Aalto University
School of Arts, Design
and Architecture

PLATE
Product Lifetimes
And The Environment

5th PLATE 2023 Conference
Espoo, Finland - 31 May - 2 June 2023

Co-creating sociotechnical visions for a circular metal economy transition in the UK

Franconi, Alessio[a]; Ceschin, Fabrizio[a]; Godsell, Janet[b], Harrison, David[a], Mate, Orsolya-Anna[c]; Konteh, Tamba[a]

a) Design for Sustainability Research Group, Brunel Design School, Brunel University London, London UB8 3PH, United Kingdom
b) School of Business and Economics, Loughborough University, Loughborough, LE11 3TU, United Kingdom
c) WMG, University of Warwick, Coventry, CV4 7AL, United Kingdom

Keywords: Circular Metal Economy; Preferable visions; Visions for 2050; Co-design research; sociotechnical visions.

Abstract: The UK government's target of achieving net-zero emissions by 2050 has created an urgent need for decarbonization and the transition towards a circular metal economy (CME). The production of steel and aluminium, critical components of modern industry, contribute significantly to greenhouse gas emissions and are the focus of this paper. This paper explores the barriers and enablers involved in moving towards a CME. Although recycling is an essential strategy for metal recovery, it may not suffice to achieve the UK government's net-zero objectives. The paper suggests twelve preferred visions for a CME, encompassing the entire metal value chain, co-created through collaboration with over one hundred industry and academic experts. These visions can serve as a foundation for co-design workshops for academics to investigate additional barriers and enablers within the metal sector. Within corporate management, these visions can be used to set targets and guide decision-making towards specific circular and sustainable goals. Finally, policymakers can use these visions to develop a roadmap or comprehend the implications and rebound effects of a CME transition for the UK.

Introduction

The urgent need to decarbonise the metal ecosystem and transition towards a circular metal economy (CME) is becoming increasingly pressing, given the UK government's goal of reaching net-zero emissions by 2050 (HM Government 2021). Steel and aluminium are fundamental elements of modern industry, yet the production and use of these elements contribute significantly to greenhouse gas emissions and climate change (Izatt, 2016). Although various downstream measures throughout the value chain, such as recycling, recovery, and reuse of products and components in some industries (e.g. automotive industry), have already been widely adopted, they are insufficient to meet the net-zero targets set by the UK government (Cooper et al., 2012). Therefore, the objective of this research, conducted as part of the CircularMetal project, a UKRI-funded research centre, is to present co-created sociotechnical visions that promote the transition towards a CME in the UK across the whole metal value chain.

To achieve this objective, we gathered insights from over one hundred experts with diverse backgrounds, including governmental organisations, businesses, NGOs, policymakers, and scholars from various academic disciplines. By utilising a co-creation approach, our aim is to develop a shared understanding of a desirable future and the barriers and enablers associated with it.

Through five research phases, we co-created twelve visions that aim to guide present decision-making and actions towards a more desirable future (Manzini, 2003). These visions highlight the necessity for simultaneous action from all parts of the metal value chain to achieve the 2050 target of net-zero emissions (Kaldrack et al., 2023).

Methodology

For the purpose of this study, we used a ‘preferable future’ to envision how a CME in the UK would look in 2050 (Fig 1). Preferable future is one that we strive to create and hope for. This future is based on our aspirations and ambitions, and it embodies our visions of a better world. As shown in Fig. 2, in this research the preferable future is encapsulated in the depiction of a scenario, a set of visions and a set of 'snapshots from the future'. *Scenario* is a complex storyline that envision a desirable future, such as achieving a drastically improved metal circulation by 2050. *Visions* are used to articulate the scenario and provide brief stories detailing aspects related to specific parts of the metal value chain. They answer the question "What would the world be like if...". *Snapshots from the future* are the most specific components 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.

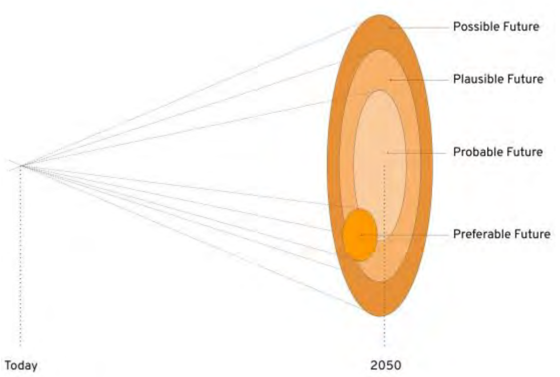


Figure 1. Future cones (readapted from Hancock, et al., 1993).

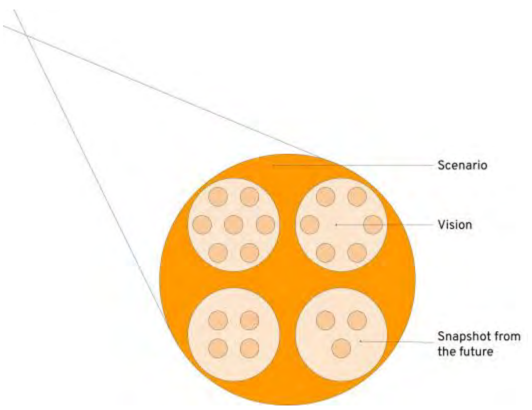


Figure 2. Visualisation of the interrelationships between various future elements employed in our study.

The study adopted a combination of qualitative research methods, such as semi-structured interviews, surveys, and co-design workshops, organised into five distinct phases as outlined below:

1. Semi-structured interviews with 31 leading experts. We carried out semi-structured interviews to gather experts' preferred visions for a Circular Metal Economy in 2050. We probed on the feasibility and implementation of their visions, with interviews lasting between 40 to 60 minutes. Our questioning encompassed the experts' future aspirations for circularity in metals, and an examination of the key enabling drivers and barriers to achieving these visions. The interviews were recorded, transcribed, and subjected to a thematic analysis to identify patterns and themes. Based on these insights, we derived eight initial visions, each illustrated through a set of "snapshots from the future" showcased in the following section.

2. Narration and illustration of the visions. The emerging visions were conveyed in narrative form, while snapshots from the future were depicted using a combination of visual and narrative approaches.

3. Internal workshop with 8 academics. The results of the previous phase were thoroughly reviewed and examined to generate novel concepts for future visions and snapshots. This led to reclustering the themes into 12 visions.

4. Survey with 25 leading experts. An online survey was conducted to gather feedback on the 12 generated visions in order to validate and refine them.

5. Co-design workshop with 29 experts. A 3-hour co-design session was carried out to further review the generated visions and to identify, for each of them, implementation barriers and enablers (taking into account political, economic, social, technological and legislative aspects).

The selection of experts for this research was based on their specialised or correlated knowledge and extensive experience in the fields of aluminium, steel, and sustainability. Additionally, these experts were chosen to represent a wide range of stakeholders, thereby ensuring comprehensive coverage of the entire metal value chain.

Figure 3. Preferred scenario for the circular metal economy in 2050, encompassing twelve different visions.

Results

In this section of the paper, we present the preferred scenario that has been developed during phases 1, 2, 3 and 4 of our research. As shown in Fig. 3, the scenario is structured around 12 visions, including: 1. Net Zero Emission Metal Production; 2. Circular Alloys; 3. Distributed Metal Manufacturing; 4. End-To-End Supply Chain; 5. Metal as a service; 6. Metal Life Cycle Data; 7. Full Metal Packaging; 8. Stop Recycling Start Repairing; 9. Repair-It-Yourself (RIY); 10. The Logic of Sufficiency; 11. Reusing, Remanufacturing, and Repurposing; and 12. Better Metal Recovery, Sorting, Upcycling and Recycling. The scenario has been crafted to present a compelling storyline for the future that is desirable for all stakeholders. To depict the envisioned future in 2050, realistic images were generated using Photoshop and other tools for each 'Snapshot from the future.' The preferred scenario is illustrated in Fig. 4, which comprises a compilation of diverse images. The full set of visions can be found in Franconi et al., 2022.

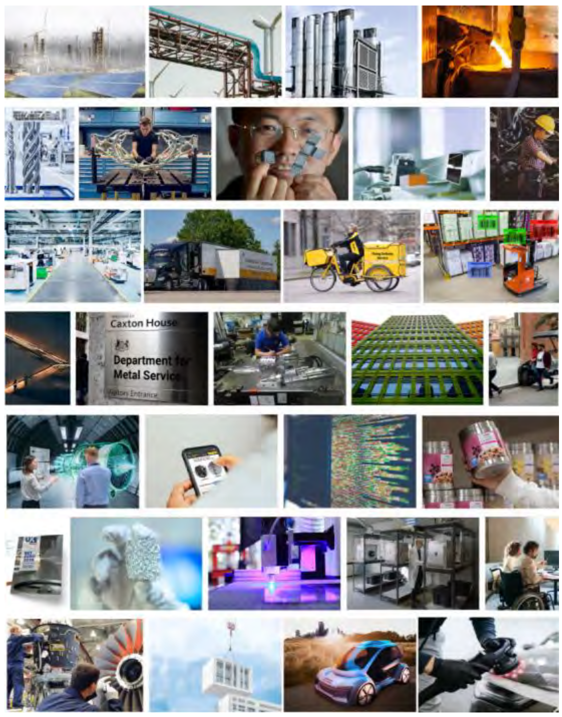


Figure 4. An overview of the images created to depict each individual 'Snapshot from the future'.

Preferable scenario
"It is the year 2050, and the UK has achieved complete circularity in the domain of metals, a remarkable achievement of human ingenuity and a virtuous pursuit towards a better world. This victory was hard-won, but thanks to breakthroughs in areas like renewable energy, energy storage, and process efficiency, we're now able to produce metal with zero emissions (1). Efforts to rationalise alloy grades and usage have resulted in the creation of novel "circular alloys" that enable a more effective closed-loop system to be adopted (2). At the end of their life, all kinds of metals are now separated and classified according to their unique and remarkable characteristics, safeguarding their distinctive qualities to be reused again and again (12).

The advent of new manufacturing technologies has led to the rise of distributed factories, promoting localised production, mitigating transportation costs, and increasing suppleness in supply chains, which fostered the growth of self-sufficient and adaptable economies. This has increased job opportunities, enhanced knowledge sharing and networking, and established a new collaborative economy, reducing regional disparities in wealth and economic development (3). Intelligent assets have been implemented, leading to complete integration and automation of the end-to-end supply chain and enabling real-time monitoring and execution of all supply chain processes (4). The UK government's open metal data infrastructure makes this feasible by providing data to all supply chain players. Due to efficient resource management, advanced metal recovery, sorting, upcycling, and recycling processes have been implemented (6).
The emergence of servitization in the metal industry has positioned the UK as a global leader. The shift towards valuing product use over mere possession has enabled companies to enhance product quality, curtail material consumption, and augment resource circularity (5 & 7). The transformation of companies into agents of good is demonstrated not only by their ability to offer services, but also by their commitment to creating products that can be utilised in multiple life cycles. This shift towards the reuse and remanufacturing industries marks a turning point in the manufacturing industry's ethos (11).

The development and consolidation of the repair industry in recent decades have given rise to new forms of work and an economy based on the repair itself (8). Repair has been embraced as a way of life for many individuals as well (9). These profound transformations in society have created long-term economic stability, shaping novel moral imperatives and ethical norms on sufficiency that unite the overall community (10)."

Stop Recycling, Start Repairing - Barriers and Enablers
In Phase 5 of our study, we evaluated the obstacles and opportunities associated with each vision. Due to space limitations, this paper focuses only on the (8) "Stop Recycling, Start Repairing" vision. This vision suggests a shift to a repair-based economy utilising advanced technologies and Metal Health Services for metal maintenance and self-healing capabilities, resulting in extended product lifetimes. With a multi-dimensional lens, encompassing social, technological, ecological, economic, and political aspects, our analysis investigates the most significant barriers and enablers that the industry is facing.

Social lens: The lack of skilled maintenance and repair experts is a significant barrier to the realisation of a vision for sustainable and efficient industrial practices. This barrier arises due to a shortage of qualified personnel capable of carrying out planned maintenance and specialised repair activities. This lack of skilled personnel leads to a higher incidence of equipment breakdowns, which can result in lost productivity, increased downtime, and higher maintenance costs. To overcome this barrier, vocational and engineering colleges should include repair education as an essential part of their curriculum. This approach would enable students to acquire the skills and knowledge needed to become competent maintenance and repair professionals. Moreover, knowledge-driven organisations should be supported and funded to develop repair knowledge in specific sectors, such as electrical repair, to encourage the growth of specialised expertise.

Technological lens: The development of smart metals (e.g., self-healing) and novel repair methods represent a promising vision for many industries. However, ensuring safe and effective commercialisation is challenging. One significant barrier is the need for safety assurance, requiring rigorous testing of smart materials to avoid risks to human health and the environment before entering the market. Safety is critical for smart materials and repair methods and evaluating and mitigating potential risks before commercialisation is necessary to unlock their benefits. Nonetheless, opportunities and enablers exist to facilitate the vision's realisation. Controlled evaluations of advanced materials and repair equipment's safety and performance based on scientific evidence are necessary to guarantee long-term quality and safety. These evaluations can identify the effectiveness and safety of smart materials and repair methods while fostering trust in their adoption.

Ecological lens: Smart metals show great promise for revolutionising various industries, from transportation to medicine. However, creating new hazardous waste from their use is a major concern, particularly for self-repair metals. It is unclear whether these metals can be recycled in the same way as conventional metals, further exacerbating the issue. To fully realise the potential of smart metals, it is important to research and develop sustainable recycling methods to avoid producing new waste streams or hazardous waste. Addressing these concerns will reduce the environmental impact and associated risks of smart metals, promoting their long-term viability and success in industries.

Economic lens: A key obstacle to a full transition to a CME is the insufficient evidence on the cost-effectiveness and environmental characteristics of new materials and repair techniques to support a repair-based economy. Without this data, the adoption of repair-based practices may be hindered. Conducting economic and environmental research on repair is essential to establish the benefits of this approach. Promoting and supporting such studies can provide insights into the economic and environmental advantages of repair-based practices, enabling informed decisions on the transition to a CE. Overcoming the barrier of inadequate evidence is crucial to realise the vision of a CME.

Political lens: Repair activities may be restricted or prohibited by laws, regulations or contractual agreements, which hinder the ability to extend the use of products. For example, warranties may limit the use of third-party repair services, restricting consumer choice, which may prevent the prolonging of the lifespan of products. To overcome these barriers, a framework is required to support repair and reuse. A contractual/legal framework that promotes repair, longer product lifespans, and multiple owners/users over a period of time is crucial for enabling a CME. This framework should establish clear rules and guidelines that support repair and reuse, facilitate access to repair services and spare parts, and promote the sharing of products between multiple users. It should also incentivise producers to design products that are easy to repair, upgrade and disassemble at end-of-life.

Discussion and conclusions

The transition towards a CME is a multifaceted and complex process. This paper's particular focus on Vision 8 "Stop Recycling, Start Repairing" has demonstrated how achieving its objectives demands a range of interventions that are intertwined across different sociotechnical domains. This becomes even more clear when we analyse all the visions in a polarity diagram that juxtaposes behavioural and social dimensions with technological dimensions, highlighting the interplay between these two transformations as illustrated in Fig. 5. While technological advancements are crucial in driving this transformation, it is equally important to consider the social dimensions that underlie the system, particularly during the usage phases. The majority of the visions outlined in the study emphasised the importance of life extension and the adoption of circular metal solutions that are low-resource intensive and have a high degree of regenerative potential. Circular business models, sustainable supply chain management, and circular design strategies all play vital roles in this transformation.

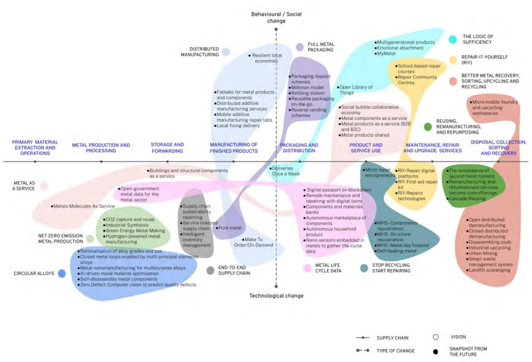


Figure 5. Circular metal economy polarity diagram with all visions and Snapshots from the Future. The vertical axis represents behavioural/social change and technological change, while the horizontal axis shows all phases of the metal chain. An enlarged version of the image is provided in the appendix 1.

Based on the barriers identified by experts, it is clear that despite the current emphasis on metal production and recycling, driven by established infrastructure and economics, government policies, and scholarly literature, a fundamental shift in societal behaviour is essential to achieve the full potential of a CME. In fact, the recurring barriers noted by experts throughout the visions emphasise the significance of orienting employees, users, communities, and businesses towards a circular mindset. Although legislative incentives may prove effective in catalysing this shift, it is essential to recognise that the creation of a CME is contingent on coordinated investments in both the scientific and physical infrastructure needed for the transition. For example, a possible coordinate investment may include the creation of novel educational frameworks aimed at facilitating stakeholder understanding of standardised circular-related data, as well as the adoption of technological infrastructure to enable effective tracking of products across the entire supply chain.

The findings of our study underscore the crucial role of collaborative efforts by all stakeholders in overcoming the barriers to transitioning to a CME. The success of this transition requires addressing multiple factors, including social, economic, technological, and environmental considerations that are integral to the system. A holistic approach that considers the entire lifecycle of materials is necessary for realising the benefits of a CME. In particular, the steel and aluminium sectors can play a pivotal role in this transition by extending the product lifecycle and adopting new business models that go beyond traditional recycling methods. This shift in mindset would enable a more sustainable use of materials, while also opening up new opportunities for innovative and profitable business models.

Sociotechnical visions of preferable futures are influential in shaping present decisions and commitments. In this paper, we have identified twelve distinct visions in the metal sector that provide a comprehensive outlook on the opportunities for transitioning towards a circular economy. Subsequently, we have conducted an analysis of the significant barriers that need to be addressed to achieve these visions. While we acknowledge that these visions are only a few of many plausible futures, using them as a target for our efforts can guide us in shaping immediate short-term actions. Overall, this research provides valuable insights into the sociotechnical implications of transitioning to a circular economy in the metal sector. It emphasises the importance of considering various preferable futures to guide present decisions and actions. Future research may focus on initiatives similar to this one, generating preferable visions and then determining the barriers and enablers to achieving useful results. Moreover, using these visions as a starting point, it would be helpful to make a road map to help all stakeholders set their goals and focus on clear, well-defined objectives.

Acknowledgments

The research project received financial backing from the UKRI National Interdisciplinary Circular Economy Research programme (NICER). The authors would like to express their sincere appreciation to the experts who took part in the study and generously shared their time and expertise.

References

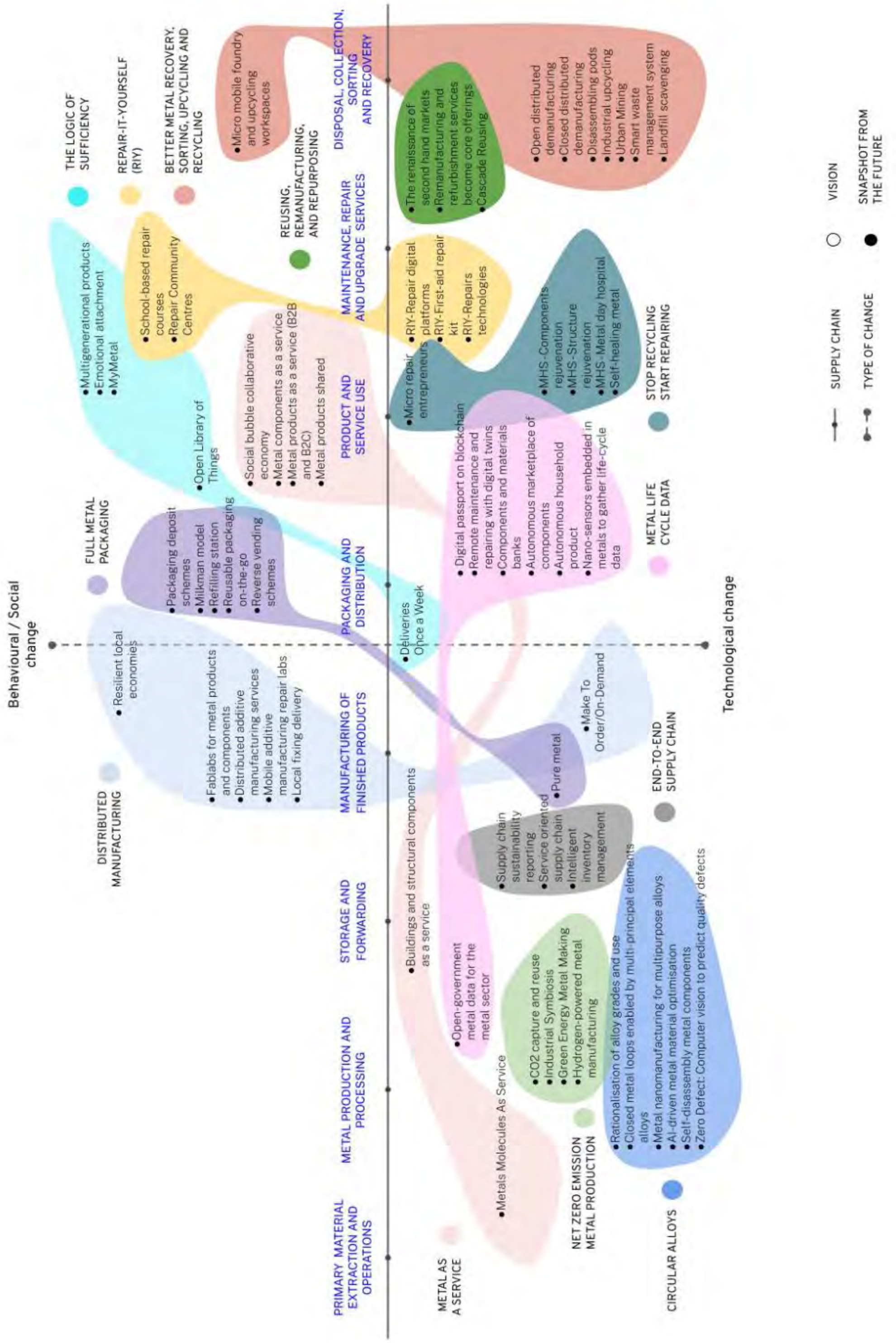
Cooper, D. R., & Allwood, J. M. (2012). Reusing steel and aluminum components at end of product life. Environmental science & technology, 46(18), 10334-10340.

Franconi, A., Ceschin, F., Godsell, J., Harrison, D., Mate, O. A., & Konteh, T. (2022). 2050 Circular Metal Visions.

GSTM - Global Steel Trade Monitor. "Steel Imports Report: Background The United Kingdom", May 2017

Hall, Russell, Wanrong Zhang, and Zushu Li. "Domestic scrap steel recycling–economic, environmental and social opportunities (EV0490)." (2021).
Hancock, T., & Bezold, C. (1994). Possible futures, preferable futures. In The Healthcare Forum Journal (Vol. 37, No. 2, pp. 23-29).
HM Government, "Industrial Decarbonisation Strategy", 2021
HM Government, "Net Zero Strategy: Build Back Greener", 2021
Izatt, R. M. (Ed.). (2016). *Metal sustainability: global challenges, consequences, and prospects*. John Wiley & Sons.
Kaldrack, I., & Nohr, R. F. Preferable Futures: An Introduction. PREFERABLE FUTURES, 9. (2023)
Manzini, E. (2003). Scenarios of sustainable wellbeing. Design philosophy papers, 1(1), 5-21.

Appendix 1


Behavioural / Social change
Technological change
PRIMARY MATERIAL EXTRACTION AND OPERATIONS
METAL PRODUCTION AND PROCESSING
STORAGE AND FORWARDING
MANUFACTURING OF FINISHED PRODUCTS
PACKAGING AND DISTRIBUTION
PRODUCT AND SERVICE USE
MAINTENANCE, REPAIR AND UPGRADE SERVICES
DISPOSAL, COLLECTION, SORTING AND RECOVERY
THE LOGIC OF SUFFICIENCY
REPAIR-IT-YOURSELF (RIY)
BETTER METAL RECOVERY: SORTING, UPCYCLING AND RECYCLING
REUSING, REMANUFACTURING, AND REPURPOSING
FULL METAL PACKAGING
DISTRIBUTED MANUFACTURING
METAL AS A SERVICE
NET ZERO EMISSION METAL PRODUCTION
CIRCULAR ALLOYS
END-TO-END SUPPLY CHAIN
METAL LIFE CYCLE DATA
STOP RECYCLING START REPAIRING
•Multigenerational products
•Emotional attachment
•MyMetal
•School-based repair courses
•Repair Community Centres
•Micro mobile foundry and upcycling workspaces
•Open Library of Things
•Social bubble collaborative economy
•Metal components as a service
•Metal products as a service (B2B and B2C)
•Metal products shared
•Packaging deposit schemes
•Milkman model
•Refilling station
•Reusable packaging on-the-go
•Reverse vending schemes
•Deliveries Once a Week
•Resilient local economies
•Fablabs for metal products and components
•Distributed additive manufacturing services
•Mobile additive manufacturing repair labs
•Local fixing delivery
•Buildings and structural components as a service
•Open-government metal data for the metal sector
•Metals Molecules As Service
•The renaissance of second hand markets
•Remanufacturing and refurbishment services become core offerings
•Cascade Reusing
•Open distributed demanufacturing
•Closed distributed demanufacturing
•Disassembling pods
•Industrial upcycling
•Urban Mining
•Smart waste management system
•Landfill scavenging
•RIY-Repair digital platforms
•RIY-First-aid repair kit
•RIY-Repairs technologies
•Micro repair entrepreneurs
•MHS-Components rejuvenation
•MHS-Structure rejuvenation
•MHS-Metal day hospital
•Self-healing metal
•Digital passport on blockchain
•Remote maintenance and repairing with digital twins
•Components and materials banks
•Autonomous marketplace of components
•Autonomous household product
•Nano-sensors embedded in metals to gather life-cycle data
•Make To Order/On-Demand
•Pure metal
•Supply chain sustainability reporting
•Service oriented supply chain
•Intelligent inventory management
•CO2 capture and reuse
•Industrial Symbiosis
•Green Energy Metal Making
•Hydrogen-powered metal manufacturing
•Rationalisation of alloy grades and use
•Closed metal loops enabled by multi-principal elements alloys
•Metal nanomanufacturing for multipurpose alloys
•AI-driven metal material optimisation
•Self-disassembly metal components
•Zero Defect: Computer vision to predict quality defects
SUPPLY CHAIN
TYPE OF CHANGE
VISION
SNAPSHOT FROM THE FUTURE