



Research advances in the Foundation Industries

TransFIRE Hub 2024

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Executive summary



The TransFIRE (Transforming Foundation Industries Research and Innovation) project was conceived to address the urgent need for innovation and sustainability within the UK's Foundation Industries—cement, ceramics, chemicals, glass, metals, and paper. These industries produce 75% of all materials, contribute around 10% of the UK's CO₂ emissions, and generate an annual Gross Value Added (GVA) of approximately £52 billion. Through its efforts, TransFIRE has demonstrated key accomplishments, including identifying energy savings of up to 20% and CO₂ emissions reductions of 25% through best practices. These successes highlight the crucial role of these industries in driving sustainability while supporting the UK economy.

A distinguishing feature of TransFIRE has been its emphasis on collaboration. By uniting over 40 investigators and researchers across 12 institutions and more than 130 companies, NGOs, and governmental bodies, the project identified shared challenges and solutions through a cross-sector approach. This methodology, pivotal to the project's ethos, was operationalised through technical working groups, knowledge-sharing platforms, and workshops, driving the adoption of sustainable practices and innovations.

The project's impact is tangible and multifaceted. Through industrial symbiosis, over 350 collaborative opportunities were identified, leading to the diversion of 10,000 tonnes of waste from landfill within a three-year timeframe. These efforts resulted in innovative products such as alkyd paint and sustainable latex, showcasing the potential for economic outputs from sustainable practices. Continued investment—both in sustaining existing initiatives and fostering new opportunities—is critical to scaling these successes.

TransFIRE has delivered numerous practical outcomes, including advancing chemical sector innovations through the TRLs, publishing findings, and facilitating intellectual property discussions. These examples highlight how targeted efforts within the Foundation Industries can create substantial economic and sustainability impacts.

The project's engagement with local communities across the UK has been crucial in identifying opportunities for collaboration and economic development, particularly through the work of TransFIRE researchers and partners, who focused on integrating circular economy practices with local needs. By working closely with circular economy groups, community organisations, and councils, the project has fostered community resilience and encouraged local authorities to play a more active role in promoting net zero practices. Specific efforts have included working with local authorities in both England and Scotland to establish links between Foundation Industries and regional heat and energy decarbonisation plans. While measurable revitalisation of local economies is still emerging, initiatives such as knowledge exchange, training, and collaborative spaces have laid the groundwork for long-term regional transformation.

TransFIRE identified key barriers to decarbonising UK manufacturing, such as insufficient recycling infrastructure and regulatory uncertainties, alongside opportunities like increasing investment in industrial symbiosis and incentivising low-carbon material use. These insights continue to shape the path toward a sustainable industrial future.

The development of a comprehensive equity, diversity and inclusion strategy and playbook has significantly improved workplace culture and inclusivity. These resources, highlighted at every TransFIRE Foundation Industry Forum, remain accessible as enduring tools for fostering equity within the Foundation Industries.



Looking ahead and supporting research

The UKRI Sustainable Industrial Futures funding opportunity offers a timely and significant platform to build upon TransFIRE's achievements and drive forward the sustainability agenda within the Foundation Industries. With up to £18 million available over seven years, this flagship investment aligns closely with TransFIRE's goals of decarbonisation, circular economy integration, and resource security. By focusing on cross-sectoral systems approaches and co-creation with industry, the initiative provides a critical pathway to scale up innovations and overcome barriers identified during the TransFIRE project. Leveraging this opportunity could enable the development of scalable solutions for low-carbon technologies, innovative waste valorisation strategies, and integration of Foundation Industries with regional decarbonisation and energy plans.

Building a skilled workforce is essential to sustaining the momentum generated by TransFIRE. Establishing initiatives like a dedicated Centre for Doctoral Training (CDT) for the Foundation Industries would ensure that the research and innovation fostered by TransFIRE and other TFI initiatives are translated into practical, industry-relevant applications. This will help bridge the gap between academic research and industrial practice, ensuring the long-term viability and competitiveness of the Foundation Industries. Other immediate support mechanisms to be pursued include dedicated clusters of iCASE awards to support PhD researchers, Knowledge Transfer Partnerships (KTPs) to strengthen academia-industry collaborations and targeted topics for the Future Leaders Fellowships (FLFs) in Summer 2025 to support early-career researchers. These approaches could accelerate the translation of research into practice while developing the skilled workforce needed to sustain progress.

Looking forward, it has also been proposed that some of the work initiated by TransFIRE will be picked up by the Foundation Industries Sustainability Consortium (FISC). This new consortium will scale up some of the efforts started by TransFIRE, addressing key challenges such as optimising existing plants for efficiency, developing next-generation sustainable processes and products, advancing the circular economy, and cultivating a skilled workforce to drive these innovations.

This integrated approach will not only sustain the legacy of TransFIRE but also catalyse further progress, bringing together stakeholders from academia, industry, and government to transform the Foundation Industries and support the UK's transition to a net zero economy.

In conclusion, TransFIRE has successfully contributed to redefining the landscape for the UK's Foundation Industries, demonstrating that immediate, low-tech changes can have significant long-term impacts. The project has established a strong foundation for continued innovation and collaboration, positioning the Foundation Industries as key players in the transition to a sustainable industrial future.

A word from our director



The TransFIRE (Transforming Foundation Industries Research and Innovation hub) consortium was developed in response to the Industrial Strategy Challenge Fund call to transform the Foundation Industries, namely: cement, ceramics, chemicals, glass, metals, and paper. UKRI allocated £4.7 million for three years to the hub to assist with technology development and transfer, new business developments and new opportunities in materials and technologies to help to achieve the net zero 2050 target.

The hub concept and proposal were co-created by academics (20 academics across 12 organisations) and industrialists in the middle of the Covid pandemic. Despite the restrictions in the first year, collaborative research and industrial collaboration began immediately to ensure productive and relevant research continued for the full three years.

The Foundation Industries have often been dismissed as too difficult to clean, too difficult to modernise and too difficult to diversify. TransFIRE has shown that the commitment is there from academia, industry and Government to start to make changes to these paradigms. New business models with a circular approach are starting to be developed in the glass sector. The 300 year old process of making pig iron for subsequent steelmaking is being questioned as the only way to make steel and now much work is being done to develop direct reduction processes, for example using hydrogen or ammonia. The British steel industry is also in the process of changing to electric arc furnaces for producing steel from recycled scrap. This is not all due to TransFIRE or the Transforming Foundation Industries (TFI) challenge but what it demonstrates is that there is now a willingness to change and TransFIRE has helped in part of that change of culture.

TransFIRE's position of taking a view of issues across sectors has been critical. Problems are not siloed, and one of the real areas of progress has been identifying the shared issues. One example is waste and the application of Industrial Symbiosis thinking which was clearly demonstrated through the TransFIRE programme across the industries and geographies. Shared thinking in how to deal with waste from one sector being used in another to create new business opportunities has been a tangible outcome from the programme. Serendipitous outcomes occurred, for example when looking at the recovery of precious metals from printed circuit boards (PCBs) it was realised that there was also a valuable source of copper from which a new business could be created, and this is now becoming a reality.

TransFIRE provided an environment where industry and academics have gained confidence in each other and could collaborate at whatever level was necessary. Collaborations were developed not only within sectoral supply chains but also across sectors, collaborations that only occurred because TransFIRE put the actors in a room together to work on the common challenges of equity, diversity and inclusion, energy, materials efficiency and waste.

I feel honoured to have had the opportunity to head up this huge challenge and I must thank all the Co-Investigators for their continued support through the three years. I would also like to thank the Cranfield team, especially Dr Sanjoo Paddea and Joanna Johnson for their amazing energy and organisational skills, keeping the programme on track, and Professor Kostas Salonitis for his support as Deputy Director of TransFIRE.

Professor Mark Jolly
Director of TransFIRE



What is TransFIRE?



TransFIRE is an UKRI funded (ISCF TFI Challenge) proactive, interdisciplinary, inclusive research and practice driven Hub with 12 research organisations based in the UK and more than 130 project partners from across the Foundation Industries (Cement, Ceramics, Chemicals, Glass, Metals and Paper), trade associations, professional membership bodies, civic sector and government organisations.

TransFIRE brings Foundation Industries and their communities together through interdisciplinary research, to support resource productivity, competitiveness, equity, diversity, inclusion and climate action.

TransFIRE is about looking at best practice and what common processes can be transferred between the industries, for example the minimising of resource use, lowering energy use and emissions, and using by-products.

TransFIRE is a proactive, interdisciplinary, inclusive research and practice driven Hub that:

- optimises the flows of all resources within and between the Foundation Industries and their supply chains.
- improves their competitiveness.
- works with communities in which they are located.
- supports UK Net Zero 2050 targets for GHG emissions.
- furthers equity, diversity and inclusion within the Foundation Industries.



British Geological Survey



PRIFYSGOL BANGOR UNIVERSITY



UNIVERSITY OF CAMBRIDGE



Durham University



THE UNIVERSITY OF EDINBURGH



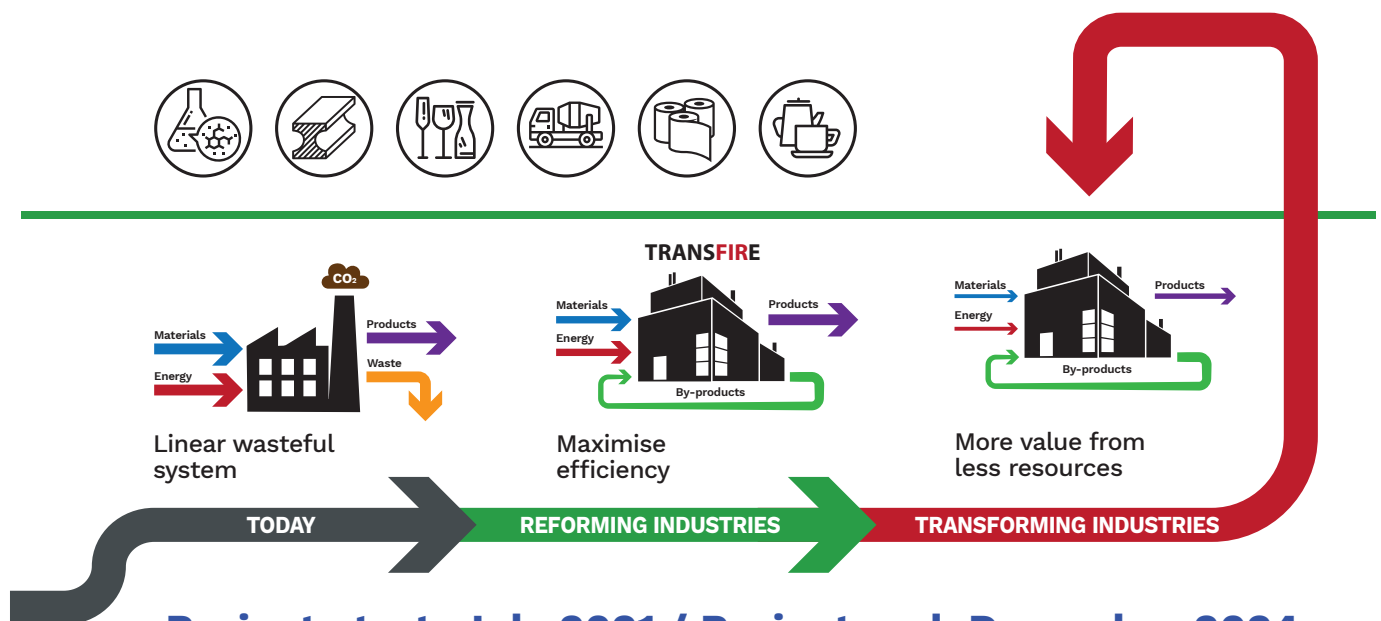
UNIVERSITY OF LEEDS



Northumbria University
NEWCASTLE

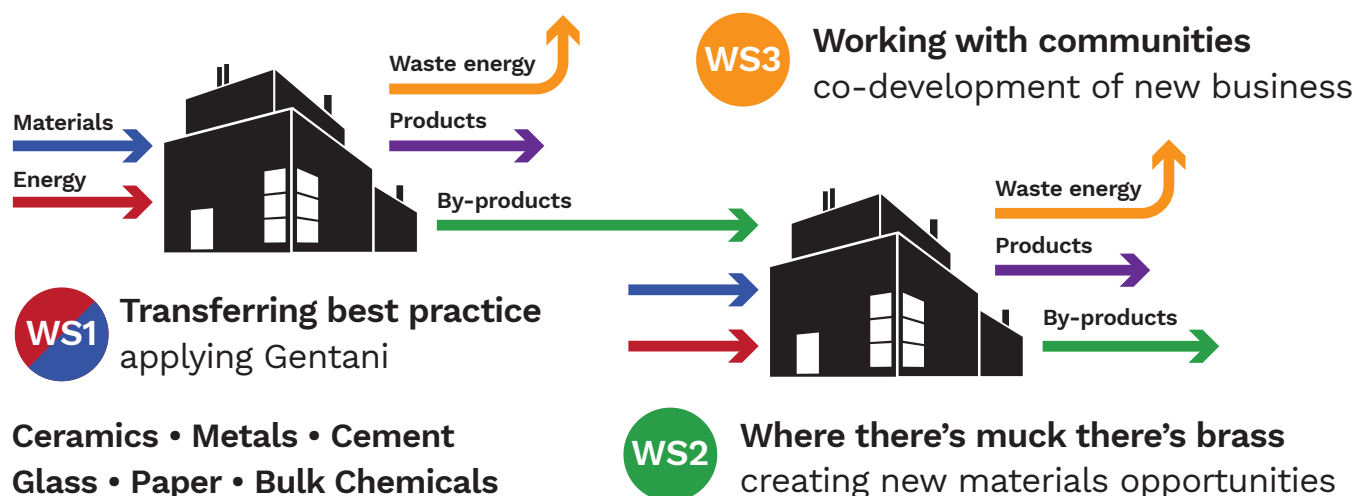


UNIVERSITY of York



Project start: July 2021 / Project end: December 2024

Key findings



Transferring best practice (WS1), Pages 21-29:

- Comprehensive energy and material flows for the six Foundation Industries (FIs), enabling comparison of UK and global performance using energy intensity and CO₂ emissions metrics.
- In-depth analysis of manufacturing processes across the six FIs, leading to the identification of best practices and opportunities for cross-sectoral learning.
- Potential energy savings of 20% and potential reduction of 25% CO₂ emissions when compared to best practice.
- Significant opportunities to implement circular practices in the UK. Our work shows that circularity can reduce emissions by 42% and up to 69% when combined with best practices.
- Establishment of an integrated benchmarking framework combining Key Performance Indicators (KPIs) and Best Available Techniques (BATs), offering a robust tool for industry self-assessment and strategic improvement in sustainability and operational efficiency.

Creating new materials and process opportunities (WS2), Pages 40-62:

- Exploration of industrial symbiosis opportunities through workshops, fostering collaboration among stakeholders and promoting resource efficiency across sectors.
- Over 350 potential synergies identified and over 10,000 tonnes of waste diverted from landfill to date.
- New products from waste streams, for example composite material from waste plastic, alkyd paint, sustainable latex etc.
- Implementation of a techno-economic approach to analyse the work in technical working groups (TWGs), facilitating knowledge sharing among industry stakeholders.
- Creation of an assessment framework that allows policy makers and companies to visualise the alignment between practice maturity, product development strategies, economic drivers and critical success factors.
- Discovering the hidden value of mineral waste: Gaining a better understanding of the composition and production of mineral waste in the UK and determine potential applications within the Foundation Industries.
- Co-producing a regional circular business model for industrial symbiosis. A series of co-production activities carried out within two regions in Yorkshire and the Humber, including two workshops with policy, academic, business and community stakeholders.

Key findings



Working with communities (WS3), Pages 64-75:

- Engagement with multiple stakeholders across the UK, including circular economy groups, community organisations and councils, to identify opportunities for collaboration and economic development.
- Mapping of contacts and assessment of locations for potential opportunities, such as heat, power, and skills, contributing to the revitalisation of local economies and fostering community resilience.
- Investigation of barriers and opportunities for collaboration between Foundation Industries and local communities, leading to insights into infrastructure development and long-term agreements.
- Promotion of peer-to-peer learning and user journey interviews, fostering knowledge exchange and collaboration between academia and industry, while driving innovation in sustainable development.
- A system perspective on policy enablers to transform Foundation Industries:
 - Change must be place-based and value-driven, with a shared direction among all business, societal and governance stakeholders.
 - UK public and private investment into skills, technology and infrastructure is essential.
 - A co-produced national UK industrial strategy is needed to give certainty and enable long-term investment into low-carbon technologies.

Equity, diversity and inclusion (EDI), Pages 12-19:

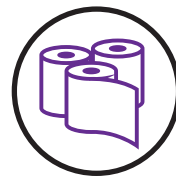
- Creation of the TransFIRE EDI Strategy: Drafting and circulating this strategy signifies a comprehensive roadmap for addressing EDI challenges within the FIs. It sets out a vision, principles, and governance framework for guiding their EDI efforts.
- Establishment of the EDI Playbook: This resource provides practical guidance and case studies for organisations within FIs and beyond to enhance equity, diversity and inclusion in their teams. It serves as a valuable tool for implementing EDI initiatives.
- The Equity Edge podcast: An innovative series of enduring resource to educate and inform both about the exciting career opportunities in the Foundation Industries and key considerations for foundation industry businesses for attracting, developing and retaining diverse and inclusive workforce.
- A draft maturity model was developed for businesses in the UK Foundation Industries to benchmark their progress towards embedding a diverse, equitable and inclusive culture.

Key findings



Technical working groups and case studies:

- Sharing of best practices at technical working group meetings.
- Collaboration with various industrial partners from across the Foundation Industries to address specific challenges and opportunities.
- Collaborative projects and case studies aimed at exploring sustainable solutions, from alternative raw materials to energy-efficient processes and sustainable waste management practices.
- 1000 cuts: Demonstrating the combined effect of multiple levers to reduce CO₂ emissions in the UK cement industry.
- Green copper refinery: In-depth feasibility report covering technical, economic and environmental facets to establishing the UK's first zero emission copper foil plant.
- Composition of glass: Sampling and analysing a wide range of container and float glass to identify properties that could bring about significant potential for energy savings in its production.
- Optimisation of ceiling tile: Investigating manufacturing processes, tile composition and other characteristics for optimal tile manufacture and to reduce waste and energy usage, capture and reuse waste heat.
- Opportunities for Foundation Industries in wind energy: Using stocks and flows analysis to model the demand for some foundation industry materials, the potential recyclates that will flow out of the wind energy system and the potential reduction in exposure to materials supply shocks.



Impacts of the TransFIRe project



25

New jobs created



£5M

Private co-investment including £1.3M cash contribution

130

New partnerships



27

Policy engagement and impact



157

Invited talks, conference presentations



£30M+
funding

30

New projects



Enhanced stakeholder engagement
Using waste heat
Increase EDI

5

Promotions

9

Further destination



42

Awards



15

Reports

55

Scientific publications





Reduce energy consumption by

20% ↓ 

Systematic mapping of energy and material flows in the UK's Foundation Industries showed potential energy savings of 20% compared to current best practices.

Hotspots for development were clearly identified where these savings could be achieved on our journey to net zero.

If all the savings are achieved, it would be equivalent to powering



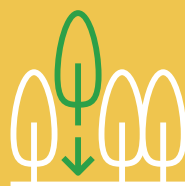
1.5 million
homes for 1 year

25% 
Less CO₂ ↓ ↓ ↓

Mapping of energy and material flows in the Foundation Industries pinpointed key materials made in the UK and their environmental impacts.

Best practices identified would **reduce CO₂ emissions by 25%.**

If all the savings are achieved, it would be equivalent to not driving 10 million miles/year
OR equivalent to planting 25,000 average trees/year.



25k



Circularity can reduce CO₂ by **40%**
and reduce energy by **17%**

Circularity rate measures the percentage of materials that are recycled and generating value compared with overall amount of materials used. In the UK there are many opportunities to increase circularity.

We show that improving circularity can **reduce CO₂ by >40%**, combined with best practices potential is **70%.**

Energy use could be **reduced by 17%** by improved circularity and **reduced by 56%** when combined with best practices.

>10,000 tonnes

Waste diverted from landfill



>350

Potential synergies



Industrial symbiosis identified **>350** potential synergies (company A using discarded resources from company B).

In TransFIRE **>10,000 tonnes** of waste, equivalent to **400 refuse lorry loads a year** were diverted from landfill because of **industrial symbiosis.**

4 New products from waste



Working on some of the waste streams from our industrial partners, the team has come up with a number of innovative new products. These have been advanced through the TRL levels. One exciting result is an alkyd resin coating for protective and decorative coatings applications from waste plastics (details on page 52).

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Equity, diversity and inclusion

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Equity, diversity and inclusion (EDI) and TransFIRe



Contributors:

Professor Sue Black, Jo Stansfield, Mike Thakoordin and Ciel Newton, Durham University.

Objective/benefits

The purpose of TransFIRe EDI programme has been to inform and support adoption of best practice for EDI within the UK Foundation Industries and beyond. We believe EDI to be requisite to embed the new learning, behaviours, process, and innovation required for industry transformation for a sustainable future and to achieve the net zero 2050 goals.

Our goal has been to establish foundations and leadership for EDI within the Foundation Industries to create and sustain this industry transformation.

The aims have been to provide a range of EDI engagement activities and resources to support organisations within the Foundation Industries (FIs) to increase EDI in their teams; to provide a forum for leaders from industry partners to convene on a variety of EDI topics; to provide a framework for FIs to benchmark their progress towards embedding an EDI culture, and to raise awareness of the FIs and the importance of EDI for the sector and general public.

Background

It is becoming increasingly apparent and widely accepted that equity, diversity and inclusion are of paramount importance in the success of any organisation or project. Yet the Foundation Industries face a specific set of EDI challenges. Research by UKRI in 2021 has highlighted:

- Lacking representation, particularly of women and younger people.
- An aging workforce and loss of skills through retirement.
- Challenge keeping pace with evolving skillsets particularly for digitisation and new technologies.
- Developing the talent pipeline poses challenges especially for small businesses.
- Bespoke, sector specific training is lacking. Engagement with higher education on curriculum is needed.
- No research has yet been conducted beyond gender and age, so little is known about the representation and inclusion of diverse identities more broadly.
- Lacking business case specific to EDI for the Foundation Industries.
- Sector image and culture are not attractive to new entrants.

In order to help tackle this important topic, the EDI team put together a range of projects and resources which are detailed here.

Equity Edge Podcast



Project overview

The Equity Edge Podcast is an accessible and enjoyable discussion-based podcast that aims to raise awareness of the Foundation Industries, and the importance of EDI for the general public and those working in these areas.

Approach

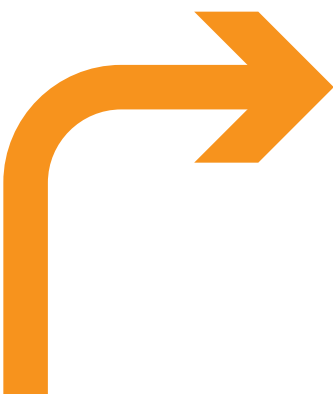
The Equity Edge is all about shaping tomorrow's Foundation Industries, with a focus on equity, diversity, and inclusion (EDI), and how it can help us achieve a sustainable and fairer future. We welcome expert guests across the Foundation Industries to discuss topics vital not only for our future workforce, but for the future of the Foundation Industries.

We bring together themes ranging from gender, race and ethnicity, LGBTQ+, disability, intersectionality and more... to environmental sustainability, decarbonisation and circularity... and on to leadership, early careers and organisational cultures.

The series has eight main episodes, and two bonus episodes and can be found at transfire-hub.org/podcast

Impact

This innovative series is an enduring resource to educate and inform both about the exciting career opportunities in the Foundation Industries, and key considerations for foundation industry businesses for attracting, developing and retaining a diverse and inclusive workforce and creating equitable workplaces. It brings together topics of EDI with transformation for sustainability and circularity to explore links and opportunities unique to the Foundation Industries.



Equity, diversity and inclusion (EDI) engagement and working group



Project overview

As part of the range of EDI engagement activities on offer, the team provided a first-of-kind forum for leaders from industry partners to convene on a variety of topics relating to EDI in the Foundation Industries.

The EDI working group was established, comprising people from across the Foundation Industries with an interest in EDI leadership, many leading EDI programmes in their businesses or externally.

Approach

Over its 2.5-year timespan, 30 members joined the EDI Working Group, in roles spanning production, operations, HR and executive leadership, and representing 19 foundation industry organisations. Organisations involved include: Tata Steel, Encirc 360, Celsa, Cellmas, Hanson/Heidelberg materials, IOM3, Materials Processing Institute, Innovate UK, Constellium, British Glass, Sheffield Forgemasters, Cast Metals Federation, Aggregate Industries, Universities: Durham, Sheffield, Cardiff, Cranfield, two independent members.

Six external experts in EDI joined as guest speakers to educate and inform foundation industry leaders and build a supportive network to share what's worked, and what hasn't, in an informal, guided discussion.

The format included an external speaker, Q&As and then open discussion amongst the participants about how this topic relates to their business and industry. This opportunity for networking and peer-learning was welcomed and led to rich discussions.

Topics included, amongst many others, mental health, anti-racism, addressing microaggressions, disability and inclusive innovation.

A range of other additional events and engagements also took place including workshops at each of the TransFIRE Foundation Industry Forums, designed to engage the audience to reflect critically on EDI opportunities in their context, a range of presentations at UK conferences and a series of site visits to various FI companies.



Professor Sue Black and Jo Stansfield speak at the FI forum



Outcome

This work has sparked engagement about the topic of EDI across the Foundation Industries for the first time. It has provided a safe space for leaders and EDI champions to come together to discuss key topics for their businesses and industry.

The EDI Working Group has led to building some strong relationships, which in turn have enabled us to capture case studies of good practices by TransFIRE's partners in the EDI Playbook and invite guests from across the Foundation Industries to speak on the Equity Edge podcast. Structured, yet relaxed discussion in the EDI Working Group sessions has been well received, enabling members to form a community, share what they've learned and achieved in their organisations, and learn from others on a similar journey.



“Thank you for everything you have done in terms of support and guidance and providing opportunities to hear from others. I don’t think we would have been as successful in our journey without your support. There is still some work to do, but it has been transformational from where we started.”

Melissa Bevington, Head of HR, Materials Processing Institute



Equity, diversity, and inclusion (EDI) playbook for the Foundation Industries



Project overview

The EDI playbook aims to drive engagement across the Foundation Industries to learn and capture shared EDI challenges and current practices. It also provides a platform for industry leaders and EDI advocates to amplify their activities and impacts.

Approach

The EDI Playbook provides a continually growing set of resources and case studies to support organisations within the Foundation Industries to increase equity, diversity and inclusion in their teams. It collects outputs from the TransFIRE EDI programme, and also links relevant research and articles from elsewhere.

transfire-hub.org/edi-playbook-for-the-foundation-industries

As well as a series of blog posts and articles, the playbook includes the following resources:

TransFIRE's EDI strategy

TransFIRE's EDI strategy is shared publicly as an example of how an EDI strategy can be structured. It captures specific EDI needs and challenges in the Foundation Industries, an EDI policy statement for TransFIRE, TransFIRE's governance structure for EDI, six strategic action themes, and success measures and KPIs. The strategic action themes are:

- **Start by listening:** Fill gaps in knowledge about EDI in the Foundation Industries.
- **Look to the future:** How EDI is an enabler for goals of clean technologies, reduced waste, and net zero 2050.
- **Engage industry leadership:** The role of leaders is vital to establish the need for change, to role model, lead inclusively, and embed best practices in their organisations.
- **Establish goals, measures and targets:** To establish the baseline state of EDI in the Foundation Industries, and evaluate the impact of all our EDI interventions.
- **Set foundations for an industry culture that is attractive to and inclusive of diverse talent:** We must work to change the perceptions to attract and retain a diverse workforce, and build more inclusive, equitable cultures for all.

This strategy provided a basis for the work of the EDI programme, and the action themes provide a structure for action and evaluation.



EDI landscape map

This lists, links, and categorises organisations that provide support and champion EDI relevant for the Foundation Industries. Over 50 organisations are listed, spanning industry groups, professional networks, resources, STEM outreach, charters, campaigns, and providing support across intersectional diversity topics including ethnicity, gender, LGBTQ+, disability, neurodiversity, and social class. The landscape map can be viewed here: <https://transfire-hub.org/wp-content/uploads/2023/04/EDI-landscape-mapping.xlsx>

2022 foundation industry survey

This survey of TransFIRE industry partners set out to measure a baseline of the EDI capabilities of organisations in the Foundation Industries in 2022, receiving responses from 20 organisations. The results from the survey provide new insight into the EDI landscape of the Foundation Industries, and highlight organisations that are demonstrating strong leadership in this area, and most commonly implemented EDI interventions. To read a full copy of the report and its findings, please download the document here: <https://transfire-hub.org/wp-content/uploads/2023/02/State-of-Equity-Diversity-and-Inclusion-in-the-UK-Foundation-Industries-2022.pdf>

Case studies

The EDI case studies are exemplar EDI interventions from TransFIRE's industry partners. They capture information about the industry and organisation, the challenge they faced, the intervention, and its outcomes. Case studies included are:

- Transforming workplace culture at the Materials Processing Institute.
- Elevating wellbeing and mental health awareness at Hanson.
- Sheffield Forgemasters.
- Glass Technologies.
- Launching member networks at IOM3.
- EDI case study: Constellium

The case studies can be viewed here: <https://transfire-hub.org/edi-playbook/#case-studies>



A model for equity, diversity and inclusion (EDI) in the UK Foundation Industries



Project overview

Beyond basic data around age and gender, there was no reliable dataset available to understand the level of understanding and adoption of EDI within the UK Foundation Industries (FIs). There was an opportunity to fill this gap in knowledge, working with TransFIRE's extensive network of industrial partners.

A draft EDI maturity model was developed for businesses in the UK Foundation Industries to benchmark their progress towards embedding a diverse, equitable and inclusive culture.

Approach

Semi-structured interviews were conducted with 17 of TransFIRE's industrial partners, covering small, medium and large-sized organisations and each of the Foundation Industries. Types of organisations included commercial businesses, trade associations and research institutes.

The results of the interviews showed many foundation industry organisations have low understanding and adoption of EDI. A set of maturity scores were created, and used to produce a draft maturity model that can be used to assess the maturity of EDI adoption across foundation industry organisations.

Impact:

The series of visits has begun discussions with many foundation industry businesses to engage with EDI topics, some for the first time. It led to new members joining our EDI Working Group (see below) where they could engage with industry peers to further their knowledge and explore topics through presentations from experts and group discussion.

An article about the draft Maturity Model for EDI in the Foundation Industries was published in *IOM3 Materials World*: <https://www.iom3.org/resource/model-behaviour-in-the-uk-foundation-industries.html>



2



Energy & resource use

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Mapping resource flows in the UK's Foundation Industries



Contributors:

Dr Natanael Bolson and Professor Jonathan Cullen, University of Cambridge.

Objective/benefit

Mapping energy, material and emission flows provides a critical evaluation of the Foundation Industries' status, enabling a benchmark that highlights our current position and potential improvements. This strategic approach not only assesses our standing but also directs us towards achievable enhancements in sustainability and efficiency.

Project overview

The Foundation Industries provide the building blocks of our society, and they are considered critical targets for decarbonisation. To effectively decarbonise these industries requires a comprehensive understanding of their status and adequate tracking of progress towards decarbonisation.

This study aimed to provide a comprehensive mapping of energy and material flows in these sectors, pinpointing key materials manufactured in the UK and assessing associated impacts. By benchmarking the UK's performance against global standards and best practices, this analysis becomes a powerful tool for monitoring progress towards the goal of net zero emissions by 2050. Additionally, the approach offers cross-sectoral insights that aid in informed decision-making and enhance the effectiveness of measures to transition towards a more sustainable future.





Approach

The study adopted an input-output approach, focusing on the Foundation Industries such as cement, ceramics, chemicals, glass, metals, and paper. The initial step involved identifying the key resource flows for each sector based on criteria like mass flow magnitude and manufacturing presence in the UK.

Research activities included an extensive literature review, utilising databases, government reports and statistics, trade information, sectoral associations, as well as peer-reviewed publications.

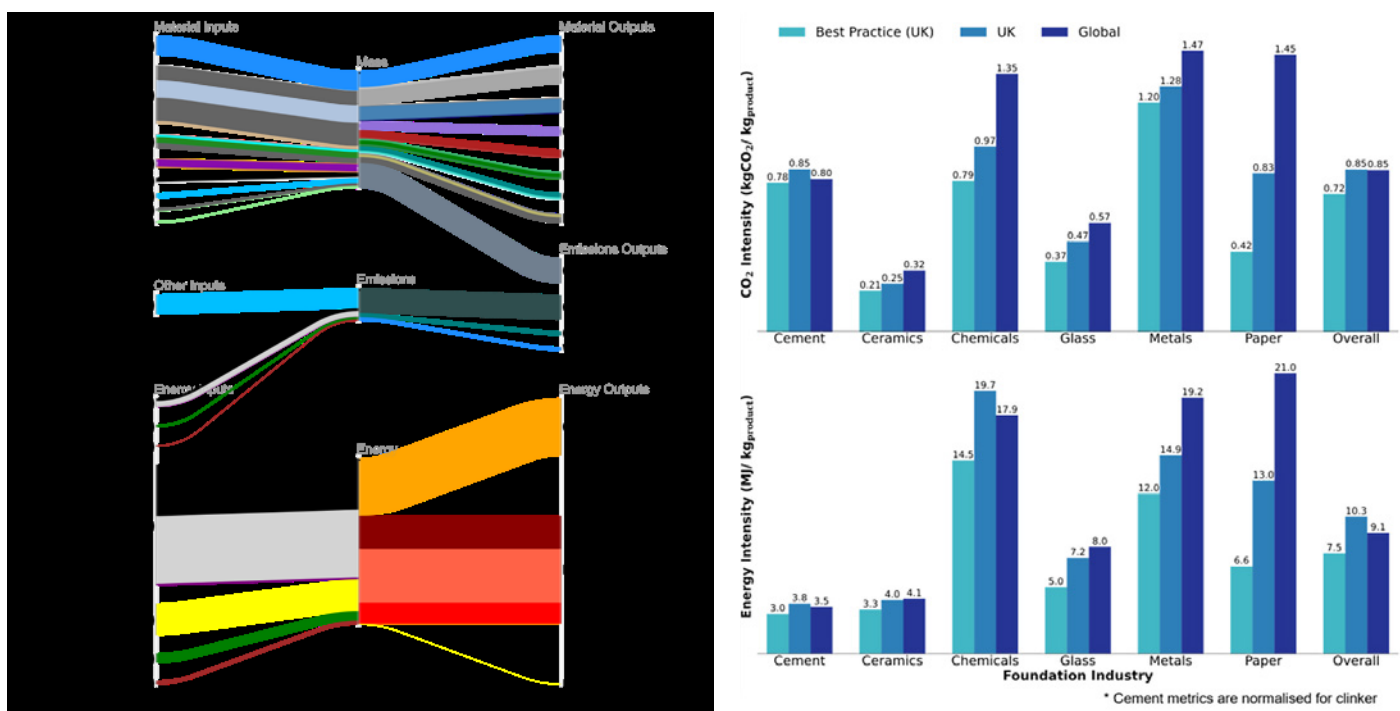
Outcome

The systematic mapping of energy and material flows within the UK's Foundation Industries not only revealed their current performance but also pinpointed crucial areas for enhancement. This robust approach presents data in a clear, transparent, and flexible manner, effectively scaling from individual companies to global contexts, and supporting temporal analysis from daily to yearly assessments. Such comprehensive data provision is vital for calculating key metrics and verifying reported figures, strongly advocating for its widespread implementation.

The figure below outlines the resource flows alongside benchmarked metrics, clearly demonstrating the various stages of the decarbonisation journey across sectors. This illustrates a collective opportunity for industries to elevate to best practice standards and become benchmarks in sustainability and efficiency.

The research provides data-driven insights into energy and material flows, enabling targeted actions and benchmarking across industries to support the UK's path to net zero emissions by 2050. The findings were presented to all Technical Working Groups, which included a range of stakeholders with decision-making authority at the company level and, in some cases, associations that directly support industries.

More details here: <https://transfire-hub.org/energy-benchmarking-of-manufacturing-processes-in-foundation-industries/>



Material circularity in UK Foundation Industries



Contributors:

Dr Natanael Bolson and Professor Jonathan Cullen, University of Cambridge; Dr Masoud Ahmadinia, Professor Rossi Setchi, and Professor Sam Evans, Cardiff University.

Objective/benefit

This study explored the potential for material circularity in the Foundation Industries and assessed the impacts of adopting these practices in terms of energy, emissions and supply chain resilience.

Project overview

As the UK aims for its ambitious net zero emissions target by 2050, the shift from mere energy efficiency to comprehensive sustainable resource management becomes crucial. This research underscores the vital role of circularity in materials such as aluminium, lead, steel, glass, and paper within the UK's Foundational Industries.

This study aims to assess current circularity levels and pinpoint areas for improvement, introducing a circularity index for each material to accurately measure usage and recycling rates. This will reveal unique challenges and opportunities that influence circularity, emphasising the complexities of achieving sustainable resource management. Enhanced material reuse and recycling are shown to considerably reduce energy consumption and greenhouse gas emissions, providing the dual benefits of material conservation and energy optimisation.



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Approach

This research, grounded in current resource flows, focuses on the technical feasibility of aligning material circularity practices with existing demands.

The study focuses on the associated changes in the industries by adopting material reuse and recycling, quantifying the impacts on energy consumption and greenhouse gas emissions.

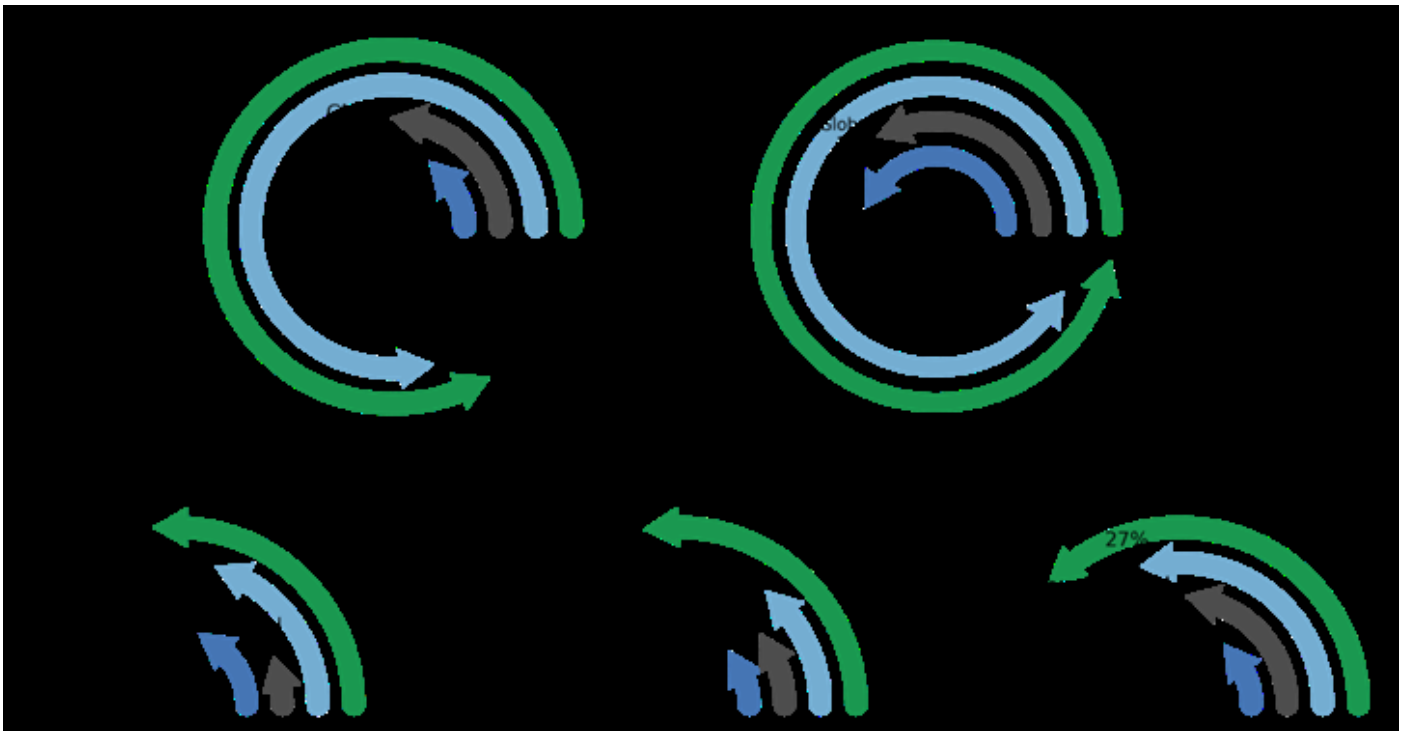
It implements a composed circularity metric that accounts for energy and material circularity, assessing current and future limitations on circularity, which also provides a quantifiable measure of the benefits of circularity.

Outcome

Foundation industries have significant potential for material circularity, which is essential for achieving net zero and enhancing sustainability. A holistic analysis has identified the share of production in a circular scenario, its effects on internal supply, and the impacts on emissions and energy consumption. The UK has significant opportunities to implement circular practices, which, to maximise benefits, must be coupled with best practices.

Specifically, the study shows that circularity can reduce emissions by 42%, with combined practices achieving up to 69%. Energy use can decrease by 17% through circularity alone and by 56% when combined with best practices.

The figure below summarises the circularity index for the materials covered in this study. It offers a perspective on where the UK stands compared to the global average and provides a clear understanding of the potential for the UK and the practical limits imposed by available technologies.



Clinker production: assessing minimum energy requirements and emissions for different raw material compositions



Contributors:

Dr Natanael Bolson and Professor Jonathan Cullen, University of Cambridge; Dr Shoaib Sarfraz and Professor Konstantinos Salonitis, Cranfield University; Dr Michal Drewniok, Dr Anusha S. Basavaraj and Dr Hisham Hafez, Professor Phil Purnell, University of Leeds.

Objective/benefit

Cement production is highly dependent on the composition of the raw meal, which is sourced locally. The material inputs can affect expected performance in terms of energy use and associated emissions. This study explores how chemical composition influences expected performance to understand the theoretical and practical limits of clinker making.

Project overview

Several roadmaps are available for the cement sector, aimed at improving energy efficiency and reducing carbon emissions. Different measures are proposed, but most of them assume a standard average raw meal composition, which cannot be adjusted.

There is a knowledge gap regarding how the chemical composition of raw materials affects the energy and carbon emissions requirements for clinker production. To bridge this gap, TransFIRE researchers have developed an open-source model that estimates the minimum energy requirements for clinker production based on different raw material compositions.

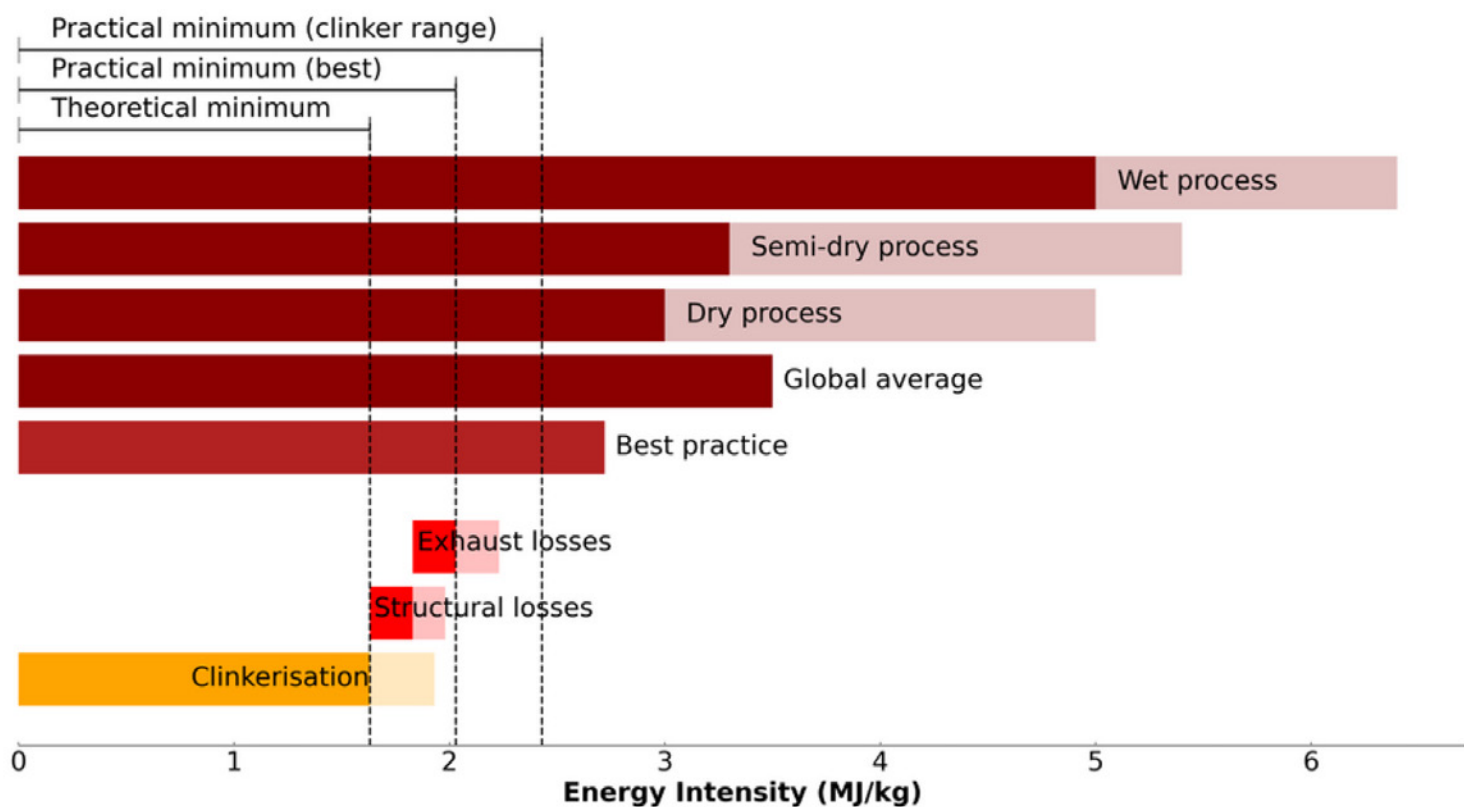


Approach

This research developed a model that examined both theoretical and practical minimum energy requirements. Theoretical minimum energy refers to the minimum energy necessary for chemical reactions, while practical minimum energy sets a more realistic target that accounts for factors such as thermal losses.

The model evaluates how the final clinker composition, which varies across different clinker production processes, impacts energy intensity and material yield. We also conducted a sensitivity analysis of clay and water content losses and analysed thermal losses from exhaust gas composition and kiln structure.

Feedback from industry suggested the possibility of selecting sites based on the composition of available raw materials, with the aim of identifying options that could help save energy. Additional comments included guidance on choosing between additives and alternative materials that could be incorporated.



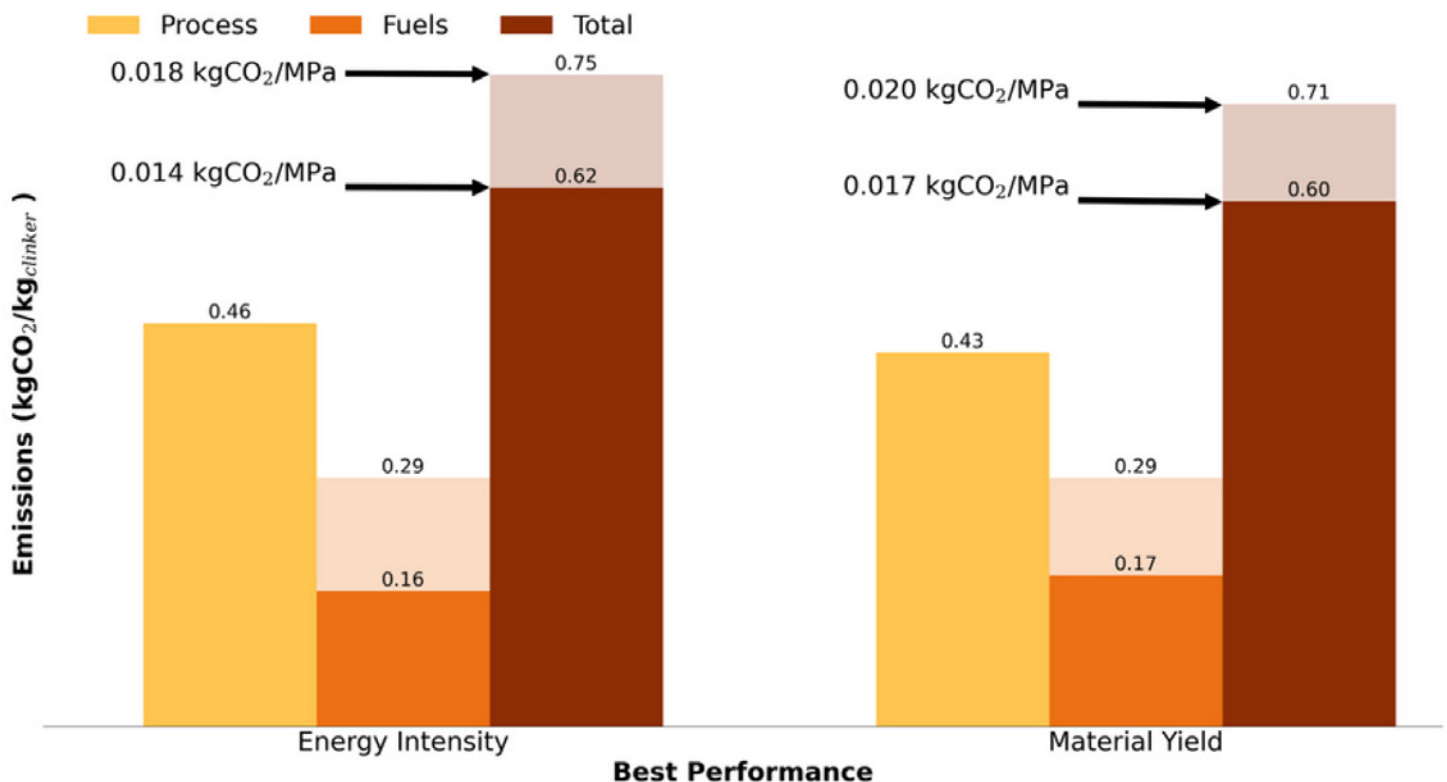
Outcome

An analysis of the theoretical minimum for the clinker-making process was conducted, covering 3,738 clinker compositions.

A detailed analysis of both theoretical and practical limits, including a range of variability associated with the clinker composition revealed that the theoretical minimum energy for clinker production is in the range of 1.6 MJ/kg to 1.9 MJ/kg, while the practical minimum is in the range of 2.0 MJ/kg to 2.5 MJ/kg.

Analysis revealed that clinkers produced with higher energy efficiency tend to have greater strength values.

This research provides critical insights into reducing the energy requirements and emissions in cement production by developing an open-source model to estimate the minimum energy needed for clinker production based on raw material compositions. It identifies significant potential for energy savings and emissions reduction, offering a baseline for improving energy efficiency and achieving lower carbon emissions in the cement industry.



Energy benchmarking of manufacturing processes in Foundation Industries



Contributors:

Dr Shoaib Sarfraz, Ziyad Sherif, Professor Mark Jolly and Professor Konstantinos Salonitis, Cranfield University.

Objective/benefit

Developing an industry-driven approach for selecting effective and relevant metrics to benchmark energy consumption and utilisation in manufacturing processes, enabling improvements in energy efficiency and sustainability for Foundation Industries.

Project overview

For industry to reduce carbon emissions, it is imperative to find ways to reduce the energy consumption by either using more energy-efficient equipment and processes or by moving towards renewable energy.

To identify areas of inefficiency and which changes will have the greatest impact, benchmarking energy consumption in manufacturing processes is a critical step. By comparing energy utilisation data to industry standards or to similar operations, manufacturers can get a greater understanding of their energy consumption and determine the areas to tackle first for the greatest effect.

TransFIRE researchers at Cranfield University have worked alongside industry and subject experts, incorporating their views, to provide a comprehensive and objective evaluation of the available metrics.





Approach:

Starting with a literature review of metrics and benchmarking approaches, the researchers undertook two surveys and conducted interviews with Foundation Industries in order to determine the most suitable criteria for evaluating the performance of energy-related metrics in the manufacturing sector.

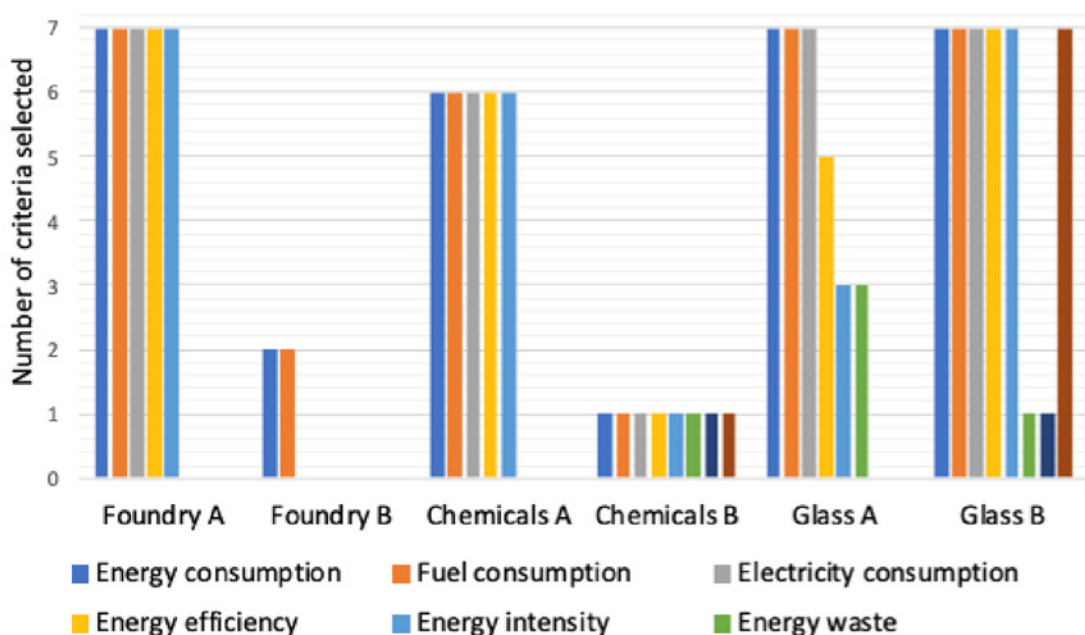
The first survey was aimed at determining the most suitable criteria for evaluating the performance of the metrics in terms of energy consumption and utilisation in the manufacturing sector. The second survey identified the most used metrics (energy consumption) as well as their effectiveness.

Outputs:

The survey results revealed a significant variability both within and across sectors, with some organisations employing a greater number of metrics, with others prioritising higher quality metrics with a greater number of criteria.

The research findings indicate the need for the industry to take several key actions to improve energy benchmarking of manufacturing processes. First and foremost, developing an accurate and reliable method to consistently collect and measure energy consumption data across different processes and organisations is critical, as proper procedures and standardisation are essential for meaningful benchmarking. Additionally, the industry should focus on employing a smaller number of high-quality, relevant energy metrics rather than a larger quantity of lower-quality metrics, as the research suggests that organisations prioritising higher-quality metrics with robust evaluation criteria gain more actionable and impactful insights. Direct engagement with industry experts and stakeholders is also recommended to determine the most suitable criteria for evaluating energy-related metrics, ensuring that benchmarking approaches are well-informed and relevant. Finally, leveraging the benchmarking process to identify areas of energy inefficiency and prioritise improvements with the greatest impact, while regularly reviewing and updating the framework to maintain its relevance, will be essential for advancing the industry's sustainability goals.

For full details of the paper, please visit <https://doi.org/10.1016/j.procir.2023.09.188>



Metrics evaluation by industry: quality vs. quantity.

1000 cuts



Contributors:

Dr Michal Drewniok, Dr Hisham Hafez, Dr Anusha Basavaraj, Professor Phil Purnell, University of Leeds.

Objective/benefit

Demonstrating the combined effect of multiple levers to reduce CO₂ emissions in the UK cement industry.

Project overview

Across the Foundation Industries, steps are being taken to reduce the eCO₂ of materials and products.

Many of these steps, for example more efficient design, lower energy processes and reducing waste, are considered separately, however, the combination of multiple steps is not considered, nor is the potential for interactions between them.

In the case of cement production, eCO₂ can be reduced by using low-carbon cement, cement replacement materials or alternative fuels. In concrete production, this can be further augmented by better concrete mix design and reduced waste. In component/site production, this can be further enhanced by optimised structural design and reduced waste again. In system terms, increased reuse and refurbishment of buildings can be implemented, reducing demand for cement.

While each of these steps have a relatively marginal CO₂ reduction, combining them in intelligent ways can make much larger CO₂ savings.

This study aimed to demonstrate the combined effect of multiple marginal actions, of things that can be done now rather than in the future, to reduce CO₂ emissions in the cement industry. This will provide a crucial stepping-stone to encourage companies in this sector to implement changes at their sites.





Approach

Various interventions are needed in the cement and concrete sector to reduce demand (dematerialisation) and reduce the carbon impact from cement and concrete production.

TransFIRE researchers at the University of Leeds identified interventions that will allow the industry to get closer to dematerialisation of cement and concrete. These include:

- Clinker replacement,
- decarbonisation of electricity,
- alternative fuels,
- thermal efficiency improvements,
- concrete concrete mix design optimisation,
- reduction of overspecification,
- extended building lifetime,
- improved design of structural elements,
- alternative binders,
- carbon capture and utilisation/storage (CCUS),
- decarbonisation of transport,
- recycling of concrete fines and,
- electrification.

There are, however, various gaps in the literature with regards to how we accurately measure the degree of decarbonisation; what the baseline to which these decarbonisation potentials are assessed and forecasting of/strategies for decarbonisation.

The University of Leeds researchers are answering these questions through a thorough review of the literature but also through discussions with various industrial partners in the cement industry, for example Heidelberg Materials, Breedon and Tarmac, on potential real-life case studies for cement-level strategies for decarbonisation.

Outcome

Early results show that high-tech, high-reward interventions such as full switch to biofuels and CCUS are less likely to cause significant cumulative decarbonisation potential enroute to 2050 due to the time limitation, high capital expenditure, high operating expense and supply chain infrastructure required for both technologies.

On the other hand, low-tech strategies such as the 30% reduction in clinker energy demand through thermal efficiency in production, 30% reduction in clinker use in cement by further use of supplementary cementitious materials such as calcined clay and ground limestone, 30% reduction in binder content based on mix design optimisation as well as the 30% reduction in concrete demand due to structural optimisation processes, combined could save up to 65% of the cumulative carbon footprint of the UK concrete market till 2050.

More details on this work:

A Resource-Bound Critical Analysis of the Decarbonisation Roadmaps for the UK Foundation Industries by 2050 <https://www.mdpi.com/2076-3298/11/7/153> and *Journal of Sustainable Production and Consumption: 1000 cuts: a realistic route to decarbonization of the UK cement and concrete sector by 2050*

Green copper refinery project feasibility report



Contributors:

Dr Masoud Ahmadinia, Cardiff University; Tom Anderson, Evolve Metals.

**EVOLVE
METALS**

Refining Redefined

Objective/benefit

Providing an in-depth feasibility report covering technical, economic and environmental facets of the green copper refinery project, a project to establish the UK's first zero emission copper foil plant, in order to help form a case for future funding bids.

Project overview

In order to bolster the UK's industrial self-sufficiency and align with national and global sustainability goals, there is a need to sustainably manage our significant copper scrap exports and also to prepare for an expected global surge in demand for copper.

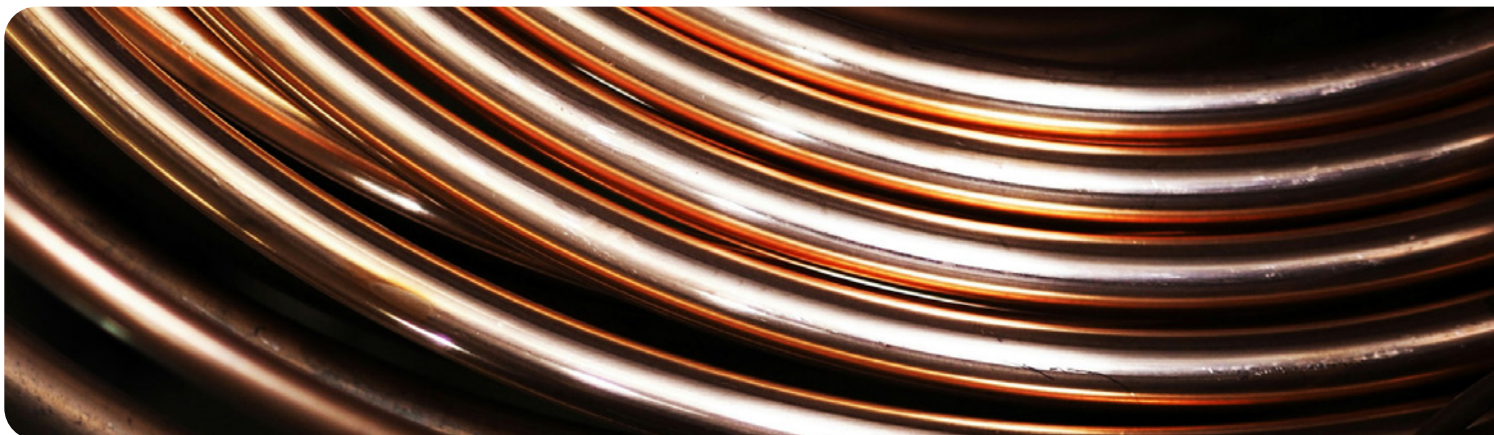
Evolve Metals, is leading the green copper refinery project, critical for battery and automobile industries within the UK.

They use a revolutionary green-hydrogen-based process that significantly reduces carbon emissions and waste, achieving over 80% energy savings and a 6-tonne reduction in CO₂ emissions per tonne of copper. TransFIRE contributed towards this project by providing a comprehensive feasibility report.

Outcome

The report produced by TransFIRE researchers at Cardiff University provided an in-depth analysis covering technical, economic and environmental facets of the project. It was pivotal in this context, offering critical insights and an objective evaluation and it has greatly influenced the project's trajectory and preparedness for substantial funding initiatives.

Tom Anderson, CEO of Evolve Metals highlighted the benefits of being part of the TransFIRE network for Evolve Metals' business development and understanding of their role in the broader UK industrial community.



Sustainable E-waste recycling and precious metal recovery



Contributors:

Dr Masoud Ahmadiania, Professor Rossi Setchi, Professor Sam Evans, Cardiff University; Tony Baker, Steve Gregory, Julian Cox, Lucia Garcia Rodriguez, Steve Giblin and Steve Clode, The Royal Mint.

Objective/benefit

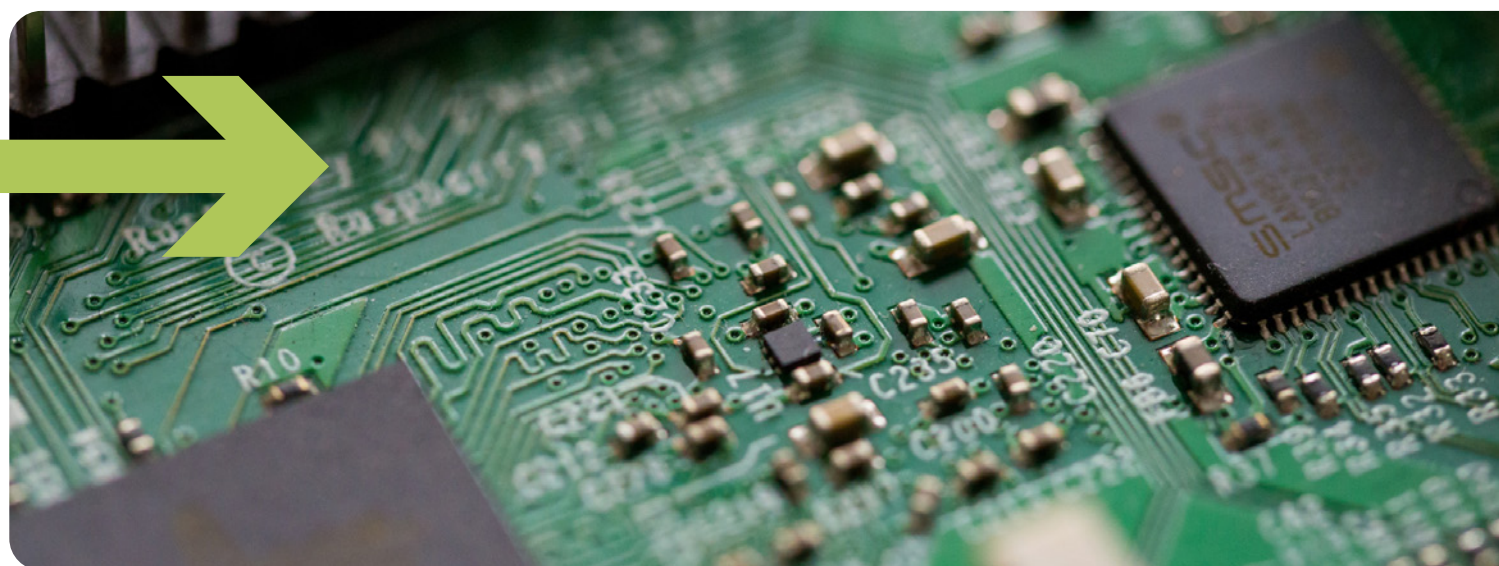
Producing detailed documentation on the energy and material flows of the reclamation and extraction of precious metals for The Royal Mint to help identify potential areas to improve energy efficiency.

Project overview

The Royal Mint runs an innovative initiative to extract precious metals from the circuit boards of electronic waste, such as laptops and mobile phones, creating a sustainable supply of gold, initially for use in its jewellery line.

Working in collaboration with Excir, a Canadian clean tech start-up, they use patented technology and innovative methodologies to enhance the efficiency and sustainability of the precious metal extraction process.

TransFIRE researchers were asked by The Royal Mint to produce detailed documentation of the entire process of reclaiming precious metals from electronic waste, from initial waste handling to the final gold extraction.





Approach

As part of this project, Dr Masoud Ahmadinia, undertook a secondment at The Royal Mint. A set of Sankey diagrams were developed to represent the energy and material flows visually. In addition, a detailed cost analysis report provided an examination of electricity consumption and associated costs in processing Printed Circuit Boards (PCBs).

Outcome

This comprehensive analysis revealed a number of variations in energy consumption across various processing stages, with the surface gold extraction process notably performing better than other processes within the extraction cycle. The research also emphasised the importance of assessing hourly and per-tonne energy consumption metrics for a holistic view of efficiency and cost-effectiveness.

The TransFIRE team at Cardiff University also actively worked to link The Royal Mint to other industrial partners such as Evolve Metals, Celsa, and MPI, leading to several ongoing collaborations. A notable example is Evolve Metals' partnership with The Royal Mint, which leveraged green-hydrogen-based technology, to explore opportunities in processing The Royal Mint's copper-rich by-product stream.

Ahmadinia, M. et al. 2024. *Transforming e-waste into value: A circular economy approach to PCB recycling*. Presented at: 10th International Conference on Sustainable Design and Manufacturing (KES-SDM 2023), 18-20 September 2023. Presented at Scholz, S. G., Howlett, R. J. and Setchi, R. eds. *Sustainable Design and Manufacturing 2023: Proceedings of the 10th International Conference on Sustainable Design and Manufacturing (KES-SDM 2023)*, Vol. 377. Springer pp. 275-285., ([10.1007/978-981-99-8159-5_24](https://doi.org/10.1007/978-981-99-8159-5_24))



“The Royal Mint’s collaboration with Cardiff University and TransFIRE has been particularly beneficial. It has facilitated the enhancement of our e-waste recycling processes and provided valuable connections with other industry partners through utilising the TransFIRE network. This has been instrumental in advancing The Royal Mint’s sustainable practices and exploring new collaborative opportunities in electronic waste recycling.”

Tony Baker, Director of Manufacturing Innovation, The Royal Mint.

Investigation into the composition of commercial glass to identify energy saving opportunities



Contributors:

Professor Paul Bingham, Dr Wei Deng, Elliott Wakelin, Sheffield Hallam University. Industrial Partners - Glass Technology Services, British Glass, Glass Futures, Encirc 360, Beatson Clark, NSG-Pilkington, Saint-Gobain, Guardian Industries, Diageo.

Objective/benefit

Sampling and analysing a wide range of container and float glass to identify properties that could bring about significant potential for energy saving in its production.

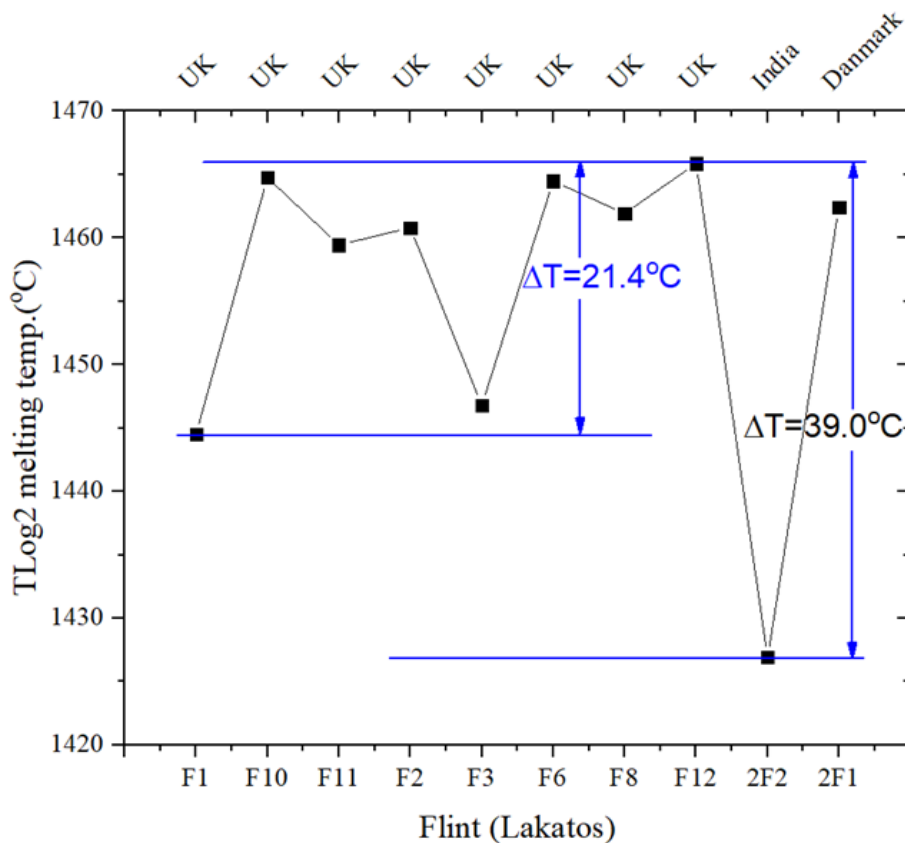
Project overview

TransFIRE researchers from Sheffield Hallam University have been investigating the composition of commercial float and container glass currently present in the UK market following a lack of recent research and data. This was based on the hypothesis that some manufacturer's glass compositions and furnace parameters were sub-optimal, thereby enabling opportunities for fuel and CO₂ reduction.

The most recent study of this kind dates back over 30 years and there is no publicly available literature on the composition of current and recent commercial glass.

This case study involved sampling and analysing the compositions of over 30 commercial container and float glass samples and a number of different properties within the glass were found. The differences in the glass could bring about significant potential for energy saving in its production through reducing furnace temperatures and thereby decreasing fuel use and CO₂ emissions.





Differences in modelled glass melting temperatures based on analysed glass compositions of UK and commercial international colourless container glasses, showing differences of over 21°C between UK glasses and up to 40°C including international glass.

Outcome

Analysis of the samples revealed that glasses of the same colour and function exhibit different properties, with a significant difference in the estimated melting temperature of over 20°C in some cases.

At present, there is a significant variation in the melting temperature among different glass factories operating at the same technological level, highlighting the fact that many may be operating inefficiently. There is a huge opportunity for reducing emissions and energy consumption simply by reducing furnace temperatures to the minimum temperature required to melt, refine, condition and form the glass.

The composition of glass has been passively reliant on the level of glass equipment technology, and many manufacturers have not yet, except for rare cases, recognised the necessity of optimising the melting temperature to minimise fuel consumption and associated CO₂ emissions in practice.

This study demonstrates that not only could many glass manufacturers reduce their furnace temperatures and melt a slightly different glass composition at a lower temperature but that this is already being done by other manufacturers, therefore massively decreasing the risk for those who may like to pursue their own formulations.

More details on this work can be found in the open access publications:

A survey of commercial soda–lime–silica glass compositions: Trends and opportunities I—Compositions, properties and theoretical energy requirements: <https://ceramics.onlinelibrary.wiley.com/doi/10.1111/ijag.16691?af=R>

A survey of commercial soda-lime-silica glass compositions: Trends and opportunities II—Principal component analysis (PCA) of glass compositions <https://ceramics.onlinelibrary.wiley.com/doi/full/10.1111/ijag.16689>

Optimisation of ceiling tile manufacture



Contributors:

Professor Graham Ormondroyd, Dr Simon Curling, Bangor University; Professor Steve Yearley, Dr Kyle Parker, University of Edinburgh; Professor Steve Cinderby, Dr Jean McKendree, University of York; Professor Jonathan Cullen, Dr Natanael Bolson, Mathilde Lavanant, University of Cambridge; Professor Matthew Unthank and Professor Justin Perry, Northumbria University; Gavin Scott, Zentia.

Objective/benefit

Investigating manufacturing processes, tile composition and other characteristics for optimal tile manufacture and to reduce water and energy usage, capture and reuse waste heat.

Project overview

TransFIRE researchers from across our technical working groups and work streams worked with Zentia, the leading ceiling tile manufacturer in the UK, to develop ways in which the company could optimise their manufacture processes and quality of their tiles and work to reduce their energy and water usage.

Zentia's factory produces ceiling tiles formed from a wet mixture of newsprint, starch, fibreglass and other minerals, which are then pressed and dried by passing through a long series of gas-fired ovens.

TransFIRE engaged with Zentia on several projects including performing materials properties tests on the company's product mixture, with the aim of better understanding how to reduce water content as well as operational losses during tile-making. Lifecycle analyses and energy audits of manufacturing process were also conducted to help identify ways of improving efficiency and reducing overall energy costs.





Approach

In order to tackle such a broad range of projects, TransFIRe acted as a hub to bring together a diverse range of technical expertise, business analysis, qualitative approaches and deliberation on policy alternatives.

Members of the Work Stream 3 (WS3) team led several ‘User Journey’ (UJ) exercises to help Zentia’s engineering and management team explore the range of transformative options available, as well as the potential challenges, barriers, solutions and outcomes of any proposed change to their manufacturing process or business model.

Possible technical interventions raised during the UJ exercise included the possibility of changing Zentia’s manufacturing process and product mixture, to reduce the overall need for active drying and/or improve the efficiency of alternative heating technologies.

In order to address this, Work Stream 1 colleagues at the University of Cambridge conducted the lifecycle and energy/material flow analyses of Zentia’s manufacturing process to help with the design of their new oven dryer system.

The Paper Technical Working Group (TWG) at Bangor University also worked with the engineering team at Zentia to perform materials properties tests – rigidity and elasticity parameters, as well as water content limits – in order to gain a better understanding of what process and composition changes might be possible in the future.

Outcomes

As a result of UJ exercises, Zentia was able to identify several high-priority aspects of their current operation that they wanted to transform, as well as a number of possible technical solutions that they were interested in pursuing in the short- to medium-term.

The Paper TWG investigated methods of determining the strength of the pulp mat, the effect of dewatering and the optimal moisture content for manufacturing tiles to reduce the break percentage and save both water and energy. The study showed a relationship between water content and mechanical strength in the wet mat which can be exploited to optimise water usage in the process and minimise the drying required to form the tiles.

Various technical issues associated with measuring these parameters were addressed by Paper TWG, helping not just Zentia but potentially the pulp production industry as a whole. The Paper TWG secured funding for a Knowledge Transfer Project (KTP) project with Zentia to further examine their production methods as the endeavour to move towards net zero manufacture.



3



Waste and upcycling

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Co-producing a regional circular business model for industrial symbiosis



Contributors:

Dr Anne Velenturf, University of Leeds

Project overview

West Yorkshire Combined Authority (WYCA) has an ambition to become net zero by 2038 as indicated by the Climate and Environment Plan (2021), and the Humber and East Yorkshire Local Enterprise Partnership (HEYLEP) have declared a climate emergency. These regions together represent the UK's largest industrial emitter of CO₂ and manufacturing constitutes one of the largest environmental concerns related to the industry's problematic waste output. Fully evidenced benefits of successfully implementing industrial symbioses, for businesses and the wider region, include:

- A reduction in operational costs and supply chain risks in terms of waste management and resource security.
- The development of new business opportunities and competitive advantage.
- Market incentives such as positive marketing and access to the growing market for reused materials and products.
- A significant reduction in greenhouse gas emissions and other environmental impacts associated with resource extraction.
- The creation of new jobs and development of new skills.

Industrial symbiosis is key to bolstering future industrial resilience and presents both an opportunity to bring new purpose and value to waste rather than disposing it in landfill or eliminating it through incineration. The region is positioned at a juncture where the transformative potential of industrial symbiosis could positively reshape its industrial future. Previous research has shown that facilitation of industrial symbiosis in the region is required for the realisation of its many societal benefits.

The work described below brought together multiple HEYLEP and WYCA stakeholders in the sector in order to begin accessing the benefits for the region described above. It collaboratively identified and agreed multiple issues and opportunities in the political, economic, social, technical, legal and environmental domains that will form the basis of further collaborative work, and then began to design business models that will allow the stakeholders to identify, create, appropriate and convert value in such a way as to encourage business development and job creation while improving environmental and social outcomes. WYCA and HEYLEP stakeholders are enabled to move forward on creating these business models and accessing the benefits that industrial symbiosis in a sustainable regional circular economy can provide.



Background

Industrial symbiosis – using the “waste” outputs from one industry as feedstock for another and vice versa – is a key enabling mechanism for moving towards a low-carbon circular economy in the Foundation Industries, by reducing the emissions and pollution associated with both primary resource consumption and waste generation. The TransFIRE Hub is supporting the co-production of a regional circular business model for industrial symbiosis facilitation in Yorkshire and the Humber. This research is building on previous projects on industrial symbiosis that were completed in 2023 with HEYLEP and WYCA. These projects highlighted the importance of long-term facilitation programmes for industrial symbiosis, while such stability in government investment was considered unlikely. Further research is being carried out to progress on the development of regional business models for long-term industrial symbiosis facilitation, alongside an international best practice review of long-running industrial symbiosis programmes.

Opportunity

The opportunity is for the WYCA/HEYLEP regions to make a step change in industrial policy and operation that moves them closer to their declared goal by implementing industrial symbiosis and circular economy principles.

Innovative solution

Previous industrial policy has been formulated without the benefit of co-production with stakeholders in a formal framework and without a full understanding of the underlying contexts and values that must be understood to implement sustainable circular systems. In this work, stakeholders worked with circular economy and industrial symbiosis expert facilitators, within a formal participatory process management framework informed by PESTEL principles, governance dynamics and regional circular business model innovation.

Approach and outcome

A series of co-production activities was carried out within two regions in Yorkshire and the Humber, including two workshops with policy, academic, business and community stakeholders:

[A] Industrial symbiosis introduction, international cases and regional context analysis. On 15 February 2024, 13:00-15:30 hrs online. Objectives - Introduce industrial symbiosis, its benefits and former activities in Yorkshire and the Humber; Share results from international cases on industrial symbiosis programmes; Collect input for context analyses of WYCA and HEY LEP areas; Next steps for coproducing regional circular business models for industrial symbiosis Facilitation. A PESTEL framework was used to co-produce a series of regionally contextual barriers and opportunities, categorised according to a traffic-light system to consider whether a context aspect is sufficiently present (green), marginally present (orange) or largely missing (red).

[B] Detailing potential regional business models for the WYCA and HEY LEP areas. On 20 March 2024, 9:00-14:00 in person at the University of Leeds. Objectives: Introduce regional circular business models, its elements and the coproduction process used in this workshop; Share results from the WYCA and HEY LEP context analysis and gather final feedback; Co-produce all main parts of a regional circular business model for industrial symbiosis facilitation; Next steps for turning the results into a long-term industrial symbiosis facilitation programme.



The outcome is a cohort of WYCA/HEYLEP stakeholders now versed in co-production methods and a clear, shared understanding of the values, issues, barriers and actors required to be considered to facilitate regional industrial symbiosis and associated circular economy goals. The resulting workshop proceedings will remain confidential, though are being used in policy advice to regional and national government bodies and written up into peer-reviewed articles. Other outputs include:

- *A Transition Management Methodology Framework towards a Circular Economy in Industrial Contexts: Reflections on the Humber Region scenario.* Rincon, J, Velenturf, A et al. In: *Proceedings of the 28th Annual Conference, International Sustainable Development Research Society. 28th International Sustainable Development Research Society Conference, 15-17 Jun 2022, Stockholm, Sweden. International Sustainable Development Research Society*, pp. 557-586. ISBN 978-91-89504-17-2
- Laybourn, Humphreys, Johnson, Velenturf, Jensen, Lombardi (2023) *Feasibility and Options Appraisal for Industrial Symbiosis Incubation to Facilitate a Sustainable Circular Economy Approach for Hull and East Yorkshire. A report to the Hull and East Yorkshire LEP and North East and Yorkshire Net Zero Hub.*
- Lassey (2023) *Industrial symbiosis report. A report for the West Yorkshire Combined Authority and the Yorkshire Circular Lab.*
- Li, Velenturf (2024) *HEY LEP context report.*
- Li, Velenturf (2024) *WYCA context report.*
- Velenturf, Li, Jensen, Domingues (2024) *Workshop proceedings: Co-producing a regional circular business model for industrial symbiosis facilitation.*
- Velenturf et al (in prep.) *A Place-Based Approach to Coproducing Systems of Circular Business Models in Sustainable Supply Chains; applied to HEY LEP and WYCA areas in: Li, Jensen, Velenturf (in prep.) Regional circular business model development for industrial symbiosis.*

Impact

The impact will be a set of industrial and public policies that help businesses and local authorities move towards a regional circular economy and deliver on their net zero aspirations. These policies are far more likely to be effective than historic policies, which were often poorly informed as to how environmental and social value can be created and formulated without the clear and transparent “buy-in” from stakeholders that formal participatory processes can provide.

Opportunities for Foundation Industries in wind energy



Contributors:

Dr Anne Velenturf, University of Leeds, Dr Masoud Ahmadinia, Cardiff University, Dr Natanael Bolson, University of Cambridge and Dr Michal Drewniok, University of Leeds

Objective/benefit

Prevention of supply bottlenecks of steel, concrete, copper and aluminium for wind turbine manufacturing.

New business opportunities for Foundation Industries as part of the growing wind energy industry. Policy dialogue for industrial and materials strategies.

Project overview

The UK is aiming for steep increases in wind capacity, especially for offshore wind. Wind deployment will demand steep increases in material use. Demand for concrete will grow at least threefold by 2030, largely owing to increases in the use of marine concrete for floating offshore wind placing serious stress on aggregate resources. Demand for steel will grow at least four to fivefold by 2030. The UK is already consuming more steel than it produces. Demand for copper and aluminium will also grow at least fourfold by 2030, outstripping UK manufacturing capacity. Understanding how these FI supply shocks can be managed will be essential to achieving HMG targets for wind power capacity.

Circular economy approaches are essential for the building of sustainable resilient supply chains to grow the wind industry. Circular economy approaches can alleviate pressures on supply chains by using less materials per turbine and/or more durable designs, and by using recycled materials in manufacturing processes. The UK Government must raise ambitions to drive forward circular economy solutions in the wind industry and avoid missing net zero targets. Policy and investment decisions for more resilient wind supply chains depend on better information on material stocks and flows.

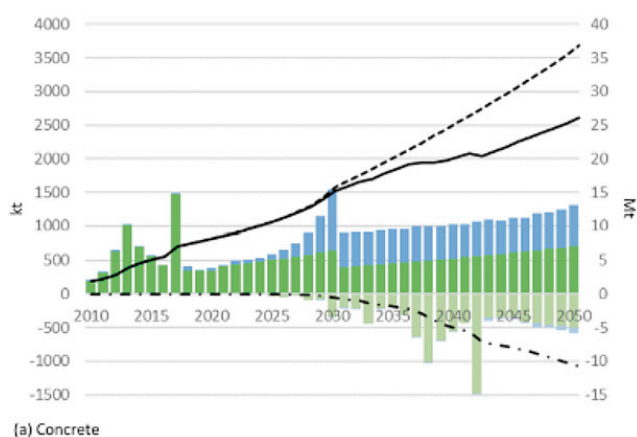
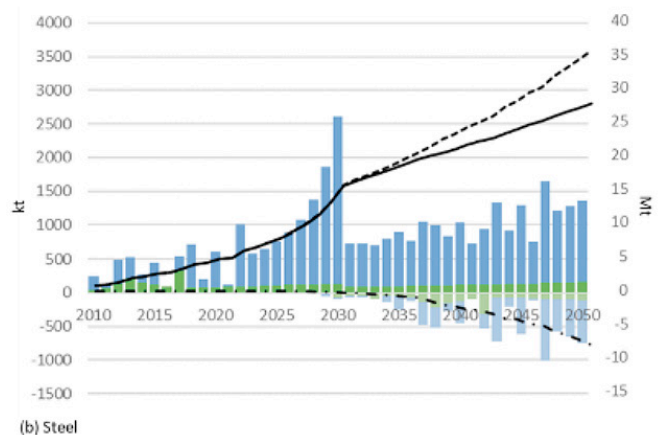
Innovative solution: Modelling the potential supply shocks in these foundation materials will allow us to highlight and quantify the problem. Designing circular economy strategies, both technical and policy-based, will allow us to manage these shocks more efficiently and increase the resilience and competitiveness of the UK wind energy industry.





Approach and outcome

We used stocks and flows analysis to model the demand for these materials, the potential recyclates that will flow out of the wind energy system, and the potential reduction in exposure to materials supply shocks that building-in recyclability and circular economy principles to the current generation of wind turbines would provide. Reuse of foundations for second-generation turbines (i.e. designing them for reuse) proved a particularly effective strategy for reducing material consumption and could save up to 30% on capital costs long term. Remanufacturing of turbines to preserve materials could provide ~7% more jobs in the wind industry. As part of this work, we also trained TransFire researchers in carbon footprinting and Sankey diagrams at a joint session with Cambridge. Over 10 presentations have been made at international wind industry events, including the Westminster launch of Circular Renewables policy recommendations (February 2023) and the Westminster Energy, Environment and Transport Forum on Priorities for maximising offshore wind potential in the UK (Dec 2023). Policy dialogue will also continue at the UK and European Investment Summit for Offshore Wind (postponed to September 2024 due to elections). We have provided policy advice linking the FIs and wind industry to DIT, EA, DESNZ and the Crown Estate, and produced a policy briefing, and collaborated with the Royal Society of Chemistry and the Royal Academy of Engineering for further policy recommendations.



Impact

Additional work mapped the supply chain for FI materials in the wind industry, resource input/output volumes and initial resource specifications means we now have >20 Industry partners along the new supply chain taking part in data collection for a research paper linking wind turbine end of use management to Foundation Industries. These and other industry partnerships have led to further joint R&D funding from the EU (€12 million for turbine blade recycling demonstration), EPSRC (£134,000 Impact Acceleration funding in partnership with Offshore Renewable Energy Catapult, European Metals Recycling and MPA The Concrete Centre) and Innovate UK (£50,000 “RESCUE - Regulations to Ensure Sustainable Circular Use at End-of-life” led by Offshore Renewable Energy Catapult and in partnership with European Metals Recycling and Ionic Technologies). We have also launched a Circular Renewables webinar series in conjunction with the IEMA (see link below).

“It is critical that in helping to address climate change the renewable energy sector does not inadvertently drive environmental problems elsewhere. At best, the sector is missing out on the growing economic opportunity and stronger supply chains that come from a circular economy, at worst, risks becoming complicit in ‘greenwashing’.”

Trevor Hutchins, GPC

Discovering the hidden value of mineral waste



Contributors:

Clive Mitchell, Tom Bide, Eva Petavratzi, British Geological Survey.

Objective/benefit

Gaining a better understanding of the composition and production of mineral waste in the UK to help refine the estimate of the amounts produced and to determine any potential applications within the Foundation Industries.

Project overview

As part of TransFIRE, the British Geological Survey (BGS) is working to gain a better understanding of the composition and production of mineral waste in the UK. This research aims to help refine the estimate of the amount of mineral waste produced in the UK and provide more data on the composition of this waste to determine any potential uses for manufacturing processes within the Foundation Industries.

Although the UK minerals industry has initiated many attempts to reduce, reuse and recycle mineral waste, no large volume applications have so far been developed beyond the more traditional uses as a filler material and other construction applications.

Approach

The BGS characterisation of the waste of mineral operations across the UK has included analysis to determine mineralogical (X-ray diffraction analysis), chemical (X-ray fluorescence analysis) and physical properties (particle-size analysis).





The explored mineral operations included ball clay, barytes, basalt, chalk, fluorspar, gypsum, kaolin, limestone, salt, sand and gravel, silica sand, and tungsten.

Mineral waste samples collected include quartz- and lignite-rich ball clay, intrabasaltic laterite, carbonate rich tailings from fluorspar processing, shale and sandstone from limestone quarrying, quartz- and mica-rich tailings from kaolin processing, tailings from sand and gravel processing, ultrafine quartz-rich tailings from silica sand processing, and tailings from tungsten processing.

Outputs

The results of this study have enabled the sharing of data and information on poorly understood stocks and flows of waste materials between different industries and is a great example of the type of research that is needed to determine alternative uses for mineral waste.

There is initial interest in silica sand tailings for use as a mineral filler in research by Northumbria University on the use of waste PET (polyethylene terephthalate) and bio-derived components to produce novel alkyd-resin polymer coatings. Other potential applications include raw material for ceramic moulds used in the investment casting process.

Read the full paper '*Fuelling the Foundation Industries: Discovering the Hidden Value of Mineral Waste in the UK*' here: <https://www.mdpi.com/2673-4605/15/1/80>



Fluorite: Cavendish Mill, Derbyshire (Fluorsid)



Finding “brass in muck” requires cross-cutting and strategic collaborations



Contributors:

Dr Lampros Litos, Nipuna Liyanage, Nikhil Karwa, Dr Sanjooram Paddea, Professor Mark Jolly, Cranfield University. Stephen Taylor, Saica. Jafar Daji, PSR.

Objective/benefit

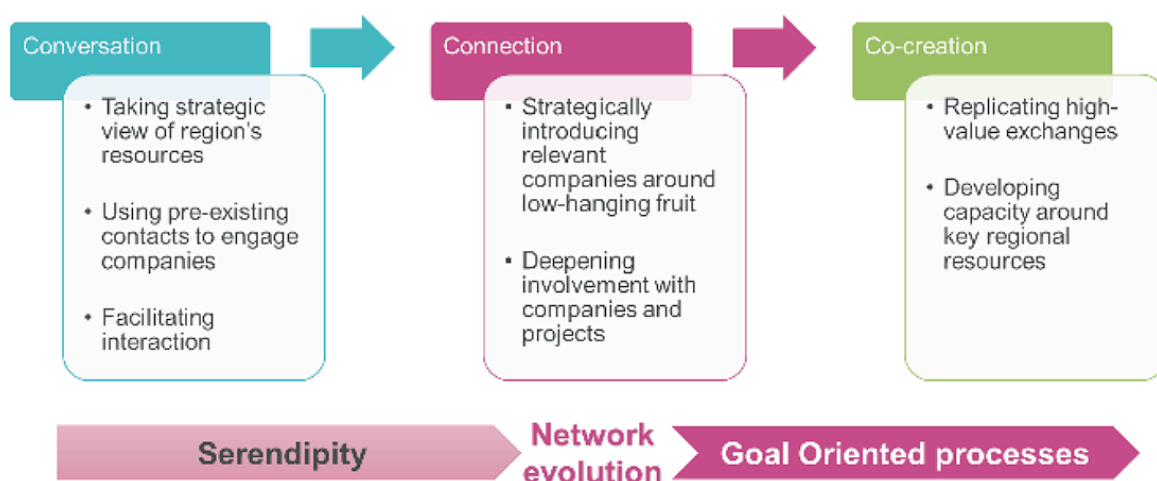
The second Transfire workstream sought to uncover the economic value and requirements for extracting value in using waste streams as feedstocks in industry. The notion of industrial symbiosis (IS) was particularly useful in discussing the possibilities and economic benefits of using waste materials (such as paper sludge, spent foundry sand or filter cake) with industry partners. Nevertheless, from theory to practice and profit (waste as feedstock) many technical challenges and a lot of uncertainty about the quality/stability of the supply remain.

Project overview

The team deployed MSc students to try to quantify and analyse the gains that could be achieved in reducing carbon emissions or resource efficiency in Foundation Industries. Interviews and frameworks were introduced and validated that offered more insights for policy makers in advancing the field of IS in practice. In the UK, the opportunity for IS remains within retrofitting existing facilities (essentially CAPEX investments) as opposed to creating a new industrial landscape from scratch (for example re-creating Kalundborg in the UK).

Objective/benefit

The team took a two-fold approach to engage with companies and better understand their realities, best practice and attitudes against IS options on a one-to-one basis, as well as creating peer-to-peer networking events to increase awareness and reduce serendipity.



(Transformation framework, MAESTRI project 2016, D4.1)



Outcome

The first strand of work helped create an assessment framework that allows policy makers and companies to visualise the alignment between: a) practice maturity, b) product development strategies, c) economic drivers and d) critical success factors. The team concludes that unless there is strong alignment between these four dimensions there is little opportunity for a company to use waste as feedstock to their processes.

The second strand of work allowed the development of a cohort of Foundation Industries into a community of Foundation Industries aiming to become more sustainable. Peer-to-peer engagements and facilitation had an observable impact on confidential information sharing between industry practitioners and with academics involved.

All data available has been published here: <https://www.sciencedirect.com/science/article/pii/S2212827124007625?via%3Dihub>

Characterisation and sustainable utilisation of Celsa Steel UK production by-products



Contributors:

Professor Sam Evans, Professor Rossi Setchi, Dr Julien Steer, Joseph Alemzadeh, Mumin Biyiklioglu and Sijie Yu, Cardiff University; Eoin Bailey, Georgi Lokmadzhiev and Neil Williams, Celsa Steel UK; Mark Sexton, Sexton Material Research Ltd.

Objective/benefit

Determining the elemental and mineral composition and physical characteristics of by-products generated by Celsa Steel UK in order to find potential applications and innovative solutions for recycling and reuse.

Project overview

In January 2024, TransFIRE researchers at Cardiff University began working in collaboration with Celsa Steel UK on a project to analyse various by-products generated by their electrical arc furnaces to find potential applications for these materials.

These by-products, traditionally considered an under-valued resource, are generated from the smelting of scrap steel and include quantities of mill scale, red dust, EAF dust, black and white slag, down day waste, and road sweepings. Each of these materials differs in terms of chemical and physical properties and present their own unique challenges, due to the presence of potentially hazardous elements and contaminations.





The project's objectives include determining elemental and mineral compositions, assessing physical characteristics, and exploring recycling opportunities. Priorities are set based on economic outlet potential and environmental impact.

Approach

Celsa Steel UK were particularly interested in the elemental composition and quantities of their by-products in order to explore opportunities for market development. They emphasised the project's role in avoiding non-productive and costly disposal.

A range of experimental and analytical techniques are used to understand the particle size distribution, water content, and thermal behaviour of the materials, as well as investigating methodologies for oil or lubricant removal and recovery.

The comprehensive experimental plan included sample preparation, sieving and particle measurement, Thermogravimetric Analysis, microwave digestion, Inductively Coupled Plasma Spectroscopy, X-ray fluorescence, X-ray diffraction and total carbon analysis.

Outcome

The work with Celsa Steel UK is ongoing and is anticipated to generate a number of environmental and economic benefits.

The study will promote resource efficiency and will mitigate potential environmental risk through sustainable by-product management. It will open potential new revenue streams from by-product recycling and will reduce costs.

It will also provide comprehensive understanding of by-product properties and sustainable methods for separating potentially hazardous components from by-products, both useful for improved steel production efficiency.



Model and simulation-based investigation on use of agriculture by-product in brick manufacturing



Contributors:

Dr Ahmed Khalil, Professor Shaowei Zhang, University of Exeter; Industrial partner, Wienerberger.

Objective/benefit

Incorporating agricultural waste and by-products into the clay brick manufacturing process to enhance sustainability.

Project overview

TransFIRE researchers have been working with Wienerberger, the world's largest producer of bricks and clay blocks, to investigate the possibilities of using agricultural waste and by-products to produce eco-friendly, lightweight clay bricks.

In this instance, the agricultural waste is sugarcane bagasse (SCB), the dry pulpy fibrous material that remains after crushing sugarcane, and sugarcane bagasse ash (SCBA), the residual waste ash from sugar mills.

Approach

Thermodynamic simulation-guided (waste) recycling strategy (ThermoRecycliSt) and other available models were used to assess the feasibility of incorporating sugar cane by-products to enhance the sustainability of brick manufacturing at the Wienerberger Brick Factory.

By leveraging ThermoRecycliSt alongside proven models, this study sought to predict the essential properties of pre-manufactured bricks, significantly reducing the need for laborious and resource-intensive lab-scale trials.

Outcome

A suggested incorporation mix of SCB and SCBA and a set of recommendations were proposed in order to optimise the technological properties, such as strength, water porosity and absorption, of the clay bricks.

Ultimately, this case study provided valuable insights into the potential of ThermoRecycliSt and similar models for enhancing sustainability in the construction industry by reducing reliance on traditional raw materials, exploring alternative raw materials, and minimising waste generation.

Recycling refractory waste



Contributors:

Dr Ahmed Khalil, Professor Shaowei Zhang, University of Exeter; Katy Moss, Zena Carden, Trent Refractories and Jafar Daji, PSR.

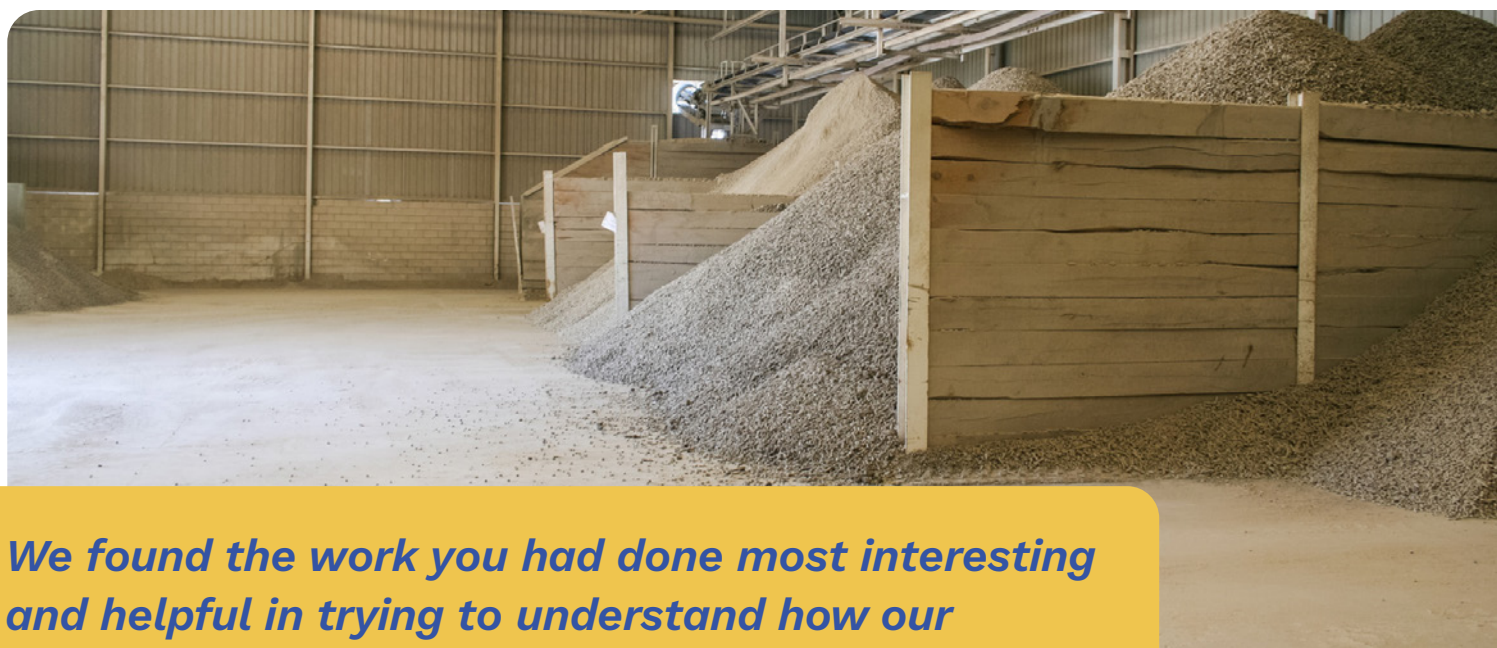
Objective/benefit

Investigating the feasibility of using ceramic waste for the production of high-performance refractories using Thermodynamic Simulation-guided (waste) Recycling Strategy (ThermoRecycliSt).

Project overview

Ceramics are diverse and can tolerate a degree of compositional and raw material changes, enabling the recycling of waste materials from ceramic and other Foundation Industries.

This case study investigated the feasibility and potential of using waste chromium alumina (CAS) slag, zirconia mullite, and spent refractories, originating from a variety of sources, for the production of high-performance refractories. This initiative aimed to reduce resource consumption, lessen environmental contamination, minimise the amount of waste sent to landfills, and promote a circular economy.



We found the work you had done most interesting and helpful in trying to understand how our material behaves and how it can vary.”

Katy Moss, CEO, Trent Refractories Ltd.

Approach

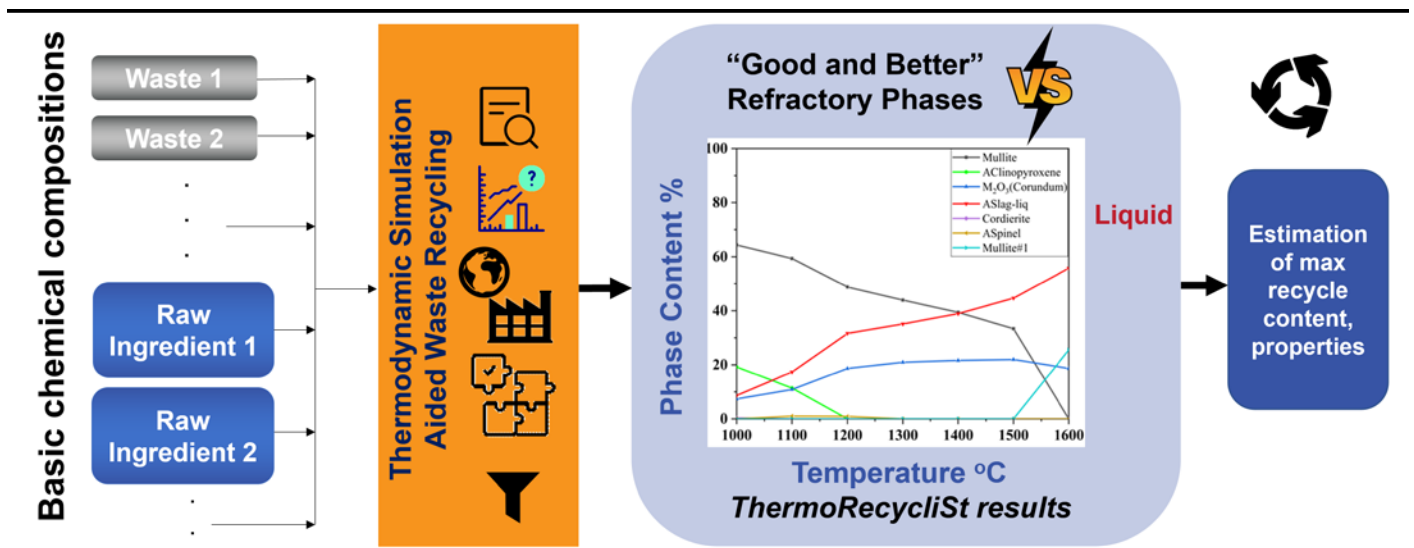
For this research, the TransFIRE researchers undertook a literature review of ceramic waste recycling and developed thermodynamic simulation-guided (waste) recycling strategy (ThermoRecycliSt) to predict phase changes and evolution of the refractory waste materials alone and in the final refractory products.

ThermoRecycliSt is a screening tool, that uses global optimisation algorithms with simulation and modelling, to eliminate unsuitable waste or alternative raw materials or combines different available unsuitable waste materials and adjusts their composition to form a new effective composite viable for the raw mix.

Outcome

This case study demonstrated the successful application of ThermoRecycliSt in predicting refractory behaviour and properties and optimising slag material incorporation. As a result of our work, Trent Refractories can now predict the behaviour of their refractory products without excessive time- and resource-consuming experimental trials. This knowledge has led to the successful substitution of a large proportion of input material, suggesting a potential pathway to long-term benefits.

The ThermoRecycliSt tool extends the capacity of refractories manufacturers and enables them to broaden and deepen their knowledge of the waste and raw materials' performance in use, predict the behaviours of their refractory products, and accordingly find suitable manufacturing materials with optimum compositions and proportions, leading to producing improved products.



New products from high-grade polymer particulate waste streams



Contributors:

Professor Justin Perry, Professor Matt Unthank, Dr James Railton, Dr Jamal Bousbaa, Bradley Thomas, Northumbria University; Clive Mitchell, British Geological Survey; Jason Davies, Jason Young, Jayplas; Sean Barr, AkzoNobel.

Objective/benefit

Creating a versatile alkyd resin coating for protective and decorative coatings applications by chemically transforming waste polyethylene terephthalate (wPET), which is outside of the recycling loop for PET, thereby replacing the demand for virgin petrochemical feedstocks with a by-product which is destined to be landfilled or burnt for energy recovery.

Project overview

Mechanical separation of mixed plastics at recycling centres produces a small proportion of cross contaminated streams of waste plastic or “flake”. These streams are typically high purity of one polymer, however they have no commercial value and are incinerated for energy recovery or sent to landfill.

With regards to PET polyester, these so called “flake losses” account for around 160 ktpa of PET lost from the closed loop recycling process in Europe alone.

A typical recycling plant in the UK generates over 200 tonnes per annum of PET flake contaminated with a percentage of polyolefins (wPET). This case study sought to valorise this high purity waste stream by conversion of the wPET into an unsaturated polyester which is an alternative for existing alkyd resin used in protective and decorative coatings applications. This substitution lowers the demand of virgin petrochemical feedstocks typically required to produce these polyesters.

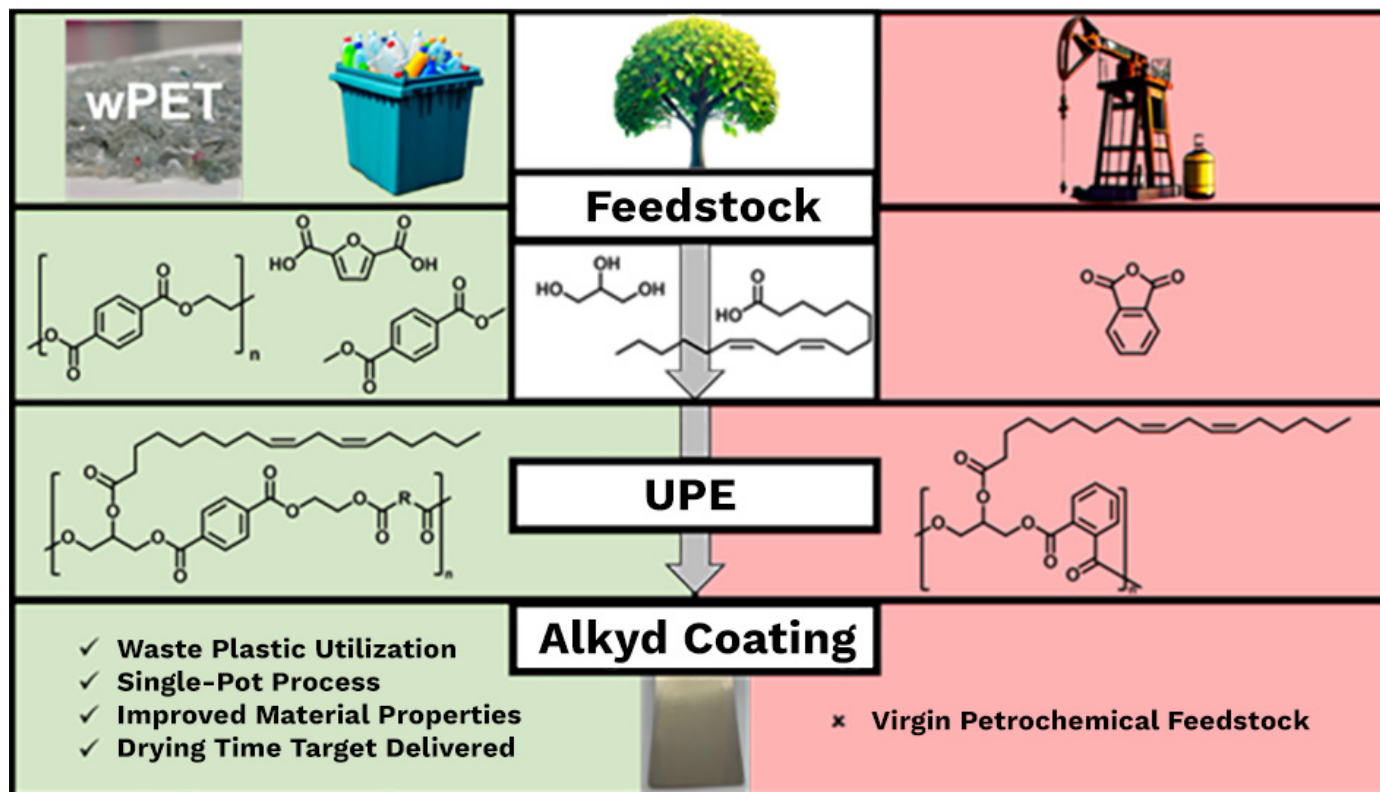
Approach

TransFIRE researchers at Northumbria University developed a one-pot partial depolymerisation-repolymerisation reaction which converted this contaminated wPET into an unsaturated polyester with greater than 95% efficiency. The reactions were optimised with the addition of waste or bio-derived monomers to improve material performance.



This Work

Traditional



The properties of the resulting material were characterised to determine drying time, microhardness, tensile stress and thermal resistance against a control polyester prepared using typical petrochemical feedstocks.

The waste and bio-derived polyesters were subsequently formulated into pigmented protective coatings, utilising inorganic foundation industry wastes (identified through the TransFIRE project) as fillers. A gloss white paint has been created with research ongoing to create a range of different colours and finishes.

In addition, there was also investigation of alternative cure chemistries to reduce the need for heavy metal drying catalysts.

Outcome

As a result of this study, a novel method to convert a valueless polymer waste into a commodity polymer for the protective coatings industry was developed.

Characterisation of these coatings (which are made from 100% waste and bio-derived resins) show that their material performance is comparable to a similar coating derived from petrochemical sources.

Conversion of Contaminated Post-Consumer Polyethylene Terephthalate into a Thermoset Alkyd Coating Using Biosourced Monomers

Bradley Thomas, Nicole D. A. Lopez, James Railton, Jamal Bousbaa, Justin J. B. Perry, and Matthew G. Unthank

ACS Sustainable Chemistry & Engineering 2024 12 (17), 6485-6493

DOI: [10.1021/acssuschemeng.3c07560](https://doi.org/10.1021/acssuschemeng.3c07560)

Surface functionalisation of waste polypropylene (wPP) and its application as fine aggregate



Contributors:

Dr Jamal Bousbaa, Professor Justin Perry, Dr James Railton, Brad Thomas and Professor Matt Unthank, Northumbria University.

Objective/benefit

Waste poly(propylene) fines (a currently valueless byproduct of recycling) can be surface functionalised so that it can provide chemical binding points to aid interactions between the components of a setting concrete and a low temperature ceramic. The resulting materials have similar material properties to existing commercially available products but use less virgin material.

Project overview

Concrete manufacture is a carbon-intensive process which also includes the use of virgin mined materials as aggregate. Technologies which could offer more durable, lighter and more functional concrete by the replacement of some of its components would offer an opportunity to dematerialise concrete use in construction, especially if the substitute materials are currently valueless by-products.

Whilst poly(propylene) has been used as an additive to concrete, its physical properties limit its interaction with other components, and hence its value as constituent. Changing its surface properties so that it explicitly benefits from the hardening reaction adds a performance advantage.

Plastic recycling plants generate a small particulate grade (“fines”) of waste poly(propylene) which is not recycled and is valueless beyond energy recovery. This material is however lightweight, of a relatively high purity and suitable for surface functionalising by chemical techniques such as plasma or acid treatment leading to a functionalised material better suited for chemical involvement in the pozzolanic reaction which is the basis of cement setting into concrete.

Approach

In this study, a range of grades of poly(propylene), including samples from Impact Recycling, were treated to implement surface functionalisation. This was then used to investigate its utility as a fine aggregate component in replacement of sand.



Outcome

Surface functionalised waste poly(propylene) was developed with hydrophilic properties and the surface stability was studied. Surface functionalised waste poly(propylene) was also found to be a suitable alternative fine aggregate. It was able to replace up to 20 vol% of virgin aggregate whilst maintaining appropriate cure times and create concrete of suitable strength for construction purposes. In addition, this inclusion changed the flow characteristics of the concrete reducing the need for expensive flow enhancers used to aid the processing of ready mixed concrete.

The work utilised wPP that would otherwise be used in energy recovery, providing an avenue for waste valorisation of a low-grade waste product, whilst dematerializing fine aggregate from concrete. The fine aggregate dematerialisation within this study was chosen for high-strength cementitious systems, however, it is feasible sand (the second most consumed natural resource) in more typical concrete could also be replaced with our functionalised wPP. The project supported a successful funding application to the Royce ICP funding call which developed the mix design, further implementation of functionalised wPP in cementitious systems and subsequent material properties testing, culminating to a submitted conference paper and a journal article in progress at the time of this publication.

Finally, the insight and skill sets developed during the project are supporting a UKRI KTP application for the dematerialisation of production lines and byproduct valorisation within a plastic manufacturing setting



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Sustainable, polysaccharide-based biopolymers for industrial applications



Contributors:

Professor Justin Perry, Professor Matt Unthank, Dr James Railton, Dr Jamal Bousbaa, Bradley Thomas, Northumbria University; Professor Graham Ormondroyd, Dr Simon Curling, Bangor University; Northumbrian Water, Welsh Water and Saica.

Objective/benefit

Using industrial by-product polysaccharides such as non-food grade starch, chitosan, chitin and cellulose to create a polymer building block to replace petrochemically derived alternatives. These polymers can create a biodegradable latex emulsion that can be used to make “plastic sheeting” and use-specific coatings for industrial applications.

Project overview

TransFIRE researchers at Northumbria University have taken waste polysaccharides, which are zero value waste materials from food production and paper production, and adapted them so that they can be used as a total replacement for petrochemically sourced polymer components such as styrene.

This process enables polymeric materials to be developed which have entirely bio-sourced origins but can be made using existing chemical technologies and processing methods such as latex emulsion polymerisation.

As well as producing plastic sheets suitable for packaging applications, we have also adapted them to be used as coatings for a number of use-specific cases. This includes the creation of a bio-composite material which, when submerged in wastewater, can host microalgae which actively removes polluting phosphate under realistic conditions. This technology is currently being trialled at a Northumbria Water treatment works in Birtley, Tyne and Wear.

Approach

The TransFIRE researchers functionalise the by-product polysaccharides so that the resulting macromonomers co-polymerise in eco-friendly aqueous emulsion with bio-sourced monomers to generate coatings or films. The chosen co-monomers are commercially available bio-sourced materials which provide the flexibility and the rigidity in existing polymers used in the coatings industry.



Algae production scale up



Loofah Biocomposite scale up



The team specifically developed synthetic methods, using eco-friendly conditions, with the potential to scale up without a redesign in chemical methodology. Where possible water has been used as solvent in line with green chemistry principles for polymers containing starch, chitosan and chitin examining the effect of chain length/viscosity.

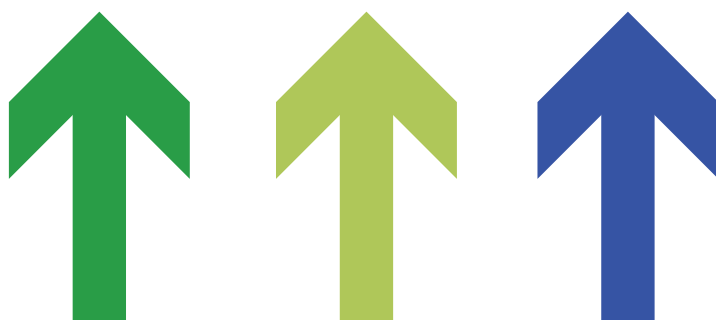
Whilst cellulose is the most abundant byproduct polysaccharide, it is also the most insoluble, and so we have used the ionic liquid 1-butyl-3-methylimidazolium chloride ([BMIM]Cl)- a similar strategy used industrially at scale for the manufacture of Tencel fibres.

Currently we are working to understand the potential breadth of properties we can obtain from our materials under industrially relevant conditions for polymerisation/ copolymerisation. Our current best performing materials contain only biosourced or biosourceable content, entirely removing the obligation to use petrochemicals.

Outcome

The TransFIRE researchers have developed an eco-friendly, easy, sustainable, and scalable method that uses an industrial polysaccharide waste product to produce biodegradable, biosourced polymer films. One iteration of this process is being used in an industrial sponsored project for the manufacture and testing of 'biocomposites' for phosphate pollution capture from wastewater in an OfWat funded research project led by Northumbrian and Welsh Water. This project will deliver a TRL5/6 demonstration of this new coating system in wastewater treatment.

Further to this, the new coating methodology is adaptable to a range of waste polysaccharides including chitosan, chitin and cellulose. This platform technology has already been the central theme in two large EU Horizon applications in the field of sustainable coatings and films.



Potential applications for spent foundry sand



Contributors:

Professor Paul Bingham, Dr Wei Deng, James Eales, Sheffield Hallam University; Dr Ahmed Khalil, University of Exeter; Dr Michal Drowniok, University of Leeds; Dr Masoud Ahmadiania, Cardiff University. Industrial Partners – Cast Metals Federation, Wm Lee (Castings) plc, John Winter Ltd, SKF Bearings.

Objective/benefit

Investigating potential alternative uses of spent foundry sand (SFS), a waste product of UK metals foundries left over after the production of sand moulds or cores for casting of metals.

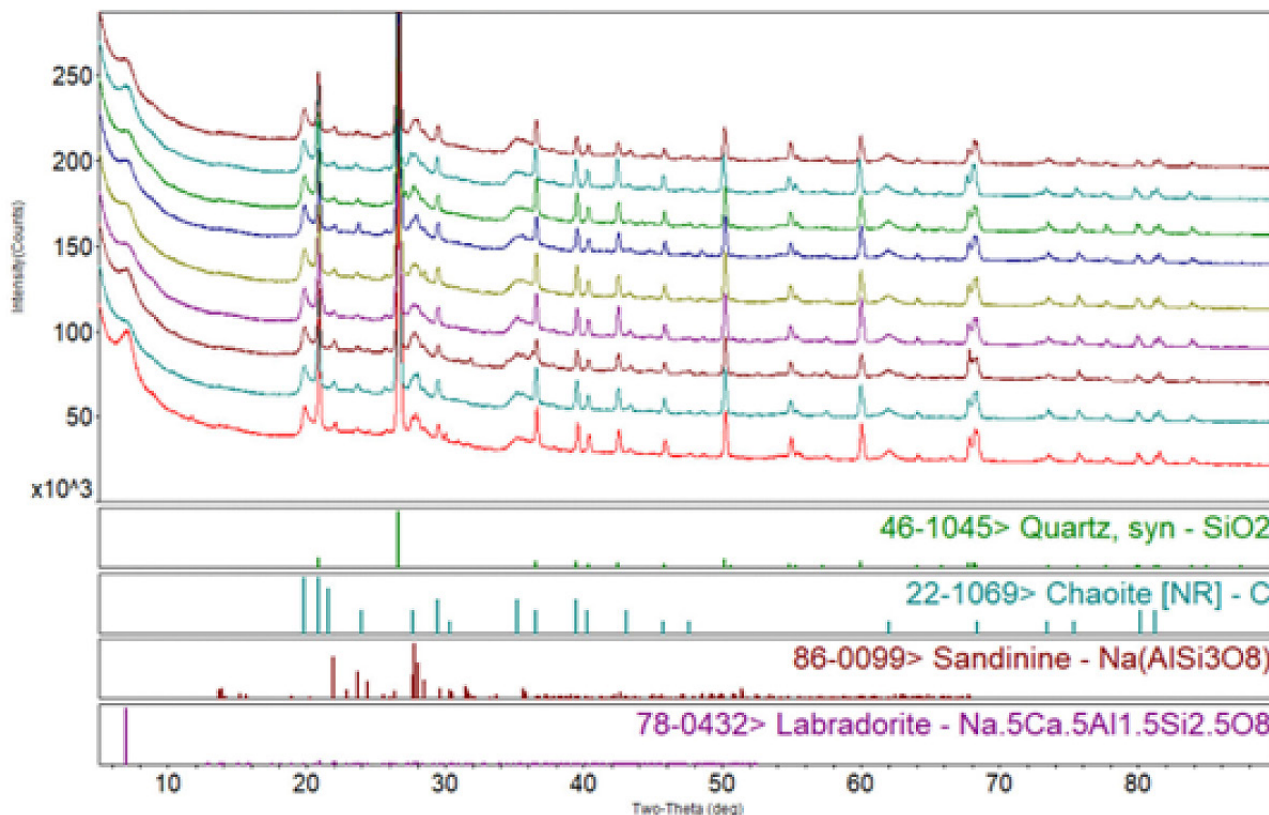
Project overview

The purpose of this case study was for TransFIRE researchers to gain a deeper understanding of, and explore potential avenues for the reusability of spent foundry sand (SFS).

Although SFS can be successfully recycled and used numerous times, the sand grains eventually degrade and their ability to bind with other substances decreases and then must be separated and removed from the process. When the foundry sand becomes unfit for use in the manufacturing process, it is classed as SFS and is generally disposed of at foundry landfills or off-site municipal landfills. Currently it is estimated that 200,000 tonnes of SFS per year are sent for disposal in the UK alone.

Re-use and repurposing of these wastes could not only divert them from landfills but save money on disposal and associated transport costs and CO₂ emissions; and also potentially generate additional economic opportunities by creating new, low-carbon alternative raw materials, new processes and new supply chains.





X-Ray Diffraction patterns for different spent foundry sand samples collected from the same manufacturer over a period of months, showing strong consistency of phases and, consequently, consistent chemical nature.

Approach

An extensive literature review and report, carried out by TransFIRe researchers with input from the Cast Metals Federation, John Winter Ltd, Wm Lee Ltd and SKF Bearings, was undertaken and a number of potential applications for re-using these huge quantities of SFS were identified within the ceramics, glass, cement and construction industries, amongst others.

In addition, a range of magnetic separation experiments on SFS (under both dry and wet conditions) to help understand its properties were also conducted at our industrial partner Bunting Redditch Ltd.

The project is now in the application phase and is focussing on assisting Wm Lee Ltd and SKF Bearings Ltd in linking with industrial end-users that are trialling, or interested in trialling, their SFS to avoid landfill and find value-added end-uses.



Outputs

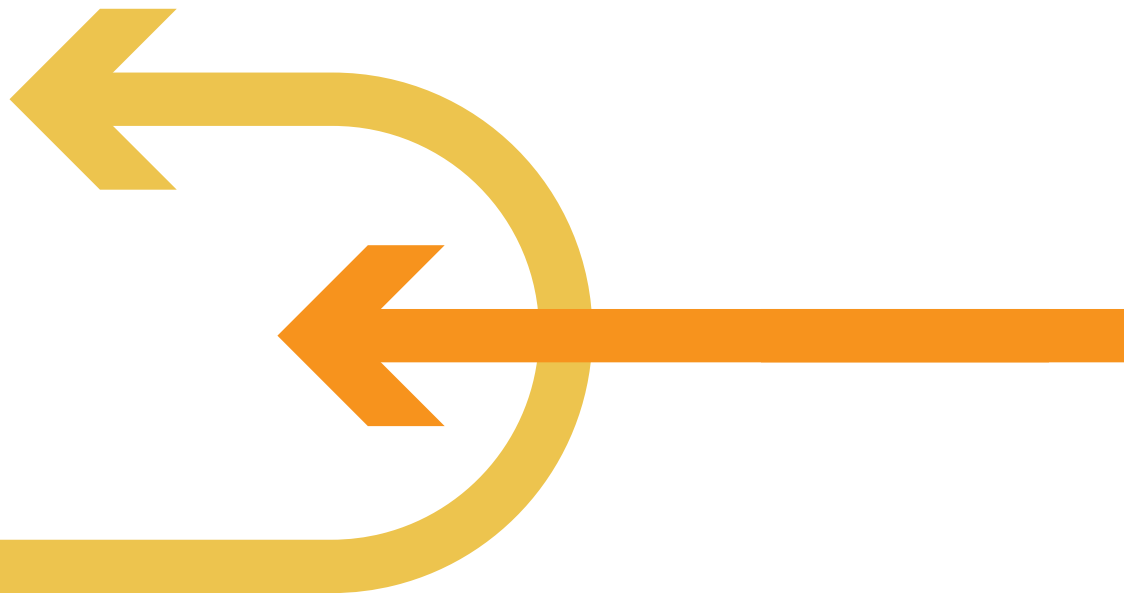
The team has developed a greater understanding of the complexity associated with the treatment and potential for alternative applications of SFS which is supporting the industrial partners in identifying and pursuing commercial opportunities for re-use of SFS and avoidance of landfill.

It was found that the physical and chemical properties of SFS depend strongly on the casting processes and the industrial sectors from which they are derived. Typically, there is some variation in the chemical composition of foundry sand from foundry to foundry, supplier to supplier, and, in some cases, from week-to-week depending on the products manufactured and the processes and materials used.

The feasibility of SFS reusability is profoundly correlated with its physicochemical properties and its physical and chemical variability.

Current research and reports on the use of SFS in the Foundation Industries indicate that SFS could partially replace a number of raw materials in several applications and manufacturing, whilst significantly reducing the costs.

The potential technical routes and economics of applying SFS as an alternative raw material in foundation and construction industries, over the use of only natural sand and other raw materials, were identified and multiple end-use trials are underway or planned.



4



Working with communities

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Barriers and enablers to decarbonising UK manufacturing



Contributors:

Professor Steve Cinderby, Dr Jean McKendree, University of York

Objective/benefit

Developing a better understanding of the barriers faced in looking to utilise the excess heat from Foundation Industries for the benefits of wider communities. Helping inform future policy to create enablers and incentives to encourage cross community resource sharing.

Project overview

For industrial manufacturing in the UK to stay competitive and meet net zero targets, there must be a system-wide approach to promoting low emission, high value materials over cheaper, high carbon products, enabling reduction of amounts required and circular reuse of materials.

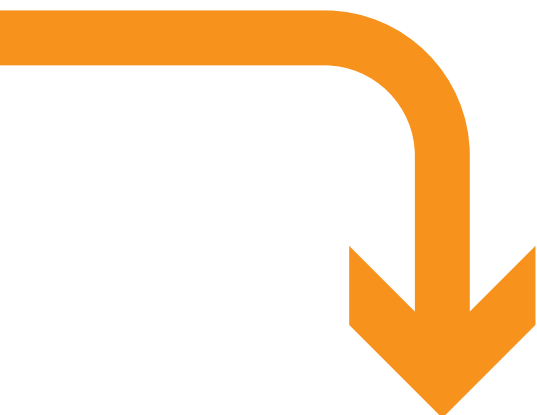
By transforming system-wide resource use, Foundation Industries (FIs) can become more competitive while supporting UK net zero 2050 targets, including opening opportunities to work with communities in which FIs are located and to improve equity, diversity and inclusion in FIs. To achieve these goals, it is critical to understand the multiplicity of barriers and potential enablers across the system-wide landscape.

Approach

TransFIRE is a large project that brings together technical experts and industrial partners. This offers a unique opportunity to access and summarise the extensive knowledge in the network and to understand the perceptions of the key players in attempting transformational change in industry.

A user journey interview approach was used to explore the challenges, key barriers and potential enablers or solutions identified by key players in the industrial sector from the technical side and the trade organisation perspective.

Two groups of partners were interviewed: 12 TransFIRE technical academic leads and seven representatives from trade organisations within the chemicals (plastics), metals (steel and cast metals), glass, cement, paper and ceramics sectors.





The interviewees were given three-to-five prompts of innovations in their industry gathered from the academic and trade literature and were encouraged to suggest other innovations. They were then asked to outline the barriers and enablers for each innovation.

Outcome

Interviews with academic experts and trade organisation representatives of UK Foundation Industries reveal a complex picture with numerous barriers and enablers in the decarbonisation journey. While some of the challenges are technical, there are many others that are driven by factors outside the direct control of the companies, such as lack of infrastructure, the high cost of energy in the UK relative to other countries, the lack of support for collaboration and research, poor public perception, and policy disincentives.

These factors that go “beyond the factory fence” bring into the spotlight the fact that all factories exist in a local context which will have different requirements and potential opportunities. Addressing this larger picture will require a system-level co-ordinated strategy and funding for industries and communities to create the necessary conditions for the aspirations of sustainable, low carbon manufacturing and a thriving economy.

The outcomes of the interviews have been summarised in a [policy document](#) that can be used to prompt discussion of approaches to system-wide change to drive transformational changes to UK industry and speed progress toward net zero. The findings were disseminated across the academic and industrial leaders in Transforming the Foundation Industries and associated LinkedIn communities through to policy makers at national and UK levels.



Peer-to-peer network of practice and sustainability metrics



Contributors:

Professor Peter Ball and Dr JR Candia, University of York.

Objective/benefit

Sharing knowledge and experiences across different type of industries on the topic of sustainability performance and sustainability metrics. Participants learn from trusted peers and share their challenges and achievements with each other.

Project overview

Foundation industries (FI) are facing multiple challenges, one of which is sustainability performance and reporting. Given the great diversity of tools, guidelines and protocols that exist to report on sustainability performance, and given the absence of a unified standard, there was a need to investigate the level of understanding FI firms had on this matter and what the best options would be for them.

This project sought to promote guided peer-to-peer learning by sharing knowledge and experiences across different types of Foundation Industries, and their supply chains, on the topic of sustainability performance. The project sought to help answer questions relating to sustainability metrics, such as: Why are you making and reporting sustainability measurements? What are your target improvements?

Key to setting up this collaborative peer-to-peer network was fostering an open, trusted and shared vision for the activities and outcomes. This was achieved with the Chatham House rule and the absence of NDAs.

Approach

In alliance with the North Lincolnshire Council in Scunthorpe, an eight-month action plan was defined consisting of three phases:

- Introductory webinar open to all industries from the region to present the challenge of sustainability metrics (Stage A, 32 participants).
- A workshop with a small group of companies for a deep dive into the discussion and explain the Network of Practice approach (Stage B, 7 participants).
- Group work with three-to-four companies (Stage C, 4 participants).

After the webinar and the workshop, four companies from Scunthorpe committed to participating in the network to share practice and gain advice.



Key sustainability challenges were shared, including how the companies demonstrate their net zero commitments in a standardised and recognisable way. Detailed information, for example, on packaging metrics, and recycling rates, were shared as well as details of how the company aligns with net zero goals. A key challenge was to try and navigate the different options for standards, regulations and policies to understand the right paths to follow.

Outcome

After the first two visits, company representatives, as well as North Lincolnshire Council staff, captured the value of being part of the Peer-to-Peer Network of Practice programme. In their view, it has been a valuable opportunity to share their sustainability strategies and challenges, receive ideas from external participants in a “safe” environment, while also better understanding the type of support they can obtain from the North Lincolnshire Council.

What was striking about the atmosphere was the mutual vision around the net zero challenge and the willingness to support each other by sharing practices. The sense of ‘place’ certainly played into this and the convening power and level of council engagement significantly enhanced the co-operation. Importantly the council treated this as part of a portfolio of wider industry engagement and support to reinforce the activities. Given the clear need for companies to further understand the issue of sustainability reporting, North Lincolnshire Council secured funding to continue working with companies in its region on the topic of sustainability challenges and metrics, by engaging external consultants.

A second webinar also took place, this time with the Wakefield Council, to evaluate its potential replicability in the future. After the webinar and the workshop, four companies (including Harlequin and Omni-pac) from Scunthorpe committed to participating in the network to share practice and gain advice.



Foundation industry value proposition for communities: identification of opportunities



Contributors:

Professor Peter Ball, Dr JR Candia, Dr Steve Cinderby and Dr Jean McKendree, University of York; Dr Mark Cassidy, Dr Kyle Parker and Professor Steve Yearley, University of Edinburgh.

Objective/benefit

To enable the Foundation Industries (FIs) to address their common challenges of competitiveness and sustainability and explore options to enhance their value creation potential in pursuit of sustainability (under a system view).

Project overview

This project sought to explore options to improve the value creation potential of FIs under a system view.

To understand the wider value proposition of FIs, a selection of eight sustainability reports from TransFIRE partners were reviewed. This was followed by direct work with industry representatives through two large scale workshops.

The aim of this exercise was to identify opportunities for collaboration with the larger community beyond the factory's fences, together with promoting a system view of the manufacturing processes of Foundation Industries.

Approach

This first workshop was part of the TransFIRE Foundation Industry Forum. The session was about promoting a system view of the supply chain and manufacturing processes of Foundation Industries.

A group exercise was carried out to stimulate creative thinking and to create conversations about eco-system thinking when participants return to their organisations. A guided discussion then took place around the waste and resources they have and could exploit in a win-win relationship. The practitioners developed credible and value adding examples including waste heat, waste materials, underutilised materials, spare land, vacant building space and excess human capacity/skills, among others.

A second workshop was part of the Institute of Refractories Engineers conference in Sheffield where the TransFIRE team conducted a workshop about sharing in an industrial context.





A wide range of ideas for alternative, “beyond-the-fence” uses, for by-products were generated for a range of hypothetical site maps. Unbeknown to the participants, these site maps were based on real UK sites and by presenting these maps as conceptual rather than real, the participants had readily engaged in generating valuable system solutions to generate revenue and lower carbon impact. They were not hampered by perceived barriers that would have occurred had they been working with real sites.

Outcome

Understanding the wider view of stakeholders and value proposition of FIs, beyond immediate clients and traditional value proposition, has the potential to enhance a firm’s sustainability contribution by better understanding and communicating their joint values.

Such wider FI societal contribution is not well understood. It seems essential to understand the linkages between them (the nexus approach) so co-benefits and trade-offs (i.e. one sustainable development goal undermines progress on another) can be identified.

Most large FIs concentrate on aspects of circularity, energy, climate change, and biodiversity in sustainability measurement and reporting, and some of the firms from the desk-based analysis also reported on SDGs, although without necessarily looking at the synergies between them. Comparing sustainability-related performance is now easier with the recent EU Corporate Sustainability Reporting Directive (CSRD) and the upcoming US ESG reporting. The former is driven by sustainable development principles while the latter is mobilised by the financial risk perspective. CSRD implementation could enhance the FI contribution towards sustainable development. Despite targeting larger companies, all sizes could benefit from the stakeholder transparency it offers.

Recommendations to address needs:

- Encourage companies to think about their wider (extended) value proposition, identifying both business opportunities as well as opportunities to enhance their sustainability performance.
- Produce mapping of co-benefits and trade-offs aligned with the sustainable development goals (SDGs) to enable companies to prioritise areas for action.
- Produce guidance and examples of good practice for how FIs can exploit the synergies between endeavours on circularity, energy, biodiversity, etc.
- Produce guidance and examples of good practice aligned with Corporate Sustainability Reporting Directive (CSRD) so FIs can readily implement change that impacts on reporting metrics.



Barriers to use of excess foundation industry heat in local heat networks



Contributors:

Professor Steve Yearley, Dr Mark Cassidy and Dr Kyle Parker, University of Edinburgh.

Objective/benefit

Developing a better understanding of the barriers faced in looking to utilise the excess heat from Foundation Industries (FIs) for the benefits of wider communities. Helping inform future policy to create enablers and incentives to encourage cross community resource sharing.

Project overview

In the drive to reduce greenhouse gas emissions and transition to lower carbon energy systems it is acknowledged that heavier industries (such as steel, paper and cement) are among the most difficult sectors to decarbonise. One characteristic that many of these industries share is extensive process heat, which in turn leads to significant levels of heat rejected into exhaust flues or cooling waters. It is becoming recognised that an important aspect of the low-carbon transition across these sectors can involve sharing resources through novel forms of engagement between industries and adjacent or related communities, “beyond the factory fence”. This work focussed on the potential for the use of excess heat in district heat networks across adjacent communities and whether this represented a means by which such communities could look to reduce the carbon intensity of their heating.

This project looked to investigate this topic and develop an understanding around the barriers that prevent the wider use of excess heat, thereby creating the opportunity to improve policy and practice in this area and provide better energy efficiency outcomes in the future.





Approach

Initial studies were undertaken to identify a number of potential cases where an energy intensive industry sat adjacent to a community. Examples identified included, but were not exclusive to, the aluminium smelter in Fort William, glassworks in Alloa and Irvine, and a paper mill in Cumberland. A number of smaller cases, not just restricted to the Foundation Industries, were also identified to help determine if the issues were unique to the FIs or more general. Some of these were also outside the UK and helped investigate potential impacts of regulatory or policy differences between the UK and other nations where district heat networks are more prolific.

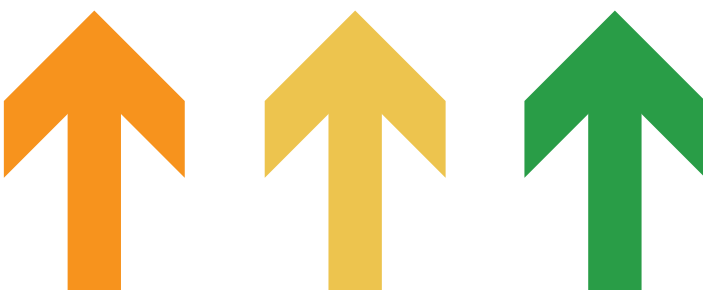
Engagement with various actors connected with foundation industry, policymaking, local community groups or heat network development was undertaken through field visits, informal interviews, attending events, e-mails and conversations. Data was analysed to identify the barriers and potential drivers to utilisation of excess heat in heat networks.

Outcome

Several interesting themes emerged. These can be summarised as:

- The lack of appropriate heat networks in the UK for industry to connect to.
- The complex regulatory and contractual arrangements around supply of heat to a network, especially as it relates to security of supply and long-term contracts.
- The temporal mismatch around long-term infrastructure development versus short-term pressures on industry.
- That heat network developers see Foundation Industries as large, complex entities to deal with, a view exacerbated by foreign ownership models and reduced local autonomy at plant level.
- Similarly, heat and energy strategies produced by local authorities often fail to incorporate industrial waste heat, due to planning complexity and low engagement.
- Other heat sources (such as heat pumps in watercourses), which are more straightforward to access, are becoming available to heat network developers.
- Sharing, or selling, heat for external use is not a key part of FI business models, with most firms lacking the capacity to engage in these activities.
- Weak financial incentives for FIs to adopt a more proactive approach to waste heat reuse: low market rates offered by heat network operators (due to need for supply redundancy) and high upfront capital costs reduce return on investment potential.
- The potential for non-financial incentives, such as improved community relations, potential carbon offset credits or scope 2 emission reductions, are unclear.
- Conversely, there are no policy or regulatory frameworks in place to force industry to dispose of and/or account for their waste heat, nor use it in a productive manner.

The main impact will be through future engagement with policymaking institutions, highlighting the barriers identified and helping to frame policy with respect to reducing barriers and encouraging Foundation Industries and heat network developers to engage with one another.



A systems perspective on policy enablers to transform Foundation Industries



Contributors:

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Objective/benefit

Foundation Industries need a system-level policy approach to enable them to compete in a green, decarbonised markets. Enablers at whole system macro-level will align stakeholders to support transformation from wasteful linear supply chains to resource efficient, circular business models exploiting innovative technologies and new ways of working operationally and strategically. Competition will be enabled by offering greater value in the marketplace whilst using less resources through collaboration.

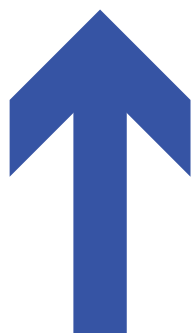
1. Change must be place-based and value-driven, with a shared direction among all business, societal and governance stakeholders to transform Foundation Industries and capitalise on opportunities across UK industry.
2. UK public and private investment into skills, technology and infrastructure is essential.
3. A co-produced national UK industrial strategy is needed to give certainty and enable long-term investment into low-carbon technologies.

Project overview

Given their importance, the question is: how can the UK support high-value, high-skill, highly competitive and low-carbon, productive Foundation Industries employing the best people for a thriving future? A whole system approach that aligns all stakeholders is necessary to enable transforming the Foundation Industries.

The numerous global and local threats to FI include high energy costs, climate change, career perceptions, policy uncertainty, and low investment, as a result Foundation Industries struggle to retain their presence in the UK and to thrive. Despite this, Foundation Industries continue to provide economic value, employment and social significance.

Innovative solution: A policy briefing drawing on TransFIRE Hub research on the barriers, enablers and strategies for transforming Foundation Industries. It provides routes to creating a political and economic context within which new sustainable business models, that offer value propositions that are a collaboration between businesses and their community, can succeed.





Approach and Outcome

The Policy brief 'A Systems Perspective on Policy Enablers to Transform Foundation Industries' calls for eight actions.

Value propositions

Transformation barriers: the sunk costs of existing plant, regulatory uncertainties and early mover uncertainties. We need value propositions including technologies for resilience; new high value materials and services; process technologies that reduce resource use.

Action 1: Enhance the value proposition of Foundation Industries.

Mechanisms to improve the “whole system” value proposition include investigating resource sharing with communities (space, skills, materials, CO₂, etc.), increasing local supply, heat sharing, facilitating industrial symbiosis, co-production and joint investments.

Action 2: Foster collaborative value propositions between diverse stakeholders not Foundation Industries in isolation.

Digital technologies covered by Industry 4.0 could enable strategic sustainable development goals to be met. Achieving carbon neutrality through decreasing energy consumption, greater integration and enhancing sustainability is critical. We need climate action plans that enhance the environment and societal development simultaneously.

Action 3: Identify, develop and communicate the full value proposition to business and society.

Skills, technology and infrastructure

Businesses and communities are interested in collaborating and learning from each other. Companies recognise the value of gaining legitimacy with local communities, this is especially true for larger businesses. Trade organisations want collaborative research (e.g. Glass Futures) to access otherwise unobtainable innovations.

Action 4: Foster collaborations to exploit skills and investment for whole of industry.

Facilitated industrial symbiosis programmes are integral to broader sustainability initiatives. E.g. the South Korean government set up an integrated finance scheme to attract investments from the local governments and businesses. The financial model should dynamically adapt to changing contexts over time and continuously improve.

Action 5: Industrial symbiosis progress needs ongoing investment to exploit the benefits.

Local Authorities and Councils play a key role in engaging and supporting local businesses, including promoting net zero practices (information, training, space for collaboration, funding). Their role is not as prominent as their achievements.

Action 6: The role of councils in knowledge exchange and resource exchange are critical to recognise and enhance.

Investment strategy

Capacity, expertise and capital costs gaps associated with district heat networks and other kinds of transformative infrastructure projects are difficult for local authorities to navigate. While public sector building are often cited as ideal ‘anchor loads’ many barriers exist including benefits, long-term contracts and the need for back up systems.

Action 7: Government must bridge the long-term contracting for heat networks and medium-term industry decisions.

Understanding how businesses, especially multinationals, sit within the community and what is the “common good” needs long term strategic thinking. Embedding businesses into a regional strategy with industrial strategy is risky. This is especially acute in situations where the long-term viability of businesses comes into question. This then extends to individual perceptions, especially for career decisions by younger members of society.

User journey mapping for container glass reuse



Contributors:

Dr Steve Cinderby and Dr Jean McKendree, University of York.

Objective/benefit

Understanding the barriers and enablers for a possible return and refill scheme in the UK.

Project overview

Glass is one of the few materials that can be recycled infinitely without losing any of its properties in a closed-loop system. In 2019, the UK recovered about 71% of single-use glass by mass, but only about 36% was used to make new containers. Challenges to circular-loop recycling of container glass raise the question of why there are not large-scale refill schemes for glass bottles in the UK. Such schemes were common historically but have greatly reduced worldwide in the last few decades.

Currently, the UK is considering implementing a deposit return scheme (DRS), in which consumers pay a deposit on drinks bottles which is repaid when they are returned to a retailer in England, Wales and Scotland in 2025. However, this scheme only includes single-use plastic bottles and cans, not glass, primarily due to push-back from business, and the scheme also is aimed solely at increasing recycling rates, not refills. Our connections within TransFIRe offered an opportunity to investigate in more depth why such schemes are not more wide spread and are not supported within the industry.

Approach

User journey interviews were undertaken to explore the container glass industry perceptions, barriers and potential solutions for a national refill scheme for the UK.





A small cross section of senior stakeholder representatives were recruited for interviews, all working within the glass industry on supply, production and sustainability.

Outcome:

These interviews revealed many regulatory, logistical, economic, social and industrial challenges to nationwide refill schemes.

The majority of challenges and solutions identified were within industries' sphere of influence, however, there would be a need for clear legislation mandating the collection process and deposit scheme which are the responsibility of the four devolved legislatures. Additionally, behaviour changes would require the public to be a key stakeholder in the successful adoption of reuse.

All interviewees said the interview process had made them think more deeply about the range of barriers and possible solutions facing any refill scheme in the UK. It also raised several important issues around conflicting policies and disincentives caused by certain regulations, such as the export of glass being more financially lucrative than keeping it in the UK.

The full conclusions can be read in the published paper:

Bottlenecks to glass return and refill in the United Kingdom: User Journeys to explore industry perspectives

Steve Cinderby, Jean McKendree

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