- Stop Recycling Start Repairing
- Repair-it-yourself (RIY)
- The logic of sufficiency
- Better metal recovery, sorting, upcycling and recycling
- Reusing, remanufacturing, and repurposing



Circular metal economy polarity diagram

On the vertical axis of the polarity diagram are the polarities of behavioural / social change and technological change. While on the horizontal axis, all phases of the metal chain are displayed. It is evident from this graphic that the predominant technology is essential for the accomplishment of the CE throughout the whole supply chain. In the phases of distribution, service, maintenance, and value recovery, behavioural modification is of particular relevance.

Net-zero emission metal production

In 2050, the UK's metal production has shifted to net zero emissions. This means that all processes related to metal production, from recycling to smelting to manufacturing, have been redesigned to release no greenhouse emissions. This has been made possible by a combination of advances in renewable energy, energy storage, and process efficiency.

The majority of the **UK's electric arc furnaces (EAFs) are now placed near by or within large, solar-powered factories and wind farms**. This has made metal production much cleaner and more efficient than in the past.

Renewable energy sources are also used to generate the **hydrogen** to power EAFs. Hydrogen-oxygen fuel cells are used to power EAFs by supplying the electrical energy needed to operate the furnace. This has led to a cleaner and more efficient process, as well as a reduction in emissions. The process is now so efficient that it is able to produce large quantities of metal without almost any negative environmental impact. This is due also to the **carbon capture, utilisation and storage (CCUS)** technologies that allow capture and either reuse or storage of carbon dioxide from metal manufacturing.

Furthermore, today the UK's metal system is one of the world's most advanced **industrial symbiotic networks**, which allows businesses to pool resources and knowledge to maximise waste product reuse, reduce waste sent to landfill, and decrease the carbon footprint of the steel sector. This shift to net zero emissions has had a major impact on the UK's economy. Metal production is now one of the most important industries in the UK, and it is responsible for thousands of jobs. The shift to cleaner production has also helped to reduce global warming, as metal production was one of the biggest sources of greenhouse gas emissions.

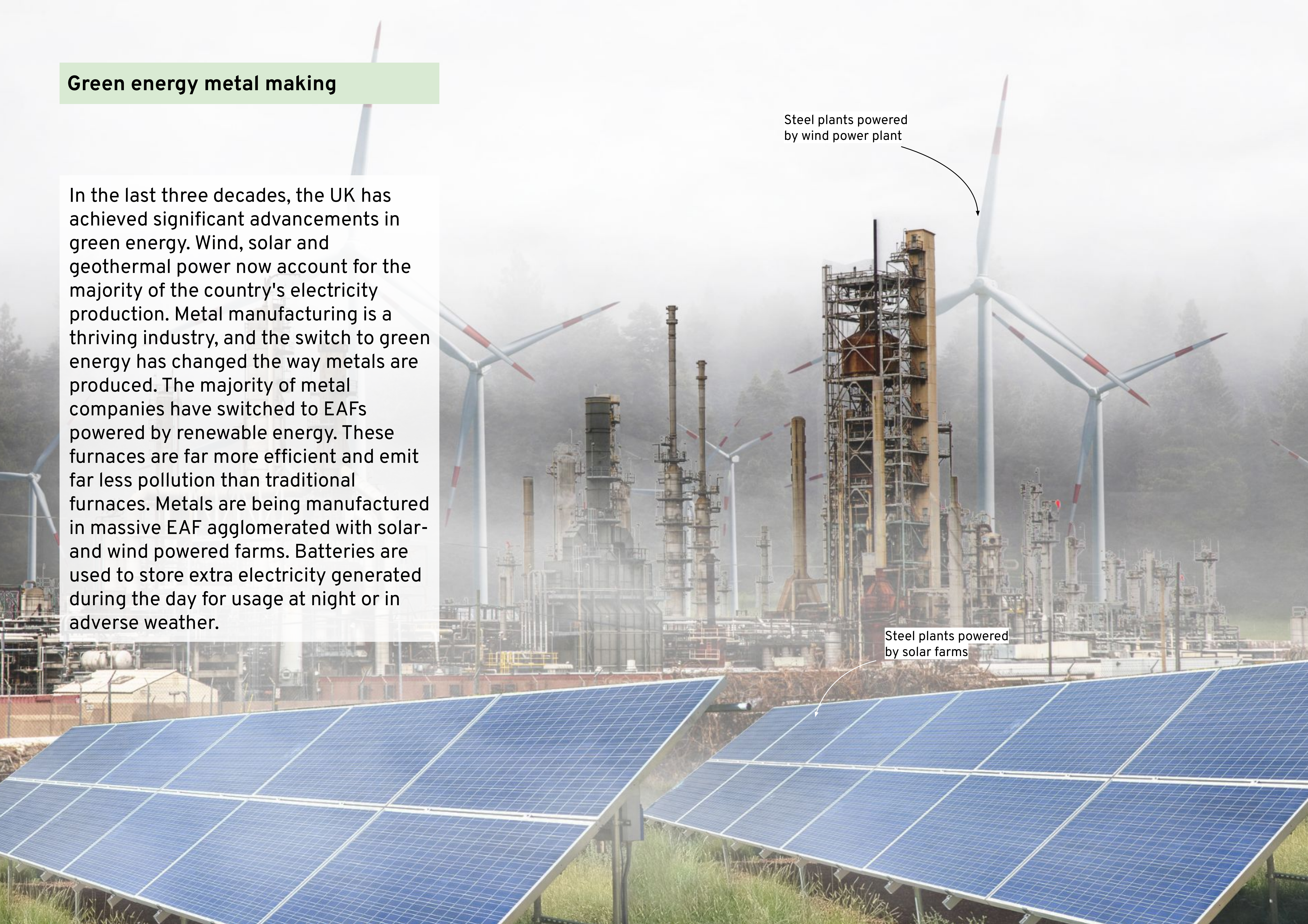
SNAPSHOTS FROM THE FUTURE:

1. Green Energy Metal Making
2. Hydrogen-powered metal manufacturing
3. CO2 capture and reuse
4. Industrial Symbiosis

Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
Reliance on yet-to-be-developed technologies for decarbonisation - The decarbonisation of the metallurgical industry is based on technologies that are still in their infancy (hydrogen, green energy, CCUS);	TECHNOLOGICAL	**Ensure a sustainable technology development** - Investment in sustainable technology advancements enabled by pioneering UK research and innovation, as well as worldwide collaboration, is critical (HM Government, 2021).
With current infrastructure, decarbonisation is challenging - In order to attain net zero emissions, infrastructure systems – such as transportation, production or energy transition equipment – should be circular and decarbonised as well.	ECOLOGICAL	**Government support for a fully decarbonised infrastructure** - The government should invest in clean metal manufacturing infrastructure (e.g. EAFs) and associated supply chain aspects to put the UK on a path to net zero emissions. To speed technical innovation, collaboration and networking must be strengthened.
Closures of metal industries affect jobs and society - Workforce disruption and societal consequences as a result of the shutdown of metal industries.	SOCIAL	**Create job opportunities** - Promote the reallocation of employment between sectors through new policy initiatives that avoid skills mismatches and other adjustment problems (OECD, 2019).
Regulatory inconsistency across nations - Metal industrial decarbonisation aspirations should be shared across many countries to avoid unfair market competition.	POLITICAL	**Stimulating clean development mechanisms (CDMs)** - Encourage environmental goals in the UK and internationally by diverting funds from primary extraction and processing to secondary metals production and processing, particularly in developing countries (OECD, 2018).
Shaping metal green future requires carbon investment - Significant upfront carbon investment necessary today to build new infrastructure for supposedly net zero steel later.	POLITICAL	**Defining the metal adaptation pathway for the UK** - Government policy, procurement procedures, and investment decisions should be based on a quantitative and/or qualitative examination of the possible carbon footprint and associated trade-offs referred to as adaptation pathways (IPCC, 2018: Annex I).
Cost and risk associated with transition investments - Developing new infrastructure, such as a hydrogen-powered metal manufacturing, would be expensive, and its viability hasn't been extensively examined.	ECONOMICS	**Highlight the potentialities of the transition** - Investing in low-carbon metal production requires a good business case and policies that include global competition. Funding and supporting political settings are required to make this happen (Mission Possible Partnership, 2021).

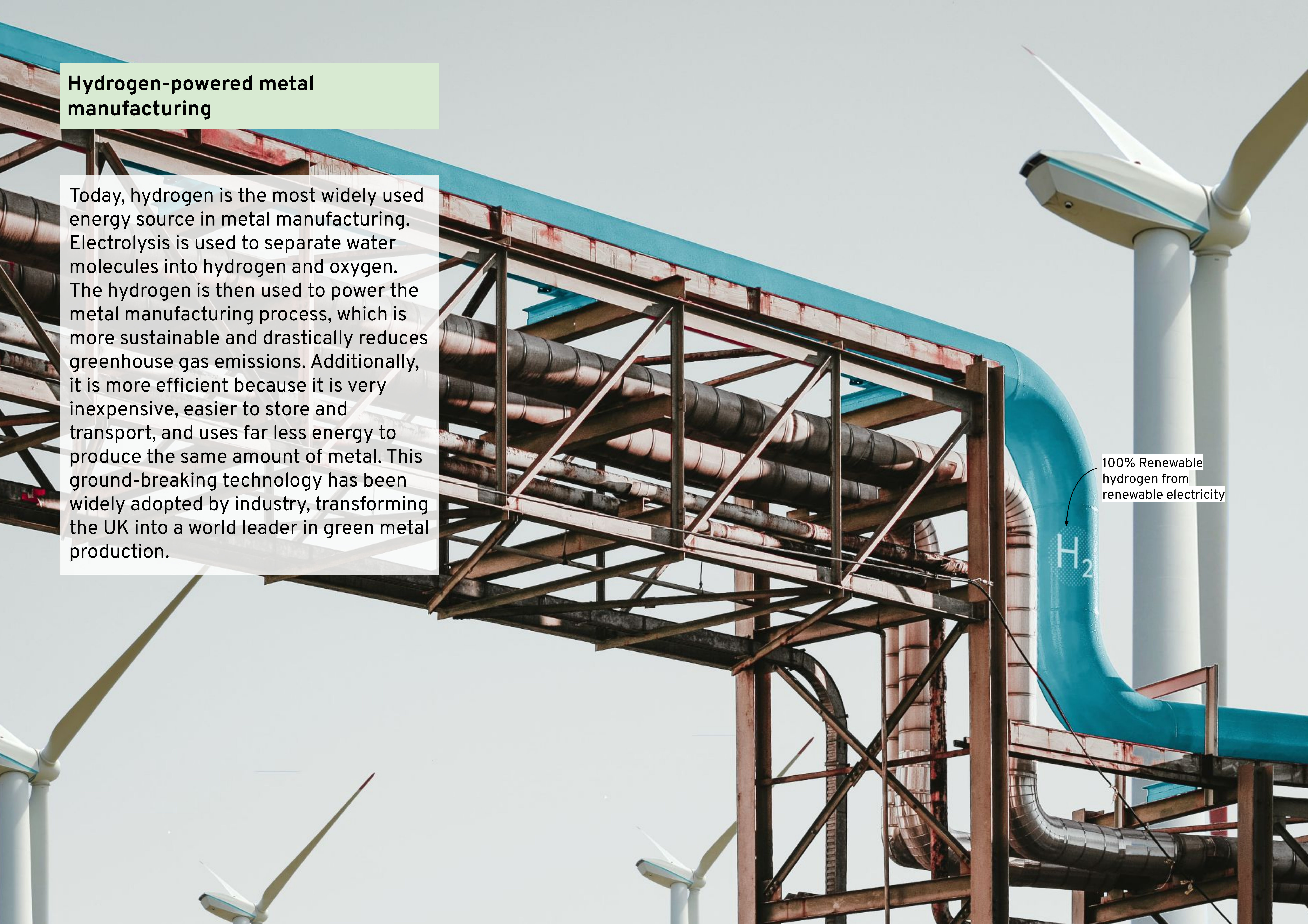
Green energy metal making

In the last three decades, the UK has achieved significant advancements in green energy. Wind, solar and geothermal power now account for the majority of the country's electricity production. Metal manufacturing is a thriving industry, and the switch to green energy has changed the way metals are produced. The majority of metal companies have switched to EAFs powered by renewable energy. These furnaces are far more efficient and emit far less pollution than traditional furnaces. Metals are being manufactured in massive EAF agglomerated with solar- and wind powered farms. Batteries are used to store extra electricity generated during the day for usage at night or in adverse weather.



Hydrogen-powered metal manufacturing

Today, hydrogen is the most widely used energy source in metal manufacturing. Electrolysis is used to separate water molecules into hydrogen and oxygen. The hydrogen is then used to power the metal manufacturing process, which is more sustainable and drastically reduces greenhouse gas emissions. Additionally, it is more efficient because it is very inexpensive, easier to store and transport, and uses far less energy to produce the same amount of metal. This ground-breaking technology has been widely adopted by industry, transforming the UK into a world leader in green metal production.



CO_2 capture and reuse

Almost all of the carbon dioxide produced by electric arc furnaces is now caught and either reused in chemical or industrial applications or stored in rocks under the ground. This has enabled metal to significantly minimise its emissions, making it one of the most sustainable and circular materials available.

Industrial Symbiosis

It is now common practice to reuse and recycle waste from steel manufacturing cycles (e.g., slag, EAF dust, mill scale, or zinc sludge) and other industrial processes along the supply chain (e.g., waste generated during product manufacturing). The metal system in the UK is today one of the most advanced industrial symbiotic networks, allowing businesses to pool resources and knowledge to maximise waste product reuse. The system combines a centralised database of waste products and their potential applications with a network of specialists who can advise firms on the most efficient method to reuse their waste. The system has helped to drastically reduce waste sent to landfill and the carbon footprint of the metal sector in the UK.

The black slag is processed inside the steel mill to be used again in different industrial processes

Circular alloys and manufacturing

In 2050, the UK has one of the most efficient metal closed loop systems worldwide. This has been made possible by research and innovation in the development, manufacture, regulation, and application of metals. In the early 2030s, the UK government successfully conducted a **rationalisation of alloys grades and use**, drastically lowering their number and application. This prompted the market to invest in high-quality metals and the development of highly efficient and recyclable alloys. For this reason, alloys with high temperature, fatigue, corrosion, and oxidation resistance, such as **multi-principal alloys**, became widely used. Technology innovation has also been critical in improving efficiency and productivity compared to the past. For example, nanotechnology, robotics, and computation have enabled the development of **metal nanomanufacturing** centres capable of producing micro-scale alloys with precise qualities for various applications.

Artificial intelligence (AI) is used to **optimise the manufacturing of metal components**, enabling the creation of metal structural components that require significantly less material and are substantially more robust. Through **automated image recognition**, AI can also locate and label any potential faults in the metal while it is being made. This technology cuts down on production waste and gives the producer useful information about the materials. 4D printing technology has enabled the development of **self-disassembling metals** for improved recyclability. All of this significantly aided the management and repurposing of metals across several loops.

SNAPSHOTS FROM THE FUTURE:

1. Rationalisation of alloy grades and use
2. Closed metal loops enabled by multi-principal elements alloys
3. Metal nanomanufacturing for multipurpose alloys
4. AI-driven metal material optimisation
5. Self-disassembly metal components
6. Zero Defect: Computer vision to predict quality defects

Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
Alloy mass simplification is challenging - Mass simplification of alloys may not be practical due to market forces and competition.	TECHNOLOGICAL	**Pure metal cycle promotion through servitisation** - Promoting innovative access-over-ownership models may change market dynamics and push competition towards the delivery of new services instead of product diversification. This enables inventory management of pure materials across worldwide supply chains, as well as the closure of multi-level reverse cycle networks (WE Forum, 2014).
Insufficient knowledge of metal flow - Even if we were able to develop metals that could follow a pure flow, we still lack a complete understanding of the flow of metals in and out.	ECOLOGICAL	**More research on metal flow and development of geo-tracking systems for materials** - Improved tools for explicitly considering metal flow (e.g., in LCA) in combination with other material information, such as time of use and additional research on metal flow can provide critical information for more informed decision-making.
Lack of a holistic circular metal approach - There is a lack of a holistic approach to supply chain management, innovation, effective methodologies, and life cycle performance with a particular emphasis on circular alloys.	ECOLOGICAL	**Embrace CE as a company strategy** - Investors and top management must make strategic decisions to identify new business opportunities, promote an integrated CSC, and coordinate the cultural and organisational changes required to accept CE principles (Maranesi et al., 2020). Also, continual research and development are crucial to enhancing circular alloys' effectiveness. To build a completely circular supply chain, public and private sectors must collaborate (European Aluminium, 2020).
Government ambiguity in CE policy innovation - It's difficult to understand how the government could encourage CE innovation as a policy because the current government's attitude on CE is ambiguous.	POLITICAL	**Develop a clear CE policy framework that outlines government goals** - Breaking down the government's plan for adopting the CE into a clear framework may help to decrease ambiguity and uncertainty on how businesses might pursue the UK CE action plan.
It is expensive to achieve material purity - The cost of making new metals with the purity needed for full circularity is high.	ECONOMICS	**Technology improvements** - Metal purity can be improved, and recycling costs can be decreased, through technological advancement. This must be done concurrently with the promotion of and transition to a secondary metals-based economy in the UK (OECD, 2019).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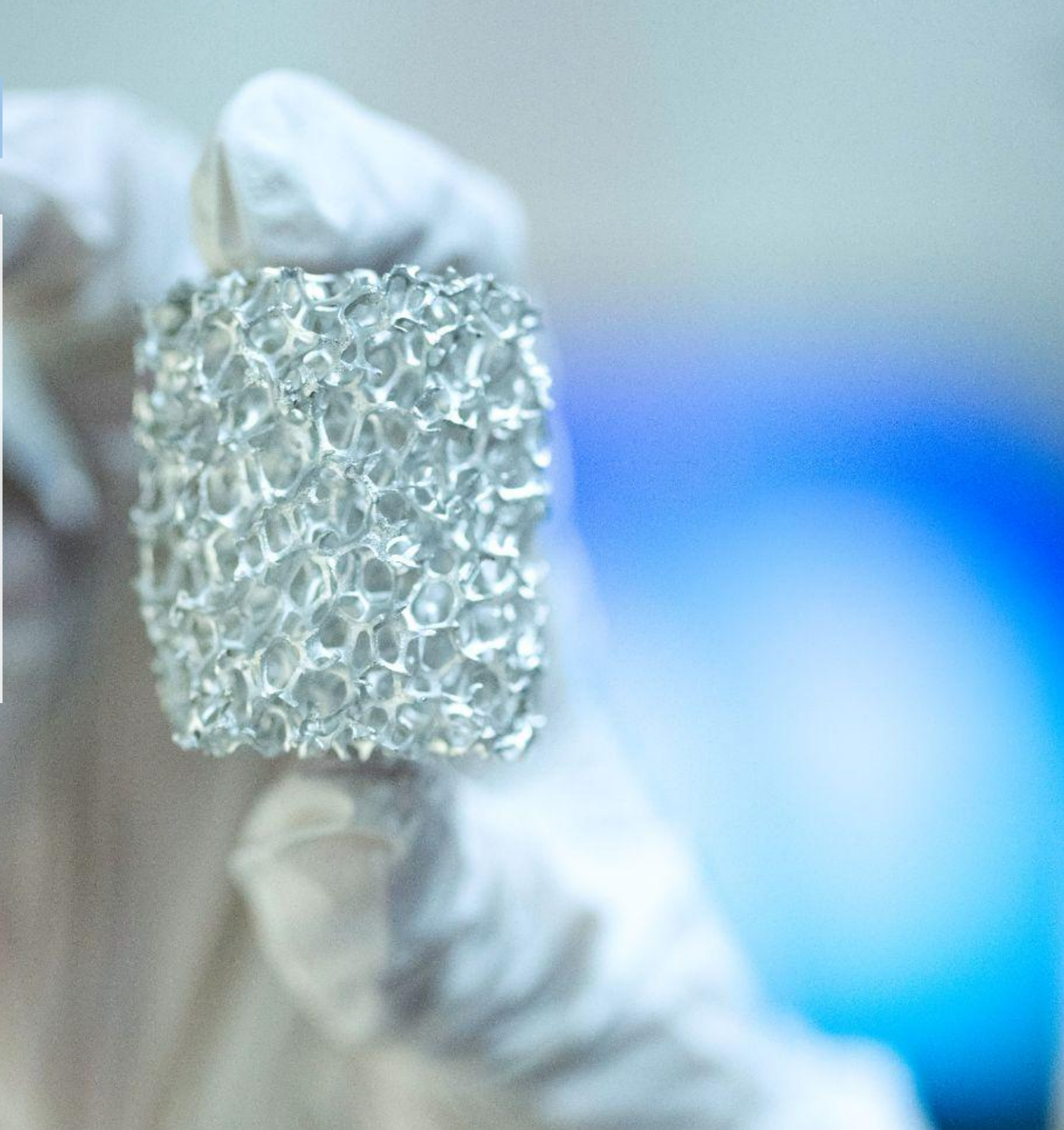
ROUTEMAP
Rationalisation of alloy grades

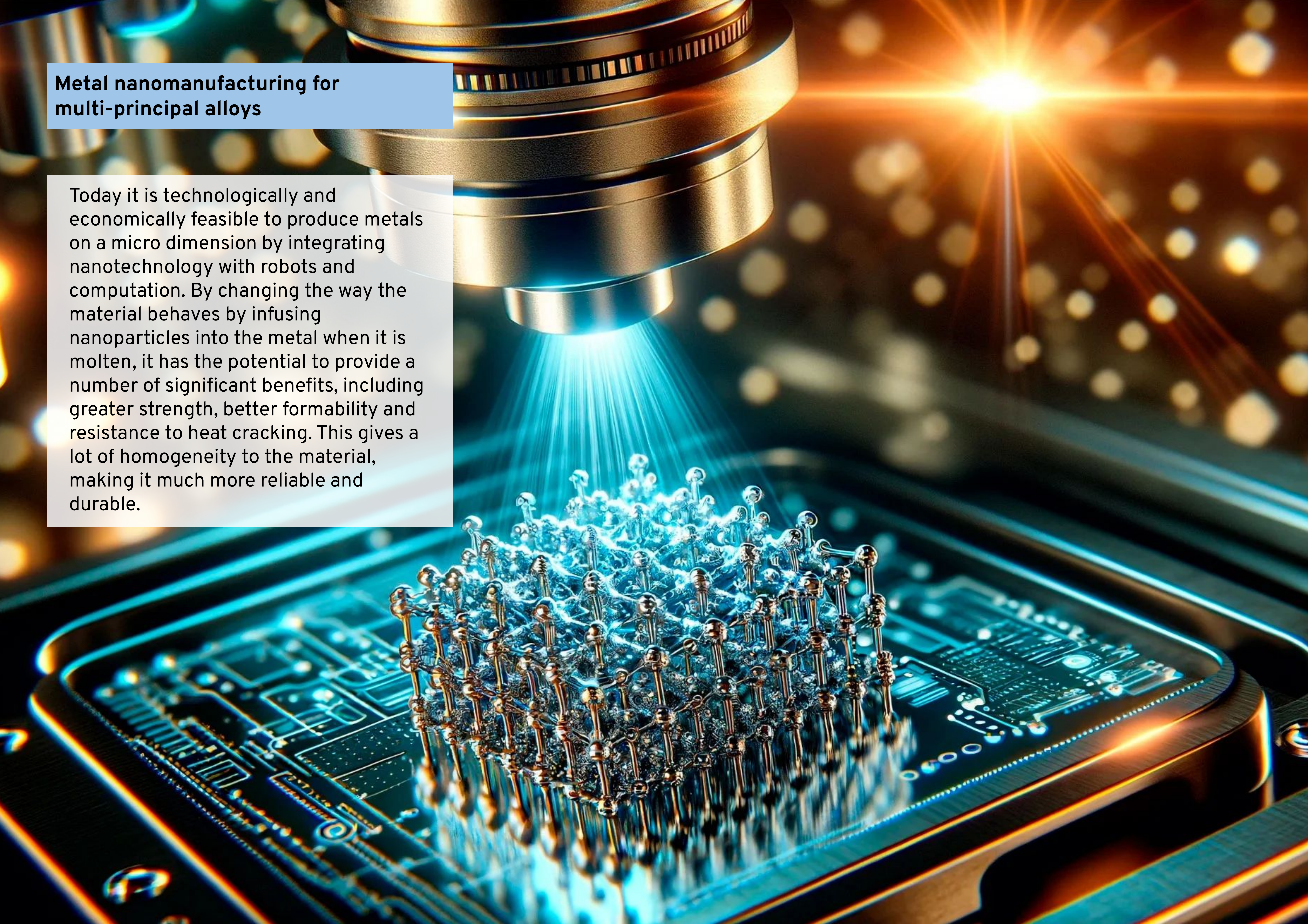
Closed metal loops enabled by multi-principal elements alloys

Today, multi-principal elements alloys, also called circular alloys, are the most widely used alloys on the market. These are alloys that meet the requirements for a wide range of applications that could not be met with a single grade alloy. They have exceptionally high temperature, fatigue, corrosion, and oxidation resistance. These grades of alloys are used in a wide range of applications and are easily recycled. For this reason they are mainly used in closed-loop businesses. Their widespread use has almost eliminated the need for numerous non-recyclable alloy grades.



Metal nanomanufacturing for multi-principal alloys

Today it is technologically and economically feasible to produce metals on a micro dimension by integrating nanotechnology with robots and computation. By changing the way the material behaves by infusing nanoparticles into the metal when it is molten, it has the potential to provide a number of significant benefits, including greater strength, better formability and resistance to heat cracking. This gives a lot of homogeneity to the material, making it much more reliable and durable.



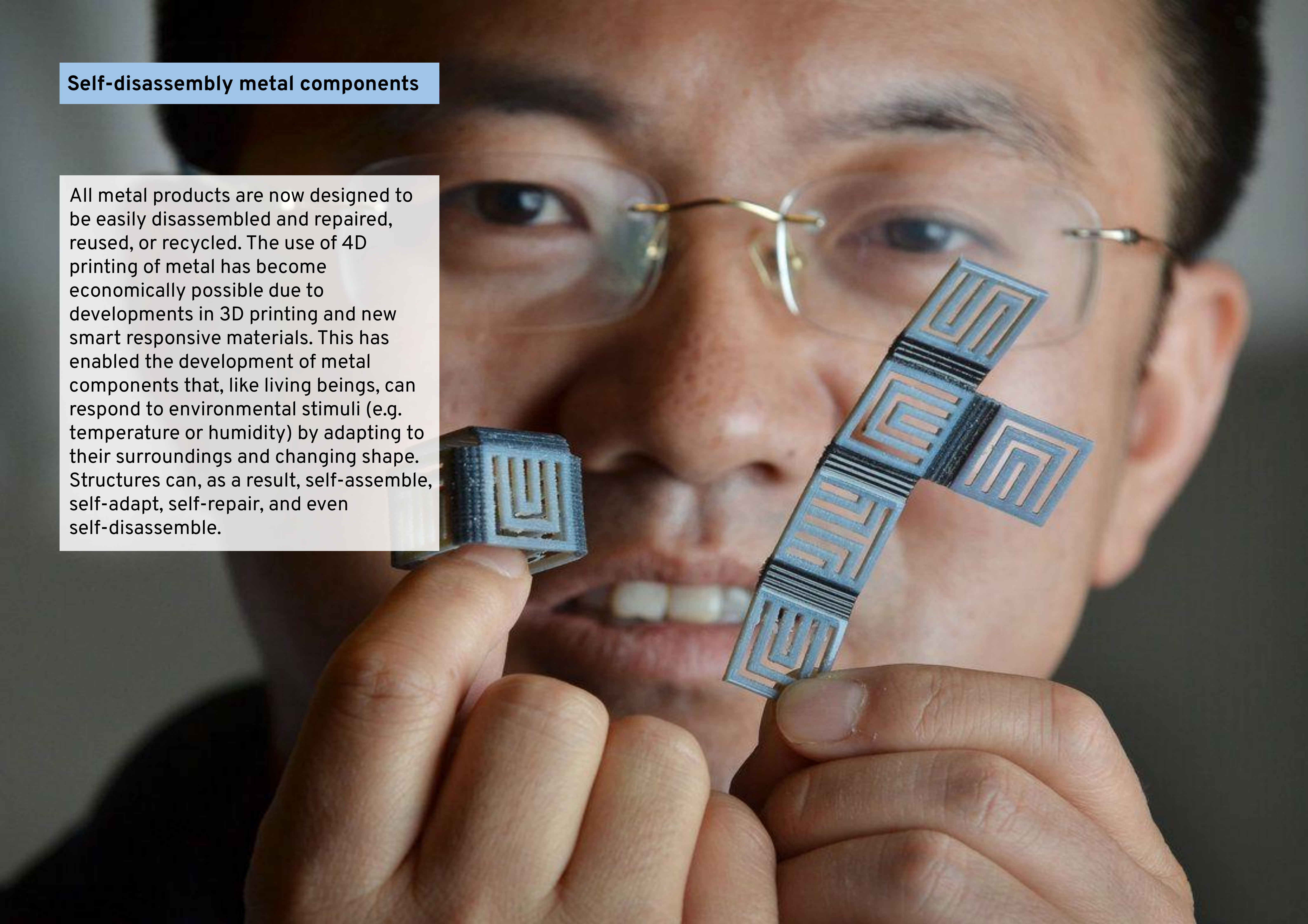
AI-driven metal material optimisation

Artificial Intelligence (AI) has made giant leaps over the past. Any metal structure may be designed entirely by AI algorithms that can optimise the shape to the structure's purpose, constraints and requirements. By minimising the amount of raw material used, businesses may reduce cost while improving the performance of products.

An ultra-light single-piece component aluminium structure for an aircraft created through generative design

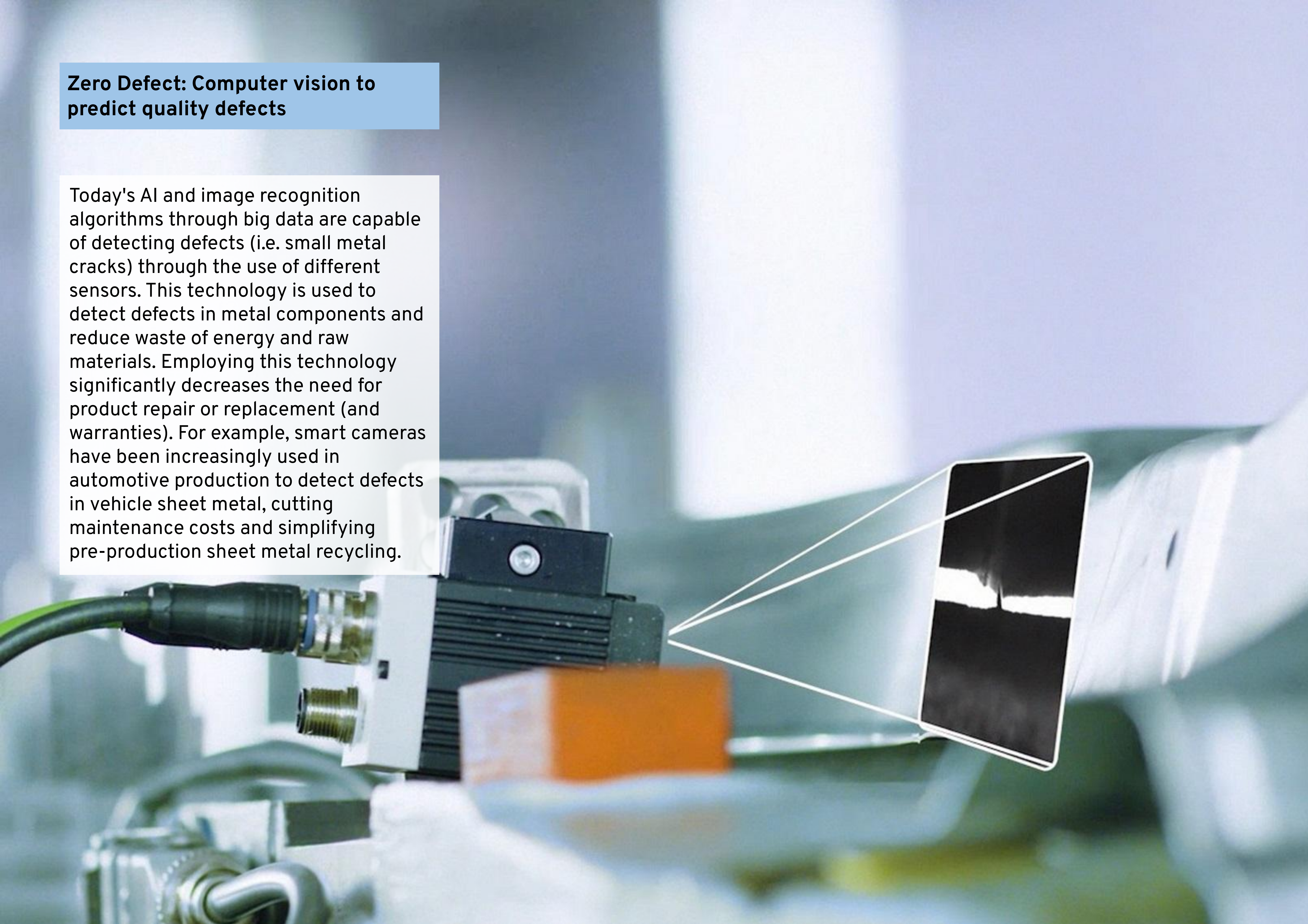
Self-disassembly metal components

All metal products are now designed to be easily disassembled and repaired, reused, or recycled. The use of 4D printing of metal has become economically possible due to developments in 3D printing and new smart responsive materials. This has enabled the development of metal components that, like living beings, can respond to environmental stimuli (e.g. temperature or humidity) by adapting to their surroundings and changing shape. Structures can, as a result, self-assemble, self-adapt, self-repair, and even self-disassemble.



Zero Defect: Computer vision to predict quality defects

Today's AI and image recognition algorithms through big data are capable of detecting defects (i.e. small metal cracks) through the use of different sensors. This technology is used to detect defects in metal components and reduce waste of energy and raw materials. Employing this technology significantly decreases the need for product repair or replacement (and warranties). For example, smart cameras have been increasingly used in automotive production to detect defects in vehicle sheet metal, cutting maintenance costs and simplifying pre-production sheet metal recycling.



Distributed metal manufacturing

In 2050, the UK has a thriving CE in which factories of today are more varied, and more distributed than those of the past. Many small and medium-sized firms, both in urban and rural areas, use innovative technologies to establish circular businesses and connect to intensive super factories for the creation of complex products. As a result, there is a proliferation of locally-based manufacturing networks and related supply chains, giving rise to **resilient local economies** that are developed around metal production, processing, maintenance, and recycling with a stronger emphasis on repair and regeneration.

Fablabs support these new local economies by providing spaces (to businesses, schools, community groups and individuals) to manufacture, repair, or customise products.

Today's **distributed production** makes it easier to deploy and adapt new **on-demand** sales models. In addition, specialised companies offer distributed manufacturing services, enabling manufacturers to produce their products locally.

Flexibility is not only related to production, but also to repairs; innovative on-demand repair models, such as **mobile additive manufacturing repair workshops** and **local repair delivery**, make repairs easier by enabling on-site replacement component manufacture.

Electric vehicles, fuel cells, and solar-powered ships all play a role in the new green logistics supporting this new way of conducting business.

SNAPSHOTS FROM THE FUTURE:

1. Resilient local economies
2. Fablabs for metal products and components
3. Distributed additive manufacturing services
4. Make to order/on-demand
5. Mobile additive manufacturing repair labs
6. Local fixing delivery

Barriers to the vision

Lenses of analysis

Opportunities and enablers for the vision

New circular manufacturing technologies will reshape the labour economy - The shift away from metal manufacturing towards metal recycling and repair using new technologies such as 3D printing will have a profound effect on the labour market.

TECHNOLOGICAL

Investment in research and education - Additional research is required to fully understand the impact of the transition to a CME on the labour market (Laubinger et al., 2020). Public help, however, is essential to prepare businesses, higher education institutions, and individuals in the metalworking industry in the UK for green job training. This decline in employment could be more than offset by growth in labour-intensive sectors, particularly in the service sector.

Lack of a metal supply chain in the UK - The metal supply chain is currently worldwide, and the UK lacks a local supply chain that can control the flow of metals.

TECHNOLOGICAL

UK supply chain circularity policy - In order for metals to circulate within the UK, politics must create the right environment for this change. Carbon taxes, energy policies and capital investments for processing equipment (e.g. electric furnaces) are just a few examples of how the UK can drive the transition. However, the metal industry cannot undertake this transition without the government's assistance.

Innovative long-term business models must be established - Businesses must gain a better knowledge of how to attract large numbers of users to switch to new business models with long-term benefits.

SOCIAL

Educate users on new business models and their benefits - Private sectors should increase their investment in research to develop easy tools that help users embrace new business models and obtain a better grasp of their long-term benefits.

Capacity and relationships are inadequate in multi-level supplier networks - A lack of capacity and relationships in multi-level supplier networks (local/glocal) prevents forward and reverse flow of the cycle.

POLITICAL

Promote collaborative efforts, supply chain transparency, and skill development - Together, both the public and private sectors should work to develop and strengthen capabilities and relationships throughout the whole supply chain. This may require facilitating collaboration between stakeholders, transparency in material supply chain, and education and skills development (Despeisse et al., 2016).

Barriers to the vision

Lenses of analysis

Opportunities and enablers for the vision

Scaling distributed manufacturing infrastructure is not a priority in the CE - Infrastructure development for distributed manufacturing will require significant investment to operate at high capacity, and this is not a priority in the shift to the CE.

ECONOMICS

Advantages for industries investing in distributed manufacturing - Businesses that invest in distributed manufacturing technologies can gain a competitive edge, enabling them to prosper in markets that few others have explored.

Models of distributed manufacturing can lead to inefficiencies and a rise in the complexity of requirements - Inefficiencies might emerge if one facility cannot create a component on schedule, influencing the overall product's manufacturing. A distributed manufacturing model may also increase transportation costs because components must be delivered between factories.

ECONOMICS

Optimise production processes and facilities to reduce transportation costs - The key to avoiding production disruptions and inefficiencies is to carefully plan and manage the distributed manufacturing process (Singh Srai et al., 2016). Just-in-time, lean, and agile manufacturing are some approaches of distributed production that can overcome these constraints.

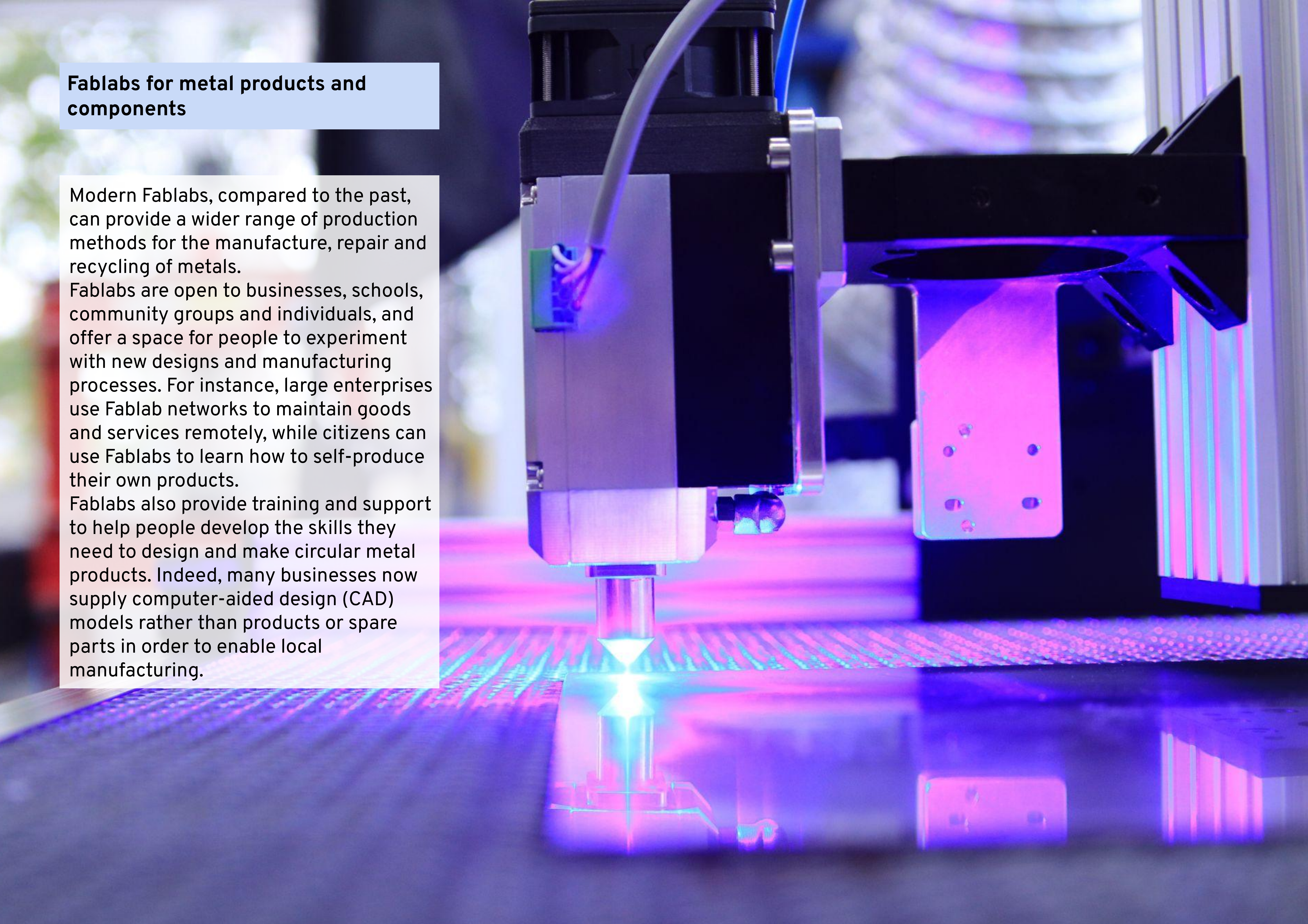
Resilient local economies

Today, the UK has a thriving network of resilient, diversified and circular local economies. District and regional cooperation is the cornerstone of these thriving economic systems, with an emphasis on local resources and community-based trade. Dedicated entities are in charge of organising and managing collaboration throughout the metal supply chain, promoting strategic partnership both within and outside of the national boundaries.

Local economies have developed around metal reprocessing, with a stronger emphasis on repair and regeneration (such as reusing, refurbishing, and remanufacturing).

Local economies become more resilient through diversification, investment in infrastructure and human resources, and the creation of a more favourable business environment. This has increased the ability of local communities to respond successfully to economic shocks and stresses.

Fablabs for metal products and components



Modern Fablabs, compared to the past, can provide a wider range of production methods for the manufacture, repair and recycling of metals.

Fablabs are open to businesses, schools, community groups and individuals, and offer a space for people to experiment with new designs and manufacturing processes. For instance, large enterprises use Fablab networks to maintain goods and services remotely, while citizens can use Fablabs to learn how to self-produce their own products.

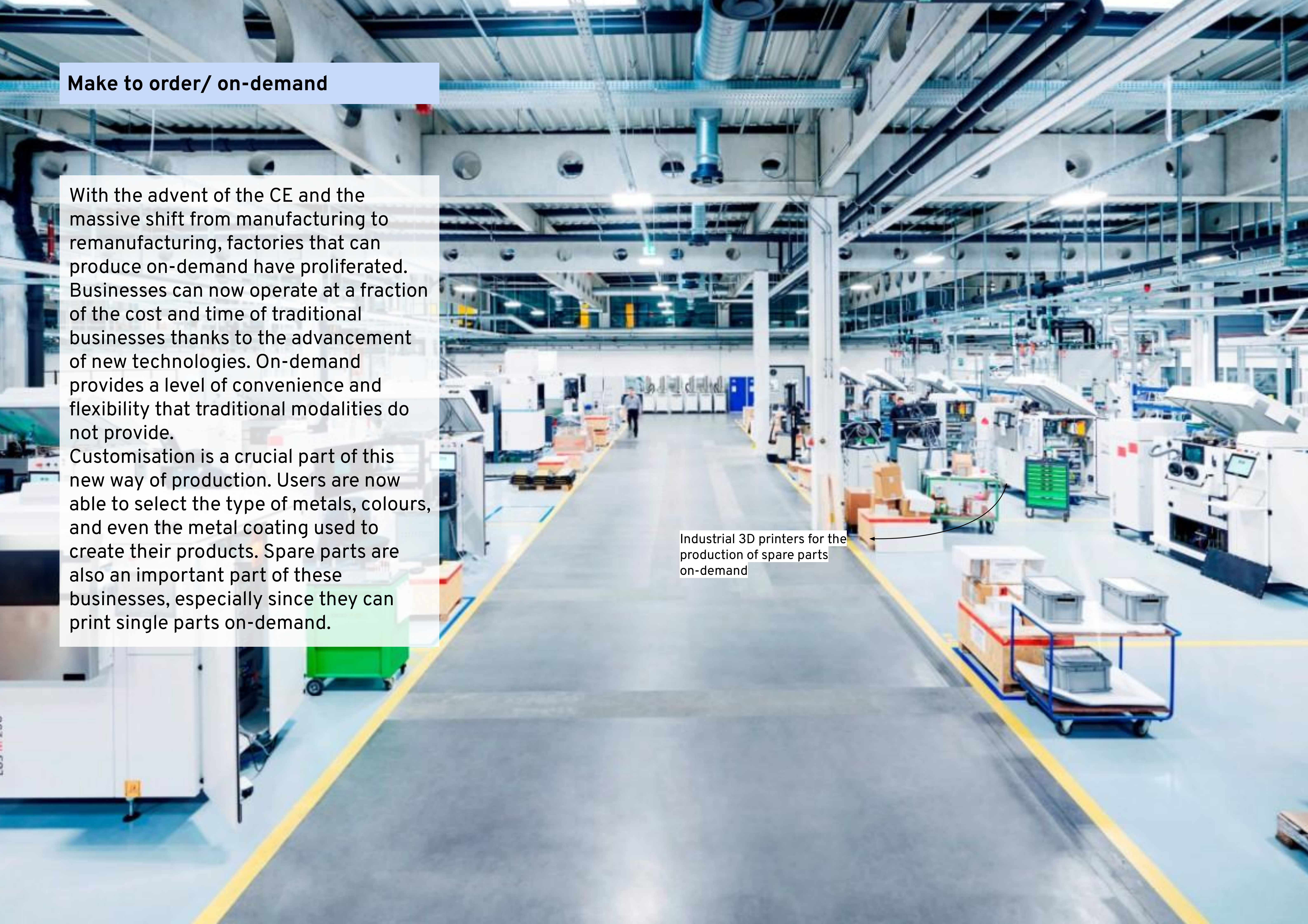
Fablabs also provide training and support to help people develop the skills they need to design and make circular metal products. Indeed, many businesses now supply computer-aided design (CAD) models rather than products or spare parts in order to enable local manufacturing.

Distributed additive manufacturing services

New specialised companies, as well as logistics providers, work with manufacturers all over the world to produce and enable repair of products on-site. Smaller, more localised facilities can respond to requests more quickly and efficiently. By eliminating numerous processes in traditional supply chains, companies have been able to reduce material inventories, lead times, logistic costs and emissions, and material waste. Metal spare parts and products can be manufactured using a variety of methods, including 3D printing, laser cutting, and welding. They can also provide a variety of finishes, such as plating, anodizing, and powder coating. Furthermore, these companies frequently provide distributed manufacturing and repair services directly to consumers. These services are provided by a network of 3D printing kiosks located in public areas such as shopping malls, city centres, etc.

Make to order/ on-demand

With the advent of the CE and the massive shift from manufacturing to remanufacturing, factories that can produce on-demand have proliferated. Businesses can now operate at a fraction of the cost and time of traditional businesses thanks to the advancement of new technologies. On-demand provides a level of convenience and flexibility that traditional modalities do not provide.
Customisation is a crucial part of this new way of production. Users are now able to select the type of metals, colours, and even the metal coating used to create their products. Spare parts are also an important part of these businesses, especially since they can print single parts on-demand.



Industrial 3D printers for the production of spare parts on-demand

Mobile additive manufacturing repair labs

As a result of technical advancements, industry-maintenance services have flourished. Thanks to the development of mobile additive manufacturing repair labs, heavy machineries (e.g. hospital equipment, heavy-duty vehicles, etc.) can be rapidly maintained, repaired, or upgraded when required. Also, mobile labs that specialise in different industrial processes (such as laser cutting, computer numerical control milling, etc.) can be linked to make a large, mobile repair infrastructure in remote areas.

Local fixing delivery

In order to encourage users to fix their own small devices, repair companies have created novel methods to provide local, fast and affordable repair services. Nowadays, the majority of repairs are performed at home, thanks to the proliferation of small mobile labs. These are equipped with additive manufacturing technologies and can offer a range of repair, alteration and upgrading services.
Almost all organisations that offer “local fixing delivery” services work closely with the local manufacturers to exchange information about their products and the most effective ways to fix them.

End-to-end supply chain

With the use of intelligent assets, the circular supply chain has radically altered the traditional constrained and silos system. The modern end-to-end supply chain encompasses all the aspects of a product lifetime. This is a fully integrated and automated system that allows for real-time monitoring and execution of all supply chain processes. In this system transparency and standardisation play a key role as they can enable **intelligent inventory management.** To encourage corporations to adapt to this new working paradigm, **sustainability reporting** is now required by all businesses. Businesses that collaborate based on data sharing are able to provide high-quality **customer-centric services across the supply chain**, such as predictive or remote services.

SNAPSHOTS FROM THE FUTURE:

1. Intelligent inventory management
2. Supply chain sustainability reporting adopted by all businesses
3. Service-oriented supply chain

Barriers to the vision

Lenses of analysis

Opportunities and enablers for the vision

The lack of instruments makes non-financial reporting difficult for SMEs - Despite their crucial role in the UK economy, many micro, small, and medium-sized enterprises (SMEs) struggle with non-financial reporting due to a lack of tools, formal scientific understanding, and international consistency required for balanced economic activity.

TECHNOLOGICAL

Non-financial reporting tools should be available to SMEs - Non-financial reporting in the metal supply chain is becoming increasingly important, and this process needs to be structured, streamlined, and standardised so that it can be used by enterprises of all sizes around the world (Krawczyk, 2021).

Standardisation of data interchange - Information exchange should be standardised and transparent in order to allow collaboration among all supply chain stakeholders, yet this is challenging because supply networks cross multiple governments, business procedures, and cultural norms (Tura et al., 2019).

TECHNOLOGICAL

Enabling the development of data standardised knowledge-sharing platforms - Platforms for information sharing may allow collaboration and information exchange across stakeholders (Ellen MacArthur Foundation, 2013). Metal supply chain networks should establish knowledge-sharing mechanisms that enable, facilitate, and safeguard intellectual property (IP) while also promoting data standardisation and transparency among stakeholders. Public funding and interventions may be used to promote and support these platforms.

Indirect carbon emissions are not calculated - To calculate their carbon footprint, corporations often overlook indirect carbon emissions (scope 3 target) generated by their supply chain, which are typically the major source of emissions in most industries.

ECOLOGICAL

Indirect carbon emission reduction policies should be implemented - Policies aimed at reducing indirect carbon emissions (scope 3 target) should be applied across the complex and interconnected global supply chain (Onat et al., 2020).

Metal supply chain opaqueness promotes mistrust and data silos - Lack of transparency in metal supply chains contributes to mistrust and fosters data segregation, limiting cycle information.

SOCIAL

Enforce supply chain reporting, labelling, and accounting regulations - The use and implementation of new technologies such as RFID, IIoT and Blockchain combined can improve transparency in the metal End-to-End supply chain (E2E-SC) (Zelbst et al., 2019) and enforce reporting, labelling, and accounting requirements to ensure information interchange across the supply chain (Bicket et al., 2014).

Barriers to the vision

Lenses of analysis

Opportunities and enablers for the vision

POLITICAL

E2E-SC management is complex, detailed, and systemic - The vast, complicated, and systemic nature of E2E-SC management has challenges and issues. Modelling techniques are needed by decision makers in order to better understand, control, design, or assess their E2E-SC.

Managing and modelling the E2E-SC requires new knowledge and frameworks - Given the complexity and difficulty associated with managing such complex information, it is important for businesses to gain more knowledge and identify new frameworks for more effectively controlling and modelling the system (Chilmon et al., 2017).

ECONOMICS

The shift to a CE may cause supply chain disruptions - Significant disruption in the metal supply chain, particularly in metal manufacturing, as some enterprises may need to reinvent themselves to conform to the CE's new standards.

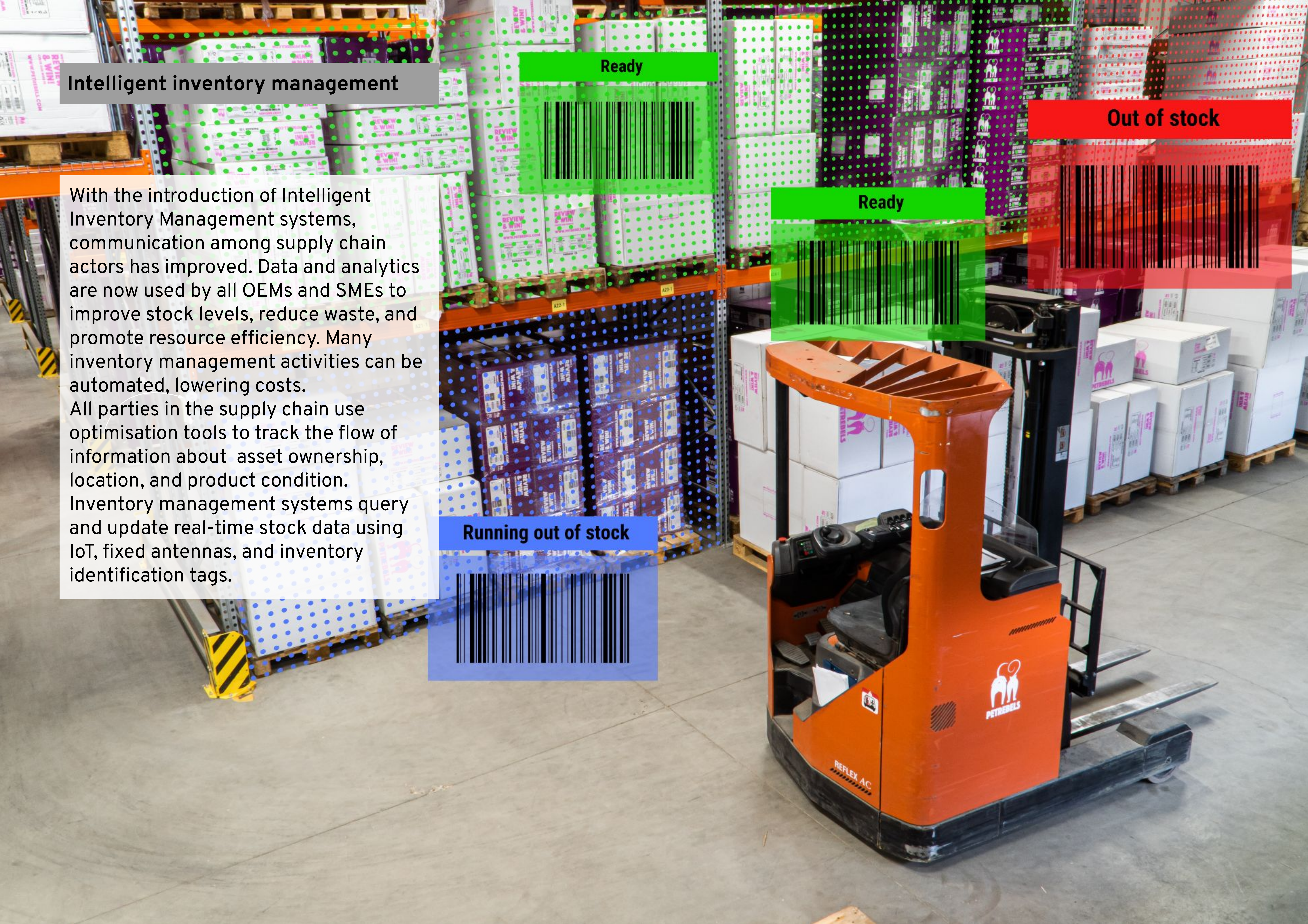
Enabling a national and local metal transition pathway - While this research is defining the issues and potential solutions for enabling a national metals transition to a CE, the next step will be to replicate the research in a local environment in order to develop visions that are locally relevant, actionable, and representative of stakeholders' perspectives. Governments may form collaborative partnerships with industries throughout the metal supply chain in order to help them rethink, innovate, and reorganise their business models in order to adapt to their new roles in the CME (Jackson et al., 2014).

Intelligent inventory management

With the introduction of Intelligent Inventory Management systems, communication among supply chain actors has improved. Data and analytics are now used by all OEMs and SMEs to improve stock levels, reduce waste, and promote resource efficiency. Many inventory management activities can be automated, lowering costs.

All parties in the supply chain use optimisation tools to track the flow of information about asset ownership, location, and product condition.

Inventory management systems query and update real-time stock data using IoT, fixed antennas, and inventory identification tags.



Supply chain sustainability reporting adopted by all businesses

Supply chain sustainability reporting is now standard practice for all businesses, and it is critical in order to remain competitive in an increasingly CE. This has fundamentally changed supply chain management, making it more sustainable and improving business transparency, resulting in better business and consumer decisions, as well as a more sustainable future.

Companies have made the supply chain sustainability reporting a competitive strategy for better user services

Service-oriented supply chain

Today, it is common for supply chain service providers to collaborate with their OEM customers to ensure that the products they maintain and repair will last for a long period of time. This collaboration extends beyond the first phases of the design process, exchanging data to improve services such as predictive maintenance and remanufacturing throughout the product's lifetime.
The close-loop potential has risen dramatically as a result of this engagement between OEMs and service providers.

A repair crew in operation after the detection of an anomaly in an aeroplane engine.

Metal as a service

In 2050, the UK is a world leader in metal as a service. As a result, the majority of firms are held accountable for their products throughout their entire life cycle (including usage and disposal). The UK was one of the first governments to create a "Department for Metal Services" to lease **metals molecules** from metals and mining corporations to UK materials industries. Also, different business models such as **metal components as a service** and **metal products as a service** are increasingly used by companies, for both B2B and B2C markets. These performance-related services are now prevalent offer models and account for the majority of business revenues. Another business model that became widely adopted by businesses, particularly for B2C, is product sharing. This has been aided by tracking technologies and product automation, allowing firms to fully monitor and control their products.
On an urban scale, cities have become more dynamic and community-driven. Today, many **buildings and structural components are envisioned as community assets**. In addition, a sharing economy has now widely permeated into society. In this respect, businesses and communities have partnered to make numerous 'product-sharing' services available to specific **social bubbles** (e.g. community car sharing).

SNAPSHOTS FROM THE FUTURE:

1. Metals molecules as a service
2. Metal components as a service
3. Metal products as a service (B2B)
4. Metal products as a service (B2C)
5. Metal products shared
6. Buildings and structural components as a service
7. Social bubble collaborative economy

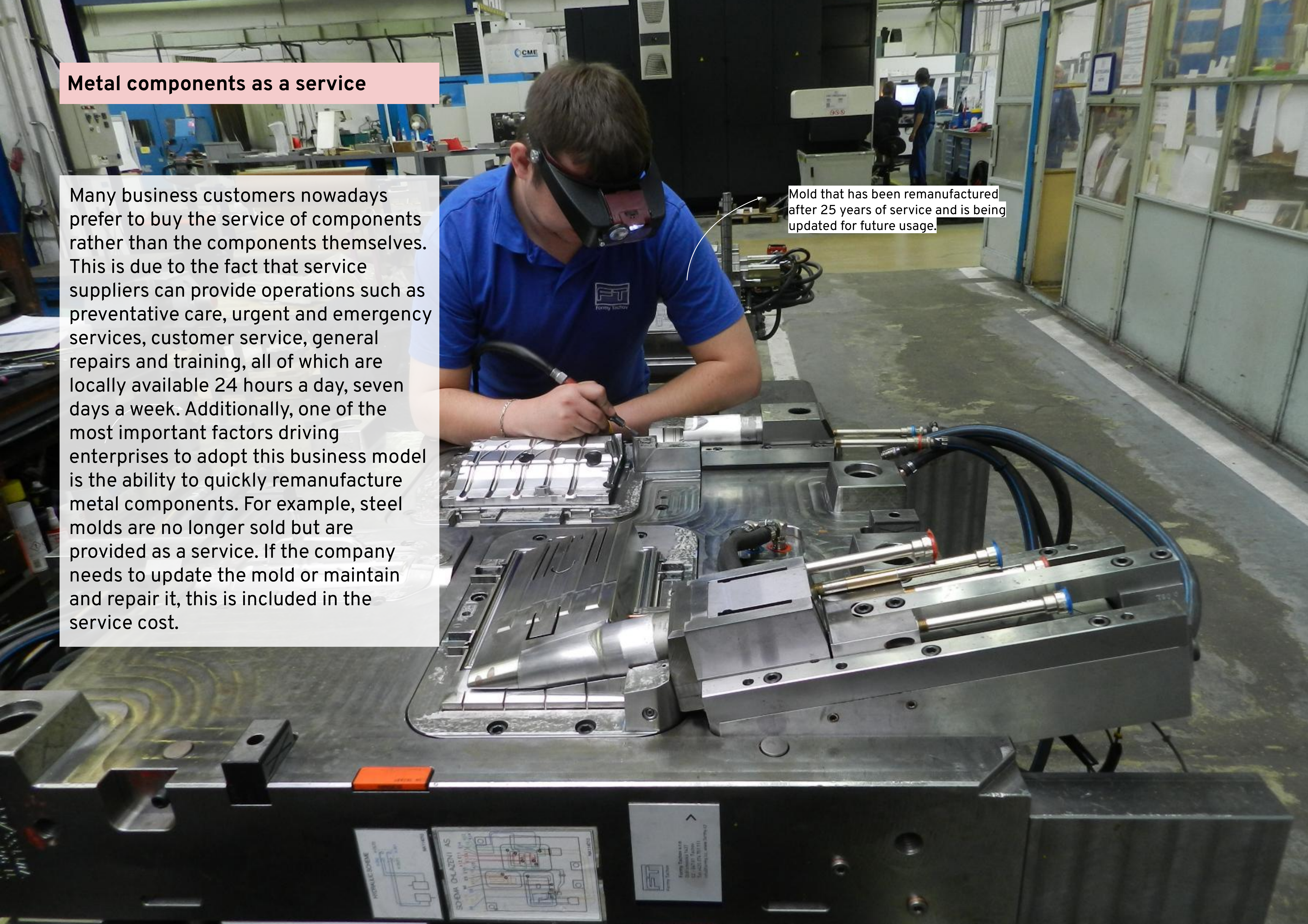
Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
Servitisation makes it difficult to gather and exchange company data - Product performance (serviceability, maintainability, repaierability, etc.) are directly related to the data collection capabilities of service providers and industry 4.0 factories.	TECHNOLOGICAL	**Enable service businesses' data collection and sharing transition** -To address the current need to transition to a servitisation-based economy, data gathering and exchange should be tailored to this objective. A structural shift that can create the requisite systemic capacities is required. For this reason, the government should prioritise funding for technologies that address critical CE challenges (Zhou et al., 2020).
Metal dissipative flow - The prolonged use of metal in product sold as a service implies the reduction of the corresponding secondary material stocks and the need to relay on geological stocks.	ECOLOGICAL	**Establish an inventory system to track and manage metal flow** - Develop methods to quantify the impact of metal dissipation based on Life Cycle Inventory (LCI) databases, to use proper background data for the implementation of service projects, and accordingly to take into consideration the dissipation of available and usable resources systematically (Beylot et al. 2020).
Changes in public perception of ownership take time - Changing people's perceptions of owning a commodity needs a fundamental shift in social and cultural thinking, which can take a long time to achieve. Furthermore, some circular models may result in inequity and exclusions.	SOCIAL	**Creating a social and cultural framework for evaluating the impact of CBM** - Developing a social and cultural framework for assessing a structural societal shift in order to assess the sociopolitical consequences of circular business model adoption (Hobson et al., 2016). Inequality and exclusionary consequences of various circular business practices should be assessed under the framework.
UK's financial and accounting systems hinder development - Inadequate financial and accounting systems in the UK to invest in new/existing businesses or initiatives that foster the development of metal circular business models.	ECONOMICS	**Policy instruments can be used to aid in the promotion and financing of the CE** - Policy instruments can help de-risk and encourage CE investments. These instruments, such as blended finance and investment guarantees, enable greater public–private partnership and financing of the CE. Private investments can be leveraged by public money. Impact investments and philanthropic donations can de-risk early-stage investments (Schröder et al., 2021).

Metals molecules as a service

In 2050, the British government formed the first "Department for Metal Services" as part of a coalition with metal production corporations to handle the leasing of metal molecules in the UK. "Molecules as a service" is a programme through which metals and mining companies own the stock of metals and provide metal to UK companies as a service. As a result, UK companies are required to establish product-service systems in order to maintain control and ensure the return of materials to the provider at the end of the lease period.

Metal components as a service

Many business customers nowadays prefer to buy the service of components rather than the components themselves. This is due to the fact that service suppliers can provide operations such as preventative care, urgent and emergency services, customer service, general repairs and training, all of which are locally available 24 hours a day, seven days a week. Additionally, one of the most important factors driving enterprises to adopt this business model is the ability to quickly remanufacture metal components. For example, steel molds are no longer sold but are provided as a service. If the company needs to update the mold or maintain and repair it, this is included in the service cost.



Mold that has been remanufactured after 25 years of service and is being updated for future usage.

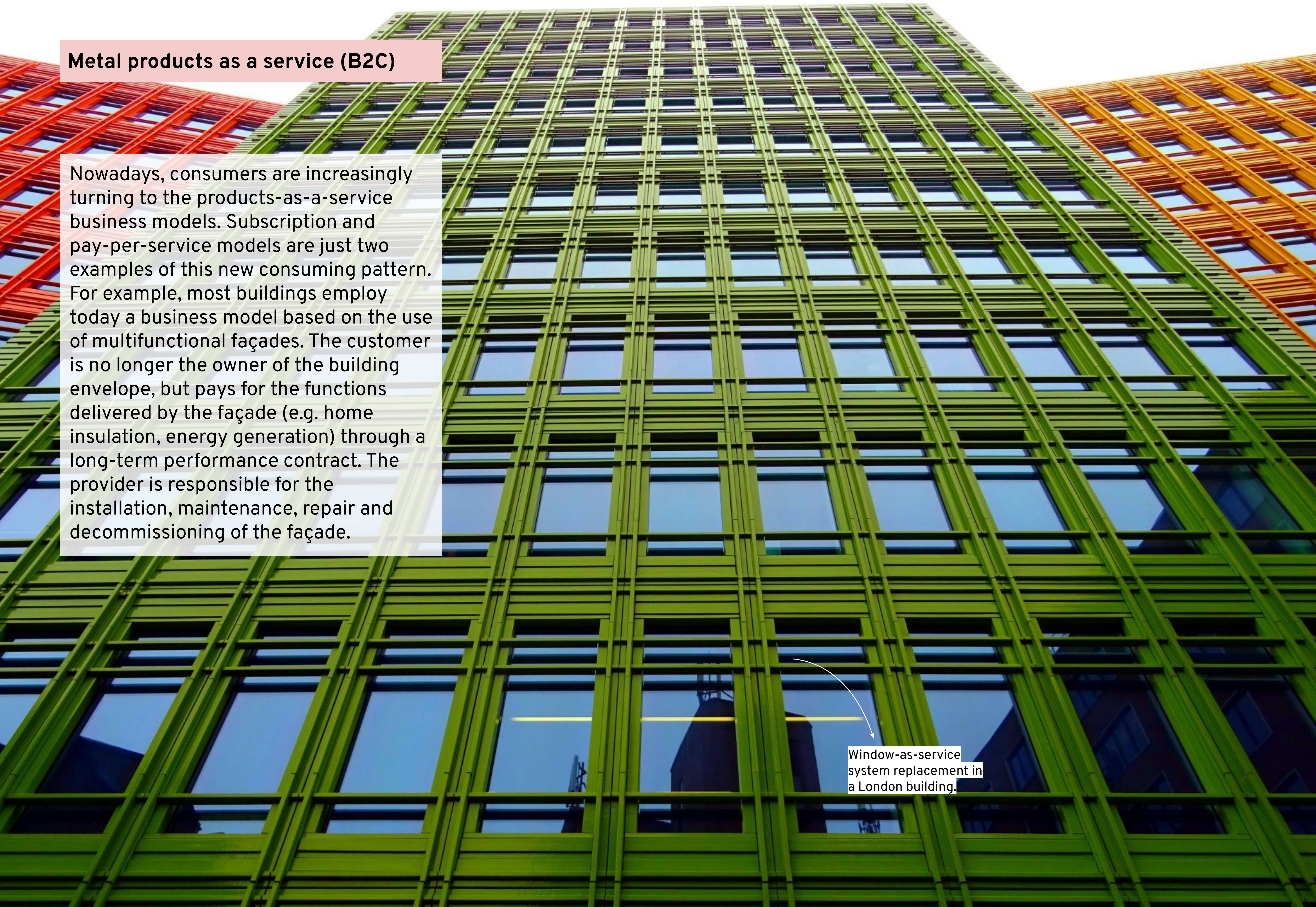
Metal products as a service (B2B)

Metal products as a service has become a popular business-to-business offering. Traditionally, firms sold and maintained their products. Nowadays, what is sold is the performance provided by the product. This includes ‘pay-per-use’ models, where customers pay for the output of the product (e.g. escalator companies are paid on the basis of the number of people transported by the escalator), and ‘functional results’ models, where customers pay for obtaining a certain result (e.g. escalator companies are paid a yearly fee for the installation and maintenance of an escalator).

Escalator companies now receive a fee for each completed hour of operation of the escalator.

Metal products as a service (B2C)

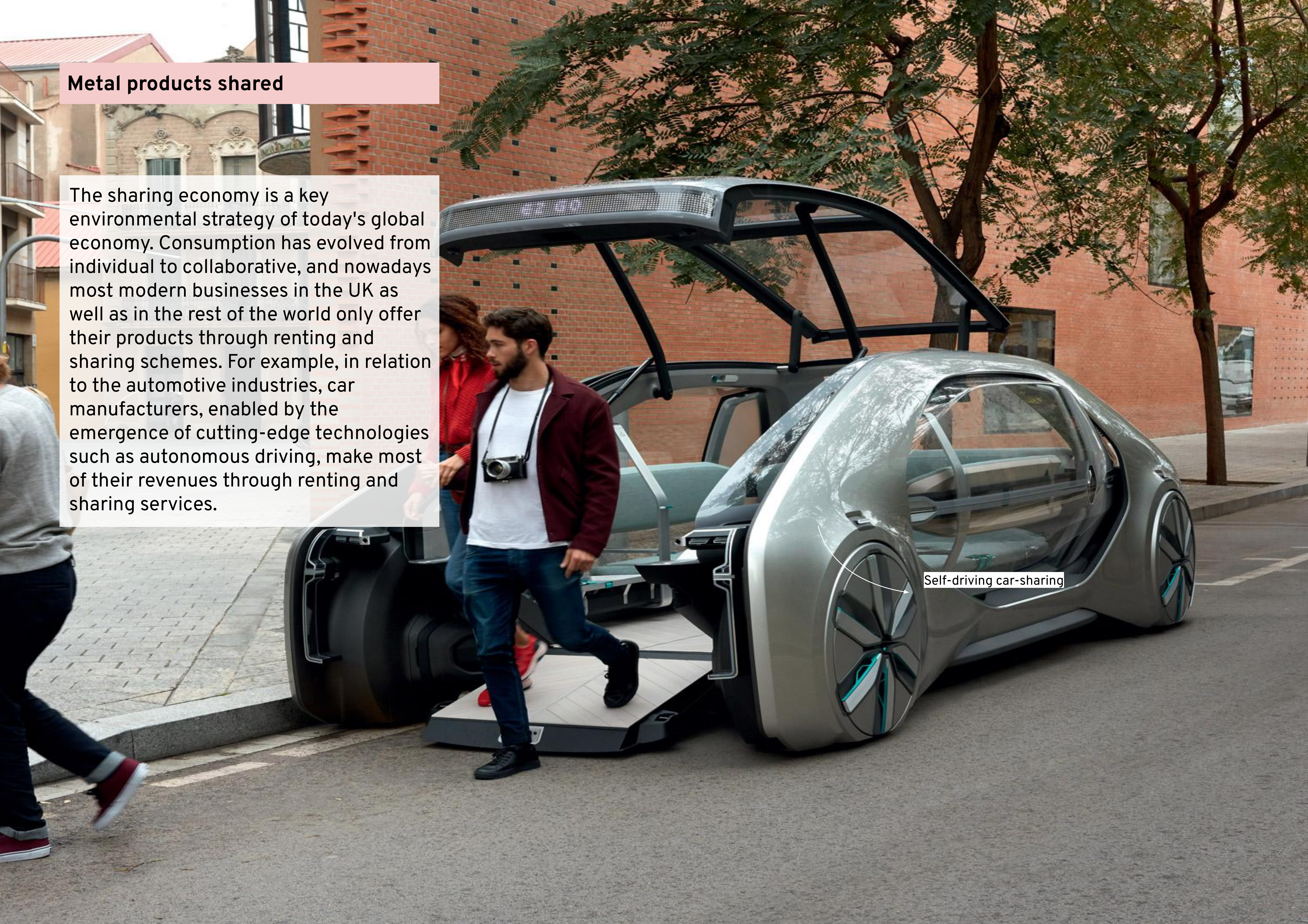
Nowadays, consumers are increasingly turning to the products-as-a-service business models. Subscription and pay-per-service models are just two examples of this new consuming pattern. For example, most buildings employ today a business model based on the use of multifunctional façades. The customer is no longer the owner of the building envelope, but pays for the functions delivered by the façade (e.g. home insulation, energy generation) through a long-term performance contract. The provider is responsible for the installation, maintenance, repair and decommissioning of the façade.



Window-as-service system replacement in a London building.

Metal products shared

The sharing economy is a key environmental strategy of today's global economy. Consumption has evolved from individual to collaborative, and nowadays most modern businesses in the UK as well as in the rest of the world only offer their products through renting and sharing schemes. For example, in relation to the automotive industries, car manufacturers, enabled by the emergence of cutting-edge technologies such as autonomous driving, make most of their revenues through renting and sharing services.



Self-driving car-sharing

Buildings and structural components as a service

Metal component and raw material manufacturers offer building structural components as a service. As a result, it is now usual to market ‘structural integrity' rather than components for civil engineering projects (e.g. bridges). Companies are paid a monthly fee to install, maintain, improve, and decommission the structure. They also offer ‘building-as-a-service' in collaboration with contractors. They own the building and rent or lease it. As such, they are incentivised by having the building used for as long as possible and decommissioned with all parts reused. In some circumstances, the service also includes the building's energy consumption.

Social bubble collaborative economy

To support the current sharing economy, cities and neighbourhoods (in the case of large cities) have developed over the years different sharing models tailored to specific social communities in relation to their specific needs. For example, a dedicated reservation system can allow residents of a specific community to book services available to them such as cars and micro-mobility to move around their neighbourhoods. The district can provide various subscriptions to meet the needs of its members as well as possibilities. Nowadays, most urban and non-urban districts are run by social cyber-physical systems that encourage community sharing of assets.

Metal life cycle data

Midway through the 2020s, the UK government built an **open metal data infrastructure** to make data available to companies along the supply chain in order to maximise metals' circularity. This was also made possible by the spread of asset-monitoring technologies such as **Digital passport on Metal Blockchain**. These technologies have increased openness and data responsibility among all stakeholders. Data collecting via increasingly implanted intelligent sensors in physical equipment has also facilitated the development of **metal digital twins**. This technology revolutionised equipment control, allowing for real-time monitoring of environmental and economic performance. Smart sensors have also enabled **material banks**, which employ disused facilities and products as material supplies for new applications. Cognitive computing and machine-to-machine communication have accelerated the development of **autonomous marketplaces** for selling/exchange of metal components. Even **household products are becoming autonomous**, gathering data and providing insights on energy optimisation and utilisation. **Metals are also embedded with nanosensors**, allowing for the collection of data that can inform humans or non-human systems in planning maintenance, repairs, and advising the user on best practices.

SNAPSHOTS FROM THE FUTURE:

1. Open-government metal data for the metal sector
2. Digital passport on blockchain
3. Remote maintenance and repairing with digital twins
4. Components and materials banks
5. Autonomous marketplace of components
6. Autonomous household product
7. Nanosensors embedded in metals to gather life cycle data

Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
Data may be difficult to keep updated - It may be difficult to keep data up to date and available throughout numerous product life cycles and long-lasting products (e.g., buildings).	TECHNOLOGICAL	**Creating an open metal data management system** - Development of an "open metal" stock cadaster enabling long-term data gathering, access, sharing, and use (Oezdemir et al., 2017).
Lack of data transparency on material stocks - Inability to obtain transparent data and information regarding material stocks and flows.	TECHNOLOGICAL	**Development of a centralised data aggregation system** - Development of a centralised data aggregation system (e.g. blockchain) that is transparent, credible and is maintained and managed by impartial players in a trustworthy environment (Kouhizadeh et al., 2019).
Environmental issues of data storage and generation - Hidden environmental implications of data storage and production, as well as their understanding.	ECOLOGICAL	**Improving data centre efficiency and energy usage** -Improving the efficiency of data centres for data storage and transmission, as well as utilising renewable energy to power data centres. Additionally, promote the representation and identification of data consumption in order to inform decision-making (Lucivero, 2019).
Data access, quality, and user privacy - Socio-ethical challenges associated with data access, quality monitoring, and user data privacy assurance.	SOCIAL	**Improve user data protection policies** - Advocate for stronger regulation of data access, quality monitoring, and user data privacy assurance. This could involve working with policymakers to develop new laws and regulations that would help to protect users' data privacy rights (Upadhyay et al., 2021).
Lack of data protection and standards - Inadequate data protection, as well as a lack of international collaboration on data standards and use, can result in data gaps, legal constraints on data use, and insecurity for the user.	POLITICAL	**Flexible data-governance frameworks enable interoperability** - Development of flexible data-governance frameworks and platforms that use common, open standards data formats and sharing to enable interoperability, security, and trust between public and private entities.
SMEs lack access to helpful databases and technology - Due to economic, organisational, and technical barriers, SMEs do not have easy access to databases and technology that can support decision-making and the adaption of circular business models.	ECONOMICS	**Foster demand for network engagement in SMEs** - Through government funding for the establishment of SMEs' networks, it is possible to enable stakeholders in the CE to collaborate on the adoption, development, and/or acquisition of CE-enabling technology (Rizos et al., 2016).

Open-government metal data for the metal sector

In 2025, the UK government established a platform for sharing open format government data in the metals sector. The UK has also partnered with other governments around the world to provide crucial information. This enabled enterprises to have access to, utilise, and share this information. In addition, the government collaborated with businesses and other stakeholders to create standards and best practices for handling and utilising data. The sector is supported by an open government data infrastructure that offers all stakeholders throughout the metal supply chain with fast, accurate, and reliable information about the sector. This infrastructure is utilised to help make decisions, drive innovation, and boost the sector's competitiveness.

Digital passport on Metal Blockchain

Over the last few decades, the UK metal sector developed a digital passport system that enables the seamless tracking of metals and metal products throughout the global metal supply chain. This was made possible by the widely used Metal Blockchain, a distributed database that enables safe, transparent, and tamper-proof record-keeping.
Companies can use this technology to trace the environmental impact of each metal throughout its life cycle and utilise this information to make more sustainable and ethical decisions. Also, the technology allows the identification of reused, reconditioned, remanufactured products and recycled materials that ensures the UK metal sector reaches its ambitious circularity ambitions.

Remote maintenance and repairing with digital twins

In 2050, most complex items and systems are being controlled, updated, and maintained by digital twins. Smart sensors embedded in physical objects and buildings can monitor critical functions and promote easy and fast decision-making, resulting in greater insights and optimisation for asset managers and better value over the life of the asset. As a result, assets now perform better in terms of both environmental and economic performance.

Digital twin of an airplane engine that is examined to see if everything is working properly

Components and materials banks

Component and material banks are key repositories of valuable metal stocks in today's modern economy. These banks are enabled by new intelligent identification systems that allow the geolocation of material/component stocks. They apply inventory quality control processes and allow exchanges between companies and users to guarantee efficient metal use. Also, even when stock is on loan, ownership rights and responsibilities are transferred through the banking system.

The Material Banks platform for components and materials reselling

Autonomous marketplace of components

The practice of selling components of used and surplus items, even in small quantities, is now commercially profitable thanks to the application of autonomous decision-making processes based on machine learning. Computers can bid, negotiate, and pay for components, materials, or services via machine-to-machine communication.

Autonomous household products

In 2050 consumer products can monitor their usage patterns and continuously assess their state and their usage time. On the basis of this, products provide a range of advices to the users. For example, if the product is under utilised or not used for a long period of time, the user is advised to sell the product or terminate the service agreement with the provider. Products can also provide insights on how to improve usage to optimise energy consumption in use.

The toaster shows how many times it has been used

Nanosensors embedded in metals to gather life cycle data

Due to developments in electronics and intelligent materials, most high-value products now have interfacing materials that can communicate information with humans or non-humans. Nanosensors coated on metals through a electrodeposition process can capture data on temperature, performance, proximity, and product condition. Collected data is used to anticipate the status of the product, as well as to plan maintenance and repair, and advise the user on recommended practices.

Information at the driver's hand to determine the condition of the vehicle and the best performance

Full metal packaging

Single-use packaging is used only when strictly necessary, and metal is the most used material in the packaging sector, for its quality in preserving food quality, prolonging shelf life, and safeguarding food from contamination. The majority of packaging is intended to be reused numerous times before being recycled to complete the resource cycle
Multiple reusable packaging models, with different degrees of user responsibility, are available in 2050, including **packaging deposit schemes, reverse vending schemes**, **milkman model and reusable packaging on-the-go**.

SNAPSHOTS FROM THE FUTURE:

1. Pure Metal
2. Packaging deposit schemes
3. Milkman model
4. Refilling station
5. Reusable packaging on-the-go
6. Reverse vending schemes

Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
SMEs lack resources for reusable packaging - Barriers to SMEs accessing or developing novel technology and infrastructure in order to make the switch to reusable packaging.	TECHNOLOGICAL	**Activating system-level change through collaboration and organisation** - Enabling collaboration and organisation among all stakeholders across the value chain to activate system-level change and establish the infrastructure required to build a standardised reusable system (WEF, 2021).
Circular business strategies are expensive - The deployment of circular business models and the associated reverse logistics face significant challenges in terms of cost and environmental effect.	ECOLOGICAL	**Reduce supply chain length and transportation distance** - Several aspects of reverse logistics, such as packaging cleaning, can be done regionally, reducing supply chain length and transportation distance. Systemic approaches, such as reusing software, can be controlled at the (inter)national level, establishing common tools (e.g. applications), protocols, and communication strategies (Brazão et al., 2021).
Lack of circular and sustainable metrics - Circular and sustainable metrics and tools such as LCA for the packaging business are lacking or not suitable - e.g., LCA does not take into account fleet emissions, material prices or local collection and sorting (CISL, 2020).	ECOLOGICAL	**Collaboration to establish packaging industry standards** - By working together, firms, research centres, investors, and regulators may co-develop and establish a rigorous set of standard measurement frameworks and tools tailored to the packaging industry.
User change is difficult due to reliance on linear economy - Change in behaviours is difficult for users due to their reliance on the linear economy and the effort involved in using reusable packaging.	SOCIAL	**Incentivising customers to reuse packing containers** - Bars, grocery stores, and supermarkets could become more reuse-friendly by incentivising customers to bring their own packing, developing and promoting reusability in the store, teaching employees to require reusable containers, and offering discounts to customers who bring their own (Erts et al., 2017).

Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
Complexity in the circular supply chain results in food insecurity - Circular supply chain complexity may lead to higher food prices, leaving low-income communities with fewer options and less access to convenient meal solutions.	SOCIAL	**Many stakeholders, one goal, one roadmap** - To avoid unintended consequences in the packaging industry's transition to CE like food insecurity, the entire value chain must be aligned on long-term objectives and roadmaps (Cornaby, 2020).
Infrastructure is a barrier to reusable packaging - Reusable packaging systems are hindered by a lack of infrastructure.	POLITICAL	**Policy support for reusable packaging systems** - Policy support, private and public investments in the creation of a standardised system of reusable packaging to reduce operational costs, create necessary economies of scale, and maximise the environmental benefits of reusable packaging systems (Brazão et al., 2021).
Lack of interdisciplinary point of view - When it comes to food waste and loss, packaging accounts for only approximately 5% of the entire carbon impact.	POLITICAL	**Incentivise community-based food systems for health** - Incentivise a systemic view of the food supply chain that considers a more local and community-based approach to encouraging sufficiency, healthy diet and, therefore, a healthy lifestyles.
SME business models need to evolve - Dependency on linear economy and infrastructure for SMEs to change their business models.	ECONOMICS	**Incentives for proactive businesses, penalties for laggards** - Tax incentives or other policies that reward forward-leaning businesses and penalise laggards.

Pure Metal

Packaging makers today use a relatively small variety of alloys and construct their own containers with the same kind of metal (i.e. monomateric packaging) in order to preserve the purity of the metal, whether it is aluminium or steel.

Unlike in the past, cans are today made of the same aluminium alloy

Packaging deposit schemes

All UK supermarkets have agreed on a standard reusable packaging system, which is shared among all supermarket brands. Today, supermarkets can recover and reuse each other's packaging. Aside from the packaging, which comes in a variety of forms and sizes, the only difference is the label. This can be readily applied, removed, reused or recycled. Users pay a deposit at the time of purchase, which is refunded when the package is returned.

An icon indicating that grocery store packaging should be returned

Milkman Model

Today most of the shopping is done directly from home rather than in conventional places such as supermarkets. Whenever possible, reusable packaging is used to deliver food & beverage, personal care items and products. Empty packaging is taken back, sanitised and reused. To reduce environmental impact, delivery and collection is optimised and carried out using electric vehicles.

Refilling station

Refilling stations have become common for food & beverage, and personal care and home care products. Reusable packaging can be borrowed from the store or brought in by the customer.

Reusable packaging on-the-go

Reusable packaging has become mainstream for take-away and on-the-go solutions. Single-use packaging is only a vague memory thanks to an integrated reuse system used by the entire restaurant industry. Thanks to these new reuse models managed by third party and used by most of the catering sector, today all services can provide reusable takeaway and delivery packaging.

Reverse vending schemes

Today, all metal packaging may be returned through reverse vending machines. The containers are sterilised and reused in large food distribution centres. Within the UK, all containers are standard and, upon return, the now widespread collection machines will refund the deposit paid with the content to the user. The credit can be repaid in various ways depending on the preferences of the users.

Stop Recycling Start Repairing

Today's economy is built on the principle of repair, while recycling is used less and less. It is now possible to easily extend the life of metal products and components thanks to cutting-edge technologies. Specialised companies provide new services for the maintenance/repair of metal products and components, known as the **Metal Health Service** (MHS). This includes services such as **component rejuvenation**, **structure rejuvenation** and **day hospital**.
Due to the presence of several **repair entrepreneurs**, repairing is not only accomplished on a large scale, but also on a micro and local level.
In addition, due to achievements in research and technical innovations, materials have improved in terms of performance and ability to **self-heal**. Metals' components can now self-heal microscopic cracks, greatly prolonging the life of goods.

SNAPSHOTS FROM THE FUTURE:

1. MHS - Components rejuvenation
2. MHS - Structure rejuvenation
3. MHS - Metal day hospital
4. Micro repair entrepreneurs
5. Self-healing metal

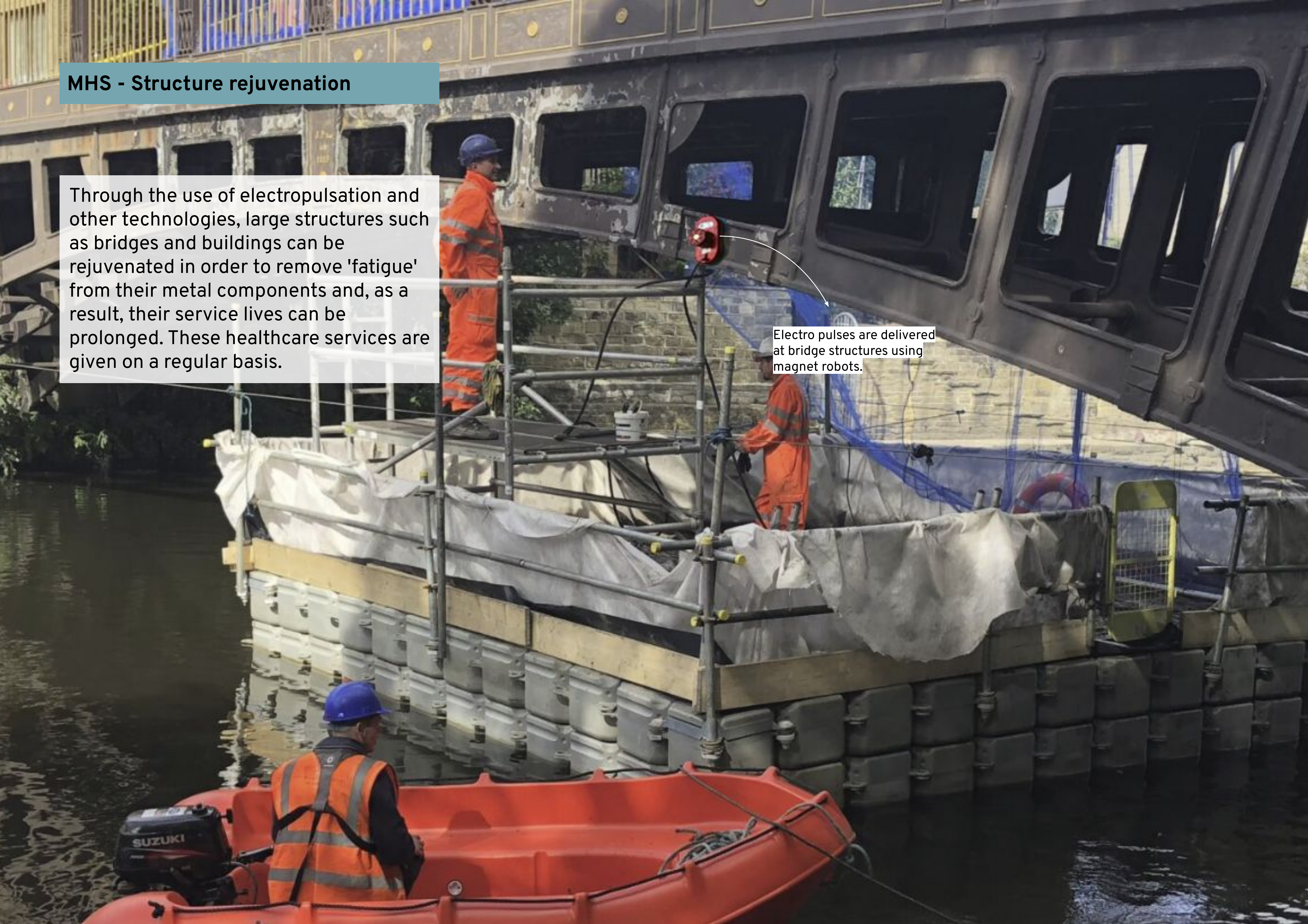
Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
Repair is challenging due to materials' complexity, technology, and lack of knowledge - The complexity of materials, technologies and a lack of specialised knowledge make it difficult to create and scale repair solutions efficiently.	TECHNOLOGICAL	**Developing frameworks for implementing circular capabilities** - Businesses need to develop new circular capabilities to respond to — and shape — changes in their environments. Organisations in the public and private sectors can develop frameworks for implementing circular capabilities at all levels of the supply chain.
Before commercialisation, intelligent materials require safety assurance - While intelligent materials and novel repair methods remain a great possibility, their quality and safety must be ensured prior to their commercialisation.	TECHNOLOGICAL	**Reviews of safety and performance** - Evaluations of safety and performance in a controlled environment are required to ensure the long-term quality and security of new materials and repair devices based on approved scientific evidence.
Smart metals can create new and hazardous waste - Advanced and smart metals (e.g. self-repair metals) can create new waste streams and hazardous waste as an unintended consequence. Furthermore, there is a lack of clarity regarding whether these smart materials can be recycled in the same way as conventional metals.	ECOLOGICAL	**More research is needed on smart metal recycling** - To avoid the production of new waste streams or hazardous waste, extensive investigation and analysis of potential rebound effects and recycling approaches are needed.
Lack of skilled maintenance and repair experts - Lack of maintenance and repair experts capable of evaluating and carrying out planned maintenance and specialised repair activities due to a lack of skills and training.	SOCIAL	**Vocational colleges should include repair education** - Vocational and engineering colleges should include repair education as an essential part of their curriculum. Knowledge-driven organisations should also be supported and funded to develop repair knowledge in specific sectors (e.g. qualification in electrical repair).
Legal and contractual restrictions may limit repairs - Repair activities may be limited by legal and contractual restrictions.	POLITICAL	**Framework is needed to support repair and reuse** - A contractual/legal framework is needed to support repair, longer product lifespans and multiple owners/users over a period of time.
Inadequate evidence on the repair economy - Lack of information regarding the cost-effectiveness and environmental characteristics of these new materials and repair techniques in supporting a repair-based economy.	ECONOMICS	**Economic studies on repair must be promoted and supported** - Economic and environmental research must be promoted and supported in order to establish scientifically that these novel materials and methodologies may benefit the transition to a CE.

MHS - Components rejuvenation

In 2050, most metal components can be effectively repaired thanks to new metal rejuvenation techniques. Specialised companies adopt different technologies such as electropulsive technology to offer treatment services to remove the 'fatigue' in metal components and as a result extend components' and products' lifespan. These treatment services are delivered in a few hours on a regular basis (e.g., for cars, every 100k km). In order to facilitate these interventions, products are designed to easily and quickly access those key components that are subject to mechanical fatigue.

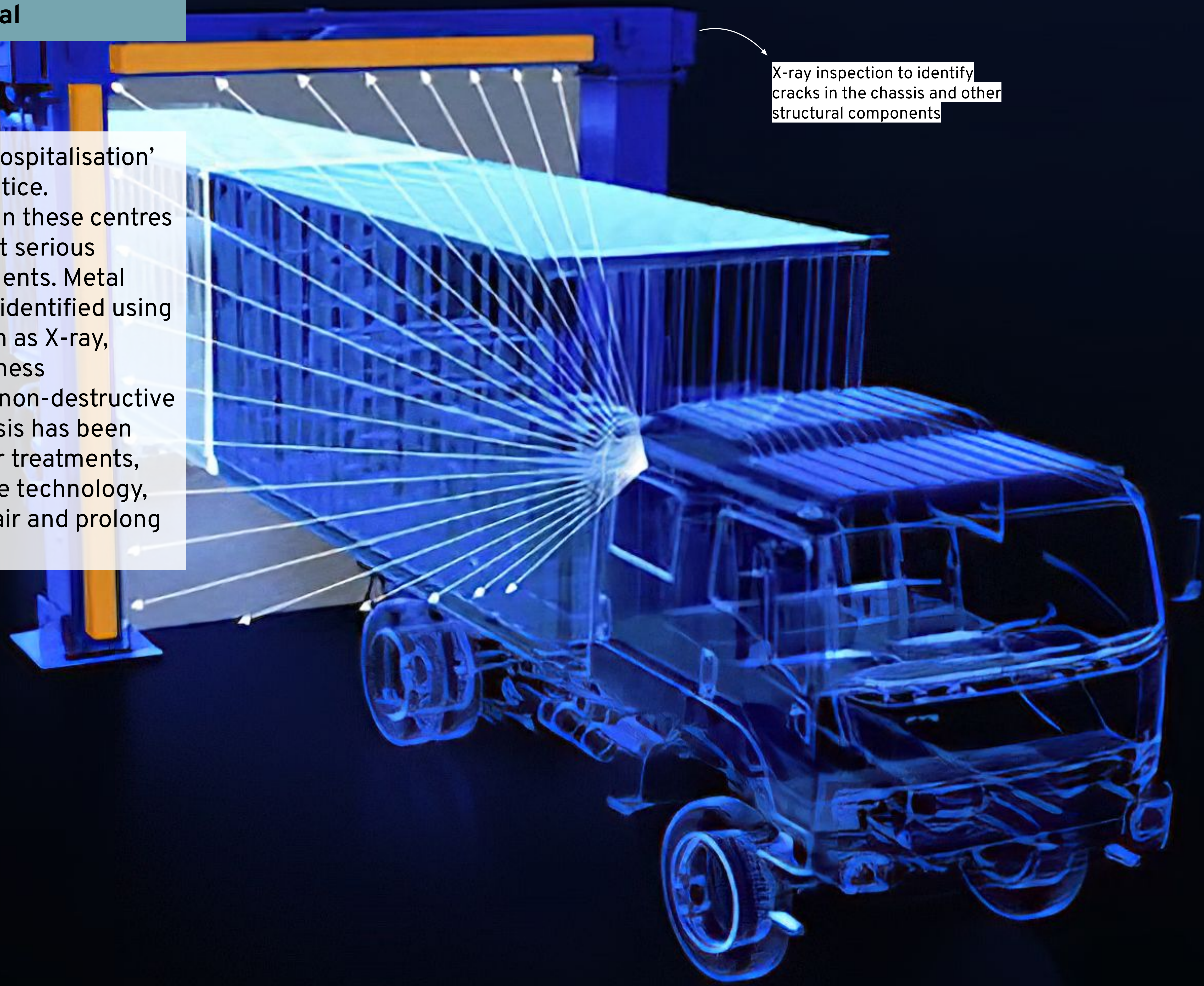
MHS - Structure rejuvenation

Through the use of electropulsation and other technologies, large structures such as bridges and buildings can be rejuvenated in order to remove 'fatigue' from their metal components and, as a result, their service lives can be prolonged. These healthcare services are given on a regular basis.



MHS - Metal day hospital

Today, the use of metal ‘hospitalisation’ centres is a common practice. Specialised companies run these centres providing services to treat serious damage to metal components. Metal component faults can be identified using various technologies such as X-ray, ultrasonic, surface roughness measurement, and other non-destructive methods. Once the analysis has been carried out, various repair treatments, based on the electro pulse technology, can be carried out to repair and prolong the life of components.

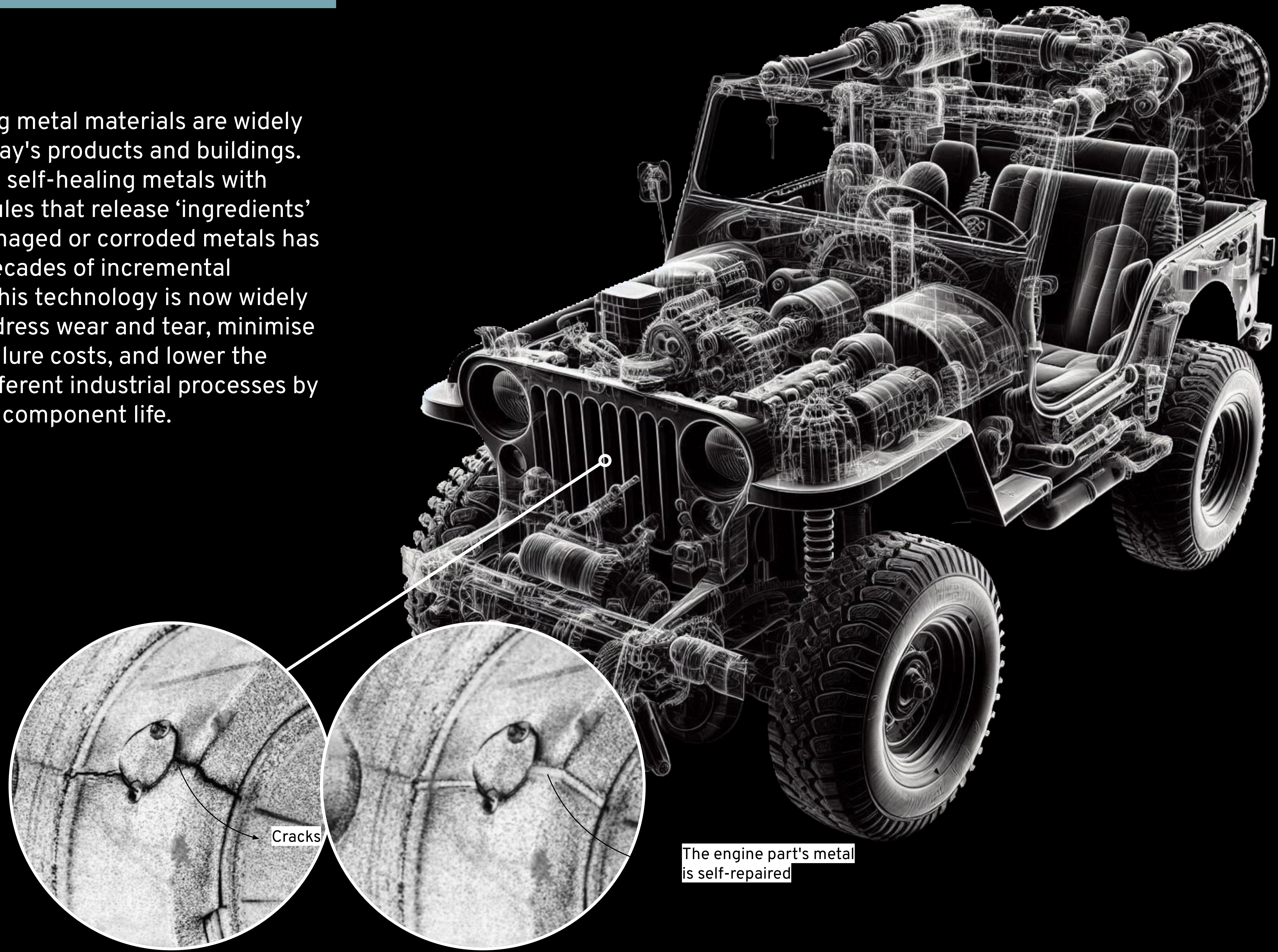


Micro repair entrepreneurs

Today, the UK has a thriving repair economy, with micro repair entrepreneurs providing local services to consumers and businesses. These entrepreneurs are exceptionally proficient at repairing everything. They use innovative techniques and tools to repair items quickly and efficiently. As more consumers use high-quality metal products, the demand for micro repair services has increased significantly during the previous three decades. For this reason, micro repair entrepreneurs are a vital part of the UK repair economy as they help to reduce waste and conserve resources.

Self-healing metal

Self-healing metal materials are widely used in today's products and buildings. Developing self-healing metals with microcapsules that release ‘ingredients’ to cure damaged or corroded metals has required decades of incremental research. This technology is now widely used to address wear and tear, minimise material failure costs, and lower the costs of different industrial processes by prolonging component life.



Repair-it-yourself (RIY)

People nowadays own fewer but higher-quality products. They are used to looking after their items and perform maintenance and repair tasks. The reuse and repair economy has outgrown the old throwaway approach, making it quicker and more convenient for customers to repair broken or damaged things rather than throwing them away and purchasing new ones. Thanks to **courses provided in schools**, maintaining and repairing products has become common knowledge. People can also learn and share practices in **repair community centres**.
Repair kits are becoming increasingly widely available. Customers use them to fix simple metal components on their own, which saves them money and time. In addition, **repair technologies** such as augmented reality are being used by people to fix more sophisticated items. Companies, on the other hand, are keen, for competitive and regulatory reasons, to facilitate these activities. Repairability is a key criterion for users when selecting products and brands. Users can obtain this type of information from any **digital platform** available today, in addition to instructions on how to do maintenance and repairs.

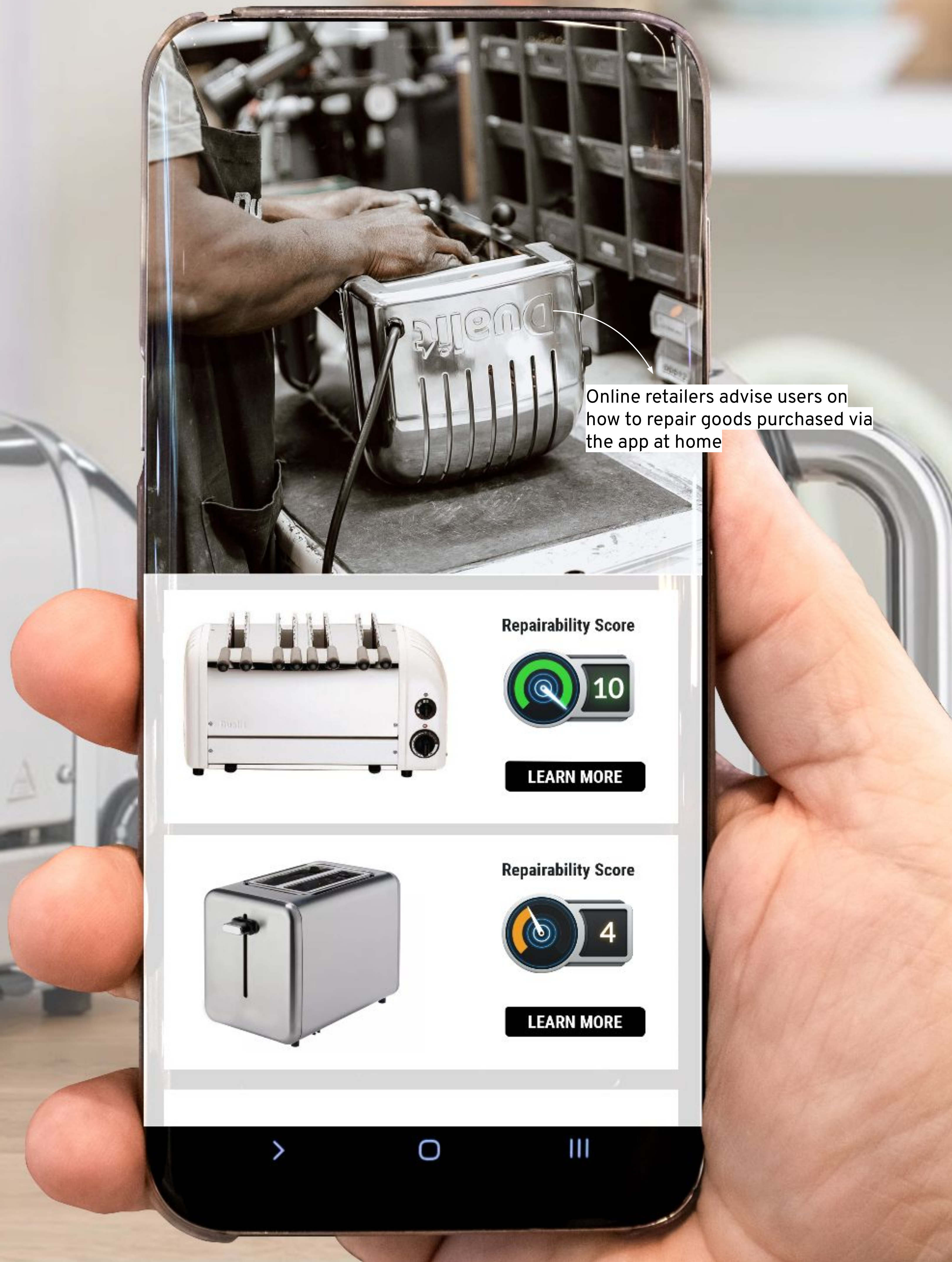
SNAPSHOTS FROM THE FUTURE:

1. RIY- Repair digital platforms
2. RIY- First-aid repair kit
3. RIY- Repairs technologies
4. School-based repair courses
5. Repair community centres

Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
Design prevents easy repair - The design of the product is a major impediment to repair.	TECHNOLOGICAL	**Create metrics for repairable product design** - New circular metal design metrics should be developed to encourage corporations to design products and to establish conditions that lead to repairability (DEFRA, 2021).
No incentive to repair after guarantee expires - There are no incentives for users to prolong the life of their products by repairing them after the guarantee has expired.	SOCIAL	**Enhance financial repair operations for non-warranty items** - The government can incentivise companies and users to repair the failed product even after the warranty has expired through repair credit (e.g. maximum credit of £500 per year to users), tax breaks for companies to extend guarantee programmes, subsidies, or other financial incentives.
Lack of support for non-traditional repair options - Inadequate contractual/legal framework and insurance mechanisms to support alternative repair options, such as independent repair or household repair.	POLITICAL	**Specifying risks/liabilities for component/product performance** - It is necessary to establish a legal/contractual framework specifying shared risk/liability for component and product performance. Open source knowledge regarding repair methods, as well as blueprints for decentralised/distributed manufacturing (3D printing), may help alleviate the negative repercussions of the centralised distribution of repair components and materials.
Lack of an internationally recognised repairability index - Lack of a repairability index that takes into account the range of "repairability" metrics and the views of potential repair stakeholders, including manufacturers, independent companies and households.	POLITICAL	**Establish repairability index to compare repair options and safety** - Establish a repairability index that considers the range of repairability metrics and the views of potential repair participants. This index could be used to help manufacturers, independent companies and households make informed decisions about repair options.

RIY- Repair digital platforms

In 2050 companies are required to provide a repairability index for all their products. The index measures how easy it is for users to repair products, and includes criteria such as availability of spare parts, ease of disassembly and so on, and a minimum threshold must be achieved. It is a compulsory requirement for all companies worldwide. The repairability index is also displayed by online retailers. Online retailers also provide maintenance and repair recommendations through their digital platforms. Evaluating the ease of disassembly of the product, the availability of spare parts and technical documentation are now crucial aspects for users before making any purchase.



RIY- First-aid repair kit

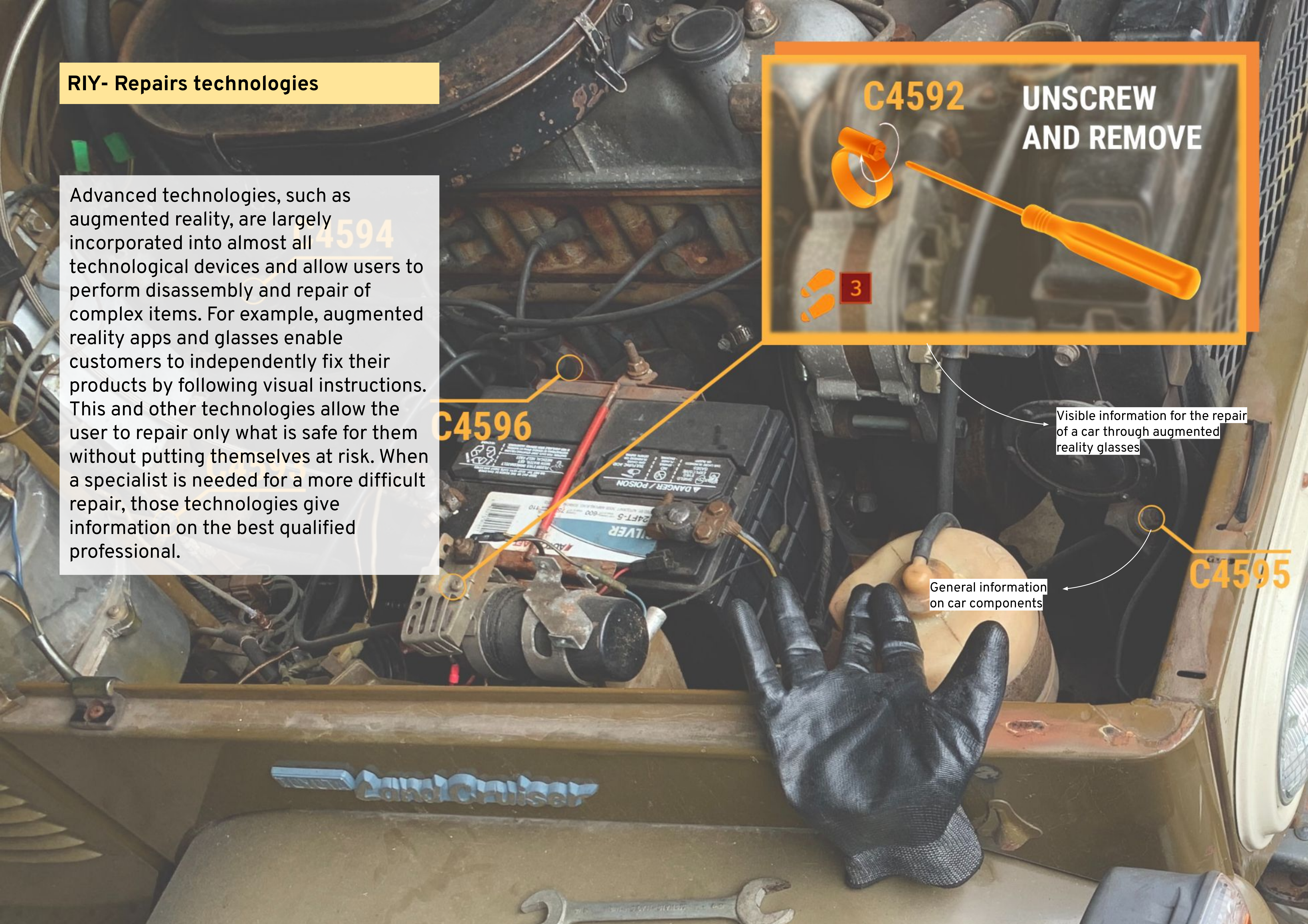
The acceptance of imperfection and the 'imperfect' aesthetics of mended products are increasingly appreciated in contemporary society. Today, repair kits for virtually any material are accessible, enabling consumers to appreciate imperfection through self-restoration. As a result, users develop emotional attachments to their products.

Putty for the repair of different high performance metals

Metal repair kit to keep at home at all times

RIY- Repairs technologies

Advanced technologies, such as augmented reality, are largely incorporated into almost all technological devices and allow users to perform disassembly and repair of complex items. For example, augmented reality apps and glasses enable customers to independently fix their products by following visual instructions. This and other technologies allow the user to repair only what is safe for them without putting themselves at risk. When a specialist is needed for a more difficult repair, those technologies give information on the best qualified professional.



Visible information for the repair of a car through augmented reality glasses

General information on car components

School-based repair courses

Primary schools play a key role in educating children about product maintenance and repair. Schools have included ‘maintenance and repair’ in their curriculum and have dedicated spaces to carry out these activities in practice.

Children learning how to fix a drone at school, instead of buying a new one

Experienced repairers who are employed by schools to teach the art of repair

Repair community centres

Repair is an aspect of many people's everyday lives today. Dedicated spaces within communities are available to allow groups and individuals to have access to repair tools and knowledge from professionals. Repair has evolved into an activity that brings people together and supports communities in becoming more resilient and sustainable.

The logic of sufficiency

In 2050, people are becoming more aware of the ethical implications of overconsumption and are beginning to adopt a more sustainable approach to consumption. People tend to possess fewer, higher-quality products, which reduces material usage and can be passed down through generations (**Multigenerational products**).
The trend towards sustainable consumption is being pushed by initiatives such as **MyMetal**, which limits the amount of metal each person can own, and by the popularity of **open libraries of things**, which are locally owned stores that allow people to borrow items instead of buying them.
However, individual ownership is still important for certain products, as people form **emotional attachments** to these items and want to keep them for as long as possible.
To reduce emissions associated with product transportation, large and small retail companies now **deliver and pick up products only once a week**, depending on the postcode area in which the client lives.

SNAPSHOTS FROM THE FUTURE:

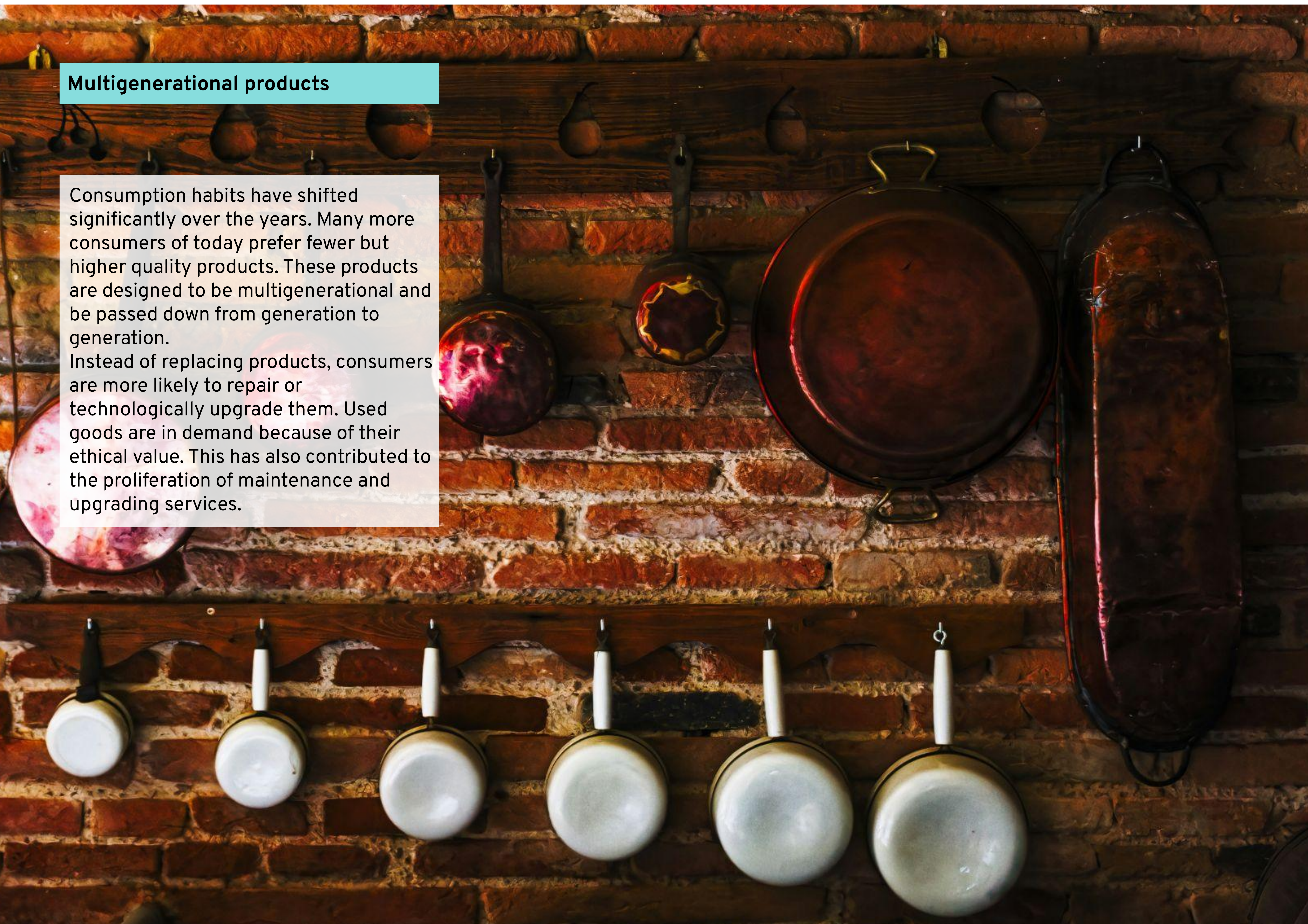
1. Multigenerational products
2. Open library of things
3. Emotional attachment
4. MyMetal
5. Deliveries once a week

Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
Adoption of new circular business models is difficult - Emerging business models based on product sharing are less appealing because they lack flexibility and simplicity for both the businesses and the users.	TECHNOLOGICAL	**Government incentives for new business model development and experimentation** - The government can offer incentives to businesses who adopt new technology and share infrastructure. These can make the sharing economy more accessible and flexible for consumers, as well as provide economic benefits for users in terms of affordable access to commodities.
Inability for businesses to shift focus to CE and sufficiency - Businesses continue to operate under a strong capitalist profit-driven model, rather than focusing on metal consumption reduction.	ECOLOGICAL	**Incentives and political considerations for a radical CE** - Concentrate national discussion, incentives, and political considerations on more radical aspects of the CE, such as reducing metal production and consumption and redesigning products to be reused safely, cost-effectively, and efficiently.
Impulsive consumption - Compulsive buying disorder can be a challenge to the transition to a sufficiency-based economy.	SOCIAL	**Encourage more sustainable behaviours through many strategies** - The government might promote more sustainable habits through education, advertising, campaigns, labelling, and social media.
Lack of understanding - Lack of understanding and/or willingness by the users to engage in CE.	SOCIAL	**Point-of-sale systems must be upgraded to provide better data to customers** - Businesses should prioritise improving information provision at the point of purchase (e.g., on labels or provided by manufacturers) as a means of encouraging customers to embrace CE behaviours (Cerulli-Harms, 2018).
Ensuring sufficiency is a political and leadership challenge - There is a lack of political will and leadership in sufficiency businesses since they are not providing significant economic benefits.	POLITICAL	**Develop new economic metrics** - Definition and application of novel indicators for measuring the circular economy that promote distinct metrics when compared to the typical linear economy indicators (Moraga et al., 2019).
Sufficiency may generate social issues - Sufficiency may lead to lack of growth, unemployment and deterioration of social well-being.	ECONOMICS	**More studies on sufficiency and its potential rebound effects are needed** - Additional research should be funded to have a better understanding of how to manage the transition to a sufficiency-based society rather than a growth-based society.

Multigenerational products

Consumption habits have shifted significantly over the years. Many more consumers of today prefer fewer but higher quality products. These products are designed to be multigenerational and be passed down from generation to generation.

Instead of replacing products, consumers are more likely to repair or technologically upgrade them. Used goods are in demand because of their ethical value. This has also contributed to the proliferation of maintenance and upgrading services.

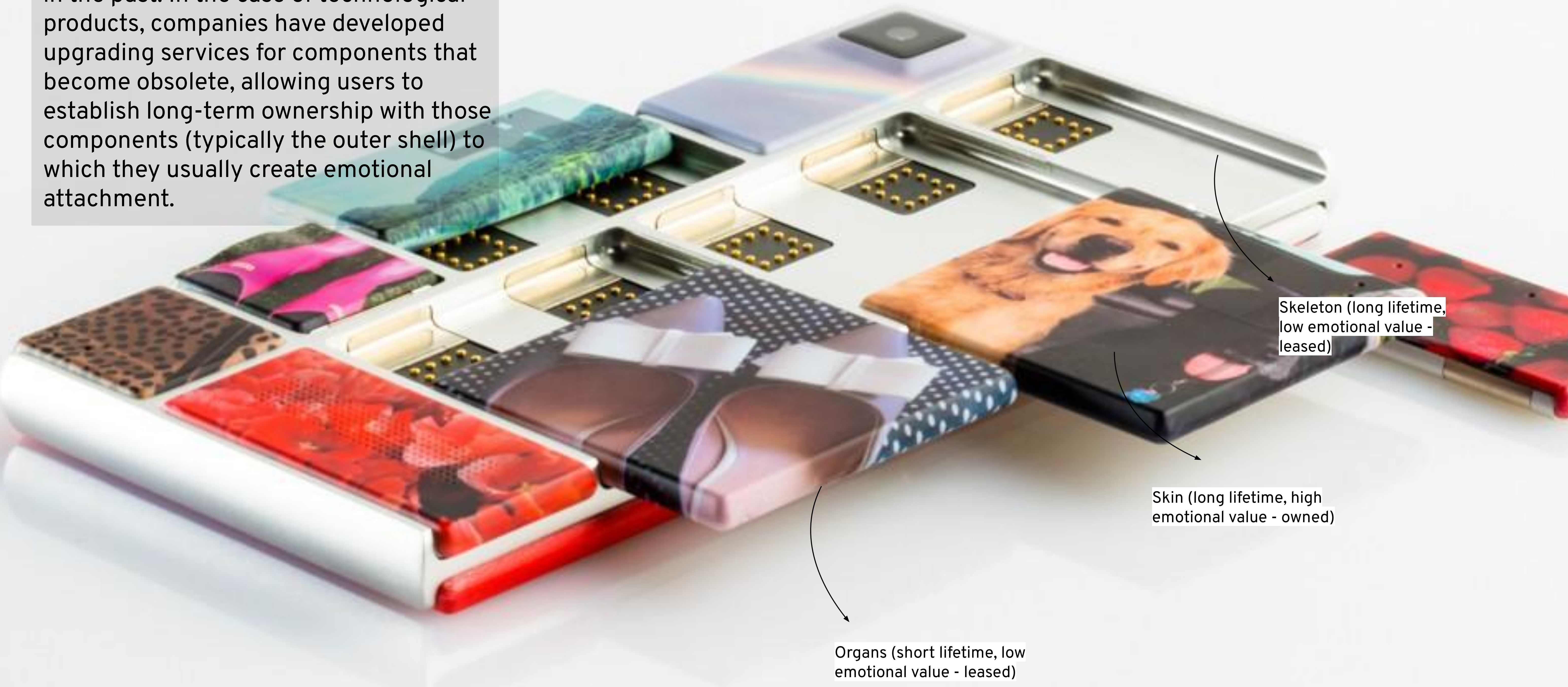


Open library of things

Today, owning a drill to make a hole in the wall once a year no longer makes sense. Products that are used occasionally are no longer owned by users, but are instead borrowed from a Library of Things. Because consumers may book and pick up goods on their own 24/7, borrowing goods is becoming more popular in neighbourhoods. The majority of the Library of Things is now a collaborative effort between communities and businesses.

Emotional Attachment

In today's society, people have fewer but higher quality products to bond with than in the past. In the case of technological products, companies have developed upgrading services for components that become obsolete, allowing users to establish long-term ownership with those components (typically the outer shell) to which they usually create emotional attachment.

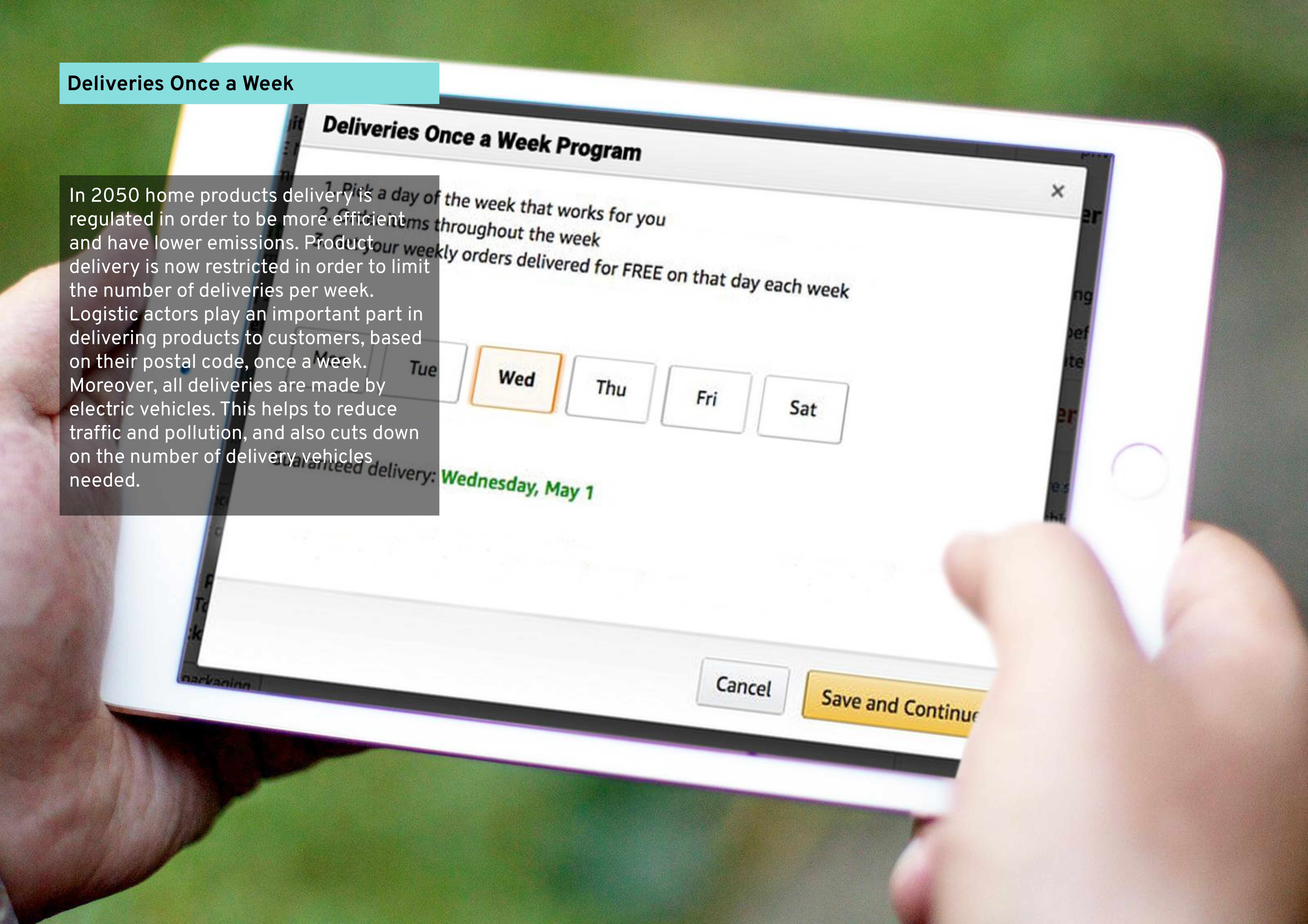


MyMetal

Due to the scarcity of metal and other materials, ownership is increasingly regulated. There is now a maximum allowance of metal that each individual can own simultaneously. This has pushed users to own fewer and higher quality products that can be passed down through generations.

Deliveries Once a Week

In 2050 home products delivery is regulated in order to be more efficient and have lower emissions. Product delivery is now restricted in order to limit the number of deliveries per week. Logistic actors play an important part in delivering products to customers, based on their postal code, once a week. Moreover, all deliveries are made by electric vehicles. This helps to reduce traffic and pollution, and also cuts down on the number of delivery vehicles needed.



Reusing, remanufacturing, and repurposing

In 2050, the UK is a world leader in reusing, remanufacturing, and repurposing products. UK waste management systems were originally built to handle the 'take-use-dispose' economy, but this has changed. Single-use items are a thing of the past, as more and more products are intended to be **reusable**, **remanufacturable**, or **repurposed**. The UK government has supported a radical shift in pace, encouraging the reuse of goods rather than the production of raw resources, via a vast infrastructure adjustment. Consumers were educated on the benefits of buying products that are made to last or repurposed. Currently, products are designed with repairability and upgradeability in mind, and manufacturers offer extensive repair and replacement options. As a result, the product recovery business is well-established and well-connected. Stable employment in remanufacturing and repurposing is a major source of economic growth.

SNAPSHOTS FROM THE FUTURE:

1. The renaissance of secondhand markets
2. Remanufacturing and refurbishment services become core offerings
3. Cascade Reusing

Barriers to the vision

Lenses of analysis

Opportunities and enablers for the vision

Lack of circular skills - Inadequate skills and expertise in areas such as product design that eliminates or minimises waste, infrastructure operation, and material handling.

TECHNOLOGICAL

Organisations should provide upskilling and reskilling training to their employees - Undergraduate courses in CE should be developed by colleges and institutions that have a strong focus on different aspects of the CE. Organisations should also provide employees with training in upskilling and reskilling in order to increase their capacity (De los Rios et al., 2016; Hina et al., 2016).

Scarcity of innovative mass automation technology for remanufacturing - There is a lack of use of innovative mass automation technology that would make remanufacturing easier, faster and more cost-effective.

TECHNOLOGICAL

Cooperation for the advancement of remanufacturing technologies - To make remanufacturing easier, faster, and more cost-effective, the public and commercial sectors should work together. This would involve a considerable initial investment, but would save money and time in the long term.

Designing for reusing, remanufacturing, and repurposing is complex - It is difficult to design the interactions between different life cycles, as well as the value that stakeholders could achieve for each life cycle.

ECOLOGICAL

New circular design frameworks should be established - Design frameworks should be developed to help stakeholders understand the various incentives and disincentives that are in place in the reuse, regeneration, and cascading economy. These can help stakeholders better understand how different life cycles are managed and how value is created in each life cycle.

Reticence of users to buy used products - Users have a negative impression of used, remanufactured or refurbished products and are hesitant to purchase them.

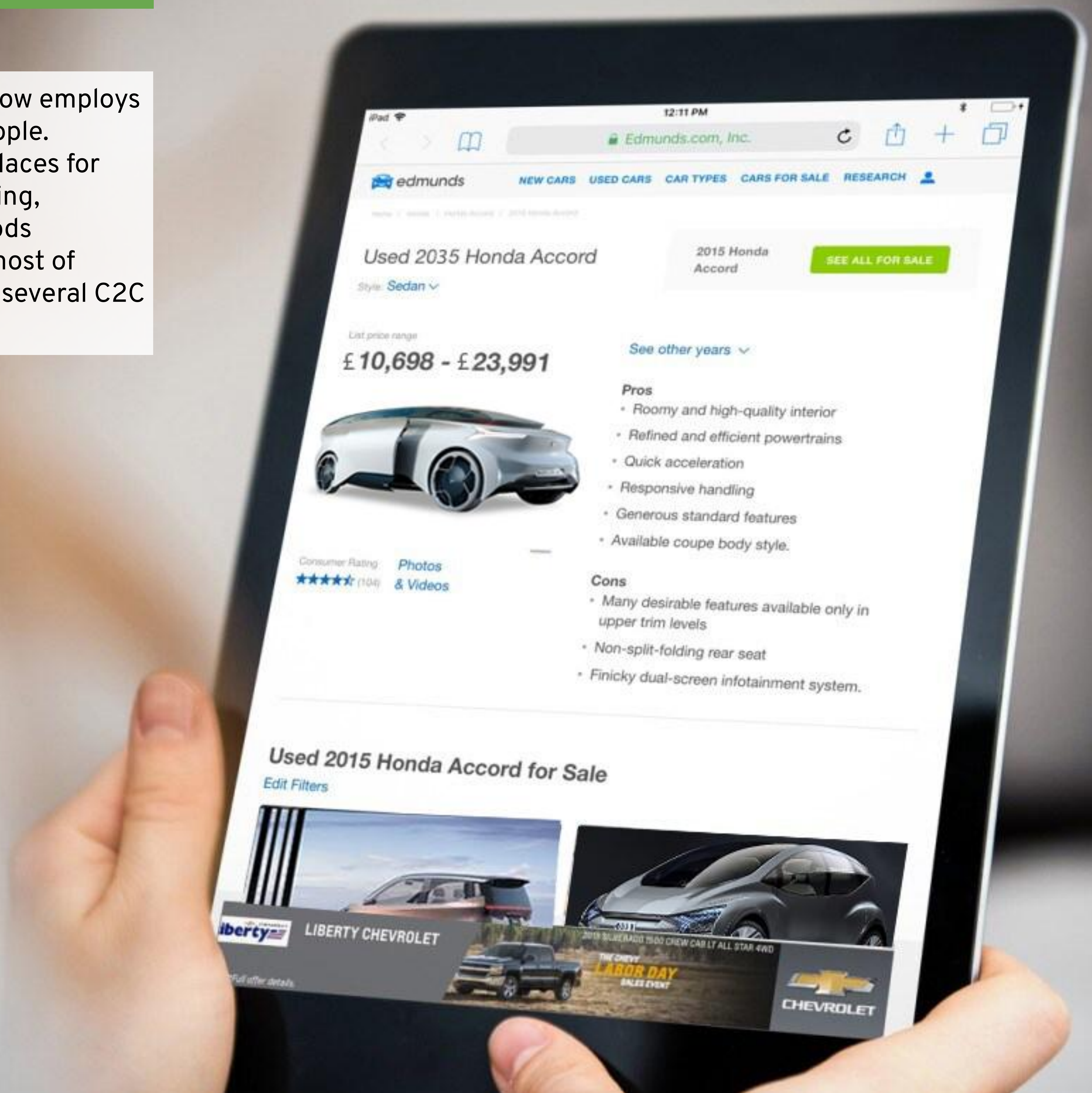
SOCIAL

A better understanding of consumer product evaluation is necessary - A deeper understanding of how consumers evaluate different used, refurbished and remanufactured products is necessary for corporations and designers to better understand the specifics of redistribution (Mugge et al., 2018).

Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
Different recovery procedures and jargon can be confusing for end users - Customers are confused by the various recovery methods and their associated terminology, and there is inconsistent information regarding the repairability or recycling of products.	SOCIAL	**Consistent and easily accessible information about recovery** - Businesses should provide customers with clear and consistent information about the various ways of recovery and the terminology connected with them. Additionally, through clear labelling and online resources, this information should be consistent and easily accessible across commodities, products and sectors (DEFRA, 2021).
National and international standards are required - To ensure that recovered items are of the highest quality, national and international standards, such as quality approval certifications, are required.	POLITICAL	**Organisations should ensure quality of recovered products** - Organisations should implement quality assurance systems to assure the greatest possible quality of recovered products. These procedures may include ensuring that all recovered goods adhere to the quality standards established by organisations such as ISO, CEN or BSI.
Not enough tax incentives for high-risk investing - Investing in high-risk new industries/markets is not encouraged by enough tax incentives from the government.	POLITICAL	**Tax incentives can encourage companies to invest** - The government can use tax incentives/credits, exemptions, or rate reductions to give direct benefits to stimulate and encourage companies to invest in and develop infrastructure for the used, refurbished and remanufactured product industries/markets. Taxation of new products is another option that could be considered (Benoy et al., 2014).
Lack of clear IP guidance hinders industry transformation - Inadequate IP management guidance and ambiguity around repair, reconditioning, refurbishing, and remanufacturing are major obstacles to industry's circular transformation (Hartwell et al., 2016).	POLITICAL	**Legislators should ensure clarity on IP management for different recovery approaches** - Legislators should issue sector-specific intellectual property management recommendations and define the legal definition of repair, reconditioning, refurbishing, and remanufacturing (Ballardini et al., 2020).
Remanufacturing requires long-term investment and labour-intensive activity - Maintenance, particularly in remanufacturing, requires a long-term investment by asset owners and a labour-intensive activity (e.g. disassembly, cleaning, inspection, testing) that can be too costly for some businesses.	ECONOMICS	**Encourage remanufacturing through public investment and data sharing** - Changing to a business model that encourages remanufacturing is an investment, and those who are willing to take the risk should be supported in their endeavours by public funding, sponsored research, and data-sharing (Benoy et al., 2014).

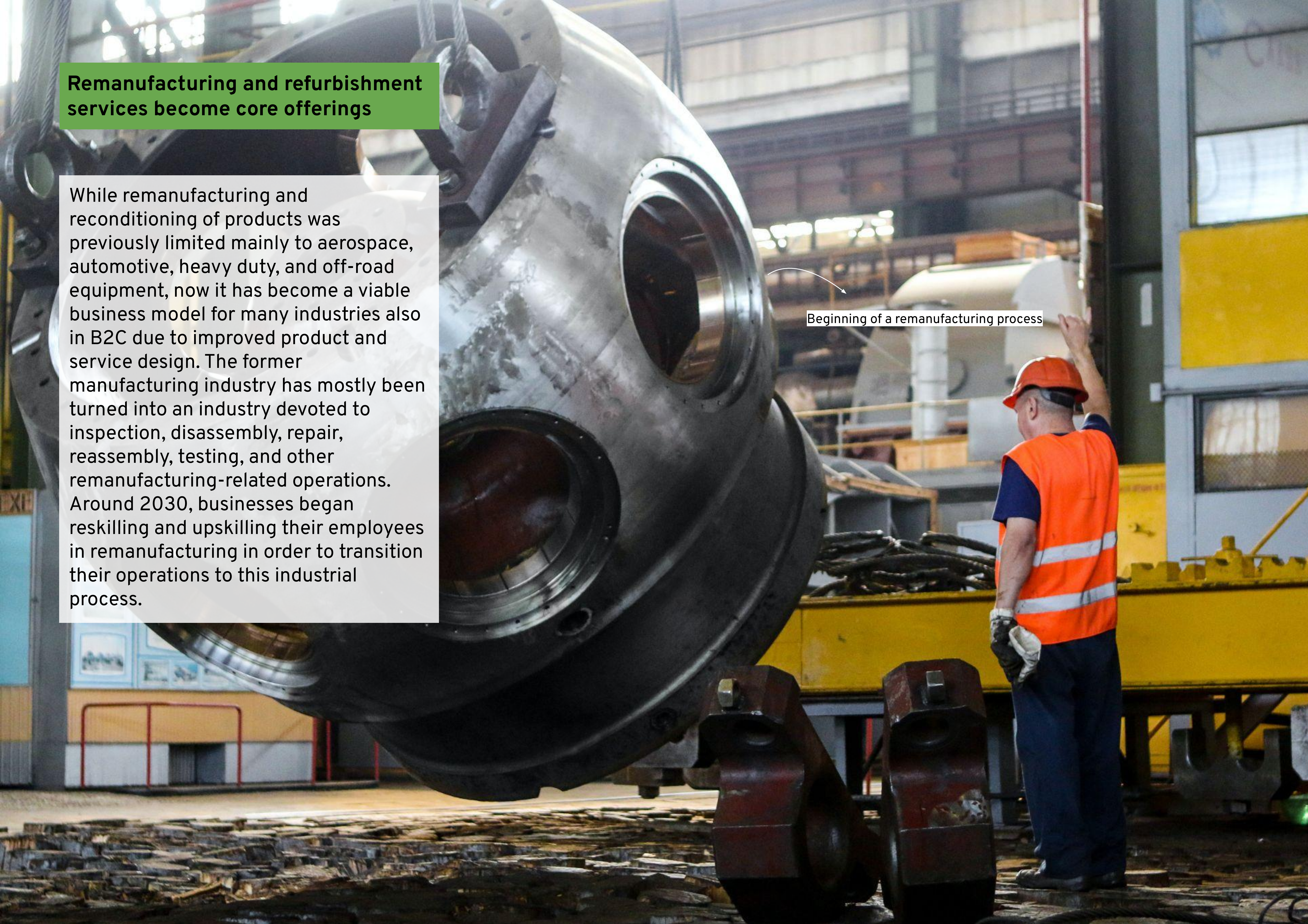
The renaissance of second-hand markets

The second-hand economy now employs a considerable number of people. Thousands of online marketplaces for selling, sharing, lending, renting, exchanging and donating goods dominate the market. While most of these are B2C, there are also several C2C and B2B marketplaces.



Remanufacturing and refurbishment services become core offerings

While remanufacturing and reconditioning of products was previously limited mainly to aerospace, automotive, heavy duty, and off-road equipment, now it has become a viable business model for many industries also in B2C due to improved product and service design. The former manufacturing industry has mostly been turned into an industry devoted to inspection, disassembly, repair, reassembly, testing, and other remanufacturing-related operations. Around 2030, businesses began reskilling and upskilling their employees in remanufacturing in order to transition their operations to this industrial process.



Beginning of a remanufacturing process

Cascade Reusing

Today, the reuse economy is flourishing in the UK. Metal cascade reuse is a key part of this economy, with businesses and government working together to ensure that metal resources are reused as much as possible. This was made feasible by a new law mandating the reuse of high-value items and components. The success of cascade reuse is heavily dependent on the design, i.e. products that can be used in multiple ways, or that can be broken down into smaller products that can be used on their own. For instance, an intermodal container can be used initially as a structure to store and transport goods, then as a dwelling, then as sheet metal for construction works, and finally as recyclable material.

Shipping containers are modular, standard and of the highest quality, making these products reusable for different purposes

Better metal recovery, sorting, upcycling and recycling

The reuse of material lies at the heart of today's most successful businesses. **Open distributed disassembly** (allowing for metal reuse by third parties) or **closed distributed disassembly** (components can be reused for the same initial function in closed loops) are common and cost-effective industrial practices used by the majority of businesses to disassemble small and medium-sized products, components and materials. Also, effective and quick **disassembling pods** are utilised for large structures, especially in remote locations.

Recovering underutilised value has never been more critical than it is today. **Intelligent waste management** systems facilitate collection and transport, through vacuum tube systems, to waste transfer stations. When reusing metal products is not practicable, **industrial upcycling** is the best option for recovering the material's value. **Urban mines** are another way to recover material value quickly and economically, especially in urban areas. This is possible by modern technological and design methods that make the disassembly process much simpler. In addition, even old landfills may be safely and sustainably mined for metal today (**landfill scavenging**), making it viable to reclaim metal from them. This is a significant advancement in recycling processes since it improves the quality and purity of the material recovered. Finally, **micro mobile foundry and upcycling workspaces** have become widespread. But technological advancement did not end with the recycling of current materials.

SNAPSHOTS FROM THE FUTURE:

1. Open distributed demanufacturing
2. Closed distributed demanufacturing
3. Disassembling pods
4. Industrial upcycling
5. Urban Mining
6. Smart waste management system
7. Landfill scavenging
8. Micro mobile foundry and upcycling workspaces

Barriers to the vision

Lenses of analysis

Opportunities and enablers for the vision

Supply chain and procurement influences - Supply chains and procurement routes must be diversified and improved in light of changes in regulations, business models, design and consumer behaviour.

TECHNOLOGICAL

Active sharing of policies, technology, and experiences - Developing global CE trade and sales requires important and successful stakeholders to actively share policies, technology, and experiences with partners. Additionally, research and academic institutions are suitable players for disseminating successful case studies (Hopkinson et al., 2018).

SMEs lack specialised circular advanced technology - Technological barriers for SMEs, particularly in terms of acquiring and/or conducting R&D on specialised circular advanced technologies, are limiting the growth of capabilities across the metal industrial sector.

TECHNOLOGICAL

Technology-specific sustainability regulations are needed - As technology evolves, businesses must rethink their capital investment strategy. To prepare for the green and circular technological transition, policymakers should collaborate with industry, academia, and NGOs. The implementation of technology-specific sustainability regulations, especially for SMEs, requires new and/or upgraded policy instruments that provide certainty, flexibility, and inclusiveness. (Söderholm, 2020).

A systematic approach for quantifying circularity is lacking - Despite the critical nature of adopting circularity indicators connected with recovery, recycling, reuse, and refurbishment, a systematic approach for quantifying circularity is lacking.

ECOLOGICAL

More research is needed to understand how to quantify circularity - Several circularity indicator methods are available or have been outlined at different phases of the product life cycle, sectors, and markets (Trollman et al., 2021; WBCSD, 2021; Pollard et al., 2022). However, due to the CE's complexity and systemic nature, the relationships between different variables, system levels and rebound effects are still largely unresolved. As a result, additional research is necessary to characterise the full scope of effects and to advance the total quantification of impacts (Harris et al., 2021).

Barriers to the vision	Lenses of analysis	Opportunities and enablers for the vision
This transition will result in less metallurgical production - The transition to more durable and circular products will result in a decline in metallurgical production, resulting in labour disruption with potentially negative effects for society.	SOCIAL	**Circular metal economy requires improved social economy understanding** - Transitioning to a CE is expected to result in a net improvement in employment rates (Lanzi et al., 2020). Numerous legal mechanisms can be adopted to assist adjustment and transition to new green jobs, as detailed in the RE-CE policy package (Chateau et al., 2020). However, a more detailed understanding of local and sectoral dynamics is critical to allow social economy groups to promote CE knowledge within their societies (OECD/EU, 2022).
Vast interest from big companies - Industrial lobbyists are powerful, and they will fight any attempt to impose a top-down policy encouraging a shift towards circularity.	POLITICAL	**Develop a network of circular advocates to place pressure on government and corporations** - Build a movement of CE advocates who can pressure government and businesses to adopt policies and practices that promote a CE. This will require building coalitions with environmental groups, social justice organisations, and others who are concerned about the negative impacts of the current linear economy.
Emphasis on recycling at the expense of other methods of recovery - There is an excessive concentration on recycling at the expense of other forms of circular recovery.	POLITICAL	**Promote sharing and reuse instead of recycling** - To shift the primary focus away from recycling and towards other forms of recovery, investments should be made to promote sharing and reuse programmes and to increase the maintenance, repair, refurbishment, and remanufacturing sectors (Welsh Government, 2021).
OEMs are not held accountable for their activities - Original equipment manufacturers (OEMs) should be made accountable for their own activities and products.	POLITICAL	**Establish and maintain a robust compliance programme** - A better and more extensive compliance programme is required to assist prevent, identify, and address any illegal or unethical activity by OEMs. A third party would need to regularly assess the compliance programme to ensure its efficacy. Strict penalties should be imposed on OEMs who do not comply with it.

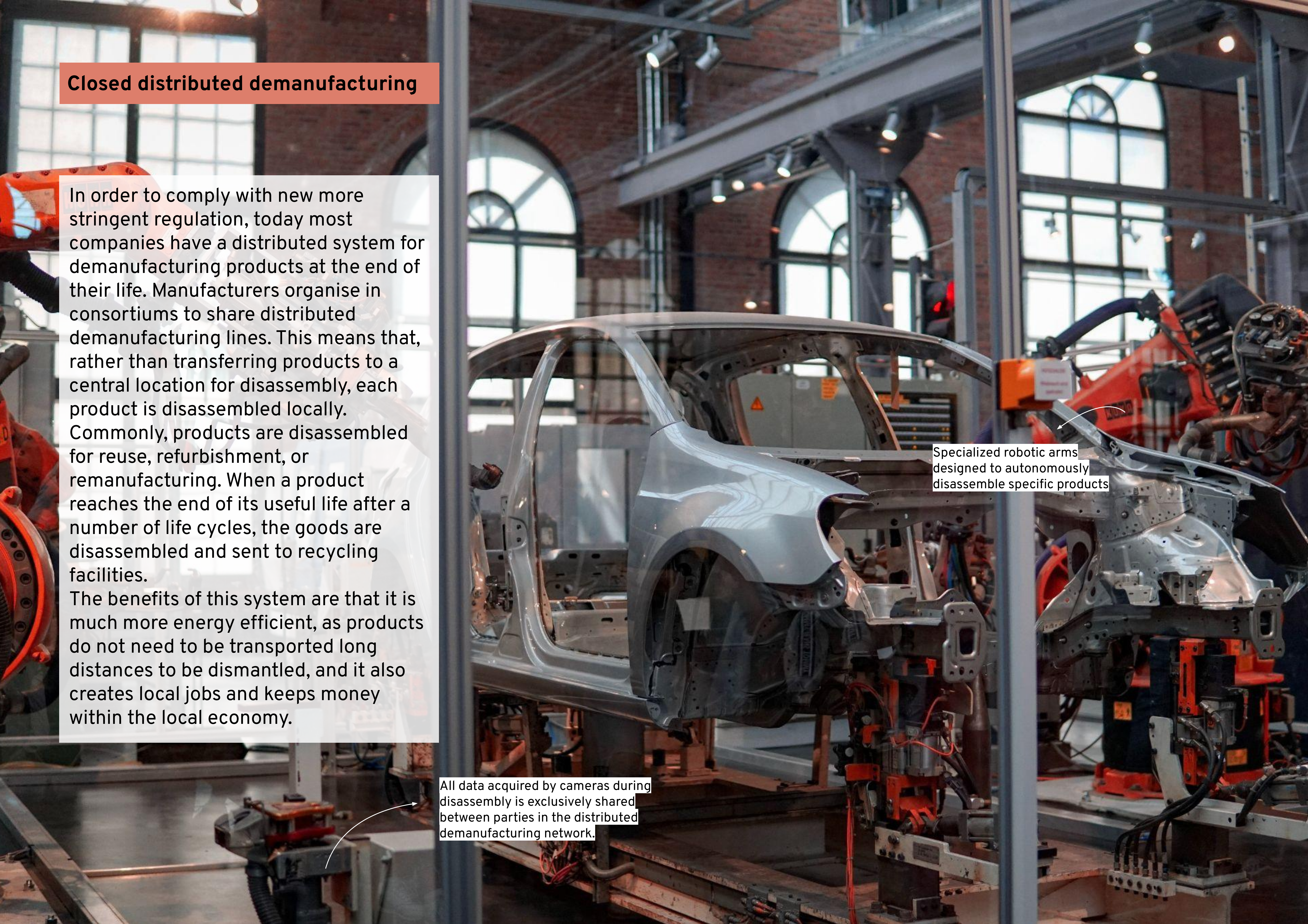
Open distributed demanufacturing

In order to comply with new, more stringent regulation on product end-of-life, some manufacturers have decided to adopt open-standard disassembly solutions to enable third-party companies to disassemble their products and repurpose related components and materials. Manufacturers are exempt from taking care of the end-of-life of their products, while third-party companies recover value by refurbishing and/or selling recovered components and materials.

Closed distributed demanufacturing

In order to comply with new more stringent regulation, today most companies have a distributed system for demanufacturing products at the end of their life. Manufacturers organise in consortiums to share distributed demanufacturing lines. This means that, rather than transferring products to a central location for disassembly, each product is disassembled locally. Commonly, products are disassembled for reuse, refurbishment, or remanufacturing. When a product reaches the end of its useful life after a number of life cycles, the goods are disassembled and sent to recycling facilities.

The benefits of this system are that it is much more energy efficient, as products do not need to be transported long distances to be dismantled, and it also creates local jobs and keeps money within the local economy.



Urban Mining

Geological mines nowadays supply just a modest quantity of material. Instead, the majority of metals used today are sourced from densely populated and industrialised areas (e.g. buildings, cars, etc.). In 2050 the mining industry uses its knowledge to support small enterprises in collecting metals and other commodities from urban areas. With technologies such as AI vision, real-time video data, material passports, and other technologies, metals are detected automatically, saving time and money.

Disassembling pods

In 2050 disassembly pods can be used to carry out decommissioning and disassembly in areas where normal supply chain linkages are restricted (e.g. rural areas, oceans, etc.). Specialised crews can disassemble large structures on-site and facilitate the recovery of materials and components.

Industrial upcycling

Today, alloys are carefully sorted and separated according to their composition at upcycling facilities. These alloys are then sent to be melted down and reformulated into the exact same alloys as they were originally. This new technique of processing alloys without compromising the material's quality is referred to as industrial upcycling. This advancement in upcycling was made possible by regulations requiring manufacturers to use fewer and higher-quality alloys, superior product design, and new infrastructures and equipment capable of properly separating metals of different grades. The metal's quality remains steady even after several industrial upcycling treatments, allowing for a more effective closing of metal cycles.

A wrench made from recycled metal

Smart waste management system

Today, the UK has a smart waste management system in place as part of the CE. This system includes a variety of sensors and smart bins that are connected to a central database. The sensors are able to detect the type of waste that is being deposited in the bins and the database is used to track the waste and ensure it is properly disposed of.

The smart waste management system has helped to significantly reduce the amount of waste that is sent to landfill sites. In fact, waste is recycled or reused where possible. This has had a positive impact on the environment and has helped to create jobs in the waste management and recycling industries.

Landfill scavenging

As metals become scarce in the 2020s, new methods were developed to recover metals wherever possible. One of the most cost-effective options has been to recover metals from historical landfills via the use of technology such as high-mobility dynamic mining robots capable of excavating, locating, selecting, and recovering metals within covered landfills. Along with the metals, the methane released within the landfill could also be recovered, eliminating environmentally damaging emissions.

Micro mobile foundry and upcycling workspaces

In 2050 technological advancements have enabled smaller equipment to melt and pulverise scrap metal for 3D printing applications. Thanks to this, it is possible to establish micro mobile foundry and upcycling workspaces and position them wherever a market exists. Many entrepreneurs have micro mobile workspaces in cities, others in production sites, and others within industries. Over time, several capsules have developed specialising in different types of metalworking that can form complex dynamic production systems.

A group of entrepreneurs who have just invested in a united workspace

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