CENTS: A Research Network for the Sustainable Transport Community

# Circular Economy Network+ in Transportation Systems


British Geological Survey
Expert | Impartial | Innovative

University of Cambridge

Cranfield University

University of Surrey

WMG
The University of Warwick

UKRI
Engineering and Physical Sciences Research Council


# CENTS Feasibility Funding Case Study Template

Title of Feasibility Study: Circular Materials for Transportation Machines (CIRCMATE-4-TMs)

1. Project Team

The project team is composed of six people from across Loughborough University.

Katherine **Adams**
School of Architecture, Building and Civil Engineering

Katherine was the Research Associate on the project and has expertise on circular economy, sustainable use of materials and waste management.

Dr Alok **Choudhary**
School of Business and Economics

Alok was a Co-I on the project and has expertise in sustainability, circular economy, and resilience in logistics and supply chain management.

Professor Chris **Goodier**
School of Architecture, Building and Civil Engineering

Chris was a Co-I on the project and has expertise in materials, future thinking, roadmaps and scenario development.

Professor Mohamed **Osmani**
School of Architecture, Building and Civil Engineering

Mohamed was the PI for the project and has expertise in circular economy, resource efficiency and designing out waste.

Dr Andrew **Timmis**
School of Architecture, Building and Civil Engineering

Andrew was a Co-I on the project and has expertise in transportation, especially the aviation sector including LCA and sustainability.


Dr Patrick **Waterson**
School of Design

Patrick was Co-I on the project and is a Reader in Human Factors and Complex Systems. His expertise includes ergonomics and rail passenger safety.

Our industry partners:

2. Executive summary (max 200 words)

CIRCMATE-4-TMS examined the circular economy (CE) potential for materials that are used within four transportation machine (TMs) sectors: automotive, maritime, aerospace, and rail. Two materials were prioritised for the resulting roadmap: steel and plastics due to their common cross-sectors' usage, and circularity potential. Steel provides greater improvement potential for material efficiency during design; and higher value recovery at EoL. Plastics offer the potential for increasing recycled content during manufacture; and increasing recycling at EoL. Findings from literature, questionnaire survey, and interviews identified the key TMs' material circularity challenges, drivers, and strategies. Challenges include the use of multiple polymers/alloys and the difficulty to sperate them at EoL, coupled with a lack of legislation. Drivers comprise reduction of environmental impact, legislation, supply chain collaboration, and better sorting technologies. The circularity strategies during the design stage include designing for recyclability and material use reduction; and the use of secondary materials and closed and open loop recycling at end-of-life stage. These findings are presented within a novel 'Re-engineer; Optimize; Share and Exchange (ROSE)' Framework. Lastly, an action orientated 'Roadmap' for steel and plastics has been developed for all TMs sectors within a future scenario approach which can be used to focus efforts going forward.

The problem (max 200 words)

The TMs sectors and related infrastructure consumes an estimated 10.8 Gigatonnes/year of resources[1].While some materials used in TMs such as metals have high recovery rates, there are still considerable opportunities for applying CE principles to metals and other materials used in TMs, such as plastics and composites throughout their lifecycle stages. Nationally, the importance of CE principles for TMs and their supply chains including the capacity to reprocess and manage materials at end of life has been recognised, coupled with the need for greater UK resource security. This is within the wider context of net zero emissions, with the UK becoming a world leader in shaping the future of mobility and promoting clean growth, and regional growth policies where transport manufacturing plays a key role. This CENTS feasibility study seeks to establish the potential for


circularity of key materials across four TMs sectors (automotive, maritime, aerospace and rail), throughout their lifecycle by identifying associated circular economy drivers, barriers, and strategies.

[1] Circle Economy (2019) *The Circularity gap report 2019,* Circle Economy, Amsterdam, Netherlands.

The approach (max 100 words)

The project hypothesises that synergies and commonalities across TMs sectors have the potential to optimise their materials' circularity and economic value. CIRCMATE-4-TMs aims to identify and assess opportunities to optimize the circularity of materials used in TMs across the four principal modes (automotive, maritime, aerospace and rail) without reducing safety, functionality, and user experience.

The adopted methodology comprised a literature review, questionnaire with project partners, interviews with representatives of each TMs sector, and a validation focus group with project partners on the main findings in the form of a roadmap.

Novelty (max 100 words)

This project is the first to investigate systematically materials' circularity potential of all four TMs sectors across their lifecycle stages (design, manufacture, use and end of life). This has involved the prioritisation of cross-TMs materials (steel and plastics) based on their level of use, environmental impact, and potential for circularity. CE strategies have been applied within a unique '**Re-engineer; Optimize; Share and Exchange (ROSE) Framework**, which underpins a novel **action orientated 'Roadmap'** for both materials across all four TMs with the ultimate aim to increase circularity.

Results (max 500 words)

**`WP1: Cross-TMs material circularity identification and prioritisation.** A literature review identified four common materials used in all TMs sectors: steel (though lower in aerospace than the other TMs); aluminium (higher in rail and aerospace compared to other TMs); composites (high in maritime (boats) and aerospace compared to other TMs); and plastics (higher in automotive compared to other TMs). The key findings of WP1 are summarised below.

There is a high circularity potential for **steel** through increasing levels of reuse and higher value recovery at end of life, due to better sorting. This is recognised as an issue for the automotive, maritime (ships) and rail (freight trains) sector, where steel is used in large quantities.

For **aluminium**, there is high potential to increase reuse at EoL, and a medium potential for higher value recovery at end of life, though the better sorting of metals. This has been recognised as an issue for rail and aerospace sectors, where aluminium is more commonly used.

The greatest potential of **composites** lies with higher value recovery at EoL, followed by higher levels of recovery at EoL.

For **plastics**, there is an opportunity to increase the higher levels of recycled content and increase the recovery levels and its value at EoL. Two cross-TMs materials were prioritised:


steel and plastics (Table 1) that were further examined in WP2. **WP1 findings are available in Milestone 1 Report.**

**Table 1: Prioritisation of materials across the life cycle stages based on literature**

| | Circular economy potential | | |
|---|---|---|---|
| | Design | Manufacture | End of Life |
| **Steel** | • Opportunities for material efficiency/ optimisation are **high** | • Opportunities for increasing recycled content are medium | • Potential for more reuse/remanufacture is **high**<br>• Potential for increased recycling is medium<br>• Potential for higher value recycling is **high** |
| **Aluminium** | • Opportunities for material efficiency/ optimisation are medium | • Opportunities for increasing recycled content are low | • Potential for more reuse/remanufacture is **high**<br>• Potential for increased recycling is low<br>• Potential for higher value recycling is medium |
| **Composites** | • Opportunities for material efficiency/ optimisation are low | • Opportunities for increasing recycled content are low | • Potential for more reuse/remanufacture is low<br>• Potential for increased recycling is medium<br>• Potential for higher value recycling is medium |
| **Plastics** | • Opportunities for material efficiency/ optimisation are low | • Opportunities for increasing recycled content are **high** | • Potential for more reuse/remanufacture is low<br>• Potential for increased recycling is **high**<br>• Potential for higher value recycling is medium |

**WP2: Cross-TMs circular material strategies.** The aim of WP2 was to identify and assess strategies to facilitate the circularity of the prioritised materials (steel and plastics from WP1) across their lifecycle stages, underpinned by the project's 'Re-engineer-Optimise & Share-Exchange (ROSE)' Framework (Figure 1).

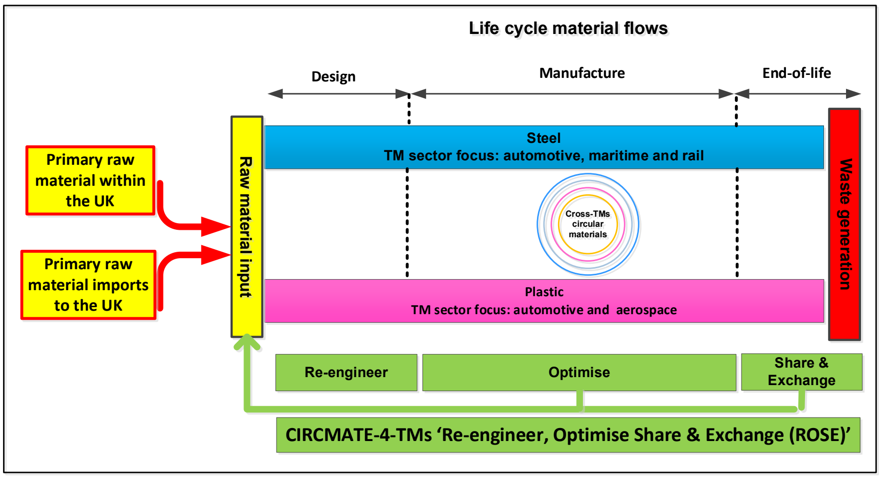


**Figure 1: The ROSE Framework**

The results of the questionnaire survey, completed by the project partners, indicated high ratings for the following CE strategies for both plastics and steel: design for recyclability; material use reduction; the use of recycled/secondary materials; closed and open loop recycling. Resell/reuse/refurnish and remanufacture were deemed critical for the circularity of steel. Additionally, the use of multiple polymers and their separation; contamination at end of life; potentially hazardous nature at EoL; and lack of legalisation were identified as the key challenges for the circularity of plastics. Similarly, the lack of legislation; combining steel with other materials; the mixing of different grades of scrap; lack of traceability, and limited consideration of using reused steel parts were found to be significant barriers to the circularity of steel. On the other hand, reduction in environmental impact, was


ranked as the highest CE driver for both steel and plastics. Other highly ranked drivers included reduction of polymer types; legislation; supply chain collaboration; corporate targets (plastics); incentives for dismantlers; increased remanufacture of steel parts; cost savings from using scrap steel; and better material sorting technologies.

The findings of the interviews with representatives of each of the four TM sectors indicated that TMs sectors are at different levels of implementation for CE, although automotive and aerospace seem more advanced than maritime and rail. All TMs sectors shared the challenges of requirements for materials in transportation environments such as safety, performance, and material quality. Reuse differs across the TMs sectors; it happens to some extent in maritime and aerospace. All sectors are using or planning on using more composite materials; the end-of-life implications of these has been recognised. There was a common view among interviewees that whilst fiscal and legislative actions are important to force change, these must be developed with consideration of the availability of existing technologies and could also be more incentive based. Research and innovation regarding disassembly techniques were deemed important as was the need for better data (which was specifically mentioned by maritime and rail interviewees). The findings of the questionnaire survey and interviews informed the ROSE Framework for TMs steel and plastics (Figure 2). **WP2 findings are available in Milestone 2 Report**.

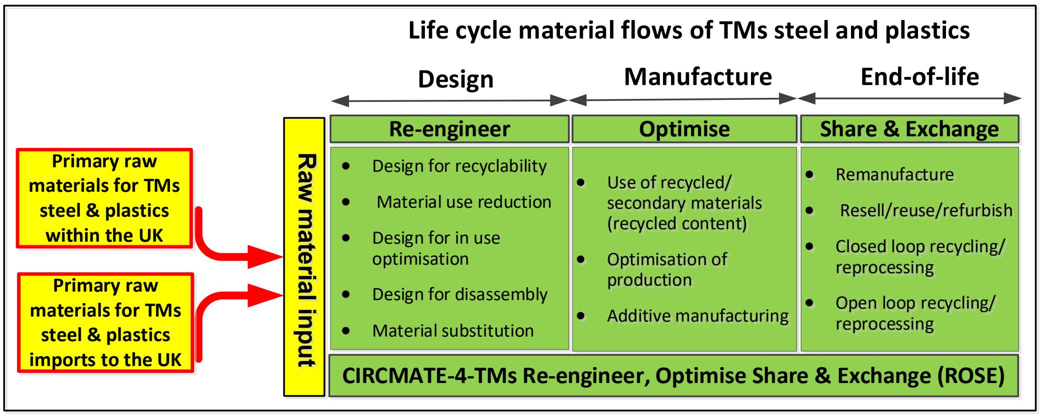


**Figure 2: The validated ROSE Framework for transportation machines' steel and plastics**

**WP3: Cross-TMs circular material Roadmap.** Responses to the questionnaire found that additional tax on recycled content; increased taxation on disposal; ban on exporting waste; mandatory recycled content targets; and innovation of new polymers are significant actions for change. These were seen to be feasible at short to medium term. For steel, increasing global carbon; additional tax on recycled content; a border tariff applied to non-recycled content; a ban on exporting waste; adoption of right to repair laws; Government support of product as service model; and innovation on new alloys were ranked the most important actions and deemed feasible at short to medium term. The final roadmaps are shown in Figure 3 (plastics) and Figure 4 (steel). Four scenarios were devised, which underpin the roadmaps based on low to high supply chain integration and local to global supply chains. **WP3 findings are available in the Milestone 3 Report.**


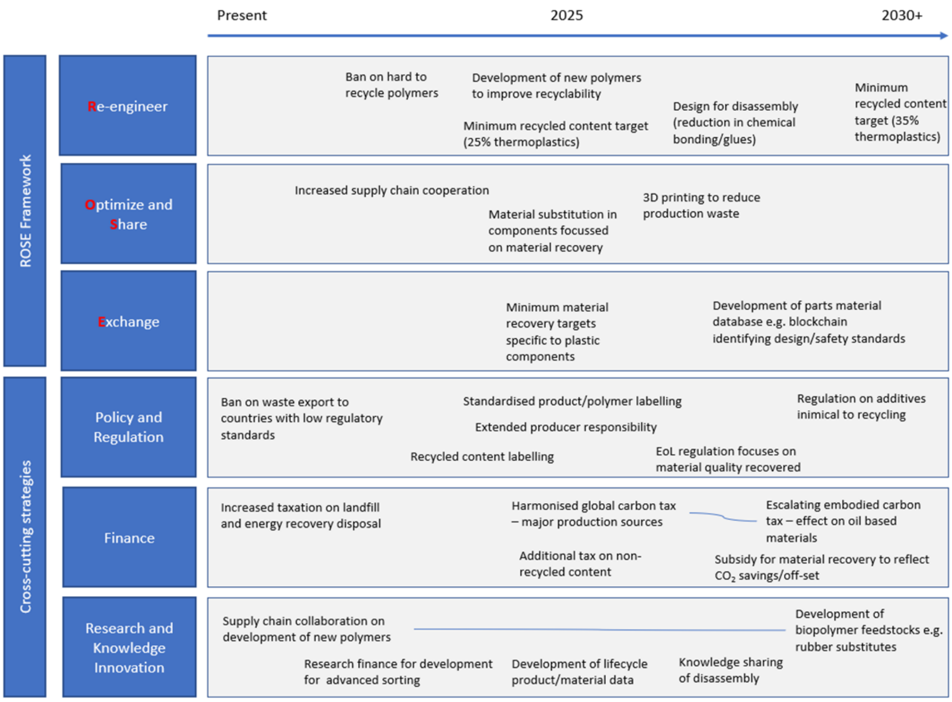


**Figure 3: Roadmap for plastics for all TMs sectors**

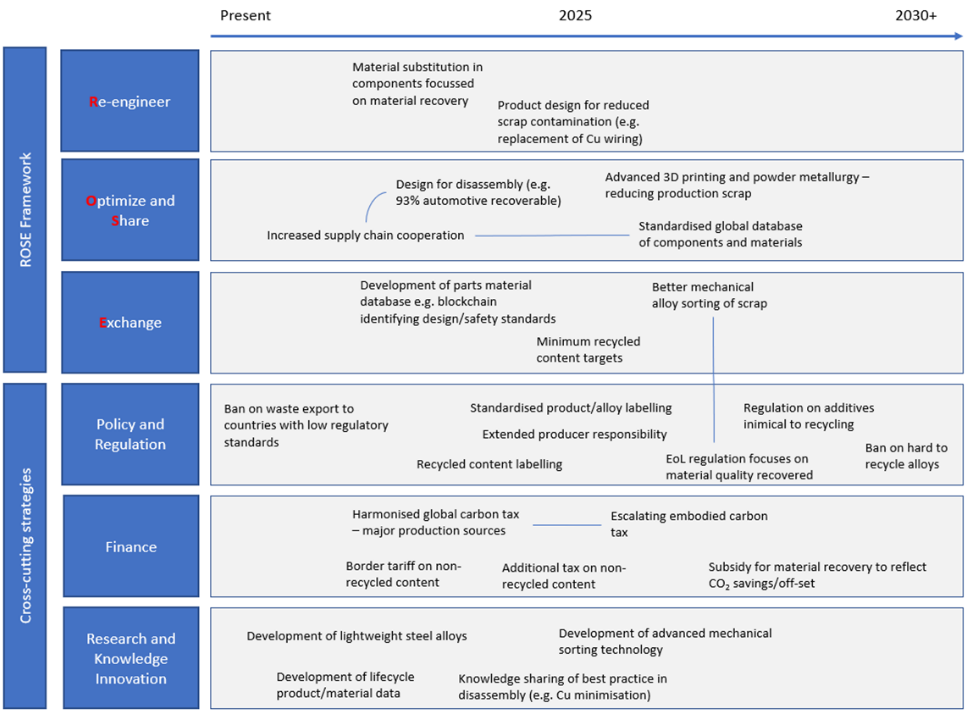


**Figure 4: Roadmap for steel for all TMs sectors**

Connect with us on Twitter @CE4Transport
For any queries, please email circulartransport@warwick.ac.uk
http://www.warwick.ac.uk/circulartransport


Key finding 1 (max 50 words)

**Validated ROSE Framework:** the most important CE strategies for plastics and steel in TMs sectors are at two ROSE stages: ‘Re-engineer’ (design stage): designing for recyclability and material use reduction; and ‘Share & Exchange’ (end of life stage): the use of recycled/secondary materials and closed and open loop recycling, with the main driver being reducing environmental impact.

Key finding 2 (max 50 words)

**Cross-TMs circular material roadmap:** priority actions to embed material circularity across TMs sectors are fiscal and legislative. Actions are prioritised on stimulating recycled material demand to enable confidence in investment and development of life cycle thinking in material recovery. TMs sectors can lead and learn from each other in product traceability, material innovation, product design and end of life recovery.

Testimonial from ECR/project team (max 500 words)

The project team was interdisciplinary, with expertise in CE, materials, supply chain, design, transportation, and scenario development/future thinking. This interdisciplinary nature of the project team gave each member an opportunity to appreciate the other disciplines and align and integrate the different strands of expertise. This is thought to be particularly important for CE where the team could bring technical, economic, and social (human) perspectives.

**Katherine Adams**, as an ECR found that working on the project has developed her knowledge considerably in the area of CE relating to TMs sectors, particularly in the role of the OEM, supply chain considerations and how TMs are designed, manufactured and utilised. This has added to her knowledge of circularity which was largely limited to the built environment; though it is interesting to note that the built environment and TMs sectors face many of the same drivers and challenges, as well as solutions, particularly for policy and fiscal interventions.

This project extended **Alok Choudharys**’ knowledge and understanding of the mapping of TMs supply chain, complexity, and CE potential. The research has expanded beyond the business domain boundary to the applied context of TMs for the first time using a complementary interdisciplinary approach. It has further helped to develop a working relationship with the team members and CENTS partner organisations.

This project has enabled **Chris Goodier** to bring some of his previous scenario development experience to the project together with his research and experience in materials. Being part of the CENTS network has broadened Chris’s knowledge and expertise of materials and CE within TMs, Chris having previously conducted work in the transport infrastructure but less so in the transport machines.

Building on his expertise on CE in built environment, **Mohamed Osmani** valued the new insights and knowledge associated with cross-TMs sectors’ supply chain characteristics and materials. The CIRCMATE-4-TMs project also provided him with a unique opportunity to gain an understanding of life cycle strategies, blockers, and enablers for the circularity of TMs materials and compare them


with the findings of his ongoing work on circular construction materials and EEE products. He will explore the replicability and transferability of the ROSE Framework, which underpins the work of this feasibility study, to other sectors, namely construction and EEE.

The project uniquely provided an opportunity to extend **Andrew Timmis**' knowledge and understanding of CE in the transport manufacturing field.  This has provided an extension of existing life cycle assessment research in the aerospace and automotive sector and to address systematic and holistic mitigation of environmental impacts through this project's inter-disciplinary approach.  Being part of the CENTS Network has provided an opportunity to develop new relationships across partner institutions.

The project enabled **Patrick Waterson** to focus on some of the main social and organisational barriers within the CE. The project also helped him gain some detailed knowledge of the technical challenges facing TMs sectors and the materials they use, as well as a range of other influences which act as barriers and enablers of their drive towards a sustainable future.

Testimonial from Industry partner(s) (max 500 words)

During the four protect meetings, all partners were fully supportive of the project and its outputs.

The received testimonials from CIRCMATE-4-TMs partners are noted below

**Matthew Moss, Knowledge Transfer Manager, Knowledge Transfer Network (KTN)**

*"Being involved in the CIRCMATE-4-TMs project has been highly insightful. End of life considerations are rarely accounted for within the maritime sector and especially not within the UK. The project has identified problematic materials common across all transport modes and produced a series of roadmaps which are useful in creating a strategy on increasing the circularity within the transport sector. I look forward to continuing engaging with the team to see these strategies realised'.*

**Nick Silk, Advanced Technology Manager, Tata Steel Europe**

*"Tata Steel Europe has supported the project from the perspective of a steel supplier to the automotive sector bringing expertise on steel manufacture, steel circularity and broader information about the automotive supply chain. The project has been very helpful in bringing together experts across all TM sectors and sharing views on the key materials used in these sectors and where opportunities arise for increased circularity.  The project has facilitated a 'compare and contrast' across transport machines and exchange of views that are representative across these sectors and supply chain partners. The interaction with academics and experts from across the TM sectors has been very beneficial in helping us define and refine our internal roadmap for the circular economic transition and identify new considerations we need to take into account.*

*The structure of the project has led us through a process of defining the 'as-is' with some peer review of this status, through a range of circular material strategies and overlaid these against each transport machine sector. This has then been used to consider where barriers exist for steel and*


*plastic and what enablers are required to migrate to a more circular economy and over what timescales. It has been possible to present this in the form of a roadmap which articulates how the ROSE framework, legislative and policy measures etc. come together to enable the transition. The process of roadmap development has been helpful in driving us to consider ranking and prioritising of barriers and enablers across transport machines, and to consider the timescales of legislative and policy measures required to enable the transition. The roadmap is useful internally within Tata Steel Europe and in addition to being consistent with other publicly available information, and it provides a more focussed view for steel (and plastics) that (because it covers all transport machines) compares and contrasts with our internal view for the automotive sector in isolation.*

*Given the constraints presented by COVID in terms of ease of informal interaction and networking the project has brought together a valuable cross sector group of exports and facilitated the development of a valuable roadmap".*

Additionally. the interviews with representatives from automotive, maritime, aerospace and rail sectors were also supportive of the project, with one stating "*we would like to follow the findings of this project and would be delighted in participating in any future project*"; and another confirming that "*this project is very interesting to us, we need to start looking at circularity in our procurement and manufacturing process and I am sure the project's outputs will aid in this*".

Impact (max 200 words)

The study focused largely on two TMs materials: plastics and steel, but the methodological approach of both 'ROSE Framework' and 'Roadmap' could also be used for other materials. It could also be used for other types of TMs sectors, namely micro mobility and/or focusing more on different modes of transportation within these sectors.

By bringing industry partners together which represented different parts of the supply chain as well as various TMs sectors, much was gained in the sharing of knowledge. It was acknowledged from the project partners and the interviewees that cross-TMs learning, and information exchange rarely happens. The resulting 'Roadmap' can be used by various actors going forward, including individual companies, trade bodies, Government, and the research community. Each roadmap action can in essence be the subject of further research, involving representatives from across TMs sectors.


Next steps (max 200 words)

A journal paper is being prepared to present the study and its findings, particularly the roadmap aspects, which will be submitted to an appropriate journal in the next few months.

There is the intention to apply for follow up funding, which was discussed at the last project meeting, partners were asked to provide their thoughts on follow on project(s). Of particular interest was how to design for circularity in rapidly changing world and the type of business models needed to support this, which was felt to be needed for all of transportation machine sectors, with the move to net zero and future mobility solutions. Feedback from the CENTs conference also indicated that the project could potentially lead to further research on EoL choices, the relationship with net zero, micro mobility solutions, and distributed networks. The 'Roadmap' in its entirety could be taken forward for research to address cross-sector implementation of CE principles or priority actions. All project partners and those that were interviewed were interested in participating in a larger project.