sustain

future steel manufacturing research hub

Annual Review 2020/2021

Engineering and Physical Sciences Research Council

Swansea University Prifysgol Abertawe

The University Of Sheffield.

WMG THE UNIVERSITY OF WARWICK

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“Sustainability is the biggest challenge of our generation and the metallurgical sciences are ready to make their contribution”

- Professor Dierk Raabe - Max-Planck-Institut

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Welcome

The SUSTAIN Team

“Steel and concrete are the working horses of the Anthropocene. But only steel offers the variety of reuse, repair and remanufacture, which is at the base of the circular industrial economy. Scientific challenges for sustainable steel include zero-carbon production and pure recovery technologies for molecules and alloys. Sustainable steel's future will come!”

- Dr Walter Stahel - Product Life Institute

Dear Partners, members and future collaborators

It gives us great pleasure to welcome you to the second Annual Report for the SUSTAIN Future Manufacturing Hub, a programme based on two Grand Challenges, five Themes and 13 Tasks. The Hub was launched in April 2019 as a National Centre of Excellence for Steel, led by Swansea University in collaboration with our Spoke partners Sheffield and Warwick Universities and industrial partners British Steel, Celsa Steel UK, Liberty Steel, Sheffield Forgemasters and Tata Steel UK.

The Hub was launched during a period of uncertainty for UK Steel to provide a platform for novel research to deliver a net zero carbon and higher digital integration for the industry. This project focusses upon diverse areas such as Carbon Capture and Utilisation, the better use of waste products and heat energy, the development of novel sensing and analysis techniques, novel steel chemistries and processing and new digital techniques, both internally and externally within the greater supply chain.

Steel is ubiquitous and a fundamental enabler of modern life. The intricacy of modern steelmaking and the sheer volume of manufacture places steel in a pivotal position to drive the circular economy – not just for steel, but for all of the modern materials that are used with it to achieve greater product functionality. Drawing upon the knowledge and esteem of the partners, the Hub continues to advance research in areas that are germane to the continuation and growth of the industry in a circular, net zero carbon future economy. Our vision is to provide a profitable, sustainable industry and supply chain with increased GVA, employment and sovereign capability for the UK's future needs.

Despite the COVID-19 pandemic, over the last two years we have witnessed the growth of an incredible collaborative partnership between the steel industry and aligned academia. Working side by side to overcome the many formidable challenges we face to enable a carbon free, truly sustainable future. We would like to thank each of our partners and collaborators for their continuous support to the SUSTAIN Hub and look forward to new members joining the consortium to drive a successful future for UK Steel.

The SUSTAIN Team

Hub Overview

The SUSTAIN (Strategic University Steel Technology and Innovation Network) Future Manufacturing Research Hub is a £35M project funded by £10M of EPSRC funds as well as by Universities, Trade Bodies, Research and Technology Organisations (RTO's) and Businesses over 7 years and aims to support the development of new, smarter and more environmentally friendly options to ensure the future of steel manufacturing in the UK.

The Hub is based at Swansea University, with spokes at the University of Sheffield and WMG, University of Warwick. Our headline industrial sponsors are British Steel, Celsa Steel UK, Liberty Steel, Sheffield Forgemasters and Tata Steel UK. The Hub currently has academic partnerships with Cardiff University, Durham University and University College London.

SUSTAIN in Numbers

44 academics & researchers working at **6** universities

6 new projects funded by the hub in 20/21

19 aligned projects secured in 20/21 totalling **£12.6m** in additional funding

>12,000 website page views from **>3,500** unique visitors

21 industrial engagement & workshop events

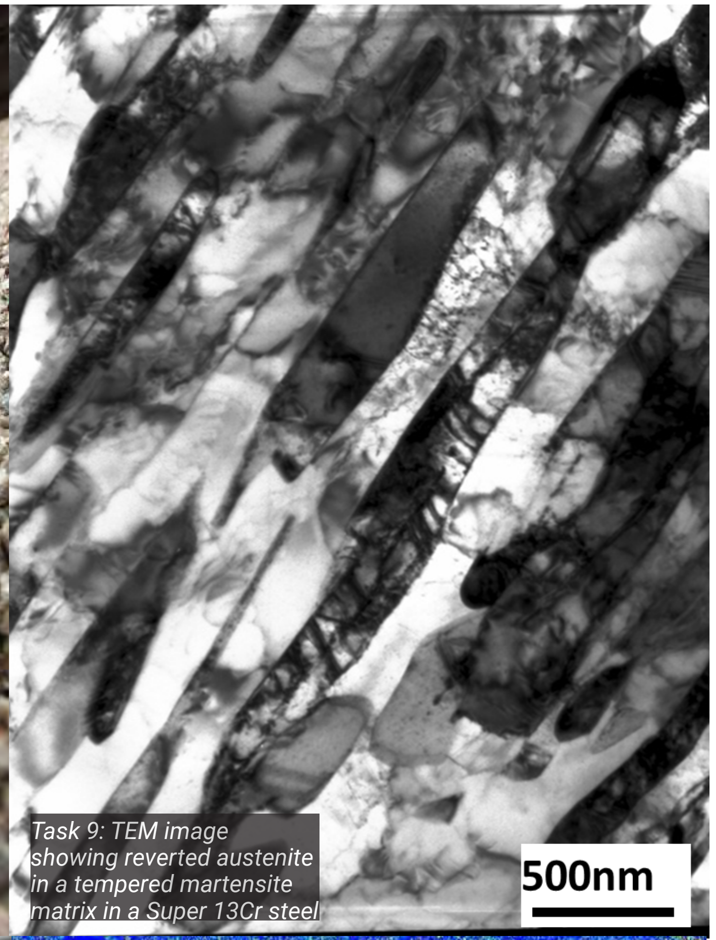
10 papers & articles published

>850 young people reached through supporting online outreach

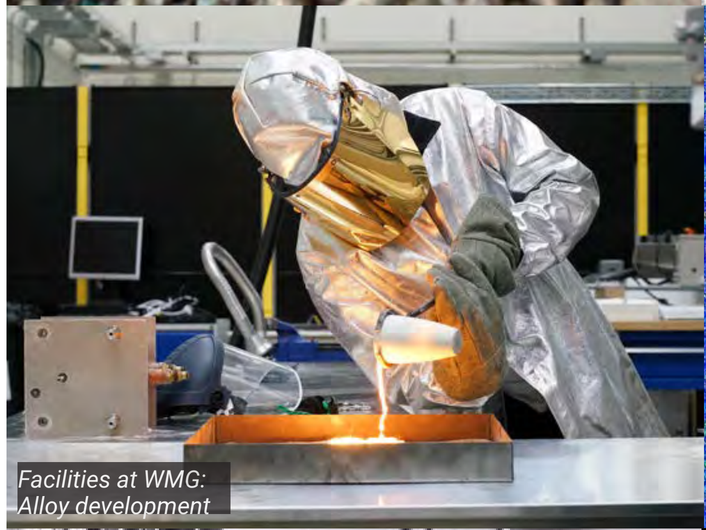
>900 attendees to hub & supported events

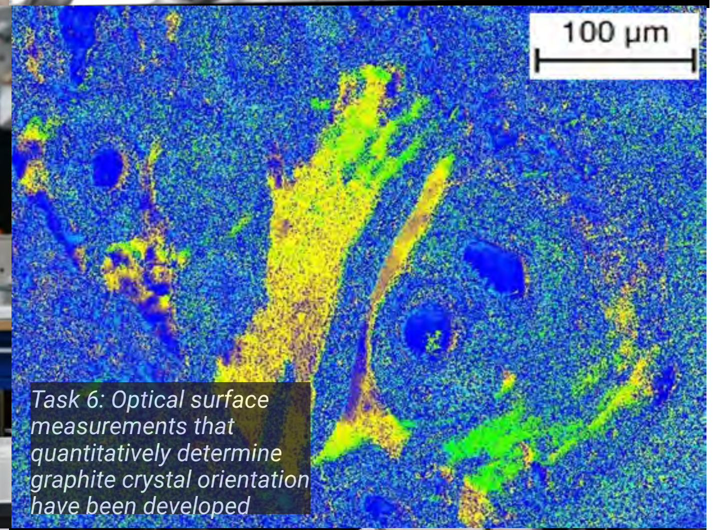
20 project partners & collaborators


Task 10: Subcoal™ in pellet form after processing



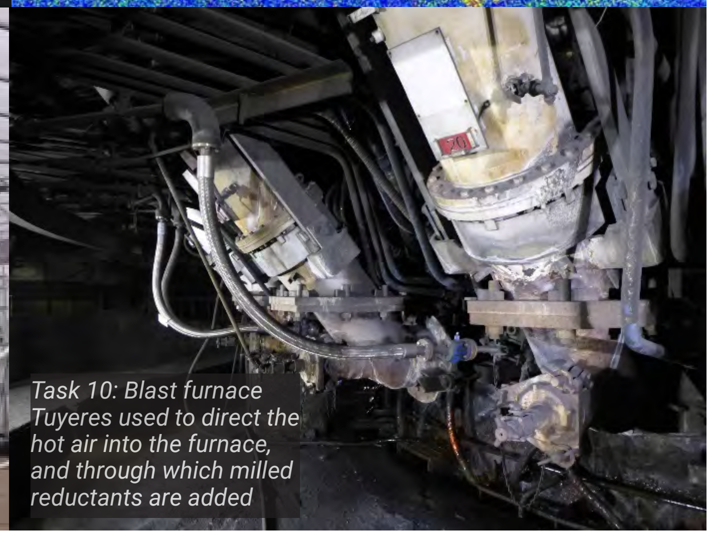
Task 9: TEM image showing reverted austenite in a tempered martensite matrix in a Super 13Cr steel


Facilities at WMG: Alloy development



Task 6: Optical surface measurements that quantitatively determine graphite crystal orientation have been developed


Task 1: Biorefinery tubular reactor stack for algae growth


Task 10: Blast furnace Tuyeres used to direct the hot air into the furnace, and through which milled reductants are added

Steel on the National Agenda

Dr Richard Curry

The UK Steel Industry, once world leading in terms of innovation, productivity and volume has been decimated in recent decades by new entrants to the saturated global linear economy. These new entrants, located in developing nations, have access to more favourable operational costs and lower national environmental targets that have applied increasing pressure to the European and US producers, reducing profit margins and potential for reinvestment and growth. As the UK moves forward post-Brexit and COVID-19, it is clear that there are vulnerabilities in many of these key areas that not only force dependence upon imports for our own infrastructure, defence and consumables, but reduce our ability to control quality and maximise profitability from the high value goods we export.

The global environmental crisis together with the diminishing availability and escalating prices of mined elements that are key to modern technology, living standards and renewable energy production are quickly showing that we can no longer exploit our 'consume and dispose' habits that exemplify the linear economy to date. To ensure the continual existence of the human race where science, technology and living standards continue to improve from generation to generation, we must quickly transition to a truly circular economy where nothing is wasted, resources are cycled from generation to generation with minimal loss. This must be achieved on a foundation of carbon neutral energy to ensure sustainability and prevent environmental catastrophe.

Due to its size, geography and history, the UK stands in a formidable position to lead the world in the transition to a true circular economy that must begin with the foundation industries as its nucleus. This must also include, influence and shape the supply chain, higher tier manufacturing and tech industries to be truly circular in terms of future generations of society. However, this change will not

"To ensure the continual existence of the human race where science, technology and living standards continue to improve from generation to generation, we must quickly transition to a truly circular economy where nothing is wasted, resources are cycled from generation to generation with minimal loss."

be easy and will require a paradigm shift in thinking and attitude - focussing upon the domestic raw materials of the future that we currently call 'waste' and making changes to the way we design and manufacture products that will appear to be anathema to the current high efficiency, high productivity manufacturing processes.

As the UK emerges from the COVID-19 pandemic, steel's sheer ubiquity, production volume and potential for recycling, places the industry in a primary position to lead the UK and rest of the world in a circular economy revolution. The SUSTAIN project, funded by UKRI, British Steel, Celsa Steel UK, Liberty Steel, Sheffield Forge Masters and Tata Steel UK together with support from the UK's leading material research laboratories and Trade Bodies, was created to lead the UK through this transition. With focus upon the main challenges to sustainability such as the sequestration and reuse of waste heat and carbon emissions, reuse of hydrocarbon wastes and end of life consumer goods, digital innovation, harsh environment sensor and measurement techniques and late stage product differentiation, SUSTAIN aims to provide a national research platform to bring together the finest UK academics, Research and Technology Organisations (RTOs), Small and Medium Sized Enterprises (SMEs) and tech companies to overcome these challenges through the application of novel research to primary steel production and the greater supply chain.

Industry Engagement

"Steel is a vital material in modern society. New grades are being developed every year to reduce the 'in use' carbon footprint of products made from steel and supply our everyday needs in the automotive, packaging, construction and engineering sectors.

SUSTAIN is helping to bring the steel industry and academia together, to address the many challenges and opportunities for this industry. How do we de-carbonise manufacturing processes? What is the role for digital in a successful and sustainable 21st century steel industry? How do we develop the next generation of engineers and scientists to work in the industry? It's been a pleasure to meet such passionate and capable people through SUSTAIN. I'm looking forward to the next steps in our journey together."

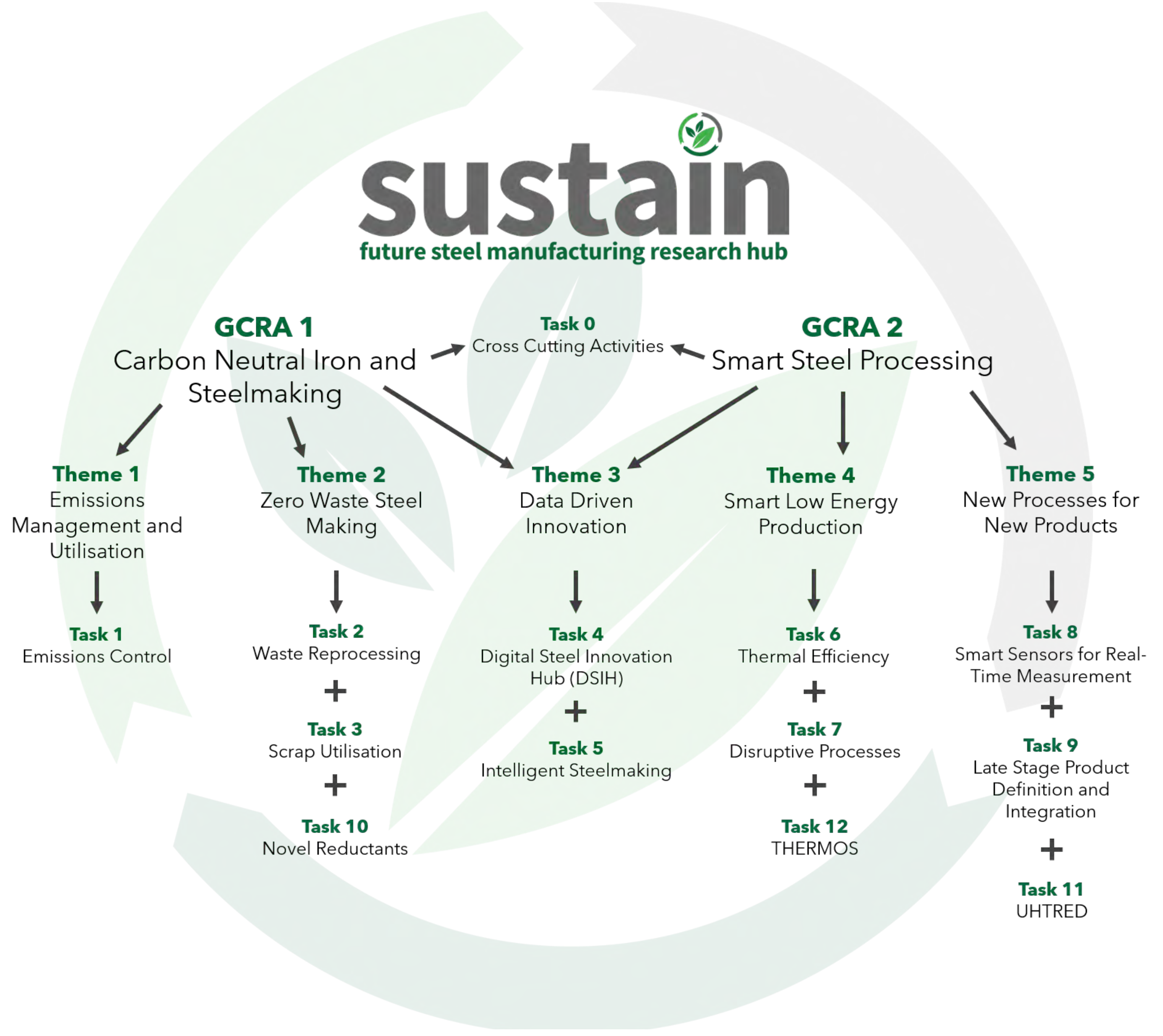
- Byron Tucker - Tata Steel UK

"SUSTAIN is a unique opportunity for the UK-based steel companies to have access to a wide variety of know-how and facilities across the Universities of Sheffield, Swansea and Warwick plus networked to other academic institutions. At one time our UK steel companies were mainly one large corporate organisation with its own corporate research facilities. This has long gone, but the advantage now is access to wider academic interests, state-of-the-art research equipment and collaborative knowledge groups. Activities of interest to Liberty Steel range from management of scrap supply, steelmaking controls, digital technologies and through to design of process and products using metallurgical principles."

- Dr Simon Pike - Liberty Steel UK

Research Programme Structure

The SUSTAIN Hub is split into two Grand Challenges, five Themes and nine main Tasks. Three additional Feasibility Studies have commenced, as well as a Task 0 which aims to monitor the impact of the Hub as a whole.



"Without the SUSTAIN initiative we would undoubtedly have fallen back into the trap of optimising steel properties per se instead of optimising steel properties per unit of environmental damage"

- Professor Sybrand van der Zwaag - TU Delft

SUSTAIN Grand Challenges and Themes

The SUSTAIN project aims to address two Grand Challenges:

Carbon Neutral Iron and Steelmaking

Steel is ubiquitous in the modern developed world; its low cost and the highly developed industry that produces it enable the standard of living we are accustomed to. From packaging to construction, transport and energy, steel plays a major part in our daily lives without us noticing. Although the steelmaking process is highly efficient, for every tonne of steel produced, twice the amount of CO_2 is liberated from fossil fuels to drive the process and its energy requirements. The first of SUSTAIN's Grand Challenges aims to develop innovative methods to eliminate the carbon footprint of the steelmaking processes and provide a sustainable method of production for a carbon neutral industry which supports global needs.

Smart Steel Processing

This Grand Challenge aims to revolutionise the steel industry through the development of steels with enhanced mechanical and physical properties, develop increased functionality and utilise the recent developments in sensor technology and digital systems. Focussing on production and supply chains, the Smart Steel Processing Grand Challenge is introducing concepts such as blockchain and tracking technologies into a mature supply chain and customer base that will explicitly describe the manufacturing process and sourced materials on a product by product basis giving the end customer and government bodies full confidence in the product's performance, ethical raw material sourcing, production and carbon footprint.

These Grand Challenges are split into five Themes:

Theme 1:
Emissions Management and Utilisation

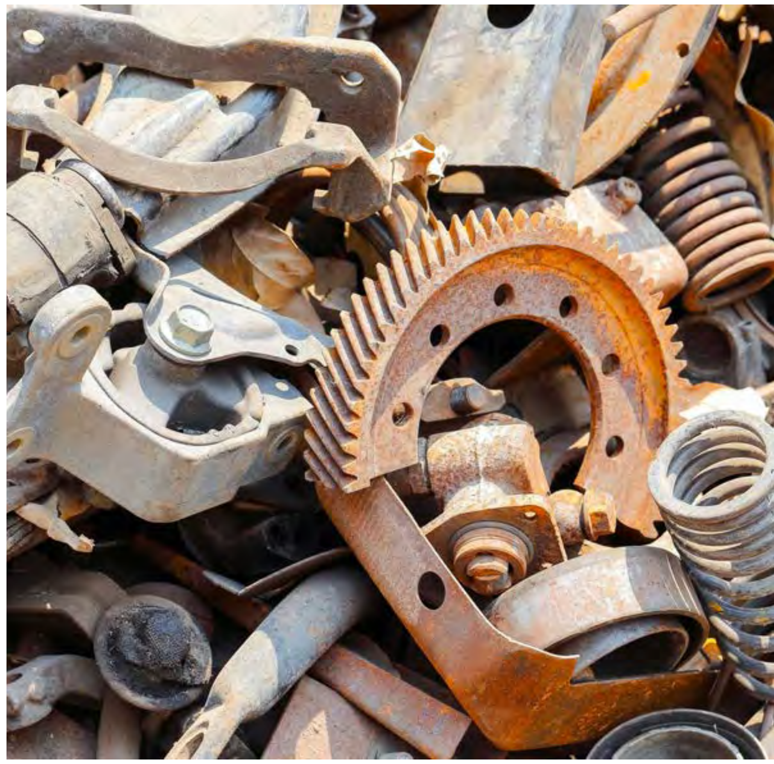
This theme focusses on carbon capture and usage of large sources of CO_2 and management of other harmful gaseous and particulate emissions.

The first challenge is demonstrating a robust recovery and separation process to extract CO_2 from a range of output gas streams. Then, the re-use of the captured CO_2 will be investigated at laboratory scale, before upscaling to industry.

Theme 2:
Zero Waste Steelmaking

This theme concentrates on the reuse of domestic and industrial waste products within the steelmaking process. The projects here focus on the substitution of fossil fuels with applicable landfill waste and the reuse of end of life ferrous materials.

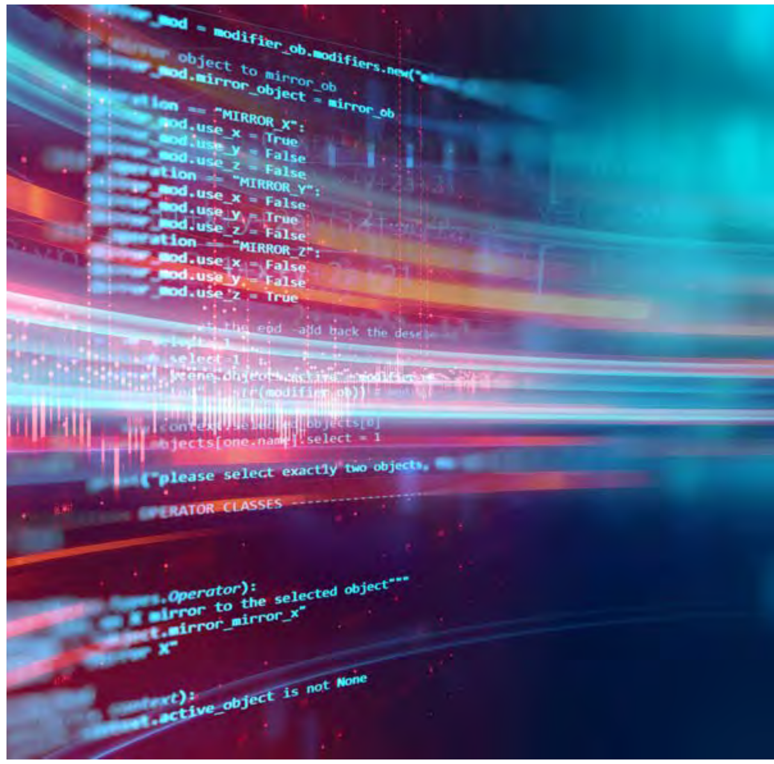
The UK currently exports approximately 10 M tonnes of scrap steel per year which could be recycled locally. The main challenge in its reuse is the management of unknown elements inherited from a range of steel types, and well as non-ferrous and non-metallic contamination, introducing impurities.



Theme 3:
Data Driven Innovation

To be transformative, the industry will have to be disruptive. The goal of this task is to ultimately generate disruptive technologies for 21st Century supply chains and business models.

New approaches to process modelling and optimised fast-algorithm techniques will be used to allow real-time simulation and prediction of complex thermodynamic, kinetic and mechanical processes.



Theme 4:
Smart Low Energy Production

This theme focusses on using smart techniques, enhanced material properties and non-carbon sourced reactants to reduce the net carbon usage and energy required throughout the steelmaking process.

Thermal energy lost as heat throughout the steel manufacturing process is considered together with both the use of new novel materials to convert conducted and radiated heat into useful electrical energy, as is the performance and durability of existing and future refractory materials.

Theme 5:
New Processes for New Products

This theme looks at the potential of using novel chemistries, processes and measurements to produce new products or improve the efficiency and consistency of existing high value steels.

One area of focus is microstructural monitoring during processing, whilst the other looks at the development of ultra-high-performance steel for improved processing efficiency, reduced process energy requirements, ultra high strength for equivalent lighter weight products and novel processes which enable late differentiation of the steel into a range of diverse products.

Progress reports by Task

As documented, the majority of the core SUSTAIN Tasks are underway and making good progress, with most PDRA positions recruited and lab work, despite ongoing COVID-19 restrictions, having commenced. T7 has an ongoing PhD recruitment drive thereby delaying commencement in time for this Review.

The introduction of four new Tasks (T0, T10, T11 and T12) has occurred over the last year, three of which appear under the Feasibility Studies section. Although in the very early stages of development, T0 will identify and nurture common challenges and focus groups across the whole SUSTAIN activity landscape, including GCRA, Platform and Feasibility funds. The objective is to then evaluate the resulting scientific industrial impact.

Task 1: Emissions Control

Start date: October 2020 Expected end date: October 2023
PIs: Professor Andrew Barron, Professor Peter Styring, Dr Enrico Andreoli
Researchers: Dr George Dowson, Dr Waqas Hassan Tanveer
Project partners: Swansea University, University of Sheffield

Project Abstract

The aim of Task 1 is to reduce carbon emissions from steelmaking processes by capturing and converting the emitted carbon dioxide into high value-added products. The development of this technology is essential as the steelmaking processes in their current form will continue to generate CO_2 for some time. Complementary Tasks within the SUSTAIN Hub are developing lower carbon technologies to further drive the industry towards a net zero future. There is a real opportunity for the overall cost of carbon capture and sequestration to be offset via valuable products made from the captured CO_2. CO_2-derived chemicals and fuels are of particular interest to us for their added value and in some cases large market scale merit, demonstrating the potential for a future circular economy based on CO_2 recycling.

Key findings:

Synthesis of CO_2 capture materials completed at gram scale for testing in dynamic breakthrough system

Lab scale CO_2 electrolyser for production of hydrocarbons operational

Protocol for preparing self-supported gas diffusion electrodes for robust CO_2 conversion completed

Biorefinery demonstrator deployed at Vale

eDME identified as the primary fuel target as a ground transport alternative to the steel works

Industry context

The future of the steel industry depends on the integration of production units where the resource use is optimised for profitability and sustainability. Blast furnace and coke oven gases contain CO_2 which, on removal, can help deliver purified components including carbon monoxide and hydrogen. Whilst the production of steel is of core importance to the industry, integrated steelworks could make additional income from by-product streams, including the conversion of CO_2 to value-added products. Thermochemical and electrochemical conversion of CO_2 to hydrocarbons and oxygenates (e.g. ethylene, DME) and algae biorefinery conversion of CO_2 to lipids and proteins are crucial to this approach.

Progress to Date

Carbon dioxide capture materials:

Amine-based (triazine-based cross-linked polyethyleneimine) materials have been successfully synthesised, characterised and prepared at gramme scale for testing in the Thermal Pressure Swing Adsorption Unit. Experiments to characterise the materials for dynamic CO_2 breakthrough are underway at the Research Centre for Carbon Solution (RCCS), at Heriot-Watt University in collaboration with Dr Susana Garcia with a research paper awaiting submission once this data has been received.

Ionic liquids supported cellulose materials are currently being optimised through the use of Instrumental Gas Analysis. The data for these ionic liquids will be evaluated and analysed to design enhanced materials which are capable of capturing CO_2 over a range of waste gas concentrations.

Carbon dioxide capture processes:

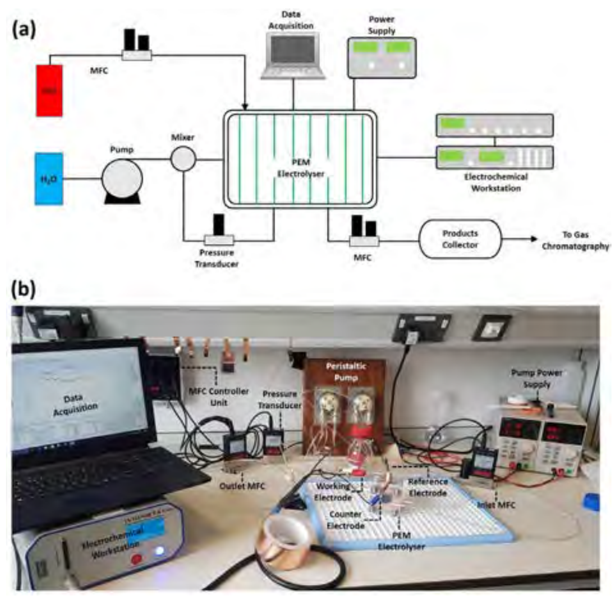
The large absorber rig is currently being prepared to commence testing. There have however been delays in acquiring a new compressor power source with pressure drop. Additional parts to allow for automation of the larger rig are currently on order for immediate installation when delivered.

Carbon dioxide thermochemical conversion:

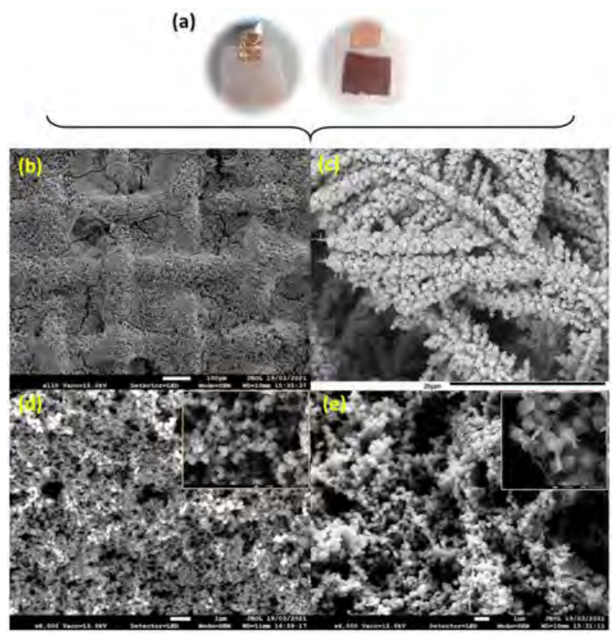
As a result of the literature reviews, it has become clear that the most beneficial route to commercialisation will be through CO_2-to-DME, using renewable energy as the input (eDME). Work has begun to redesign a reactor to perform the CO_2 to methanol conversion and subsequent methanol to DME step. This will be carried out on a laboratory-based sub-pilot plant. The DME unit will first be optimised using commercial Vulcanol before progressing to using our own CO_2-derived methanol. This will allow us to streamline and expedite the overall process development.

Carbon dioxide electrochemical conversion:

The design, assembly and calibration of a bench scale CO_2 electrolyser has been completed. Self-supported copper-based gas diffusion electrodes have been prepared and are undergoing tests for operational stability.



Above: (a) Schematic representation of CO_2 fed electrolyser setup. (b) Snapshot of the actual testing station.



Above: Self-supported gas diffusion electrodes for CO_2 electrolysis. (a) Photo of a copper mesh before and after the copper foam deposition. Microscopy images showing the general structure (b) of the microscopic structures of foams (c-e) using different deposition conditions.

Planned Impact:

Providing the UK steel industry with designed scalable options for carbon dioxide valorisation

Additional Task 1 activities: Collaboration with Reducing Industrial Carbon Emissions (RICE):

Carbon Dioxide Biorefinery - The biorefinery demonstrator is currently being installed at Vale's Clydach Nickel Refinery. Progress has also been made in assembling the bioreactor in the polytunnel. Assembly of one section of the Perspex tubing housing the growing algae has been completed with commissioning and testing due to commence shortly.

The green hydrogen production unit has now been running 12 months at Hanson UK, replacing some of the natural gas used to process slag for aggregate.

Pressure Swing Adsorption Unit (PSA) - A PSA unit is under development for the separation of CO_2 from industrial emissions and process gasses. The PSA design has been finalised and a prototype is under construction.

Task 2: Waste Reprocessing

Start date: June 2020 Expected end date: June 2023
PIs: Professor Peter Holliman, Dr Richard Thackray
Researchers: Dr Eurig Wyn Jones
PhD students: Fawas Ojobowale
Project partners: Swansea University, University of Sheffield, Tata Steel UK, N&P Recycling

Project Abstract

Blast furnace ironmaking uses fossil fuel carbon (e.g. coke and coal) to provide energy and to reduce iron oxide to liquid iron. In this task, life cycle analysis will be combined with experimental testing to investigate using non-fossil fuel carbonaceous waste to displace fossil fuel carbon within the ironmaking process. By using non-fossil fuel sources of carbon we aim to reduce net carbon dioxide emissions and so help to decarbonise the overall process.

Planned Impact:

To displace fossil fuel carbon from ironmaking to reduce CO_2 emissions

Key findings:

We have shown that:

Non-renewable waste can be milled to different particle sizes

Thermal analysis can study the kinetics of thermal processes for fossil fuel and non-fossil fuel carbon

Ultra-fast pyrolysis GCMS can study the sort of ultra-fast thermal processes found in a blast furnace

Slow motion imaging can help to understand ultra-fast thermal processes

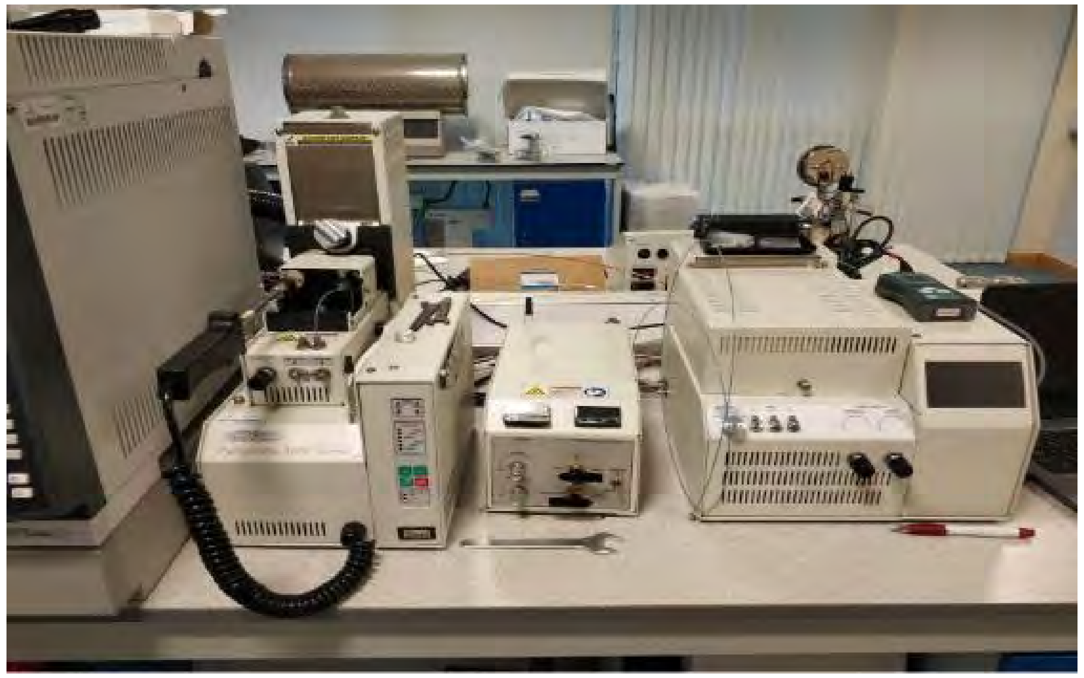
In collaboration with Cardiff University we can study the chars produced from a drop tube furnace using pyrolysis GCMS

Above: Examples of non-recyclable waste

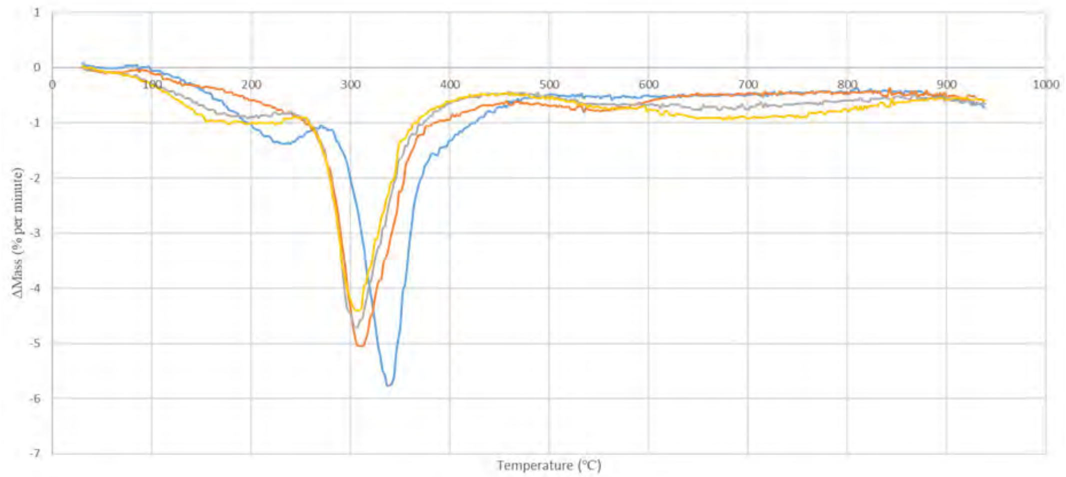
Progress to Date

Progress has included commissioning and testing new methods for studying ultra-fast (100ms timescale), high temperature (>1000°C) processes in extreme environments (oxidising/reducing) with a focus on in situ metrology wherever possible. To achieve this, ultra-fast pyrolysis has been combined with sophisticated time of flight GCMS to study the volatile fraction of fossil fuel and non-fossil fuel (e.g. non-recyclable waste, plastics, biomass and modified biomass) to begin to build a library of data and to understand the presence and influence of heteroatoms. Ex situ sample analysis has also been started to examine sample heterogeneity. Processing methods to both prepare samples for analysis and to co-mix materials have also been developed. More recent developments have included the development of in situ image analysis (ultra-fast digital imaging and fast thermal imaging). After a period where travel was not possible, a visit has been made to Cardiff University and a discussion held about initial char samples produced from their drop tube furnace. These chars have experienced different residence times at high temperature and we are studying the balance between solid and volatile matter by combining the DTF with pyrolysis GCMS.

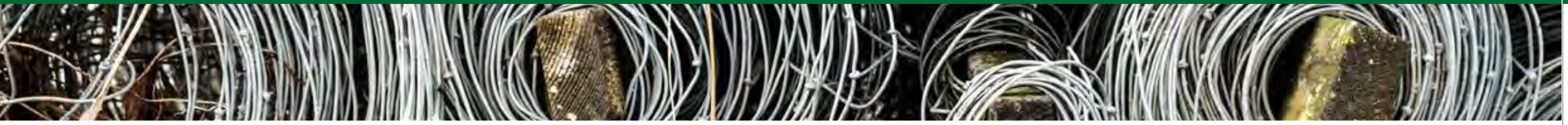
The Sheffield EngD project has been advertised and the start date for the successful applicant will be September 2021.



Left: Ultra-fast pyrolyser with pressure reactor



Right: dTG data for mixed carbon sample at different heating rates



Task 3: Scrap Utilisation

Start date: December 2019 Expected end date: December 2022
PIs: Dr Zushu Li, Professor Claire Davis, Dr Richard Thackray
Researchers: Dr Ishwar Kapoor
Project partners: WMG University of Warwick, University of Sheffield, British Steel, Celsa Steel UK, Liberty Steel, Sheffield Forgemasters, Tata Steel UK

Project Abstract

Significantly increasing the use of the UK-generated steel scrap in steel production has become a strategic direction for the UK steel industry. This project provides fundamental understanding and technology development to maximise the scrap usage in manufacturing high quality steel products more economically, by investigating the influence of residual elements inherited from steel scrap on the processability and properties of typical steel products. It focuses on downstream processes of steel manufacturing – casting, re-heating, hot-rolling, cold-rolling, annealing and mechanical properties. This will help achieve net-zero emissions and maintain the sustainability and profitability of the UK steel industry.

Industry context

The UK has the unique resource of abundant domestic steel scrap supply. The combination of scrap-based steel manufacturing and renewable energy presents a real opportunity to produce high quality steel at low or zero carbon output. The biggest challenge for the increased use of scrap is the impurities inherited from the scrap that influence the steel processing and service properties of steel products, particularly for automotive, aerospace, energy and railway applications. The outcomes of this project will provide recommendations to the steel industry to increase the residual tolerance of impurities in steels while maximising the scrap usage and reducing CO_2 emissions.

Key findings:

Impurity and alloying elements for steel scraps and typical steel products have been identified, which is used for the design of the research matrix

Metallurgical understanding about the behaviour of various residual elements, individually and synergistically at high (>1200°C) and low temperatures (<1200°C) during the casting process, has been critically reviewed, with a focus on local enrichment and cracking caused by the residual elements

Three existence forms of copper have been found in the as-cast low carbon free cutting steels (LCFCS). Their evolution caused by the heat treatment at 1200°C has been studied

The co-existence of copper and manganese silicate oxides and their evolution upon heat treatment has been investigated

Progress to Date

We have extensively engaged with industry partners (i.e. steelmakers) and beyond (metal recyclers, trading bodies, independent consultancy, etc) to identify the impurity levels for different categories of steel scraps and for different steel grades. This has been used to help design the research matrix.

We have carried out a critical review of the current metallurgical understanding about the behaviour of various residual elements, individually and synergistically at high (>1200°C) and low temperatures (<1200°C) during the casting process, with a focus on local enrichment and cracking caused by the residual elements. This helps the steel community to increase the utilisation of steel scrap for steel production by identifying the current constraints and opportunities.

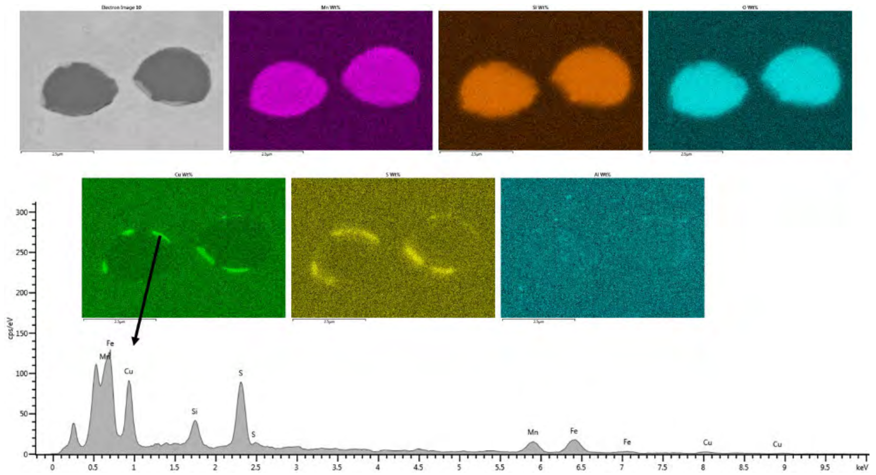
Based on the experimental layout and chemistry designed, we used the melting and casting facilities at WMG (Warwick) to make typical steel grades in the laboratory, that is, low carbon free cutting steel (LCFCS) and low carbon steel (for comparison) while the industrial samples were not available.

We have been characterising the as-cast and heat-treated steel samples using the advanced characterisation techniques at WMG, with a focus on the existence forms of impurity Cu and its evolution due to heat-treatment. We have advanced understanding on the co-existence of CuS and manganese silicate oxides and of CuS and (Fe,Mn)S and its evolution due to the heat treatment at 1200°C.

The Sheffield PhD/EngD project associated with the task has been advertised and the successful applicant will start in September 2021.

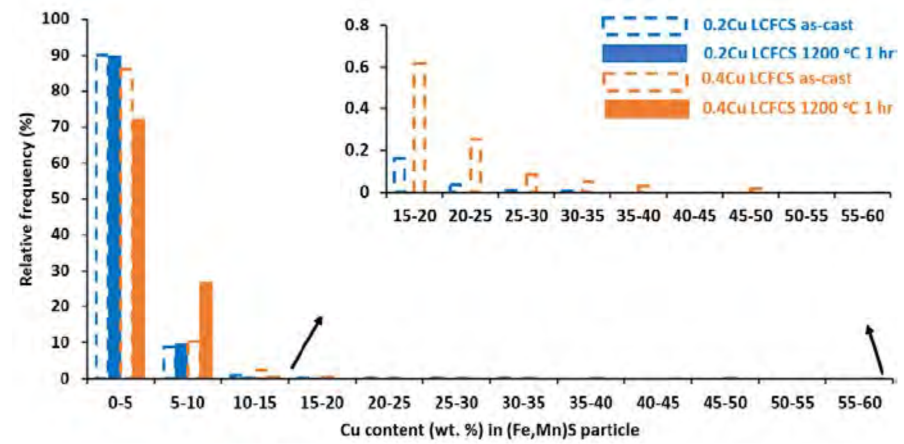
Planned Impact:

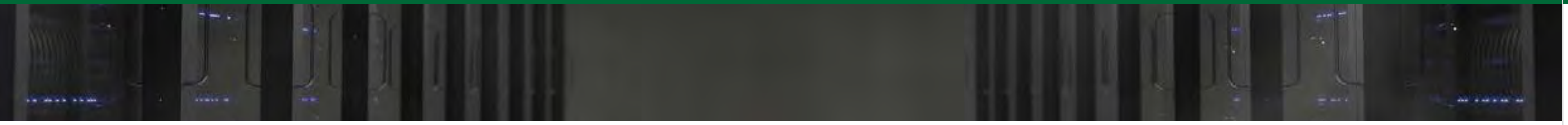
To advance the fundamental understanding of the effects of residual elements on steel processability and product quality and consequently enable the UK steel industry to maximise scrap use in producing high quality steel economically



Left: Co-existence of CuS with manganese silicate oxides in the as-cast low carbon steel containing 0.4 wt%Cu

Right: Cu content in (Fe, Mn)S particle in the as-cast and heat treated steel samples





Task 4: Digital Steel Innovation Hub (DSIH)

Start date: September 2019 Expected end date: October 2023

PIs: Professor Janet Godsell, Professor Giovanni Montanna, Professor Arnold Beckmann

Researchers: Dr Zakiah Suhaimi, Dr Sagar Uprety, Dr Qiushi Cao

PhD students: David Ireland

Project partners: WMG University of Warwick, Swansea University, British Steel, Celsa Steel UK, Sheffield Forgemasters, Liberty Steel, Tata Steel UK, nChain

Project Abstract

T4 aims to create a data-driven step-change improvement in the competitiveness of UK steel supply chains (SCs). It will utilise recent developments in technologies to both harness and analyse data that can improve the value-added and productivity of products, processes, and UK steel industry SC. The project will explore how the adoption of industrial digital technologies (IDTs) could improve steel SC productivity and sustainability. Deep reinforcement learning algorithms will be developed to train multiple robotic agents to collaboratively solve tasks such as object manipulation using direct input from mounted cameras. In addition, the project will assess the use of a demonstrator tool in enabling real-time predictive maintenance and facilitating product-related knowledge and data sharing among different stakeholders.

Industry context

T4 has been working with a number of industrial partners to provide them with the opportunity of identifying rapidly promising data-driven innovations. Several exploratory meetings have been organised to look at potential future synergies on blockchain applications (Swansea, nChain, and Celsa Steel UK) and the use of intelligent robots for automation in the steel industry (WMG and Tata Steel UK).

Planned Impact:

To improve competitiveness of UK steel supply chains in a sustainable and value-adding way

Key findings:

A novel hybrid approach that combines statistical AI and symbolic AI can be proposed to facilitate and automate predictive maintenance in steelmaking

The programmed RDF data generator can be used to generate simulation data regarding steelmaking process

The robotic manipulation task of lifting a long/heavy bar in the air can be made more sample efficient using Hierarchical reinforcement learning, which breaks down task into two sub-tasks; gripping the bar, then lifting it to a target location

Progress to Date

Computer Science

Regarding the real-time predictive maintenance demonstrator, several Stream Reasoning techniques have been studied, C-SWRL and C-SPARQL have been chosen as rule language and query language to perform reasoning; A RDF data generator has been programmed to generate RDF data streams. These RDF data streams are treated as simulation data to be injected into knowledge models for stream reasoning; a high-level Industry 4.0 ontology has been selected as a foundational ontology. This ontology will be specialised into the steelmaking domain.

For the blockchain demonstrator, initiative research ideas have been proposed: blockchain will be used to build a trusted distributed network of stakeholders; Semantic technologies will be used to facilitate the sharing of product information and enhance semantic interoperability.

WMG Data Science

The existing state-of-the art robotic simulator containing one robotic hand to two robotic hands has been extended. Cooperation between two robotic hands to pick and place a bar using stated inputs has been implemented. The implementation of camera input-based learning algorithms for robotic hand manipulation is ongoing.

Supply Chain: MSc projects

2019/2020: Four company-based projects were received, three are complete, one is pending.

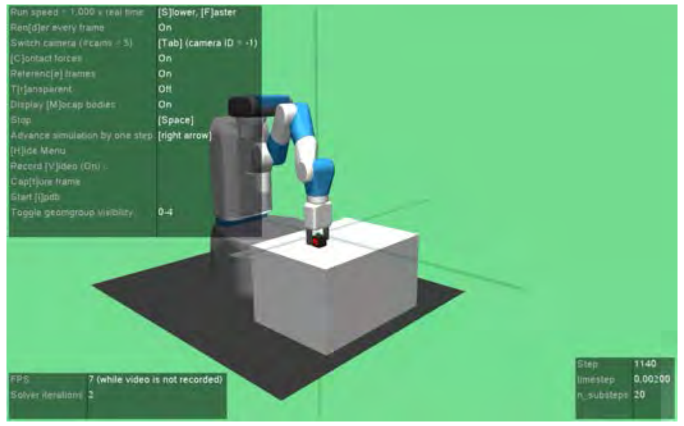
2020/2021: Currently working with Liberty Steel on project 'Evaluation of inventory control management'.

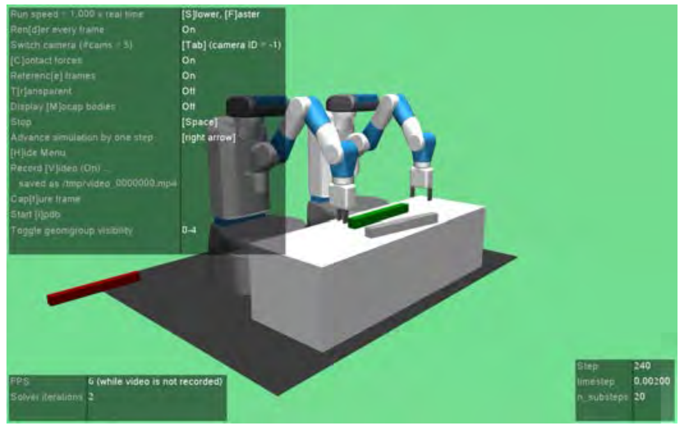
Company case studies

January 2020: Organised a workshop with all industrial partners and agreed to have a 2-stage case study approach:

Stage 1 - Liberty Steel and Forgemasters

Stage 2 - Tata Steel and British Steel



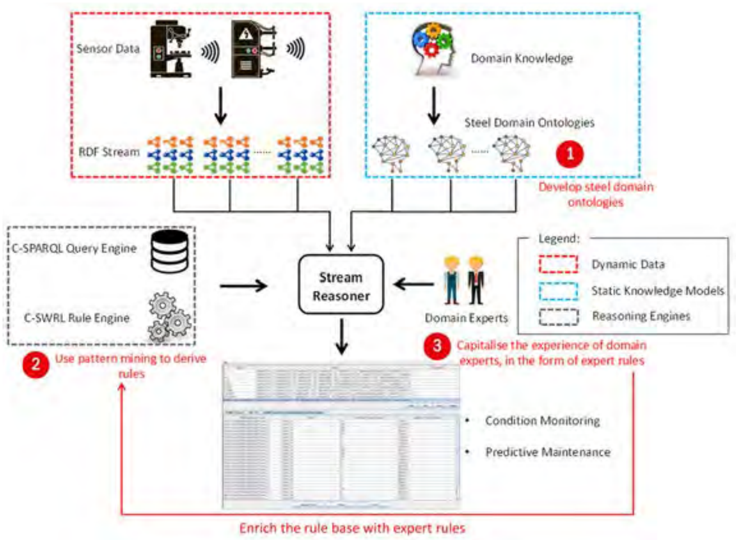


Due to COVID-19, project partners were severely affected with a large number of key staff furloughed. As a contingency, we adapted our approach by re-aligning our existing SC research projects. A joint project between SUSTAIN, Transforming Construction and ESRC Productivity was formed to explore the concept of SC productivity across different sectors. As a result, a large-scale survey was developed. The research output will be made available in the form of industry reports and a peer-reviewed academic journal paper.

October 2020: Re-engaged with Liberty Steel as furlough reduced. The project has been re-scoping and the focus shifted to steel demand from aerospace customers (e.g. Boeing) to the Bolton Air Service Centre and then to the Stocksbridge site. Detailed research design was developed and the approach could be adopted by other steel companies.

Relaunch of SC programme

March 2021: With the current climate, it is quite challenging for all companies to commit to the case studies. To give some flexibility to industrial partners, a new SC programme with three-phase activities was relaunched. The activities include IDT assessments, developing an IDT adoption roadmap, and case-study interventions.



Top left: existing state-of-the-art simulations wherein a single agent picks a object and places it at a target

Bottom left: our simulation where two agents collaborate to push a long bar to target location

Above: A novel architecture for real-time predictive maintenance

Task 5: Intelligent Steelmaking

Start date: October 2020 Expected end date: December 2023

PIs: Dr Richard Thackray, Dr Michael Auinger

Researchers: Dr Aurash Karimi, Dr Uchenna Kesieme

Project partners: University of Sheffield, WMG University of Warwick

Project Abstract

Many existing process models for steel production do not allow for process alignment and are too complex for meaningful real-time predictive use. The primary aim of Task 5 is to take a different view on steel production in its entirety by not seeking to improve product qualities but by focussing on decreasing energy usage and building links over the entire process chain. This will be achieved by development and optimisation of process level models supported by experimental verification, analysis of process data and by benchmarking current process routes to quantitatively assess how efficiently industry currently uses both energy and materials.

Planned Impact:

Delivery of coherent process level model and assessments for fast and efficient optimisation of the process chain with respect to cost, energy flow and material usage

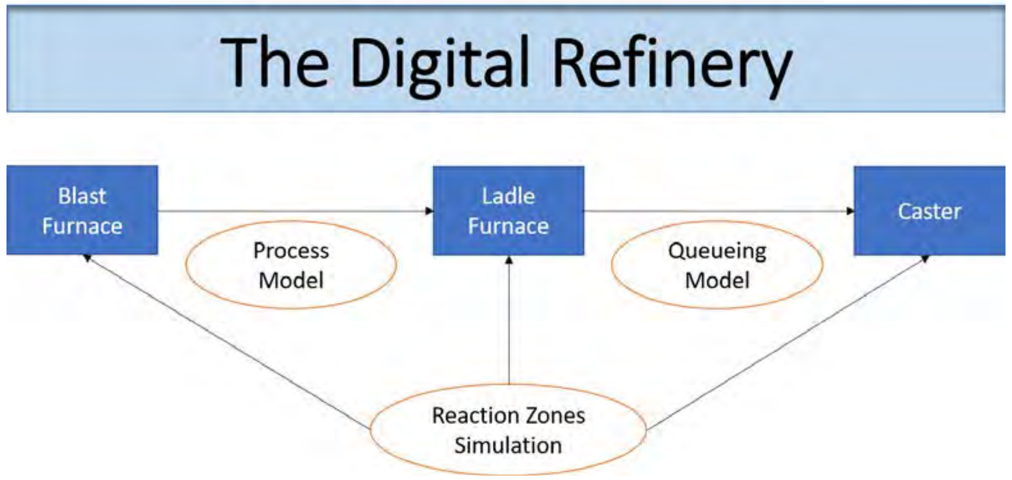
Industry context

The context to industry is to make use of existing (old) programmes and develop new fast modelling routines for fast predictions. Depending on the interest of the industrial partner, this can be relevant for optimising day-to-day process strategies or develop mitigation scenarios for unwanted production stops or equipment breakdown.

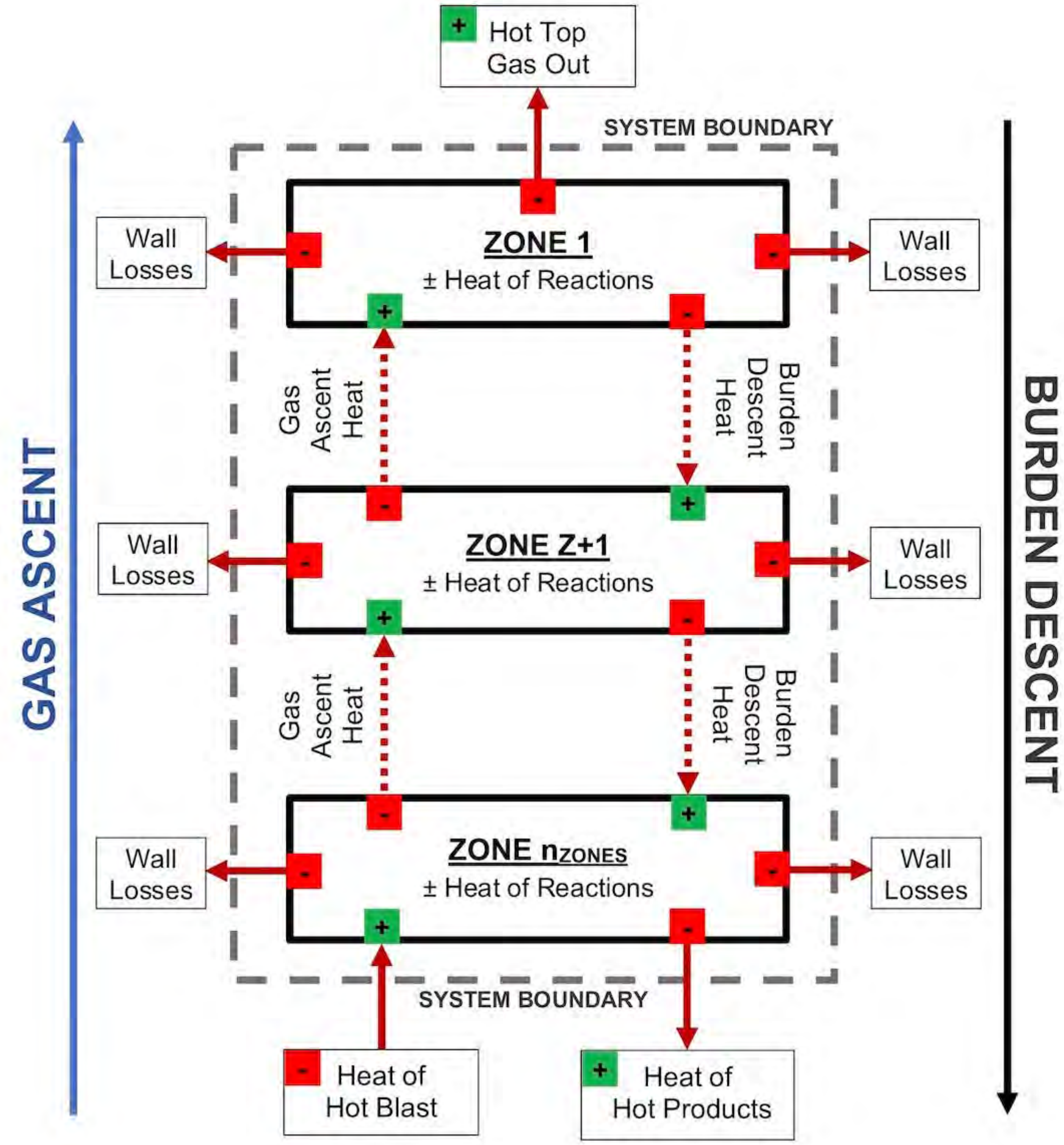
Progress to Date

The PDRAs have been recruited and are in place since late 2020.

The project team is now operational and we have designed and circulated a questionnaire to the SUSTAIN industrial partners to re-evaluate their modelling interests which might have changed, or become more specific during the past year. A literature review for fast process optimisation for ladle metallurgy has been finished and preliminary data from industry for part of the LCA analysis has been shared with the team.



Left: Schematic view of the digital process model, based on the Reaction Zone approach



Above: Schematic reaction zone model for a blast furnace

Key findings:

Inventory of Existing Process and Efficiency Flows

Analytics of Process Data

Optimisation of the Building Blocks

Life Cycle Assessment to Quantify Efficiency Gains

Task 6: Thermal Efficiency

Start date: January 2020 Expected end date: January 2023

PIs: Professor Cameron Pleydell-Pearce, Dr Karen Perkins, Dr Hollie Cockings, Dr Matthew Carnie

Researchers: Dr Matthew Burton, Dr Michael Dowd, Dr Ria Mitchell

PhD students: Geraint Howells

Project partners: Swansea University, British Steel, Celsa Steel UK, Liberty Steel, Sheffield Forgemasters, Tata Steel UK, Vesuvius PLC

Project Abstract

Task 6 aims to develop understanding of technologies that reduce heat loss through improved insulation and maximise waste heat recovery through both thermo-electric generation and heat storage materials. This relies on understanding key materials and associated processes. The project focusses primarily on two main technologies, refractory materials and heat storage and energy generation. Initially the technologies are progressing in parallel with the intention to integrate these highly complementary technologies towards the end of the task. The project is continuously expanding its scope through complementary funding and will soon initiate work in the area of process metrology and control, heat storage and the impact of emissivity on radiative heat transfer.

Key findings:

High resolution multimodal imaging techniques have been developed that provide novel insight into refractory structure

The techniques have helped develop structure – property, and structure – process relationships for refractories in service

Novel castable thermoelectric systems have been created that permit integration with complex geometries

Soon the task will expand to include heat storage materials and systems for steelmaking and heat transfer efficiency in furnace

Industry context

The steel industry is one of the UKs largest emitters of waste heat; a typical steel works emits ~ 20 PJ/yr from cooling water alone. If 25% of that heat was recoverable at 5% efficiency, savings could be £10M/year (based on £0.15/kWh electricity price). Therefore there is commercial and environmental impetus for reducing heat loss and recovering industrial waste heat. In secondary liquid steel processing alone, each 1°C improvement in thermal efficiency saves ~£2m per annum. Further, the temperature of steel through process is the most important parameter to control to produce high quality steel. Improved efficiency will reduce demand on the National Grid and consumption of fossil fuels for power generation, subsequently reducing the CO_2 footprint of steelmaking.

Progress to Date

Key research has focussed on: 1) the development of advanced characterisation approaches for refractory lining materials and 2) the development of thermoelectric materials through a novel 'near-net' manufacturing process. These will be complemented by studies on heat transfer efficiency at metal surfaces and heat storage technologies.

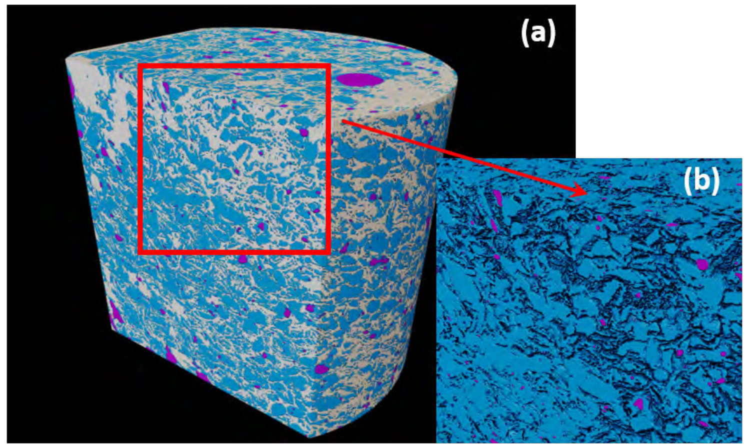
The refractory characterisation has been approached with increasing complexity. First we developed and refined acquisition and segmentation approaches for X-Ray Computed Tomography (XCT) data of carbon bonded refractory structures. The table in figure 1 shows how these have developed to match the product, whilst the images illustrate how we can show structure segmentation. We then developed correlative complementary microscopy techniques to provide a richer information set including a novel optical technique for measuring graphite orientation (figure 2) which has been shown to have an effect on thermal conductivity in other systems [1]. In parallel we have conducted laboratory oxidation experiments which measured the decarbonisation kinetics of the graphite/phenolic based binder that occur during pre-heating and between use cycles. We are in the process of correlating these observations with characterisation methods to understand the structural sensitivities of the kinetics. Towards the end of the task we will look at more complex liquid metal/slag interactions with refractories.

The development of thermoelectric materials builds on previous work within the SPECIFIC® IKC that has developed novel manufacturing techniques for castable 'near-net' materials (figure 3) [2]. Early research focussed on: 1) the development of a tube geometry test bed to test prototype generators in more complex geometries and 2) exploration of earth abundant, non-toxic and cost competitive systems suitable for widespread adoption in the steel industry. The test bed is ready and a number of P and N type material options have been explored. The doping of these systems is being optimised to improve device efficiency. In parallel we are investigating earth abundant half-Heusler compounds. We intend to determine the high temperature stability of the devices and examine the potential to develop self-powered temperature sensors for steelmaking ladles.

The task is now set to expand through complementary funding sources to examine a wider range of potential technologies including heat storage and radiative heat transfer efficiency of metals. The work in this task has been well complemented by the feasibility studies at Durham University and UCL and we are looking to work together to progress our complementary technologies.

Planned Impact:

The project aims to reduce waste heat production through insulation, process control and efficiency and thermal energy harvesting



Component	High Resolution	Low Resolution	Material Composition*
Zirconia	2%	23%	2%
Alumina	48%	37%	54%
Matrix/binder	50%	39%	35%

* Assumes zero porosity (~10-20% in reality)

Fig 1: 3D high resolution X-Ray Computed Tomography data of an Al2O3 – Carbon refractory structure segmented to reveal (a) all constituents and (b) the aggregate structures.

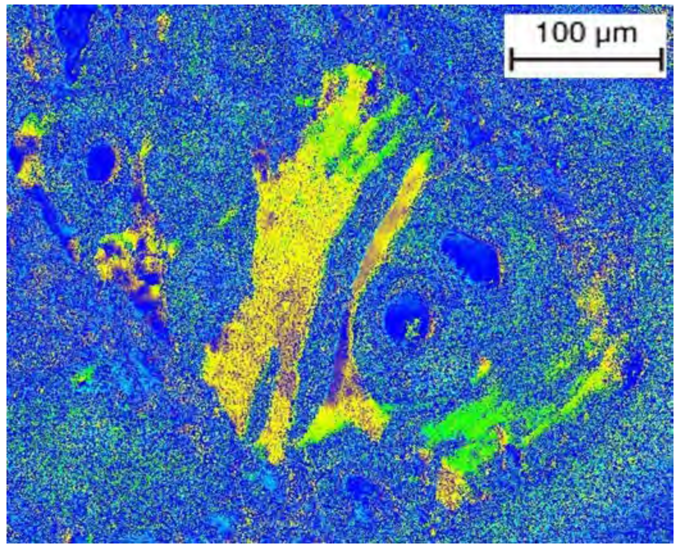


Fig 2: Optical surface measurements that quantitatively determine graphite crystal orientation have been developed.

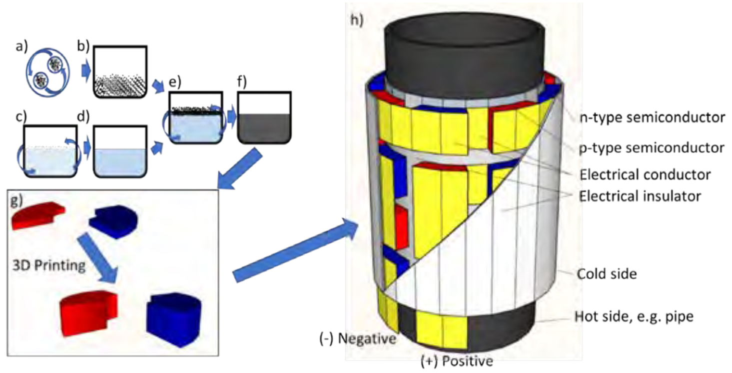


Fig 3: The manufacturing method for cast near net shape thermoelectric devices and schematic of how this can be applied to more complex geometries.

References
[1] Lu. Yang et al. Materials Chemistry and Physics, Volume 257 (2021) 123702
[2] M. Burton et al. Advanced Energy Materials, Volume 9 (2019) Issue 26 1900201

Task 8: Smart Sensors for Real-Time Measurement

Start date: August 2019 Expected end date: August 2022

PI: Professor Claire Davis

Researchers: Dr Frank Zhou

Project partners: WMG University of Warwick, University of Manchester, Primetals Technology Limited, British Steel, Liberty Steel

Project Abstract

Improved monitoring of steel production allows for greater digitilisation and control, leading to more efficient, less energy intensive manufacturing. Improved monitoring of processes is a key part to sustainability, growth and modernisation for the steel industry. Great improvements have been made for real-time monitoring and feedback control but several areas have been highlighted where insufficient information is currently available requiring new and improved sensing approaches. One area is microstructural monitoring during processing and electromagnetic (EM) sensors are ideal candidates. The project is focusing on development of new EM sensors and signal-microstructure relationships for use in steel processing.

Industry context

The production of advanced high strength steel grades is challenging as tight process parameter control is required to achieve the complex microstructures and real-time feedback is desired. Commercial sensor systems are available for cold strip steel monitoring, where sensor signals are correlated to mechanical properties. Currently the only commercial system for hot strip steel microstructural monitoring is the EMspec system, produced by Primetals Technology Limited using University of Manchester licensed technology, with relationships between microstructure, magnetic parameters and sensor signal developed at WMG. There is a need to extend knowledge and application to non-strip steel geometries and grades.

Key findings:

A four EM sensor head array system has been designed and built and is sensitive to changes in steel microstructure

A COMSOL FE model for the sensor array has been developed allowing sensitivity of sensor signal to microstructure and sample geometry to be determined

In-situ high temperature laboratory EM sensor measurements for annealing of rod samples has shown that pearlite spheroidisation and recrystallisation behaviour can be continuously monitored

Progress to Date

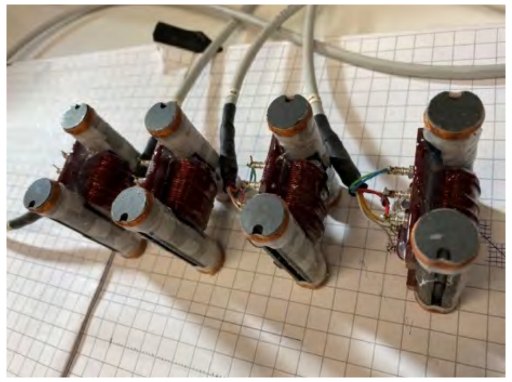
The new EM sensor array concept has been modelled and optimised design determined (sensor head size/number/spacing). The design was carried out in collaboration with long term partners at the University of Manchester (feedback and discussions with Professor Tony Peyton). Consideration of the potential industrial applications (narrow strip mill at Liberty Steel and wire/rod mill at British Steel) and laboratory demonstration run out table was taken into account for geometry constraints. The final sensor array design was passed to Dr Stephen Dickinson (Organised Technology Limited) for construction (funded within a High Value Manufacturing Catapult project to upgrade the WMG furnace-roller table containing an EMspec system). The sensor array has been completed and experimental tests carried out for sensitivity to different steel samples and calibration of the developed COMSOL FE model. A canister design has also been finalised by Dr Russ Hall, with input from Primetals Technology Limited and Dr Frank Zhou and is under construction. Once complete the array will be installed in the furnace-roller table and trials will commence.

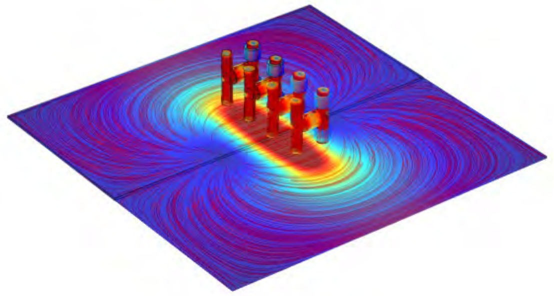
High temperature annealing of two rod grades, provided by British Steel, in a laboratory high temperature EM sensor have been performed to support development of microstructure – magnetic signal relationships. The results show the microstructure changes can be monitored by the EM signal and modelling is being carried out to determine the low magnetic field permeability changes. Further tests will be carried out on a different steel grade (from Liberty Steel). Consideration, with University of Manchester, will then be needed on how to move from a non-deployable laboratory sensor to a sensor design suitable for use in an industrial furnace. High temperature magnetic property measurements for full BH behaviour are also being pursued in collaboration with the University of Manchester via laboratory testing of a high temperature Epstein frame they have developed.

Planned Impact:

EM sensor arrays for real-time in-situ monitoring, characterisation and control of steel microstructures during steel processing for a range of grades and applications

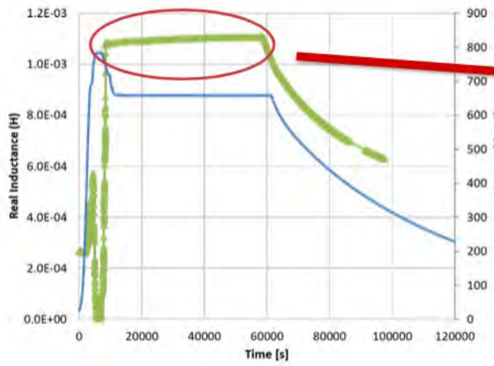
Right: Sensor heads for the sensor array and COMSOL model. The model was used to optimise the sensor array design (sensor head size and spacing)

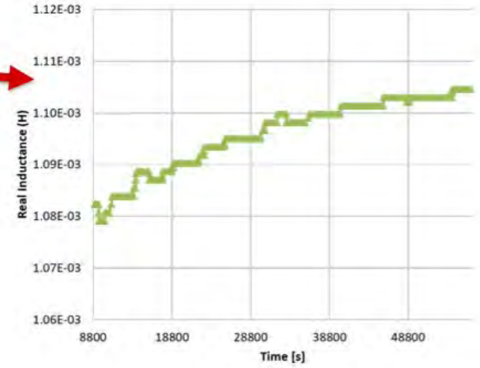


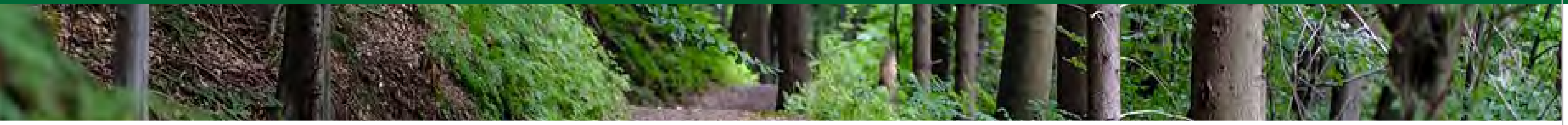


Left: High temperature laboratory EM sensors (showing sensor coils, left, and after high temperature potting, right)

Right: EM sensor signal (green) and temperature (blue) with time for in-situ EM tests showing the change in EM signal which is related to spheroidisation of pearlite







Task 9: Late Stage Product Definition and Integration

Start date: October 2020 Expected end date: October 2023

PIs: Professor Mark Rainforth, Professor Eric Palmiere, Dr Martin Strangwood

Researchers: Dr Peng Gong

Project partners: University of Sheffield, WMG University of Warwick, Liberty Steel, British Steel, Tata Steel UK

Project Abstract

Efficiency in steel production requires relatively minimal changes in the upstream procedures with product differentiation occurring during the latter stages of processing. The austenite transformation to various transformation products is probably the single most important factor in determining the final properties of most steels. The role of local segregation is also critical in the transformation and subsequent heat treatment. The ability to exert greater control over the transformation gives the ability to have greater control of the transformation product and subsequent final properties of the steel. This applies across all steel types, whether long products, strip or sections.

Industry context

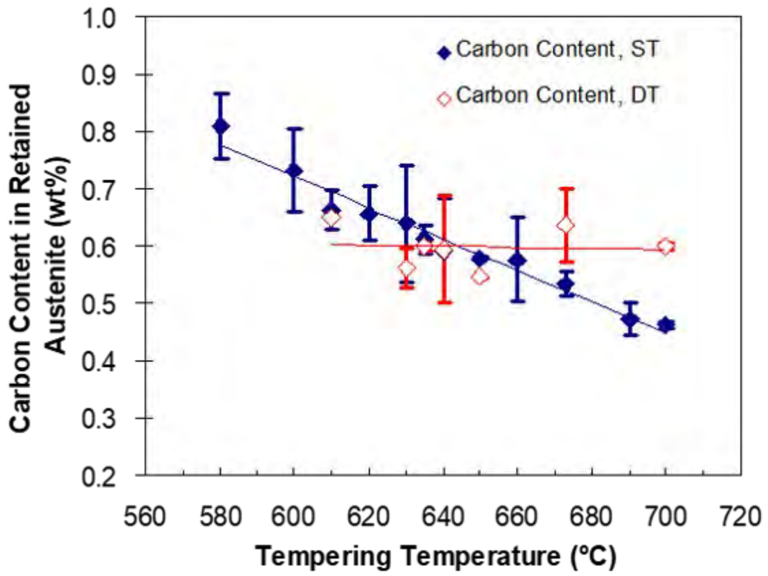
Efficiency in steel production requires minimal changes in the upstream procedures (i.e. steelmaking) with product differentiation occurring during the latter stages of processing. Efficiency in product use requires design of high-quality steels with appropriate mechanical properties and life-time durability. This activity considers both of these aspects, focusing on different steel grades and product portfolios but utilising the strength of UK metallurgical research to provide new products and processes to position the industry at the forefront of development. This project has generic applicability across all the steel manufacturers in SUSTAIN.

Key findings:

The carbon content in reverted austenite is a linear function of the tempering temperature

A subsequent second temper results in redistribution of both carbon and nickel

The second temper results in austenite that is much more resistant to strain induced transformation, as a result of solute redistribution



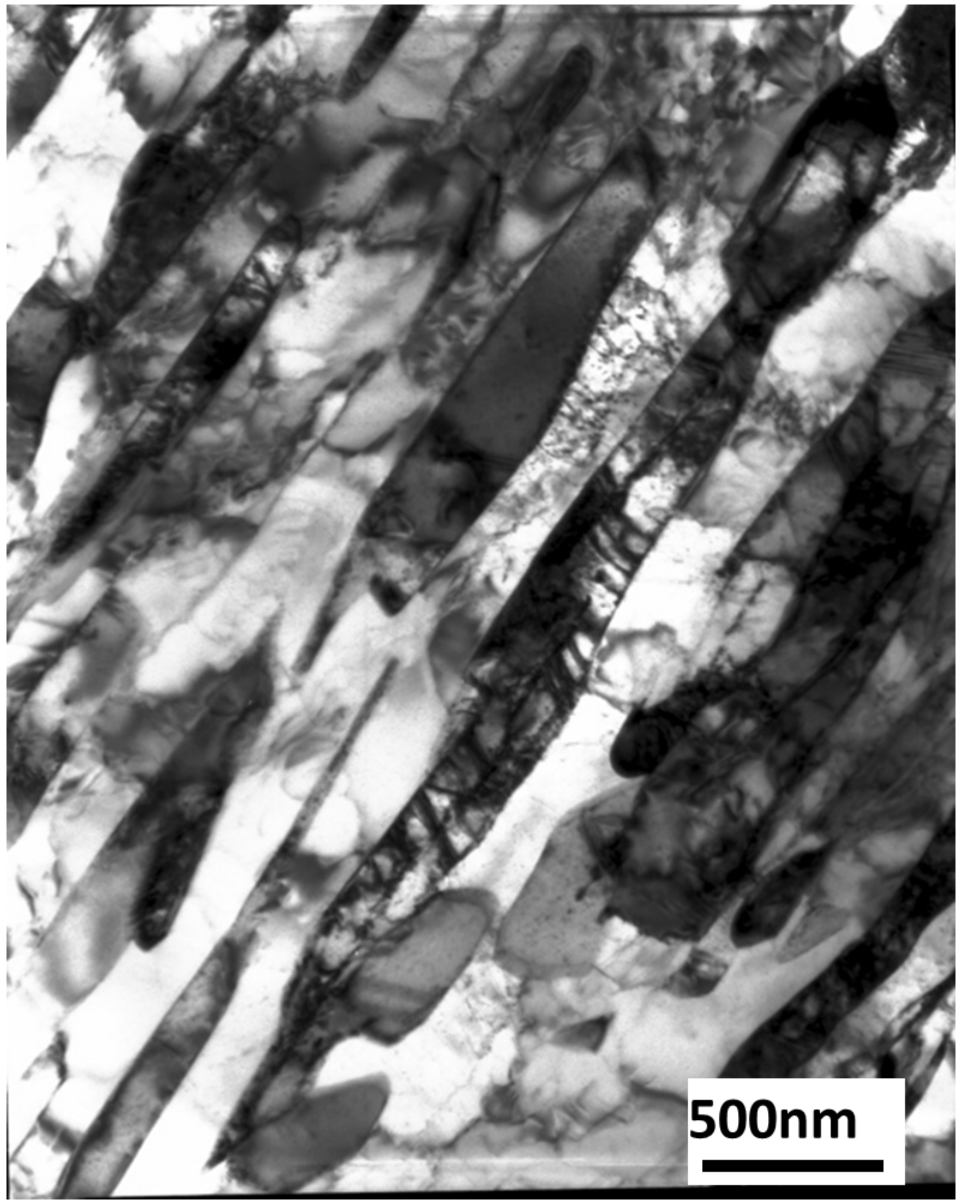
Above: Carbon content in reverted austenite for single and double tempered samples

Progress to Date

A critical review has been undertaken on the control of Sv (austenite interfacial area per unit volume) through thermomechanical processing for the selected steel grades. Through experimental analysis of the cast to cast, and in-cast variations in composition of the Super 13Cr steel, a range of steel compositions have been determined that will allow the effect of a) high Mn content (with otherwise target composition), b) high Ni content (with otherwise target composition) and c) both high Mn and high Ni. These casts are being produced in-house. A thermomechanical process route has been devised that will allow systematic changes in the austenite interfacial area per unit volume. The transformation behaviour will therefore be studied as a function of Sv. This will allow a separation of the effects of composition from thermomechanical process conditions.

The PhD position has been advertised but has not received any eligible applications yet. The reports of effects of pre-conditioning on austenite stability, thermodynamics and kinetics are being reviewed.

Right: TEM image showing reverted austenite in a tempered martensite matrix in a Super 13Cr steel.



Planned Impact:

The research will lead to adjustments in the hot rolling and heat treatment schedules to improve properties and deliver a more consistent product

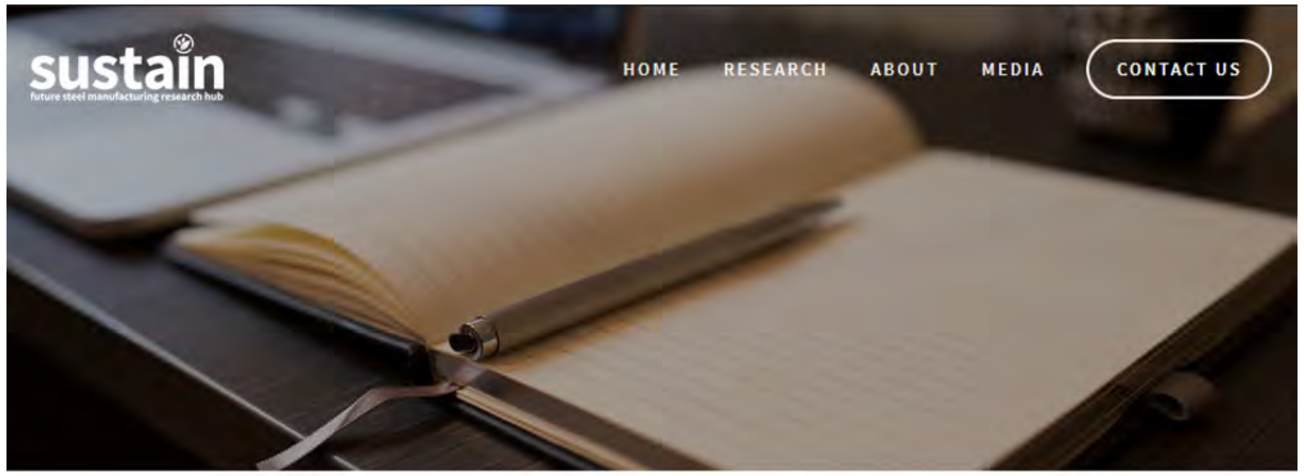
Feasibility Studies

In Summer 2020, the Hub launched its First Call for Feasibility Studies, initially offering funding for three feasibility studies to conduct novel research which aligned with the Hub's two Grand Challenges: Carbon Neutral Iron and Steelmaking and Smart Steel Processing. Research proposals had to be aligned to and complement the current research programme.

This Call was designed to attract new partners to the project which may have potential to lead to further collaborations and future funding bids and is our primary mechanism to introduce new academic collaborators and develop additional research spokes.

This first call was open to UK academics eligible to receive EPSRC funding, for a maximum duration of six months, and a maximum value of £50,000 (80% FEC). Three new Tasks (10 - 12) were funded in this round.

Due to restrictions, the entire call was conducted virtually, using Webinars and a Virtual Sandpit session held via Zoom meetings and Meeting Mojo (thanks to KTN for arranging the use of this platform). The Hub was pleased with the level of engagement received from the community in this new virtual environment - from the submitted applications to everyone who gave their time to support this activity, the response was impressive and encouraging.



SUSTAIN First Call for Feasibility Studies

The SUSTAIN Future Steel Manufacturing Hub is initially offering funding for three feasibility studies to conduct novel research which aligns with the Hub's two Grand Challenges: *Carbon Neutral Iron and Steelmaking* and *Smart Steel Processing*.

The SUSTAIN Future Steel Manufacturing Research Hub is looking for research projects are aligned to and compliments our current research program. We would like to attract new partners to the project with this call for applications and have potential to lead to further collaborations and future funding bids.

This first call is open to UK academics eligible to receive EPSRC funding and is our primary mechanism to introduce new

Task 10: Drop-tube Furnace to Investigate Novel Reductants for the Decarbonisation of Ironmaking

Start date: December 2020 Expected end date: May 2021
PI: Dr Julian Steer
Project partners: Cardiff University, Tata Steel UK

Project Abstract

Blast furnace Ironmaking utilises coal injection alongside coke in the process, and this project investigates the technical feasibility of using alternative reductants as a substitute for carbon units. The project investigates the opportunities and issues surrounding the use of an alternative commercial reductant called Subcoal™. This material is a mixture of paper and plastics produced from residential waste which is non-recyclable and would otherwise be landfilled. Due to its higher hydrogen content, it has the potential to reduce CO_2 emissions associated with the process by substituting some of the mined coal and utilising biomass derived paper/cardboard material.

Progress to Date

Incorporating a new reductant into a blast furnace could lead to process stability issues with serious consequences on the production of Iron. So far, work has concentrated on investigating the incorporation of paper/plastics in the form of the commercial Subcoal™ product, blended with typical coals used for blast furnace injection. Over 60 samples have been tested in a drop tube furnace, to mimic, as closely as possible, the raceway region characterised by short residence times and high heating rates.

A range of blend compositions have been tested at different residence times to establish how they compare to the standard coals and the partially burnt residues will also be tested, to compare the char gasification reactivity. A kinetics study has been run to understand and compare its behaviour in combustion, gasification and pyrolysis conditions; this has been carried out to help establish conditions for evaluation in a fluidised bed gasifier.

Industry context

After discussion with Tata Steel UK, it was raised that sample composition variability, due to the very mixed nature of this material, would be an important variable to measure. It was also stressed that the project output needs to be in a format that production can relate too, so standard proximate analysis tests will be used alongside other academic output. As a result, samples of separate delivery batches of Subcoal™ have been obtained from N&P recycling. These have been incorporated in the test plan and are in the process of being evaluated.

Key findings:

Comparable sample burnouts have been measured in some Subcoal™/injection coal blends

Subcoal™ blends have similar carbon contents to typical injection blends

Initial work suggests comparable performance of different Subcoal™ deliveries

Pyrolysis of Subcoal™ blends results in higher hydrogen and methane contents in the decomposition gas mixture

Top: Paper and plastic collection and processing

Bottom: Subcoal™ in pellet form after processing

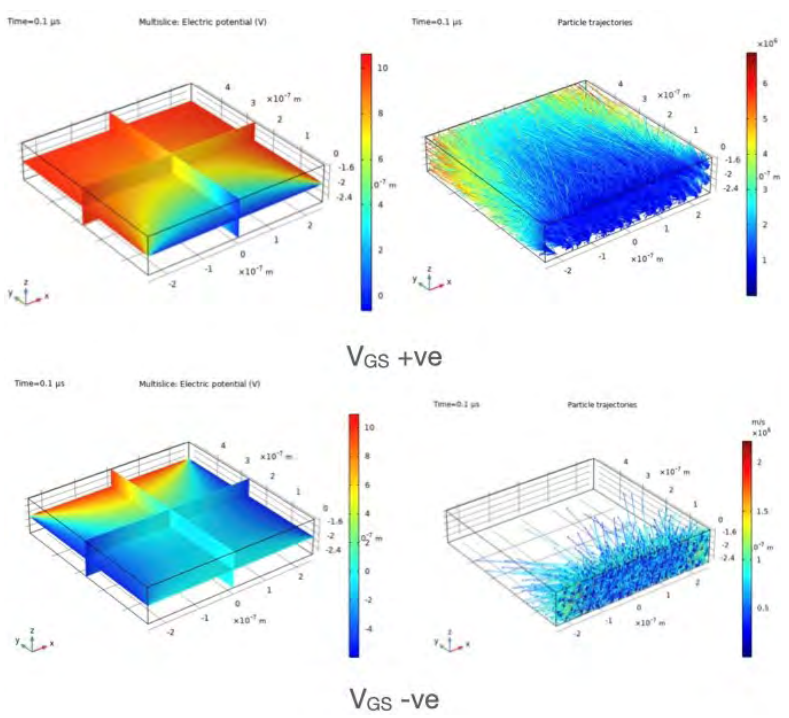
Task 11: Ultra-High Temperature Reliable Electronics Development (UHTRED)

Start date: September 2020 Expected end date: February 2021
PIs: Dr Alton Horsfall and Dr Andrew Gallant
PhD students: Jonathan Hammler
Project partners: Durham University

Project Abstract

In the steel industry, operating temperatures above 400°C are commonplace and monitoring materials and systems in these conditions is essential. However, semiconductor-based transistors are unsuitable for use in extreme temperature environments.

This study will explore the use of materials, designs and circuit models based around microscale vacuum channel transistors. The target is to produce device and circuit designs which are capable of operating over a wide temperature range, from 25 to 1000°C.



Progress to Date

Identification of suitable materials for the manufacture of the transistors has been completed. The current intention is to utilise Ir on HfO_2, however close-coupled multi-physics simulations are being utilised to fully optimise the work function offsets and the effect on the transistor characteristics.

Simulations of the initial lateral channel structure has confirmed the operation of the transistor under the required operating conditions. A revised structure to mitigate the issues of gate control in the channel has been devised and are being incorporated in to the model.

Initial steps towards design toolkit for circuit development now completed and further optimisation based on the simulation data is underway.

Key findings:

Viable, manufacturable structure identified

Transistor characteristics under a range of suitable operational conditions

First logic primitive circuits simulated

Task 12: Techno-economic Feasibility of Net-Zero Emission Solutions for Metal Heating (THERMOS)

Start date: November 2020 Expected end date: October 2021
PI: Dr Yukun Hu
RA's: Xiaoyuan Cheng and Xiyao Sun
Project partners: University College London, Warwick Manufacturing Group, Air Products and SWERIM

Project Abstract

This study will focus on the metal heating process and the proposed sustainable net-zero emission solutions, which involve hydrogen and ammonia gas. The project will investigate if the UK could introduce carbon-free heating for furnaces at all its rolling mills.

The project will analyse combustion behaviour and scale formation using computational fluid dynamics and reaction kinetics models. A furnace 'digital twin' will be used to demonstrate the proposed net-zero emission solutions. The work will provide new insights into the transition pathway of reheating furnaces that might be systemic weaknesses in a green steel economy.

Industry context

The metal heating facility, such as a reheating furnace, is an indispensable thermal facility in steel production. The energy consumption of heating still accounts for about two thirds of the rolling process and about 20% of the energy consumption of steel production, which directly affects the production cost and energy consumption of the steel industry. Today's best practice values for heating a tonne of steel to temperature for rolling or forging is still above 1.0 GJ/tonne. If no disruptive innovation to the existing heating process is put in place, steelmakers will likely struggle to achieve further reduction in energy consumption and CO_2 emission.

Progress to Date

WP1: Combustion behaviour under different environments has been investigated based on the burner designed provided by AirProducts.

WP2: A mixed gas emissivity model has been developed which can be incorporated into the integrated furnace model to calculate mixed gas emissivity in real-time.

WP3: A scale formation model is being developed using neural-network algorithms, with training and test data obtained from literature of steel scale formation.

WP4: Time needed to incorporate the results and models developed in WPs 1-3, as a digital-twin of the pilot-scale furnace provided by Swerim to investigate the technical feasibility of the proposed heating solutions.

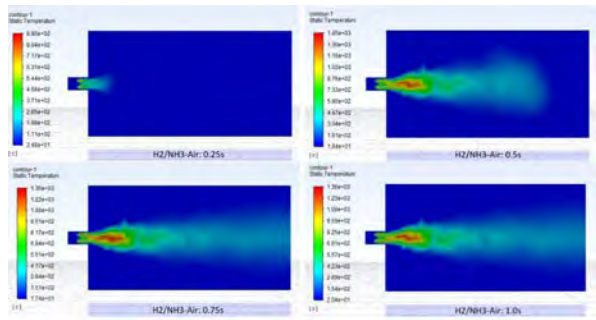
Key findings:

Pure NH_3 is hard to ignite in air, but H_2 and NH_3 mixture can ignite and combust stably with 1% H_2

The flame temperature of H_2 and NH_3 mix combustion increases with H_2 fraction

Even in the absence of a suitable catalyst, due to moderate temperature, the reaction of NH_3, H_2 and air mainly produces N_2 and H_2O

Both H_2O and O_2 promote scale formation at high temperatures (>700°C), and the excess O_2 should be reduced as much as possible in the oxyhydrogen combustion environment

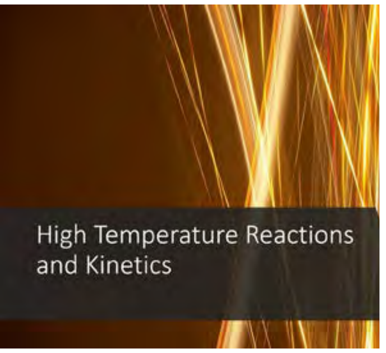


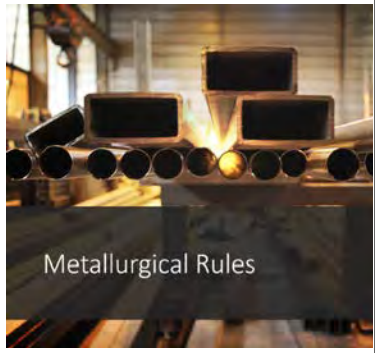
Above: Transient temperature contours of H_2/NH_3 mixture firing with air

Early Career Researcher Platform Call

In Autumn/Winter 2020 the Hub launched its first Early Career Researcher (ECR) Platform Call, with a call for proposals to conduct novel research which aligns with the Hub's two Grand Challenges: Carbon Neutral Iron and Steelmaking and Smart Steel Processing.

The call was open to ECRs based in existing SUSTAIN Hub and Spoke institutions (Swansea University, University of Sheffield and University of Warwick), designed to provide ECRs with an opportunity to apply for EPSRC funding as part of this Hub. Research proposals aligned to and complementing the current research programme were encouraged, especially (but not limited to) the following areas:





Microstructure and magnetic properties relationship at high temperature

Start date: May 2021 Expected end date: May 2022
PI: Dr Lei (Frank) Zhou
Project partners: WMG University of Warwick, University of Manchester, Primetals Technologies Limited, Tata Steel UK, British Steel

Electromagnetic (EM) sensors have shown enormous potential in non-destructive characterisation of steel microstructure both offline and on-line during processing. EM systems are routinely deployed on-line in cold structural strip steel mills providing information on strength levels, and more recently the EMSpec™ system has emerged for transformation monitoring on-line during hot steel processing. The development of EM sensors for high-temperature on-line measurement drives the need for better fundamental understanding of the interrelationship between temperature, microstructure parameters and magnetic properties in steels.

The project aims to study how multiple microstructure parameters affect the magnetic properties of steels with varying field strength at elevated temperature (in the range between room temperature and 770°C). The magnetic properties of steels will be measured inside a furnace using high temperature Epstein frame setup. The fundamentals of how temperature and microstructure parameters affect the magnetic energy terms and hence the domain structures will be studied. The outcome of this research project will enable better predictive capability for the magnetic properties of steel with different microstructures at high temperature which will make a significant impact on future intelligent on-line processing control applications.

Sustainable Investment Assurance Model: SIAM

Start date: April 2021 Expected end date: November 2021
PI: Dr Stephen Spooner
Project partners: Swansea University, Celsa Steel UK, GB Recycling, BEIS

Sustainability is the theme of our generation. A plethora of research, business activity and policy intervention is aimed at tacking the take-make-waste society the linear economy has built. These initiatives have great intentions to reduce an activities effect on climate impact, generate stable economics and support communities. However, an individual aspect tends to take precedent of activity drive.

The SIAM project intends to build a foundation industry approach to joining the wider aspects of sustainability together in a quantifiable relatable way. Much the same as how nutrition is displayed on groceries, SIAM aims to generate values on consumer products quantifying environmental, fiscal, competition, community and education contributions of a given product or project. This will be achieved through extensive understanding of LCA impacts and symbiotic supply chain and activities – for example steel production reduces the CO_2 emissions of the cement industry through slag-based lime substitution, which should and must be recognised formally. Once consumer relatability is achieved a precedent for inclusion in industrial and government decision making will naturally follow.

The project will begin by building an initial framework against measurable pillars of sustainability through interaction with national experts in the relevant fields and literature support, followed by three case studies of varied application:

1. International, national, and circular manufacturing of reinforcing steel bar
2. Cold steelmaking – a pathway to responsible competitive UK steel manufacturing
3. Sustainability measured project management – quantifying progress as a tool for improvement

Process design of new reduced activation ferrite martensite (RAFM) steels for nuclear fusion reactors

Start date: May 2021 Expected end date: April 2022
PI: Dr Peng Gong
Project partners: University of Sheffield, University of Birmingham

Reduced activation ferritic/martensitic (RAFM) steels are considered promising candidates for the first wall and blanket of the fusion reactors. Until now, the challenge for the operation of RAFM steels is the short service life in these extreme service conditions. A new type of RAFM steel has been developed in this study with significant refinement of the grain size and high temperature stable intermetallic precipitation. The dynamic recrystallisation and the strain-induced ferrite have been developed through the designed hot rolling process to improve the mechanical properties. Intermetallic precipitates, stable at high temperature, were introduced on the grain boundaries to improve the stability during service in the temperature to even 650°C.

During processing, dynamic recrystallisation has been achieved along with strain induced precipitation on the grain boundaries. Compared with the current RAFM steels, during ageing at 650°C for 48h after hot rolling, the grains in the new designed RAFM steels have no significant coarsening, with the grain size a factor of one times smaller. The next step of the project will determine the conditions in which strain-induced ferrite is formed continuously.

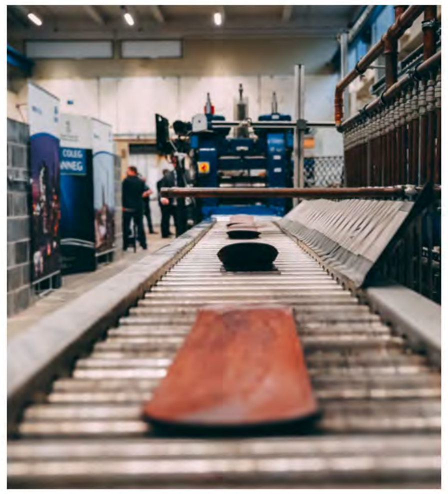
Facilities

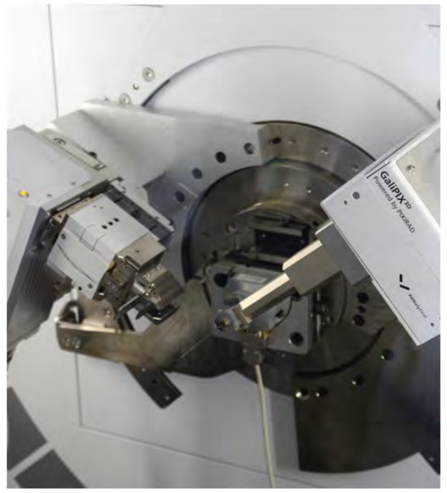
Across SUSTAIN's Hub and Spoke institutions, there is a wide variety of facilities for alloy development and production, thermomechanical processing and characterisation. These include:

Swansea University
Steel and Metals Institute (SaMI)
Advanced Imaging of Materials (AIM)
SPECIFIC® IKC Lab facilities

University of Sheffield
Royce@Sheffield

Warwick Manufacturing Group, University of Warwick
Advanced Materials and Manufacturing Centre (AMMC)
Advanced Steel Research Centre (ASRC)



Steel and Metals Institute (SaMI) Swansea University

Swansea University Prifysgol Abertawe | Steel and Metals Institute Sefydliad Dur a Metelau

Creating a 21st Century Steel and Metals Industry

The Steel and Metals Institute (SaMI) at Swansea University supports the steel and metals industry in the challenge to decarbonise through next generation low carbon products, reduced carbon emissions, and creation of a circular economy. SaMI is an open access facility where research partnerships are focused on collaborative working, bringing together an extensive network of academic specialists and industrial innovators to deliver practical innovative solutions for the steel and metals industry.

Research Capabilities

Our adaptable environment enables the design and implementation of bespoke research specialising in:

Industrial decarbonisation and circular economy utilising our highly specialised facility that enables process simulations and testing under service representative conditions where extreme environments are required

Developing next generation steel and metal low carbon products through pilot scale simulation equipment for alloy development

A wide range of mechanical testing and materials characterisation techniques to support the research of the Institute and provide a service to the industry

Above: Vacuum induction melt (VIM) for alloy development up to 50kg

Left: Swansea University PhD researcher Fawaz Ojobowale using the ultra-fast pyrolysis gas chromatography–mass spectrometer (GC-MS)

SaMI's expert team of researchers work closely with industry to determine how best to support their research and innovation. For more information please contact:

www.samiswansea.co.uk
enquiries.sami@swansea.ac.uk

The open access Steel and Metals Institute (SaMI) was founded at Swansea University with Welsh Government funding

Alloy Research and Design Capabilities Royce@Sheffield

The University of Sheffield and the Henry Royce Institute house world-class alloy research and development expertise and unique equipment. Their facilities offer development capabilities relevant for all metals, with alloy processing from grams to tens of kilograms, alongside a suite of advanced characterisation techniques allowing for a full-service approach to alloy design and research for academia and industry. Funding opportunities are available to support access for target groups.

Alloy Development

Cold Crucible Arc Melting Furnace and Casting Module
Used for research and prototype production, it offers the ability to melt, cast and rapidly solidify metal alloys of nominal 200g mass using a clean, ceramic free cold crucible process, at temperatures exceeding 3,000°C.

Vacuum Induction Melting Furnace
Used to meet the requirements of alloys which are often used in very demanding applications. There are two furnaces for small-scale development, up-scaling and research.

Strip Caster
This melt spinner casts a thin ribbon of rapidly quenched amorphous material in 100g batches. It uses induction melting in an inert atmosphere and a water-cooled, variable speed copper wheel to quench the metal and generate the ribbon.

Whether researching and designing alloys for traditional processing methods or for newer techniques such as additive manufacturing, Royce@Sheffield has a variety of equipment ideal for developing alloys, taking them through laboratory scale experimental simulations of industrial thermomechanical processing, and for characterising the new alloys developed.

Email Royce@Sheffield.ac.uk to discuss access.

Characterisation

X-Ray Diffractometer
This new in-situ multi-functional XRD system allows the study of advanced materials under in-service and extreme conditions.

Transmission Electron Microscope
The TEM provides high sensitivity materials analysis.

Hyperprobe Electron Probe Microanalyser
This EPMA uses an electron beam as the excitation source, is equipped with up to 5 channels of WDS, and is capable of elemental analysis of micro areas with a high energy resolution.

Field Emission Scanning Electron Microscope
This SEM is suitable for observing fine structures on the surface of a specimen. It is equipped with a Schottky electron gun and incorporates a wealth of the latest technologies for high-resolution image acquisition with bias voltage applied to the specimen.

Thermomechanical Processing

Reversing Hot Rolling Mill
Designed specifically for this facility to roll steels, titanium and nickel-based alloys from a maximum starting thickness of 80mm to a finished thickness of 3mm at up to 1300°C and includes a detachable run-out cooling table capable of accelerated cooling conditions.

Thermomechanical Compression
This machine was designed and built to simulate a wide range of industrial metalworking processes and is essential in the understanding of the influence of processing on both microstructure and properties.

Advanced Materials Manufacturing Centre (AMMC), WMG, University of Warwick

Through Process Development:

The Centre supports full through process development of new and novel products, starting from trained computational simulation of both thermodynamic and process topologies of a given alloy design. The theoretical investigation can then be reinforced from our industrially benchmarked rapid through-put suite which includes **1g to 10kg vacuum alloy melting**, followed by casting, thermomechanical processing and finally surface treatments including PVD. Once test samples have been produced, we can interrogate a range of product performance attributes including environmental conditioning and mechanical testing in a range of environments and temperatures. Key equipment includes: **Arc and induction melting, hot and cold laboratory rolling mill, PVD coater and ETMT Themo-mechanical tester.**

High Temperature Reactions and Kinetics:

This programme makes use of bespoke high temperature furnaces, including the ability to replicate ironmaking/steelmaking gaseous environments while maintains addition and sampling of a system. Coupled with bulk laboratory experiments the team makes use of in-situ measurements techniques including our **High-temperature Confocal Scanning Laser Microscope (HT-CSLM)**, which allows micro visualisation of samples undergoing compression/tension and liquid interaction/phenomena up to 1,800°C. To understand how material may behave at high temperatures further we also have **DSC/TGA** capable of up to 1550°C and high temperature viscometry. These facilities have been applied to investigations including raw material interrogation, simulation of novel ironmaking, direct reaction rate measurements and oxidation/carburisation.

Flagship Equipment

- Gleeble HDS-V40
- Confocal Scanning Laser Microscope
- Vacuum Induction Melter
- Hot and cold rolling

AMMC Website

Correlative Characterisation

The Centre houses a powerful suite of **electron microscopy** equipment. When combined with the co-location of the high power spoke of the national X-ray facility, which houses the first **micro focused 750kv X-ray computed tomography scanner** amongst other technologies, we can conduct highly specific correlative studies. An example would be capturing 3D internal of porosity and inclusion fraction of thin slab cross sections, which can be selectively located under **SEM** for composition and texture mapping, before moving on the further selected **TEM** to uncover aspects such as porosity ledging and complex inclusion structures.

Events and Outreach

Events Organised by the Hub

SUSTAIN 19/20 Annual Review meeting

On the 5th and 6th May 2020, the Hub was due to host its first annual review meeting at Swansea University's Bay Campus. Due to the current global situation, the team arranged for the event to go ahead using the Zoom platform, to catch up with Task progress, convene the newly formed Strategic Advisory Board and update the Operational Committee on progress and develop plans going forward. There were over 50 attendees to the task updates, with 8 different presenters covering a plethora of topics, addressing all stages of the steel manufacturing process across the various plant technologies utilised in the UK sector.

SUSTAIN First Call for Feasibility Studies

In Summer 2020, the Hub launched its First Call for Feasibility Studies, conducted through Webinars and interactive virtual sandpit sessions.

Scrap Workshop

In August 2020 the Hub organised a hybrid workshop where we were delighted to host experts from the scrap industry to facilitate initial internal discussions around the state of scrap in the UK, and how we can make the most from this important resource in the future.

SUSTAIN Early Career Researcher Platform Call

In Autumn/Winter 2020 the Hub launched its first Early Career Researcher (ECR) Platform Call.

SUSTAIN Inreach Seminar series

In March 2021 the Hub launched an internal seminar series, to give PDRA's and PhD students the opportunity to present their work and develop a greater understanding of the scope of the Hub and identify where collaborations between existing tasks can be developed.

Events Contributed to by the Hub

Bessemer Masterclass and Workshops

The Sir Henry Bessemer Lecture was held virtually for first time in 2020 allowing for more than 500 to tune in to see Professor Dave Worsley present his lecture. Due to the uptake in attendance and international exposure, the Iron and Steel Board are considering holding all such events virtually in the future. The Bessemer Laureate also presents a Masterclass to invited young engineers from the steel industry. This year there were 50 attendees and a variety of speakers hand picked to talk about the steel industry from the materials supply chain through to application by SMEs in construction and transportation.

IOM3 Steel Strategy Seminars

On 27th October and 24th November 2020, the Institute of Materials, Minerals and Mining (IOM3) hosted two steel strategy seminars sponsored by the SUSTAIN Hub. The focus of these seminars was Industry 4.0, and brought together industrial and academic specialists to present on and discuss the progress and challenges the UK Steel Industry faces here.

Submission of Evidence to the 2070 UK commission: Teesside Taskforce

Does Teesside have a place for Steel? Does Steel have a place for Teesside?

ACT Steel technical working group

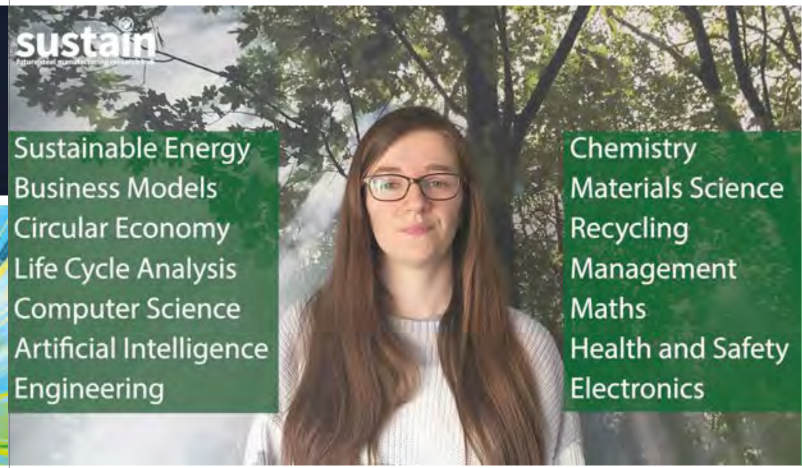
Road mapping carbon emissions

Durham Energy Institute Joint Conference with North of England Institute of Mining and Mechanical Engineers

The Transition to Net-Zero in the North of England - on panel of 'Clean Energy and Manufacturing Solutions' discussing 'Net-Zero Carbon Steelmaking'

Online Engagement

SUSTAIN's project website (www.sustainsteel.ac.uk) continues to be developed and updated to feature up-to-date research, events and staff profiles. Over the last 12 months the website has received more than 12,000 page views from 3,500 unique visitors. Our project newsletter, as well as the LinkedIn and Twitter profiles have gained subscribers and followers throughout the year, and continue to provide a great platform for interactions with those both internal and external to the Hub.



Community Outreach and Engagement

Outreach for school and community groups has continued online where possible. Becky, SUSTAIN's Outreach Officer has been involved with the organisation of live microscopy sessions for Swansea and Cardiff Science Festivals, as well as recording videos for Swansea Science Festival, virtual school careers fairs, Get up to Speed with STEM virtual event, British Science Week at Techniquest and STEM Ambassadors. She is also involved with the Discover Materials working group, a national outreach programme involving academics and outreach officers from most of the Universities in the UK which offer Materials Science and Engineering degrees. Over the last year Becky has helped organise and deliver two digital events (Discover Materials this Winter and Discover Materials during British Science Week 2021) to introduce, and inspire school children to study Materials Science and Engineering.

Task Engagement Highlights

T1: RSC Materials Chemistry Division's discussion forum on "Materials chemistry for carbon capture, utilisation and storage - improving economic viability"

T2: Webinar presentation to South Wales Materials Association, 16.03.21 "It's not easy being green!" Prof. Peter Holliman

T3: SUSTAIN Scrap Workshop presentation, 26.08.20 "Research leading to increased scrap utilisation in UK steel industry" Dr Zushu Li

T4: Joint webinar with Liberty Steel for the Future Steel Forum, 11.06.20

T6: TATA Steel and Vesuvius Refractories, "Novel Approaches to Low conductivity linings"

T8: Presentation at the on-line EM sensors research review meeting for projects between WMG and Manchester University

T9: The Engineer, 25.02.21 "New steel manufacturing method could lower emissions" Prof. Mark Rainforth

T10: WMG Webinar "Opportunities to reduce greenhouse house gases from Ironmaking" Dr Julian Steer

Awards

IOM3 Awards 2020:
Bessemer Gold Medal - Professor Dave Worsley, Swansea University

The Sir Henry Bessemer Laureate award is given by the Iron and Steel Board (IOM3) in recognition of the outstanding services to the steel industry made by Professor Dave Worsley. The subject of Professor Worsley's lecture was coated steel products in the UK, and in India and Mexico where the Tata Steel team are engaged with local communities to repurpose simple printing presses to make solar cells local to where they are needed. He presented real world examples of solar powered buildings and described the way in which spare power can be deployed to drive the electric vehicle revolution or provide power for communities who may never have grid connections in the way we view them currently.

Thornton Medal - Dr Walter Stahel, Product Life Institute

Presented to a speaker invited to present at either Institute conference or other specially convened meeting.

Verulam Medal and Prize
Professor Mark Rainforth
University of Sheffield

In recognition of distinguished contributions to ceramics including refractories.

Top 100 Women in Supply Chain 2021:
54 - Professor Janet Godsell, University of Warwick

St David Awards 2020:
Innovation, Science and Technology award winner 2020 - Professor Dave Worsley, Swansea University

The St David Awards are the National awards of Wales and are nominated by the public. The award for Innovation, Science and Technology: Intended for those who have developed techniques or solutions that meet new requirements and who have provided effective products, processes, services, technologies, or ideas that are available to society at large. During his 30-year career at Swansea University Professor Worsley has secured more than £140 million of research funding and his current EPSRC grant portfolio of over £55 million is one of the largest in the UK and drives many partnerships within Wales.

Publications, Articles and Media

Journal Paper: L. Zhou, P. Kok and C. L. Davis, [2021]. Steel microstructure - Magnetic permeability modelling: The effect of ferrite grain size and phase fraction. *Journal of Magnetism and Magnetic Materials*, **519** (167439). DOI: 10.1016/j.jmmm.2020.167439

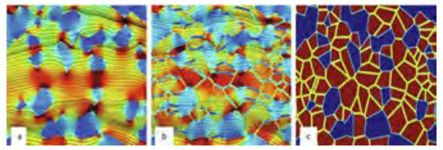


Fig. 6. FE Modelled results of magnetic flux distribution for the 0.17C steel sample (30% pearlite in ferrite matrix): a) distribution only considering phase balance and b) considering phase balance and grain size (20 μm grain size). (Streamline: magnetic flux density); c) representative images from 2D microstructure models, where red represents ferrite, blue pearlite and yellow the grain boundaries.

Journal Paper: P. Gong, B.P. Wynne, A.J. Knowles, A. Turk, L. Ma, E.I.Galindo-Nava, W.M. Rainforth [2020]. Effect of ageing on the microstructural evolution in a new design of maraging steels with carbon. *Acta Materialia*. 196, 101-121 DOI: 10.1016/j.actamat.2020.06.029

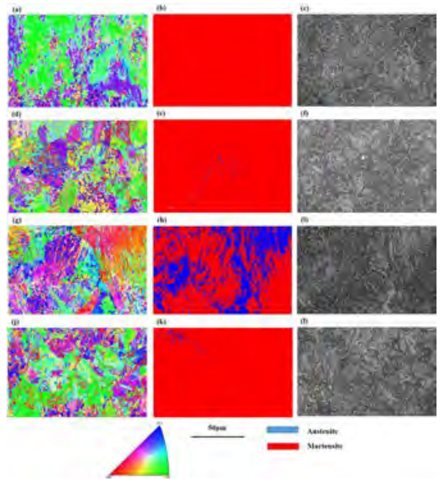


Fig. 9. EBSD maps of Cr2Mo showing the aged microstructure evolution from (a-c) 510 °C for 5 h; (d-f) 510 °C for 8 h; (g-i) 510 °C for 16 h; (j-l) 510 °C for 48 h. Inverse pole figures (IPF) maps (a,d,g,j) show the grain orientations with respect to RD (rolling direction); (b,e,h,k) phase maps with blue for FCC reverted austenite and red for martensite; (c,f,i,l) Band Contrast maps showing the morphology of the two phases.

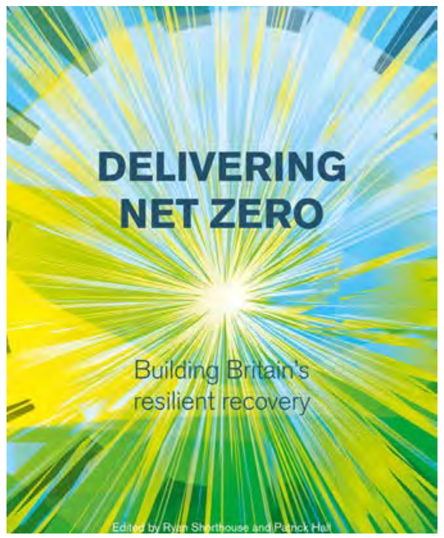
Journal Paper: P. Styring and G.R.M. Dowson, [2020]. Oxygenated Transport Fuels from Carbon Dioxide. *Johnson Matthey Technology Review*, **65**, (2), 170-179. DOI: 10.1595/205651321X16063027322661

Journal Paper: G.R.M. Dowson, P. Styring and J. Cooper, [2021]. Reactive Capture Using Metal Looping: The Effect of Oxygen. *Faraday Discussions*. DOI: 10.1039/D1FD00001B

Review Paper: I. Kapoor, C. Davis, Z. Li [2021]. Effects of residual elements during the casting process of steel production: a critical review. *Ironmaking & Steelmaking*. DOI: 10.1080/03019233.2021.1898869

News and Views: E. Andreoli [2021]. CO_2-to-ethylene electroreduction gets a boost. *Nature Catalysis*. **4**, 8–9 DOI: 10.1038/s41929-020-00568-9

Essay: R. Curry, G. Fletcher, [2020]. A steely solution. *Bright Blue Delivering Net Zero*. 144-150
Online: brightblue.org.uk/wp-content/uploads/2020/05/Final-Delivering-net-zero.pdf#page=145



Magazine Article: R. Waldram, [2020]. Supporting the development of Greener, Cleaner, Smarter Steel industry in the UK. *Swansea University Engineering, A Call for Engineers*. 16
Online: online.flippingbook.com/view/572041/16-17

Online Article: W.M. Rainforth [2021]. New steel manufacturing method could lower emissions. *The Engineer*.
Online: theengineer.co.uk/new-steel-manufacturing-method-could-lower-emissions

Online Article: [2021]. From concrete to steel, how construction makes up the 'last mile' of decarbonization. *Fortune*.
Online: fortune.com/2021/02/16/concrete-steel-construction-design-climate

Online Article: S. Spooner [2021]. Automotive recycling - can we stop downcycling our materials? *ATF Professional*.
Online: atfpro.co.uk/automotive-recycling-can-we-stop-downcycling-our-materials

Webinar: P. Holliman [2021]. It's not easy being green. *South Wales Materials Association (SWMA)*
Online: Zoom recording

Webinar: C. Pleydell-Pearce [2021]. SUSTAIN from nothing to now. *Sheffield Metallurgical & Engineering Association (SMEA)*

Key People

Management Team

The Management Team will provide the Hub with a clear direction over its lifetime and beyond. It is comprised of representatives from each of the Spoke institutions and the Programme Manager. The purpose of the Management Team is to evaluate submitted proposals for academic content, resource allocation, progress monitoring and dealing with arising issues.

Professor Dave Worsley - Director, Swansea

Dave is a Tata Steel sponsored Professor at the Faculty of Science and Engineering, Swansea University and focusses on practical industrial engineering and technology for sustainability. He has close ties with the UK metals and steel industries and has brought the UK's largest volume steel producers together to tackle the environmental and sustainability issues head on with the SUSTAIN Hub.

Professor Cameron Pleydell-Pearce - Deputy Director, Swansea

Cam has a long history of interfacing with industry and has significant experience of managing industry/academic research collaborations and relationships. Currently he is focused on consolidating and enhancing this environment locally and has a leading role nationally in steel research, development and innovation.

Professor Claire Davis - Spoke Director, Warwick

Claire holds a Royal Academy of Engineering / Tata Steel Chair in Low Energy Steel Processing at WMG, University of Warwick. She leads the Advanced Steel Research Centre based in the Advanced Materials and Manufacturing Centre at WMG, which comprises over forty researchers working on steel projects.

Professor Mark Rainforth - Spoke Director, Sheffield

Mark holds a POSCO Chair in Iron and Steel Technology at the University of Sheffield. His research interests focus on high resolution characterisation of microstructures, in particular interfaces and surfaces and cover metals, ceramics and coatings.

Dr Richard Curry - Programme Manager, Swansea

Richard is the SUSTAIN Research Programme Manager, based at Swansea University, and has a background in Electronic Engineering, Biomedical Sensors and Holographic Lithography. Richard's interests lie in circular economy, decarbonisation and Industry 4.0.

Strategic Advisory Board

With representatives from academia, industry and government, the purpose of the Strategic Advisory Board is to evaluate industrial and academic impact, provide technical and scientific steer, provide strategic guidance and support on the influencing of policy and assess overall progress of the Hub against its objectives.

Dr Louis Brimacombe (Chair) - Consultant

Louis is a Fellow of IOM3 and a chartered Chemical Engineer. Currently working as a consultant and business advisor specialising in sustainable development and life cycle assessment (LCA). His leadership skills, innovative approach and vision has helped businesses to develop R&D programmes and embed life cycle thinking in their R&D and product marketing strategies.

Mr Mike Greenall - NSG

Mike is the Chief Technology Officer of NSG, a global flat glass producer. He leads R&D for the Group and is based at the NSG Technical Centre in Lancashire. The Glass industry and Steel industry face common challenges. He is looking for opportunities to exchange ideas and solutions especially in the fields of AI, emissions and recycling.

Dr Robert Quarshie - KTN

Robert currently leads all materials activities at KTN. He holds a PhD in Materials Science/ Electrochemistry (Development of High Energy Density Batteries) and a Postdoctoral Fellowship in Steel Metallurgy. Worked in various senior management roles in the steel industry, including R&D, Manufacturing, Customer Technical Services, Product & market development and strategy.

Professor Dierk Raabe - Max-Planck-Institut

Dierk Raabe studied music, metallurgy and metal physics. After his doctorate in 1992 at RWTH Aachen he worked at Carnegie Mellon University and joined Max Planck Society in 1999. His interests are in sustainable metallurgy, alloy design, computational materials science and atom probe tomography.

Dr Elizabeth Saunders - EPSRC

Senior Portfolio Manager in the EPSRC manufacturing team, I manage the materials, leaders and international portfolios. I previously managed the bioenergy portfolio in the renewable resources for clean growth team at BBSRC. My research background is in biochemistry, where my work focussed on physiological studies of industrially relevant bacteria.

Mr Gareth Stace - UK Steel

Gareth became Director General of UK Steel in April 2015. Gareth has acted as the voice of the sector, during the 2015-16 steel crisis and beyond. He has clearly set out to government, MPs and the media, the steps which need to be taken to give the British steel sector a chance to compete on a level playing field, within the global marketplace.

Dr Walter Stahel - Product Life Institute

Stahel is an architect by training (ETH Zürich), researcher by experience, risk manager by necessity, Professor at University of Surrey by invitation, author and keynote speaker by conviction, member of the Club of Rome and Scientific Advisory Boards to pass on to others his circular economy experience of 45 years.

Professor Sybrand Van Der Zwaag - TU Delft

Sybrand van der Zwaag has been a full professor at the TU Delft for 29 years. His research deals with phase transformations in chemically simple steels as well as structure-property relationships in metals, polymers, ceramics and meta-materials. He pioneered the development of self healing materials.

Operational Committee

The Operational Committee members represent some of the main organisations involved in steel manufacturing in the UK. Its purpose is to review project proposals to ensure that there are opportunities for the research to be applied within the industry to confirm relevance. The SUSTAIN Management Team also sit on the Operational Committee, plus our EPSRC representative.

Chris Vaughan
Technical Director
British Steel

Dr Gari Harris
R&D Manager
British Steel

Chris Hagg
Head of External Affairs,
Celsa Steel UK

Eoin Bailey
UK Innovation Manager,
Celsa Steel UK

Cathy Bell
Manager Research & Forensic
Metallurgy, Liberty Speciality Steels

Dr Simon Pike
Chief Technology Officer, Liberty
Steel UK; General Manager,
Liberty Powder Metals Ltd

Prof. Jesus Talamantes-Silva
Research, Design and Technology
Director, Sheffield Forgemasters

Dr Laura Baker
Head, Product Management &
Development, Tata Steel UK

Dr Phil Clements
Director Technical,
Tata Steel UK

Byron Tucker
Head of R&D at Swansea
Technology Centre, Tata Steel UK

Alan Scholes
Chief Technology Officer,
Materials Processing Institute

Richard Warren
Head of Policy and
External Affairs, UK Steel

Investigators

Dr Enrico Andreoli
Swansea University
Theme 1, T1

Dr Michael Auinger
WMG, University of Warwick
Theme 3, T5

Prof. Andrew Barron
Swansea University
Theme 1, T1

Prof. Arnold Beckmann
Swansea University
Theme 3, T4

Dr Matthew Carnie
Swansea University
Theme 4, T6

Prof. Claire Davis
WMG, University of Warwick
Theme 4, T7; Theme 5, T8

Prof. Janet Godsell
WMG, University of Warwick
Theme 3, T4

Prof. Peter Holliman
Swansea University
Theme 2, T2

Dr Yukun Hu
University College London
Theme 4, T12

Dr Zushu Li
WMG, University of Warwick
Theme 2, T3; Theme 4, T7

Prof. Giovanni Montana
WMG, University of Warwick
Theme 3, T4

Prof. Eric Palmiere
University of Sheffield
Theme 5, T9

Dr Karen Perkins
Swansea University
Theme 4, T6

Prof. Cam Pleydell-Pearce
Swansea University
Theme 4, T6

Prof. Mark Rainforth
University of Sheffield
Theme 5, T9

Dr Martin Strangwood
WMG, University of Warwick
Theme 5, T9

Dr Andrew Gallant
Durham University
Theme 5, T11

Dr Julian Steer
Cardiff University
Theme 2, T10

Prof. Peter Styring
University of Sheffield
Theme 1, T1

Dr Richard Thackray
University of Sheffield
Theme 2, T2,3; Theme 3, T5

Dr Alton Horsfall
Durham University
Theme 5, T11

Researchers


Dr Matthew Burton
Swansea University, T6


Dr Qiushi Cao
Swansea University, T4


Xiaoyuan Cheng
UCL, T12


Dr Michael Dowd
Swansea University, T6


Dr George Dowson
University of Sheffield, T1


Dr Peng Gong
University of Sheffield, T9
ECR project


Dr Eurig Wyn Jones
Swansea University, T2


Dr Ishwar Kapoor
WMG, Warwick, T3


Dr Aurash Karimi
WMG, Warwick, T5


Dr Uchenna Kesieme
University of Sheffield, T5


Dr Ria Mitchell
Swansea University, T6
(now University of Sheffield)


Dr Stephen Spooner
Swansea University,
ECR project


Dr Zakiah Suhaimi
WMG, Warwick, T4


Xiyao Sun
UCL, T12


Dr Waqas Hassan Tanveer
Swansea University, T1


Dr Sagar Uprety
WMG, Warwick, T4


Dr Frank Zhou
WMG, Warwick, T8
ECR project

PhD and EngD Students


Geraint Howells
Swansea University, T6


David Ireland
WMG, Warwick, T4


Fawaz Ojobowale
Swansea University, T2

Jonathan Hammler
Durham University, T11

Development Champions


Dr Hollie Cockings
Swansea University, T6


Dr Elizabeth Sackett
Swansea University

Operations Team


Sarah Roberts
Project Officer


Paula Toft
EA to the Hub Director


Dr Becky Waldram
Outreach Officer


Lydia Webber
Administrative Coordinator

sustain

future steel manufacturing research hub

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