CENTS: A Research Network for the Sustainable Transport Community

Circular Economy Network+ in Transportation Systems

British Geological Survey

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:
Smart and Sustainable Coatings

Executive summary

This work has explored current and future coating options for sustainable transport and beyond where polymer-based substrates are being used. A range of current and future technologies including vitrimer, peelable coatings and zero coating technology options have created a basic framework for a sustainable understanding of the dynamics and difficulties operating within mixed material systems in the CE.

As major innovation and changes in a coating system have knock on effects throughout the circular economy, two (extreme) scenarios can be employed. 1. Create a flexible, dynamic and responsive system of innovation throughout. 2. Simplify and stabilise innovation and changes in the system.

Since it can be assumed innovation will be required to meet net zero challenges it is therefore likely that considerable change will be required throughout the entire CE chain and beyond into wider sectors, creating multiple sub-loops and bottle necks in our current operating systems. On the positive side this creates considerable opportunity for SMEs to enter and impact the market.

Starting from the question of 'how do coatings limit the recyclability of components, and how could they be made more recyclable', we have undertaken a thorough investigation into current commercial approaches to environmentally friendly coatings, and also investigated state-of-the-art techniques that could in future become commercialised. During this investigation, we performed an extensive review of both the academic literature and published patents, alongside a survey of businesses working in this field. Further, the impact of innovation at specific places in the CE loop was considered and areas identified which could create bottle necks, sub-loops or disruptive new circular patterns operating within the bigger CE system.

Project Team

Vannessa Goodship (PI)

Vannessa's work spans the technical interface of academia and industry with over 50 publications across this remit. Her areas of specialism are plastics materials, their processing, and recycling. She has undertaken many research projects across this scope, in multiple sectors, including looking at multifunctional surface materials for aerospace and automotive. As well as relevant experience in surface technologies, plastic and composite recycling, her current activity also includes work in Waste Electrical and Electronic Equipment (WEEE) and battery recycling.

Allen Alexander

Allen Alexander- Allen is a senior researcher, investigating the role that innovation and knowledge-based capabilities play in enabling a transition toward the Circular Economy (CE), in particular focussing on Circular Acceleration. At product/service level this considers Circular Innovations; at firm-level Circular Business Models and at regional, national or societal-level, how CE principles contribute to socio-economic transition theories. His prior engineering career provides him with unique skills and has enabled him to work alongside colleagues from different disciplines to apply his research to sector-specific issues.

Ruth Cherrington

Ruth has over 10 years of experience supporting research and development projects in collaboration with industrial and academic partners. She currently provides focussed support to SMEs helping them to realise their growth potential through innovation. The project aims to improve productivity and deliver economic growth by stimulating early stage Research Development and Innovation (RD&I) activity. Her research within this project is looking at the role of innovation within circular economy across individuals and organisations. She is also interested in how certain values (such as environmental sustainability) impact and direct innovation and how emerging innovation ecosystems are supporting the businesses within them.

Jean Marshall

Jean has a background in Polymer Chemistry and recent research experience in short-loop recycling. She undertook two postdocs at University of Cambridge on an EU-funded collaborative research project and a directly industry funded project around 'smart' polymers (including maternity leave) before taking up an industrial position at Domino Printing

Sciences. Since joining WMG she has supported two Faraday Challenge projects on battery recycling and reuse and polymer solid state batteries.

Industry Partners

Princess Yachts

Project Rationale

This project is the first to combine a technical interest in new materials for recyclable coatings, with a focus on the innovation-based aspects of recyclable coatings in the circular economy and has bought together four very diverse skill sets to achieve its aim.

Key Findings

1) The coatings market is facing increased pressure from legislation to reduce environmental impact, at the same time the market demands improved long term performance, and in some instances, consumers are driving the need for more sustainable coating solutions (without having to pay an increased price). Industry engagement through this project has found that even though there are signs of commercialisation, there are still several challenges involved with implementing a new material such as; the inherent low value of polymer materials, limited recycling infrastructure, ensuring product compliance, the need for restrictive confidentiality agreements to support cross-sector knowledge exchange.

2) Coating technologies for polymeric substrates continue to develop scientific answers and opportunity towards the CE. Multiple options and recycling strategies however can actually cause confusion for downstream recycling systems. Innovation in the plastics sector, has seen multi-material components, different resin composition and high levels of contamination making separation of materials challenging at end of life. The complex value chain of plastics will have to be changed in significant ways to create viable management approaches towards achieving environmental and economic gains. Further support for SMEs is required to invest in research, development and innovation (RD&I) alongside skills and education needed to embed life cycle thinking at all stages.

Background

Coatings are used extensively in polymer and composite applications for aesthetic effects, and to impart hardness and durability. However, coatings can limit a component's recyclability, creating mixed waste streams, for example, when a thermoset coating is applied to an otherwise easily recyclable thermoplastic material. For the circular economy, it is important to consider the whole component, and to consider how the waste materials need to be separated if they are to be efficiently recycled. New technologies may create more easily recyclable components, but these will only aid the circular economy if the recycling process is economically viable. It is therefore a challenge encompassing both technology and business innovation.

The scope is therefore to consider both the technical and innovation opportunities, to roadmap a direction towards sustainable coatings (for polymeric substrates) with the aim of investigating the role that innovation and knowledge-based capabilities will play in enabling a transition and accelerating that transition toward the Circular Economy. Knowledge gaps and opportunities should be readily identified once these actors are in place.

Results

Commercial approaches to environmentally friendly coatings have focused on removal of volatile organic compounds (VOCs) from coating formulations (e.g. by using ultraviolet (UV) curable or water-soluble binders) or replacing traditional binder materials with bio-derived polymers. Future approaches could include manipulating the components' surfaces to remove the need for coatings, creating new materials and formulations for coatings, or making 'stick-on' coatings so that removal from the component at end of life is straightforward.

Challenges in effectively recycling coatings include: the often low value of the coating materials (and the substrate) the difficulty of finding second uses for recycled coating materials, the limited available infrastructure for recycling, and requirements for product compliance. From our survey of industrial partners in this field, we learned that specific challenges can also include a lack of customer demand for recyclable coatings (especially if such coatings increase the price of the component) and the labour-intensive nature of some recycling processes.

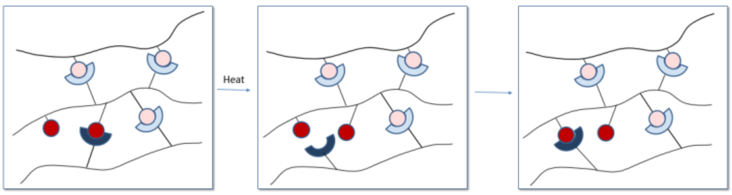

Figure 1. Mechanism for flow in vitrimer networks.

Future approaches we identified that could make coatings more straightforwardly recyclable include the use of biodegradable resins or replacing dyes and pigments with structural colouration components. Even more promising is a new technology termed the 'vitrimer' approach, which incorporates a new class of materials. Vitrimers are covalent networks of molecules, which contain bonds that can 'exchange' at elevated temperatures, giving them thermoplastic properties. See Figure 1 for the mechanism underlying this process.

The vitrimer approach is rather new, with the term only having been coined in 2011; see Figure 2 for a visualisation of how interest in these materials has increased over the last decade. Commercialisation of these materials seems likely to be imminent, they have already found commercial use in the sports sector and at least one start-up company (Mallinda) having raised significant venture capital to produce vitrimer materials for industrial sectors including automotive. Using vitrimer materials instead of traditional binders could impart desirable properties typical of thermosets to the coating material, while also allowing the coating to behave as a thermoplastic and be recycled with an underlying thermoplastic component.

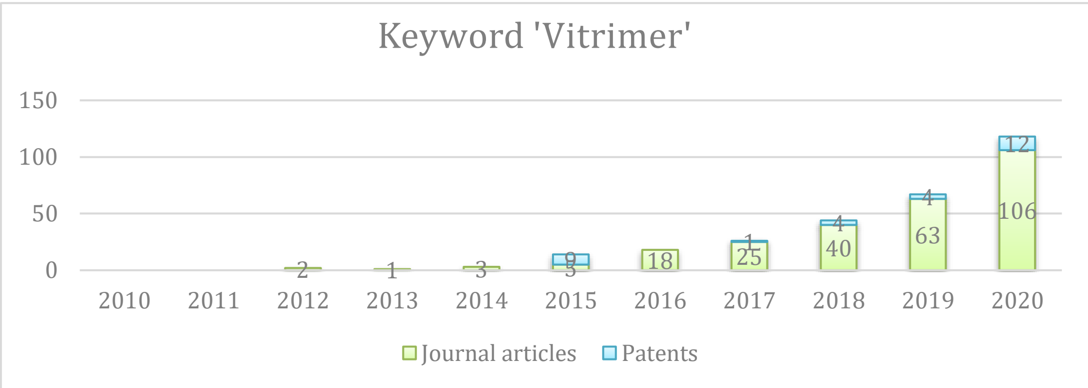

Figure 2. Graph to show the increasing number of publications on 'vitrimers' over time. Figures are based on a search in Scifinder on the keyword 'vitrimer'.

An alternative scenario using vitrimer is the coating is discarded entirely and a single system behaving like a thermoset in service but a thermoplastic at end of life could massively change the trajectory and dynamics of both the coating and thermoset industry. Either way vitrimer technology is likely to play a leading role in the CE as the technology is developed and deployed. Innovation in both compliance and infrastructure of the CE will be required to change as vitrimer materials will be need to be readily identified (perhaps by new marking) and new new 'unzipping' technologies deployed. Thermoset technologies seen to be in rapid decline as light weighting and recycling have been seen as more 'desirable' for thermoplastic applications may see a trend reversed as durability and service life become more prominent as transport systems extend their expected service lifetimes beyond those currently assumed. 20+ years is not seen as unreasonable for future automotive models.

Whilst there are other coating technologies which have been reviewed during this study, vitrimers are the only technology reported here in depth as it lends itself to the scenario modelling being undertaken during this work. Local changes and fluctuations in any CE supply loops will affect actors in all stages of the system and stabilising such a complex series of technological changes will be problematic and not immediately visible due to the lifetimes of materials in the system. These changes do lend themselves to digital model creation, and it is suggested that this is an area highly likely to expand both academically and commercially in the future as modelling will show opportunities not immediately apparent to drive future investment and innovation.

Impact

As CE is still an emergent activity, we need an understanding of what works and what does not, to enable adoption. This study considered how technological transitions are adopted by industry and to further understand the interaction of actors, environments, and innovations in the context of plastics. A nasent plastic technology identified for transport - vitrimers, gives an opportunity to explore these interactions moving forward in both transport and beyond having being originally identified from sports sector applications. The importance of cross sector interactions and cross fertilisation of knowledge, technology and ideas is paramount and has been is clear in both the materials of study and the complex interactions of substate and coating throughout the plastic and composite sectors for recycling infrastructure. This has much broader impact moving forward. Further the smaller fluctuations bought about by small changes in bigger systems have broader impacts for modellers attempting to capture the intricate workings of the CE.
The links between customer drivers and environmental implementation was also clear and will require further interventions in some sectors to overcome this resistance to change.
The work surrounding these technological transitions can be applied to further industries such as the emerging offshore renewable sector and beyond.

Next Steps

This research will be expanded to more broadly look at the role of plastics with a CE. There are several initiatives being implemented looking at how we can reduce the impact that plastic has on the environment and retain value in the system. These include the use of reusable or compostable plastic, the elimination of problematic or unnecessary single-use items through redesign, innovation or reuse delivery models and the increased inclusion of recycled material. Many businesses in developed economies have reacted to this high-profile topic, revising the current philosophy of distributing and consuming plastic, however extensive confusion exists about the most appropriate solution. Existing policies emphasise reductionism and end-of-life approaches. Exploring a CE driven transition for plastics allows us to focus on design for circularity and target production toward zero waste.

A paper is currently in press to Polymer (Q1), a further joint paper is in draft (Q1), one conference paper has being submitted, and a joint funding proposal with Exeter and Warwick is in current development and expected to be submitted shortly.

Testimonials

From the Early Career Researcher(s)

"This project has provided an invaluable experience to apply circular economy thinking to an industry challenge. I have learnt from the unique expertise and experience of each team member and stakeholder. As a modern researcher, there are huge expectations in terms of securing funding, contributing to grand challenges, having an awareness of the potential impact of your research and developing relationships with stakeholders. This project has provided the opportunity to develop collaborations, share opportunities and ideas to support my career development." Ruth Cherrington

"Collaborating with colleagues from Exeter Business School has raised my level of understanding of the CE beyond just the technological and made me consider much wider and longer term business impacts for UK PLC and beyond. This is massively beneficial to me as a researcher moving forward and I have greatly enjoyed the opportunity this funding provided to expand my understanding of CE" Vannessa Goodship

From the Industry Partner(s)

"*With over 50 years experience in yacht manufacture we recognise the importance of environmental sustainability throughout the lifecycle of our product.*
We aim to create a unique product while minimising its environmental impact and striving for continual improvement.
Understanding how we can embed circularity into our products and processes is of particular interest. Paint coatings are used on our composites structures for aesthetics, surface treatment and protection and research which highlights opportunities to improve environmental performance, where possible, is valuable for us to recognise future areas for improvement."

Princess Yachts Limited, Plymouth , UK