Hydrogen and Industrial Decarbonisation

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Case Studies in this section:

Challenge

South Yorkshire has long stood at the heart of the UK's industrial faculty, with advanced manufacturing, steel, glass and ceramics sectors driving regional growth and job creation for decades. The new South Yorkshire's Growth Plan, published in September 2025, recognises this heritage and sets out a renewed vision to build on this manufacturing legacy, utilising the region's capabilities and expertise in clean energy, innovation and research and development (R&D).

With a population of 1.4 million, South Yorkshire represents a significant regional economy (£39.6 billion gross domestic product (GDP)[1]) transitioning from its industrial heritage toward advanced manufacturing, healthcare and digital services. Manufacturing continues to be the bedrock of the region's economy, accounting for 15.3% of gross value added (GVA), significantly higher than the national average of 9.8%[2], which is now being supercharged by advanced manufacturing and clean energy. Indeed, South Yorkshire now ranks as the UK's third-largest region for employment in clean power and hydrogen[3].

Stretching from Sheffield to Rotherham, Don Valley, home of the University of Sheffield's Advanced Manufacturing Research Centre, is an established innovation district, with global significance. With 30 cutting edge R&D facilities sprawling over four adjacent sites, the internationally recognised translational research facilities set the region apart, supporting over 1,200 businesses with more than 3,500 employees and attracting world-leading advanced manufacturing companies, such as Boeing, Rolls Royce and McLaren Automotive[4].

At the national level, the region's capabilities in both advanced manufacturing and clean energy sectors are recognised in the Modern Industrial Strategy's Clean Energy[5] and Advanced Manufacturing Sector Plans[6]. The government named these and another 6 industries as key for future prosperity and economic growth, both at regional and national levels. The emphasis is placed on transition to low-carbon manufacturing, recognising this as not only a necessity to meet net-zero by 2050 targets, but also a strategic and economic opportunity for regions to sustain jobs, attract investment and lead in the manufacturing economy of the future.

However, key challenges for the region remain. At the end of 2025, the employment rate for South Yorkshire was 73.3%, 2 percentage points below national average. Both unemployment (4.7%) and economic inactivity (23%) rates exceed England's average (with 3.7% and 21.4% respectively) and the proportion of workers in severe job insecurity ranks second highest amongst all combined local authorities at 21.7%[7]. Furthermore, the advanced manufacturing together with other strategic sectors prioritised for growth, such as healthcare and digital skills, are all the fields with projected skill shortages in the region for 2026[8].

Whilst skill shortages might stagnate growth, some of the cornerstone companies are struggling to stay in operation. The recent Defence Growth Deal

1 ONS (2025) Regional economic activity by gross domestic product, UK: 1998 to 2023. Regional gross domestic product: all ITL regions. 2023 data.
2 Pratap Executive (2025) South Yorkshire Growth.
3 SYMCA (2025) South Yorkshire's Growth Plan.
4 Ibid.
5 UK Government (2025) The UK's Modern Industrial Strategy. Clean Energy Industries Sector Plan.
6 UK Government (2025) The UK's Modern Industrial Strategy. Advanced Manufacturing Sector Plan.
7 Yotru (2026) South Yorkshire Labour Market Data 2026: Employment, Wages + Apprenticeships.
8 Ibid.

identified South Yorkshire as one of five leading places in the UK in the defence industrial economy; the region provides specialist steel for use in the defence sector through Forgemasters, BAE Systems and Special Melted Products[9]. However, Speciality Steels UK, crucial to national defence, aerospace and energy industries due to their highly specialist, world-leading steel production capabilities[10], was placed in receivership in 2025 and is now under UK government control. This came after several years of financial uncertainty, during which most of the company's workers were placed on indefinite furlough, not only affecting multiple jobs, but also entire communities in Stocksbridge. Stocksbridge retains a strong sense of identity, rooted in its steelmaking heritage with British Steel and its predecessors historically being central to both the economic and social life of the town, providing welfare and community functions.

This issue is not limited to Stocksbridge. The steel industry in South Yorkshire has undergone significant change over the last 40-50 years. In 1971, 140,000 people were employed in the steel industry in Sheffield alone. This accounted for half of all the city's jobs. In just over a decade this fell by more than half to 57,000 in 1987[11]. This decline in employment numbers continued in the 1990s and 2000s. By 2024 metals production and manufacturing industries were estimated to employ around 15,000 people across South Yorkshire[12].

9 SYMCA (2025) South Yorkshire's Growth Plan.
10 Community Trade Union. (2025) Statement - Liberty Steel.
11 Hudson, R and Sadler, D (1989) The international steel industry: restructuring, state policies and localities. Routledge, Abingdon.
12 Office for National Statistics (2025) Business Register and Employment Survey.

With a population of **1.4 million**, South Yorkshire represents a significant regional economy of **£39.6 bn GDP**

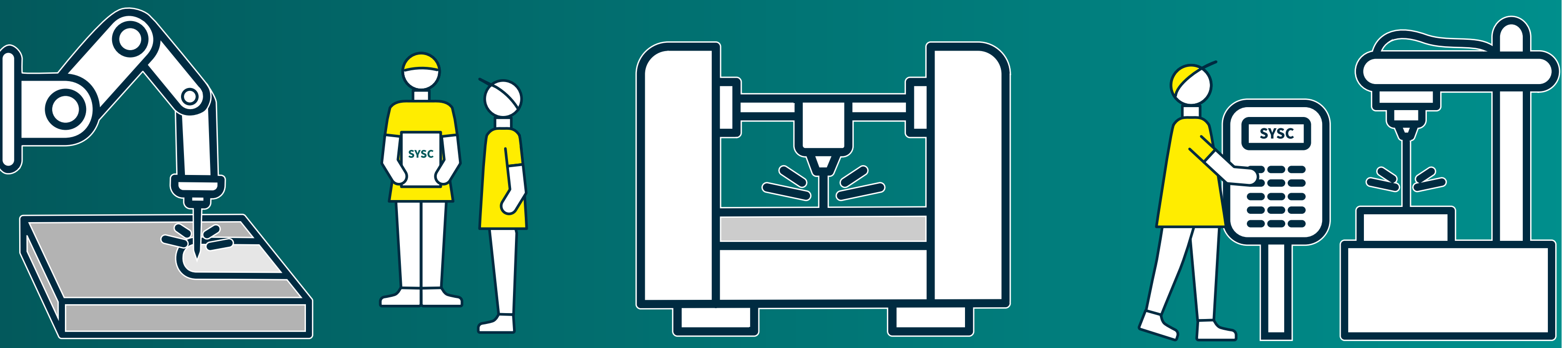
Its history of heavy industry is transitioning toward advanced manufacturing, healthcare and digital services

Manufacturing continues to be the bedrock of the region's economy

Manufacturing accounts for

15.3% GVA South Yorkshire

9.8% GVA national average



Additionally, steel and other energy intensive manufacturing industries within the region such as glass and bricks, require significant investment to decarbonise, or risk production moving elsewhere or ceasing entirely. These sectors are not only energy intensive, but also are defined by their hard-to-abate emissions profiles, due to the high temperatures needed. Electrification is not always possible to meet these challenges and decarbonisation via hydrogen potentially requires significant changes to production processes.

If done right, transitioning to low carbon manufacturing could ensure a prosperous future for the region and its residents, with green growth and clean energy supporting manufacturing and innovation hubs that are rooted in the region's history and heritage.

Research Response

Industry and manufacturing decarbonisation, especially of heat-intensive industries such as steel, ceramics and glass making, presents a substantial challenge that requires collaboration between local authorities, industry and academia to overcome. With this goal in mind, South Yorkshire Sustainability Centre (SYSC)' convened key stakeholders and partners across the region - including South Yorkshire Mayoral Combined Authority (SYMCA)', Forgemasters, Marcegaglia, Ardagh Glass, Aggregate Industries, Chesterfield Special Cylinders, E.On, Cadent to name but a few - to hold open discussions through the Industry Decarbonisation Roundtables series. During these discussions, some of the key challenges and barriers to decarbonisation were identified, including: the lack of clear, long term policy steer from the national government, high risk, high operational and capital costs of hydrogen, hydrogen supply uncertainties, readily available volumes of hydrogen in the region and further large scale feasibility studies required.

SYSC's research has sought to ascertain hydrogen economy readiness, benchmarking hydrogen economy maturity of the UK (in terms of investment, legislation, and strategy) against other G20 nations. The study found the UK to be one of the frontrunners, together with the US and China in hydrogen economy maturity. For the UK, and particularly regions such as South Yorkshire seeking to embed themselves in the hydrogen economy, this benchmarking provides insight into the country's competitive positioning relative to other G20 members.

This supports SYSC's State of Hydrogen in South

The steel industry in South Yorkshire has undergone significant change over the last 40-50 years

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Yorkshire report findings. The report aimed to provide readily actionable recommendations for South Yorkshire's Investment Zone and consists of analyses of national and regional policy landscapes, regional manufacturing and innovation capabilities, supply chain maturity, and production capacity and demand. The report also assessed the opportunities and challenges to grow the sector in South Yorkshire. With hydrogen expected to account for 20-35% of UK energy consumption by 2035[13], the report found that South Yorkshire has the potential to be a national and even global leader in hydrogen and the way it is used safely, but quick and decisive action by regional policymakers is needed.

Although South Yorkshire is not within a hydrogen cluster at the moment, it is well connected to two large emerging hydrogen clusters, at Tees Valley and Humberside, whilst also holding 0.37 GW (enough to produce ~1,944 GWh annually) hydrogen production capacity (albeit currently restricted by grid headroom availability). Still, the report identified that the real strengths of the region and its leadership potential lies in hydrogen research, hydrogen use demonstrators and manufacturing for the hydrogen supply chain. The State of Hydrogen in South Yorkshire report was also presented to the SYMCA's South Yorkshire Energy Board, where it received positive feedback from Mayor Oliver Coppard and the Chair of the Board, David Bond. It was also featured at the UK Clean Energy Summit, hosted by the University of Sheffield, and in one of the Sheffield City Chambers of Commerce newsletters.

Another SYSC project further investigated how resilience could be built into hydrogen supply chains. The project identified the main challenges within the hydrogen supply chain to be raw material dependencies, weather risks, integration challenges, and sensitivity to stakeholder perceptions. In South Yorkshire, this means that resilience planning should be integrated with environmental regulation, energy market design, and community engagement. Supporting renewable energy communities and decentralised production would enhance both technical resilience and social equity, requiring cross-disciplinary collaboration. The project identified supply network integration as another driver of resilience. Building partnerships across transport, manufacturing, logistics, and heavy industry can foster collective resilience, reduce vulnerabilities, and create high-value jobs, supporting a just transition.

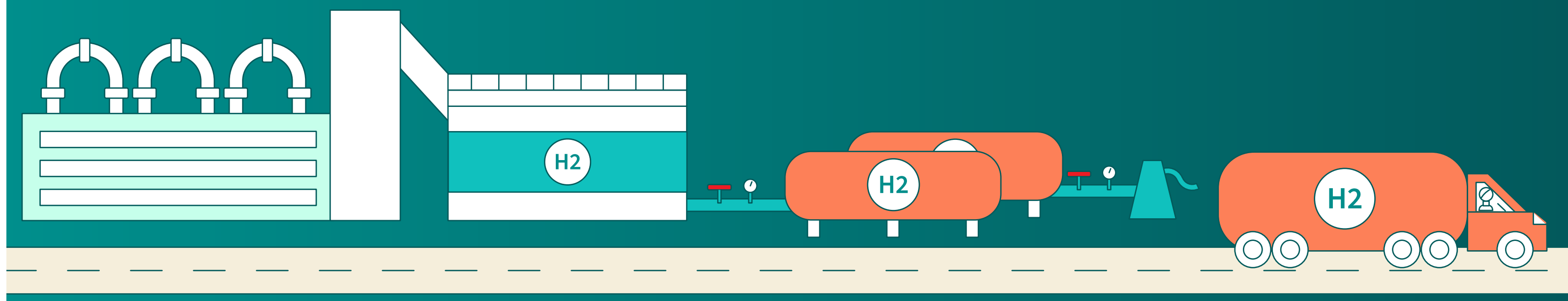
Another study utilised the regional optimisation model AENi to understand where hydrogen clusters could be established to achieve a cost optimal scale-up of hydrogen supply in South Yorkshire. The study considered 21 energy, heat and emission intense manufacturing companies of variable size in South Yorkshire. The AENi software, developed as a spin-out from the Brown group at University of Sheffield, was used to find a cost optimal network linking these sites to the grid supply point at Thurcroft. Although this was just an initial modelling exercise and further in-depth collaboration is needed to develop a more accurate model, including economic analysis to predict the most favourable roadmap for roll out, the current project findings show that a hydrogen network for industrial sites is likely feasible using existing electrical grid connections.

13 Illustrative demand based on analysis for the Hydrogen Transport and Storage Networks pathway (2023), as referenced in GOV.UK (2024) Hydrogen investment roadmap: Leading the way to net zero.

It is important to note that successful hydrogen deployment depends not only on technical feasibility, but on societal and institutional readiness. Hydrogen storage and road-based distribution systems will operate within industrial estates, logistics corridors and alongside residential communities. The existing evidence base is heavily weighted toward techno-economic modelling and carbon intensity analysis, with comparatively limited research examining multi-stakeholder social acceptance, particularly for storage and transport infrastructure. The Hydrogen Storage as a Service (HySaaS): Securing Social Licence for Hydrogen Storage and Distribution

Hydrogen is expected to account for
20-35% of the UK's energy consumption by 2035

South Yorkshire holds **0.37 GW hydrogen production capacity** - enough to produce ~1944 GWh annually



in South Yorkshire project aimed to address this gap by providing a structured, multi-stakeholder assessment of social acceptance focused specifically on hydrogen storage and distribution, the parts of the value chain most visible to communities and emergency responders.

The research found that acceptance of hydrogen storage and distribution is broadly positive but strongly conditioned by perceptions of safety and risk. Across all stakeholder groups, safety emerged as the dominant determinant of acceptance. Crucially, all groups responded positively to enhanced monitoring and transparency. More than 80% of public respondents indicated that additional monitoring systems would increase their comfort with hydrogen storage and distribution. This suggests that visible, data-driven safety mechanisms can materially improve acceptance.

The findings suggest that hydrogen storage and distribution can secure social licence if deployment is treated as a governance and trust challenge as much as a technical one. To improve social acceptance and reduce perceived risk, hydrogen demonstrator projects in South Yorkshire should aim to combine monitored assets, responder training and community engagement, thus strengthening the commercial case for hydrogen investment.

Beyond Industrial Decarbonisation

Lastly, it is important to note that hydrogen is relevant not only for industrial decarbonisation, but also essential for Sustainable Aviation Fuel (SAF) production. The UK's SAF Mandate, which came into effect in 2025, requires 2% of total UK jet fuel demand to be supplied as SAF, rising to 10% in 2030 and 22% in 2040[14]. This policy, designed to reduce aviation emissions, forces fuel suppliers to meet these targets or buy certificates, similar to Renewable Energy Guarantees of Origin (REGOs) certificates issued by Ofgem to certify electricity generation from eligible renewable sources - used as a mechanism for companies to prove renewable energy sourcing.

As SAFs require no engine modifications and because they can be produced from waste products, they are seen as an interim solution for

14 DfT (2025) Sustainable Aviation Fuel (SAF) Mandate.

Safety emerged as the dominant determinant of hydrogen storage and distribution acceptance **across all stakeholder groups**

Crucially, all groups responded positively to enhanced monitoring and transparency

More than **80%** of **public respondents** indicated that additional monitoring systems would **increase their comfort** with hydrogen storage and distribution

This suggests that visible, data-driven safety mechanisms can materially improve acceptance

emissions from aviation.

There are several certified routes for preparing SAF that differ in feedstock and/or processing methods to obtain synthetic paraffinic kerosene (SPK), which is then blended with conventional fuels, with the exact blend proportions variable and dependent on the pathway. All of these routes, apart from one, require hydrogen for their processing.

However, several key challenges remain in advancing SAF development and deployment, such as a lack of lifecycle data, limited evidence on the resilience of SAF supply chains under different feedstock, technology, and trade scenarios; and a persistent uncertainty over which SAF pathways should be prioritised, as each involves trade-offs among economic cost and scalability, environmental performance, technological maturity, and broader social and political acceptance.

SYSC research aimed to address these gaps through a comparative analysis of all certified waste-derived feedstock SAF life cycle assessments, supply chain resilience analysis and a stakeholder engagement study, which aimed to gauge perspectives across the SAF value chain and translate them into structured evaluations of competing pathways. One of the key findings from this research is that SAF deployment targets are likely to outpace the sustainable supply of biogenic waste feedstocks, creating potential bottlenecks and competition with other sectors. This highlights the need for diversified feedstock sourcing and resilient, internationally coordinated supply chains, integrating both biofuels and synthetic (power-to-liquid) fuels to achieve the necessary scale-up. For policymakers, the research highlights the need for stronger and more targeted incentives. SAF mandates, subsidies, and funding mechanisms should be designed to only favour pathways with the strongest evidence base for environmental sustainability and supply chain resilience.

Hydrogen and Industrial Decarbonisation Recommendations for Regional Policymakers

1. Local policymakers should commit ongoing resources to support the continuation of the existing **Industrial Decarbonisation Roundtables so that there is a permanent, robust forum in which policymakers, regional industry leaders and academia can collaborate** to a) to identify, scope and deliver regional demonstrators and b) co-design regional policies that directly address policy gaps, barriers to growth and the operational requirements of the sector.

2. To support Local Growth Plan ambitions, policymakers, industry and academia should convene a **working group to determine how South Yorkshire can capitalise on its existing strengths to emerge as a national leader in the technologies and components that underpin hydrogen production, storage and transportation**, such as catalysts, storage tanks and pipeline materials. This offers significant potential for long term economic growth and national leadership.

3. In continued partnership with industry and The University of Sheffield, **local policymakers should identify and create defined hydrogen production and user site clusters** in South Yorkshire, and **take responsibility for attracting, directing and scaling business activity** in existing and emerging clusters.

    i. Scoping a Hydrogen Network for the South Yorkshire Region using the Network Optimisation Model AENi.

4. To promote regional readiness and support the region's Local Growth Plan, l**ocal policymakers should work with South Yorkshire's hydrogen projects**, such as ITM Power, GeoPura, Lhyfe, and Clean Power Hydrogen group **to ensure that they meet or are working to meet international certification requirements**, ensuring competitiveness in global supply chains.

    i. Towards a Unified Hydrogen Standard: Benchmarking G20 Nations' Hydrogen Economy Maturity.

5. **Produce an 'inclusive industrial transition' strategy** which centres on how large investments in industrial decarbonisation can capture value for the region as a whole, provide pathways to good and inclusive work, and benefit the region's SME base. This can build from current on-going work between SYSC and SYMCA on principles for an inclusive industrial transition.

    i. Implications of Steel Decarbonisation for Workers and Communities.

6. **Support industrial workers to become active participants in green industrial future realisation.** This includes access to skills provision and job support where retraining is required, but more broadly to provide open communication and engagement around opportunities and challenges of green industrial futures. Trade Unions can play an important role within this, alongside businesses and policy organisations.

    i. Implications of Steel Decarbonisation for Workers and Communities.

Further Research Opportunities

Hydrogen sector: More research needed to understand the optimal balance between policy support and long-term independence, particularly the extent to which subsidies enable growth but may reduce adaptability and innovation.

Scoping a SY hydrogen network:

- Carry out further partner engagement to understand which decarbonisation option is preferable/intended.
- Develop a methodology for analysing the economics of sub-sections of the network to predict the most favourable roadmap for rollout.
- Collaborate with partners in areas where the network cost is lowest in order to develop a more accurate model, and gauge willingness to pay.

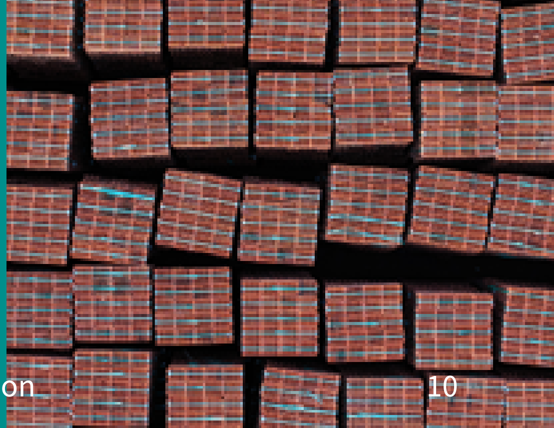
Jobs and work: Research could support the development of a community-rooted taskforce in Stocksbridge to lead community and infrastructural renewal.

Inclusive industrial decarbonisation: There is ongoing research underway with SYMCA to develop a broader approach to 'inclusive industrial decarbonisation' that seeks to set out a framework for delivering sustainable industrial futures that also addresses key social, economic and cultural challenges.

Public acceptance: Further research should track how public attitudes evolve as hydrogen infrastructure becomes more visible and explore how monitoring data can be translated into meaningful public-facing safety indicators.

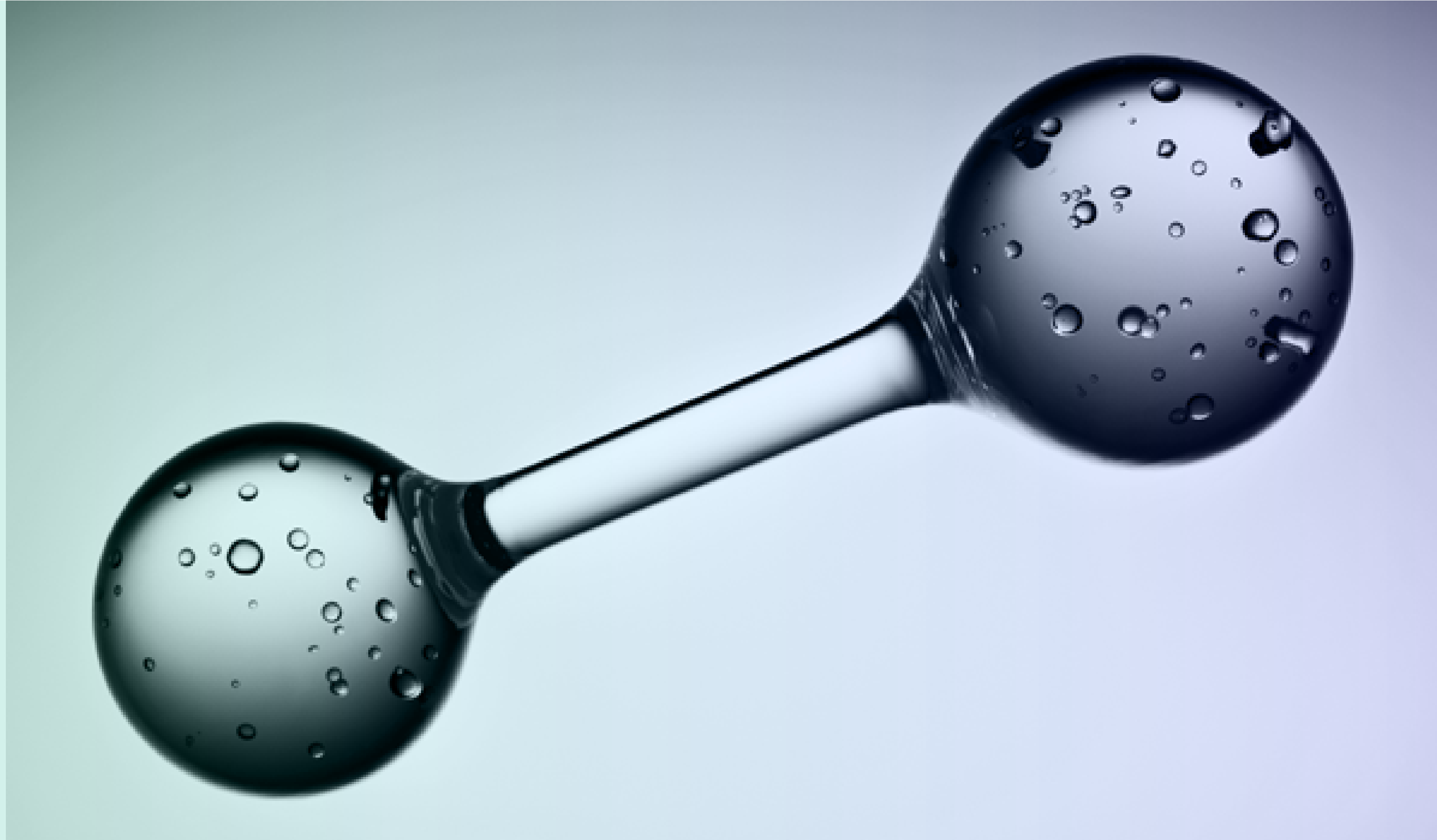






Towards a Resilience Evaluation Framework for Hydrogen Supply Chains

Project team:
University of Sheffield: Prof. Lenny Koh, Prof. Vania Sena, Prof. Darren Robinson, Dr Matthew Wood, Liang Kong



Challenge Statement

The case study responds to urgent challenges exposed by current geopolitical tensions, such as instability in the Middle East and the Russia-Ukraine war, where global disruptions have highlighted the limits of traditional resilience practices such as contingency planning. These reactive approaches have proved inadequate for the scale and complexity of modern supply chain shocks[1]. In today's volatile environment, organisations require proactive mechanisms that enable not only recovery but also adaptation and evolution. This is particularly vital for hydrogen supply chains (HSCs), which face raw material dependencies, weather risks, integration challenges, and sensitivity to stakeholder perceptions. Yet no framework currently guides firms in progressively building resilience, leaving a clear gap this study seeks to address. Current evidence supports this view[2]. Existing maturity models remain fragmented and function-specific, with few pathways, limited empirical evidence, and especially scarce hydrogen-specific insights despite the sector's importance to net-zero.

For South Yorkshire, these challenges are immediate. Hydrogen is central to the UK's industrial strategy, but its success depends on supply chains that are robust, adaptable, and sustainable. Funded by Research England, this research develops a conceptual maturity model for hydrogen resilience, providing a tool to strengthen supply chains and support a competitive, fair, and sustainable hydrogen economy.

Research Response

Research contributes to tackling resilience challenges in HSCs by offering structured approaches that reflect the sector's unique vulnerabilities. This study develops a resilience capability maturity model (RCMM) that provides a phased framework for assessing resilience across maturity levels, tailored to hydrogen's regulatory, market, and technological contexts. Drawing on complex adaptive systems (CAS) theory, the model explains how firms adapt and self-organise under disruption. Unlike existing maturity models, which are either sector-specific or largely conceptual, this framework addresses hydrogen's challenges such as hazard management, sustainability demands, and market volatility. It enables benchmarking, identifies capability gaps, and provides actionable insights, while laying the groundwork for broader empirical validation.

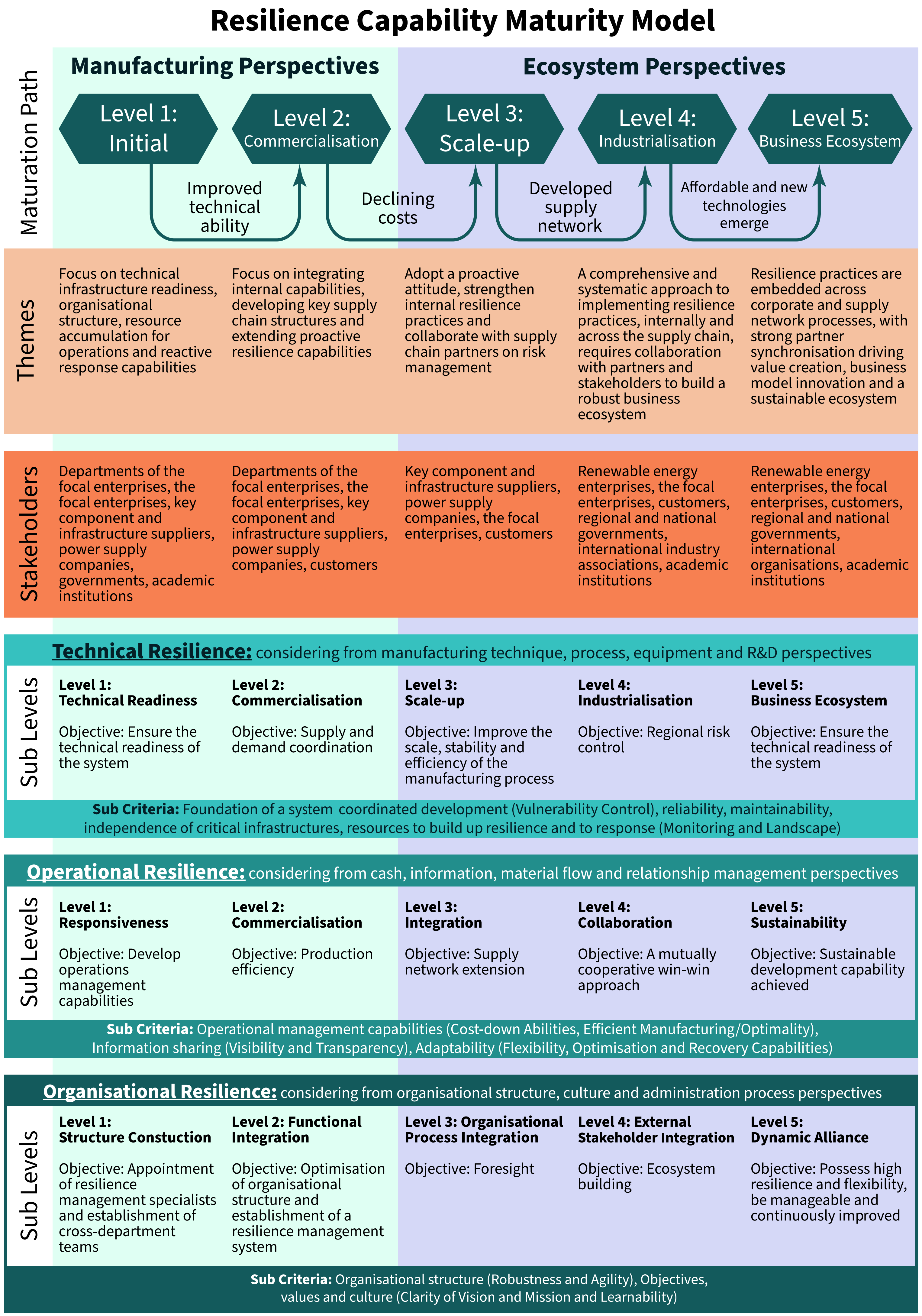
Where hydrogen is central to energy and net-zero strategies, the challenge lies not only in scaling technologies but in ensuring the value chains remain resilient and adaptable. Heavy reliance on subsidies risks dependency and reduced adaptability. The RCMM helps address this by equipping firms with tools to benchmark resilience, identify weaknesses, and pursue continuous improvement. Emphasising technical independence, organisational learnability, and ecological resilience, the model supports firms in anticipating risks, building adaptive capacity, and sustaining competitiveness in volatile markets.

The project's goal was to create a sector-specific model for HSCs, operationalising resilience management through defined maturity levels, from reactive recovery to ecological resilience. Tested through exploratory case studies, it offers a roadmap for organisational progression, supports benchmarking, and provides a basis for validation across sectors and regions.

Evidence and Outputs

Existing maturity models in supply chain management are either sector-specific or largely conceptual, making them insufficient for addressing the resilience needs of HSCs. To address this gap, a conceptual RCMM tailored to hydrogen was developed. The model demonstrates a progressive pathway: early stages focus on manufacturing resilience through reactive responses and recovery capabilities, while higher stages emphasise ecological resilience, characterised by proactive adaptation, external network integration, and long-term sustainability. Exploratory case studies of seven companies across three continents showed that the RCMM can identify capability levels, highlight gaps, and provide companies with a roadmap for advancing resilience maturity. The research indicated that firm size and age matter, with larger and older firms generally better positioned to recover and adapt due to accumulated resources and experience. The research also highlights trade-offs. Hydrogen technologies are resource-intensive, with high energy and leakage risks. At the same time, policy dependency, particularly on subsidies, was found to risk undermining long-

1 Koh, S. C. L., Suresh, K., Ralph, P., & Saccone, M. (2024) Quantifying organisational resilience: An integrated resource efficiency view. International Journal of Production Research, 62(16), 5737–5756.
2 Kong, L., Koh, S. C. L., Sena, V., Robinson, D., & Wood, M. (2025) Towards a resilience evaluation framework for hydrogen supply chains: A systematic literature review and future research agenda. International Journal of Hydrogen Energy, 99, 589-606.



term resilience, indicating the need for strategies that balance short-term support with sustainable independence.

The main output is a conceptual maturity model (the RCMM) that functions as both a descriptive and comparative tool, enabling firms to assess their resilience maturity, benchmark against peers, and develop strategies for improvement. Incorporating five levels across technical, organisational, and operational dimensions, and grounded in CAS theory, the model offers guidance for companies and policymakers. While designed for HSCs, it has potential transferability to other sustainability-focused industries, though further empirical testing to confirm its generalisability.

Interim access to the framework can be provided upon request through the research team. Please email liang.kong@sheffield.ac.uk for access.

This research has also been published and the research paper can be viewed here.

What does this mean for the region?

For South Yorkshire, where energy affordability is a regional concern, resilience planning should be integrated with environmental regulation, energy market design, and community engagement. Supporting renewable energy communities and decentralised production would enhance both technical resilience and social equity, requiring cross-disciplinary collaboration. The RCMM identifies supply network integration as another driver of resilience. Building partnerships across transport, manufacturing, logistics, and heavy industry can foster collective resilience, reduce vulnerabilities, and create high-value jobs, supporting a just transition.

South Yorkshire can apply the RCMM in regional clusters such as hydrogen transport hubs and decarbonised steel, while also positioning itself as a national and international leader in resilience-focused hydrogen development. By exporting governance frameworks alongside technologies, the region can attract investment and strengthen its reputation.

For the UK and globally, this research informs and highlights the critical need to evaluate maturity and resilience of HSCs, as part of the hydrogen, energy and net-zero policies to maximise sustainability and security.

Next Steps

To maximise the impact of this work, the next step is to apply the maturity model more widely across different firms, sectors, and regions. The model could be embedded into hydrogen clusters such as transport hubs, industrial decarbonisation projects, and renewable energy communities. Doing so would provide benchmarking data, guide targeted interventions, and demonstrate the model's value as a regional policy tool. Embedding the framework into industrial strategies and net-zero roadmaps would also ensure that resilience is systematically assessed alongside growth and sustainability goals.

The research also highlights new questions that warrant further exploration. One important area is how firm characteristics, such as size, age, and resources, shape progression through resilience maturity levels. Another concerns the balance between policy support and long-term independence, particularly the extent to which subsidies enable growth but may reduce adaptability and innovation (Kong et al., 2025). There is also scope to adapt the model to environmental challenges such as energy demand, water use, and hydrogen leakage, linking resilience more closely with environmental governance.

Collaboration is key to advancing this agenda. Partnerships between academia, industry, and regional policymakers could establish pilot projects where firms apply the model and share data to build comparative insights. Cross-regional and international collaborations could further position South Yorkshire as a leader in both hydrogen technology and resilience governance. By pursuing these opportunities, the region can strengthen its evidence base, attract investment, and accelerate progress toward a just and sustainable hydrogen economy.

Figure 1 (left): Proposed RCMM Abstract, credited by Liang Kong, Prof. Lenny Koh, Prof. Vania Sena, Prof. Darren Robinson, Dr Matthew Wood

Towards a Unified Hydrogen Standard: Benchmarking G20 Nations' Hydrogen Economy Maturity

Project team:
University of Sheffield: Prof. Lenny Koh, Dr Moein Shamoushaki, Eleanor Borrill

Challenge Statement

Hydrogen is widely regarded as a cornerstone of the global net-zero transition. However, its development and deployment face significant obstacles due to regulatory fragmentation and policy inconsistency across G20 nations.

One of the key challenges is the lack of a universally accepted hydrogen standard. Different definitions – such as the varying use of the "green hydrogen" label – undermine perceptions of quality and create barriers to trade compatibility. A second challenge stems from policy misalignment, with inconsistent national approaches generating uncertainty for investors, complicating infrastructure planning, and impeding the integration of international markets. Finally, uneven levels of national maturity further exacerbate the issue: while some G20 members have developed strong legislation, strategies, and investment programmes, others remain without clear plans or regulatory frameworks.

Research Response

Contribution of Research

This study represents the first comprehensive review of hydrogen standards, financial commitments, national strategies, and future plans across the G20. Using a Weighted Scoring Model (WSM), the analysis rates each nation on a scale from 1 (lowest maturity) to 10 (highest maturity) across these dimensions. This enables direct cross-country comparison, identification of maturity gaps, and the development of a structured basis for international policy alignment.

Regional Relevance

For the UK – and particularly regions such as South Yorkshire seeking to embed themselves in the hydrogen economy – this benchmarking provides insight into the country's competitive positioning relative to other G20 members. It also identifies opportunities for strategic investment and informs policy design that reflects and aligns with emerging global standards.

Evidence and Outputs

Research Findings

The study highlights the US, China, and the UK as frontrunners in hydrogen economy maturity. These countries already combine standards, strategy, and investment, giving them significant influence over global market rules and trade. Their leadership sets the direction for others, and they are well-positioned to drive international standard harmonisation, scale manufacturing, and provide technical and financial support for emerging markets.

Other advanced economies such as Germany, France, Italy, and Australia show strong progress in policy and investment but need to focus on moving from ambitious strategies to binding regulations and large-scale deployment. Japan demonstrates strong planning but underinvestment, while Brazil, South Africa, Argentina, and India face uneven progress across criteria. These countries would benefit from closing gaps between strategy and financing, building institutional capacity for certification and safety, and deploying pilot projects that match local resources.

At the lowest maturity, Mexico and Russia lack clear hydrogen strategies or standards, which risks their exclusion from future global markets. For these countries, the priority is to establish basic national roadmaps and regulatory frameworks, while leveraging multilateral and bilateral support to develop pilot projects and build institutional capability.

Overall, the results show that the frontrunners must take responsibility for shaping international standards and financing mechanisms, while lagging countries urgently need targeted support to build the foundations of hydrogen economies. Without this alignment, fragmented approaches and investment gaps will slow progress toward a global hydrogen market and delay the role of hydrogen in achieving net-zero goals.

Published academic papers on this research project can be found here[1].

Scalability and Commercialisation

The findings offer clear pathways for scaling hydrogen deployment. In South Yorkshire, maturity benchmarks can help target investment towards production, storage, and distribution projects that comply with international certification criteria. More broadly, the maturity scoring model can be applied to other regional clusters or international groupings to assess and benchmark progress.

Nuances and Trade-Offs

Some trade-offs must be considered in the pursuit of hydrogen market development. While global standardisation could slow short-term deployment due to the negotiation and alignment process, it is essential for ensuring long-term interoperability and stable market conditions. Furthermore,

1 Shamoushaki, M., Koh, S.C. Lenny, Novel maturity scoring for hydrogen standards and economy in G20, Renewable and Sustainable Energy Reviews, 212, (2025).

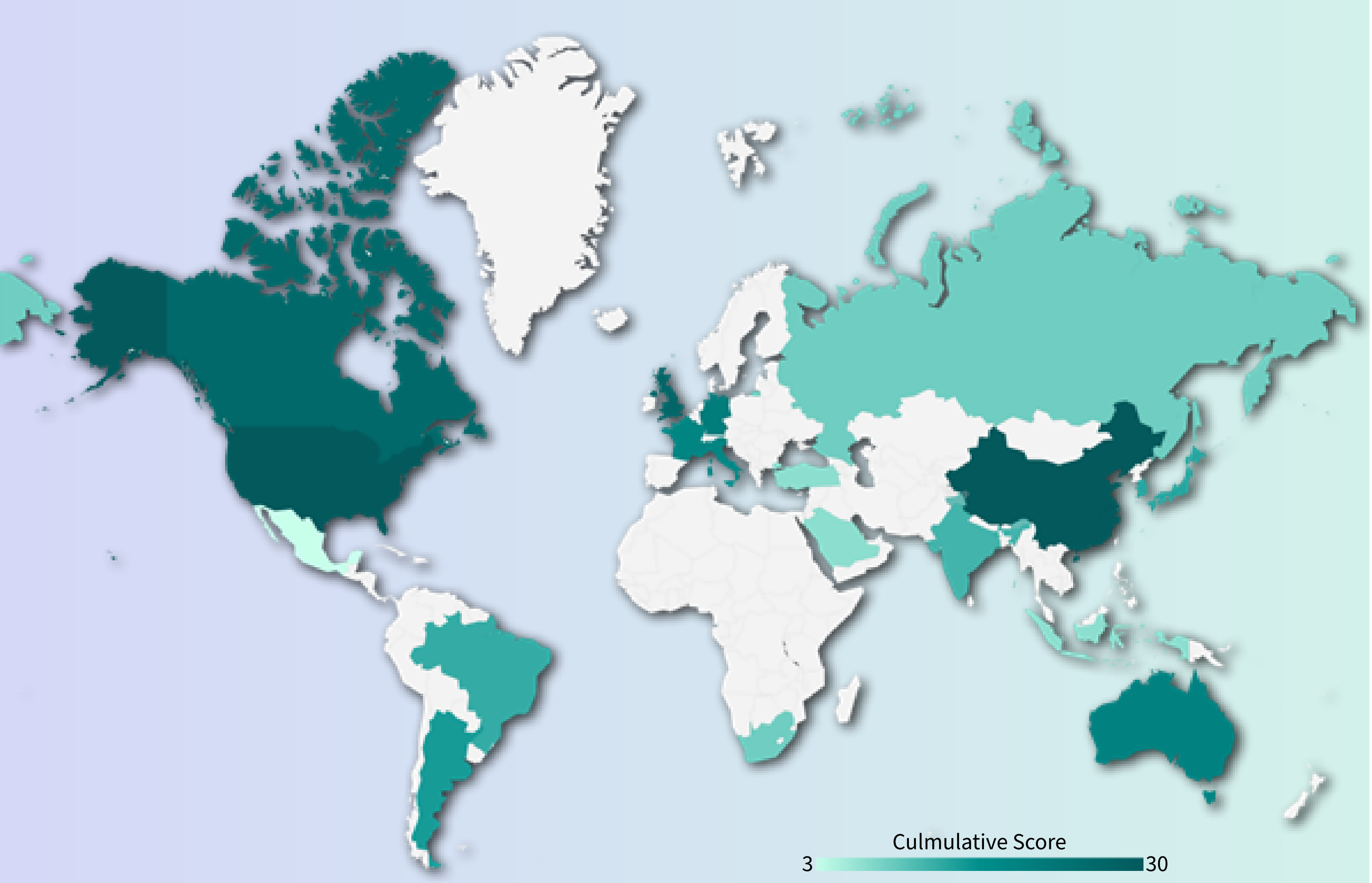


Figure 1: Maturity of hydrogen standards in G20 Countries demonstrated on a world map

regions must carefully balance the pursuit of unique strategic advantages with the need to remain aligned to global frameworks, avoiding potential isolation from emerging international markets.

Policy Insights

While the findings of this research hold global importance as it compares the hydrogen economy in all G20 countries, actionable recommendations can be drawn for South Yorkshire. The following section sets out key policy insights, building on the conclusions and recommendations drawn from the selected publications.

1. Continue to leverage first-mover advantage

   - The UK Low Carbon Hydrogen Standard provides a benchmark for emissions that can be used in international comparison, as well as the UK Low Carbon Hydrogen Certification Scheme – Consultation & Response, and the UK's Hydrogen Strategy which has sections on trade and exports, and explicitly states the importance of keeping "standards and certification for low carbon hydrogen consistent with international standards and schemes where appropriate."

   - As one of the few countries with a formal hydrogen standard, the UK can influence global certification frameworks and international trade agreements.

2. Continue to close strategy–investment gaps

   - In the 2022 UK public sector hydrogen research and innovation document, the government includes "international initiatives" among its focus areas, as well as within UK's Hydrogen Net-Zero Investment Roadmap, there is mention of developing business models for hydrogen transport & storage, export opportunities, and supporting alignment via certification work.

   - Further initiatives are required to ensure the UK's hydrogen strategy is backed by proportionate investment to maintain credibility and leadership, avoiding the "policy–investment mismatch" observed in other G20 nations.

Regional

1. Align with global standards

   - Promote regional readiness by positioning South Yorkshire's hydrogen projects, such as ITM Power, GeoPura, Lhyfe, and Clean Power Hydrogen group, to meet international certification requirements, ensuring competitiveness in global supply chains.

2. Strategic investment has been targeted

   - South Yorkshire Mayoral Combined Authority's (SYMCA's) partnership with Schroders Capital includes infrastructure investment focus via hydrogen generation and storage among other clean energy infrastructure, bringing in external capital.

   - It is recommended to use the Hydrogen Economy Maturity Index to prioritise local investment in hydrogen production, storage, and distribution.

3. Build capacity and skills

   - Work with Sheffield's universities, colleges, Advanced Manufacturing Research Centre (AMRC) training centre, and industry to create specialist training (e.g. accredited courses/ apprenticeships) in hydrogen technologies, ensuring a skilled workforce for scaling.

Next Steps

The research identifies several immediate and longer-term actions. At the international level, the UK should lead diplomatic and technical initiatives aimed at finalising a global hydrogen standard. The Hydrogen Economy Maturity Index should be updated regularly to reflect new standards, financial commitments, and national strategies. In parallel, hydrogen standards should be integrated into trade agreements to ensure that policy frameworks align with market access and competitiveness.

Further research is required to apply the maturity scoring model at sub-national scales and within industry sectors. In addition, economic analyses should be conducted to assess how the adoption of global hydrogen standards will influence trade flows and national competitiveness.

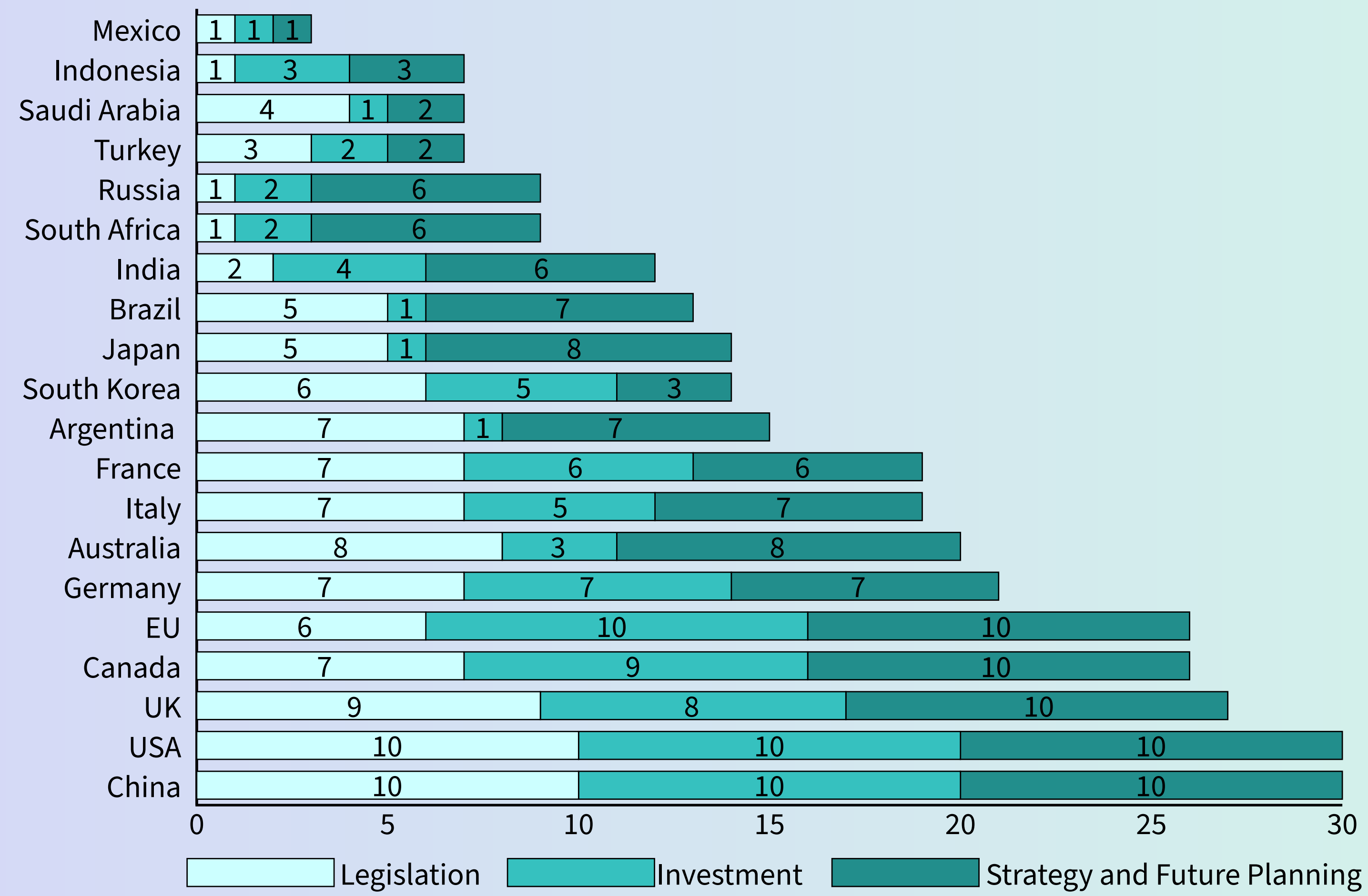


Figure 2: Maturity of hydrogen standards in G20 Countries

Implications of Steel Decarbonisation for Workers and Communities

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Challenge Statement

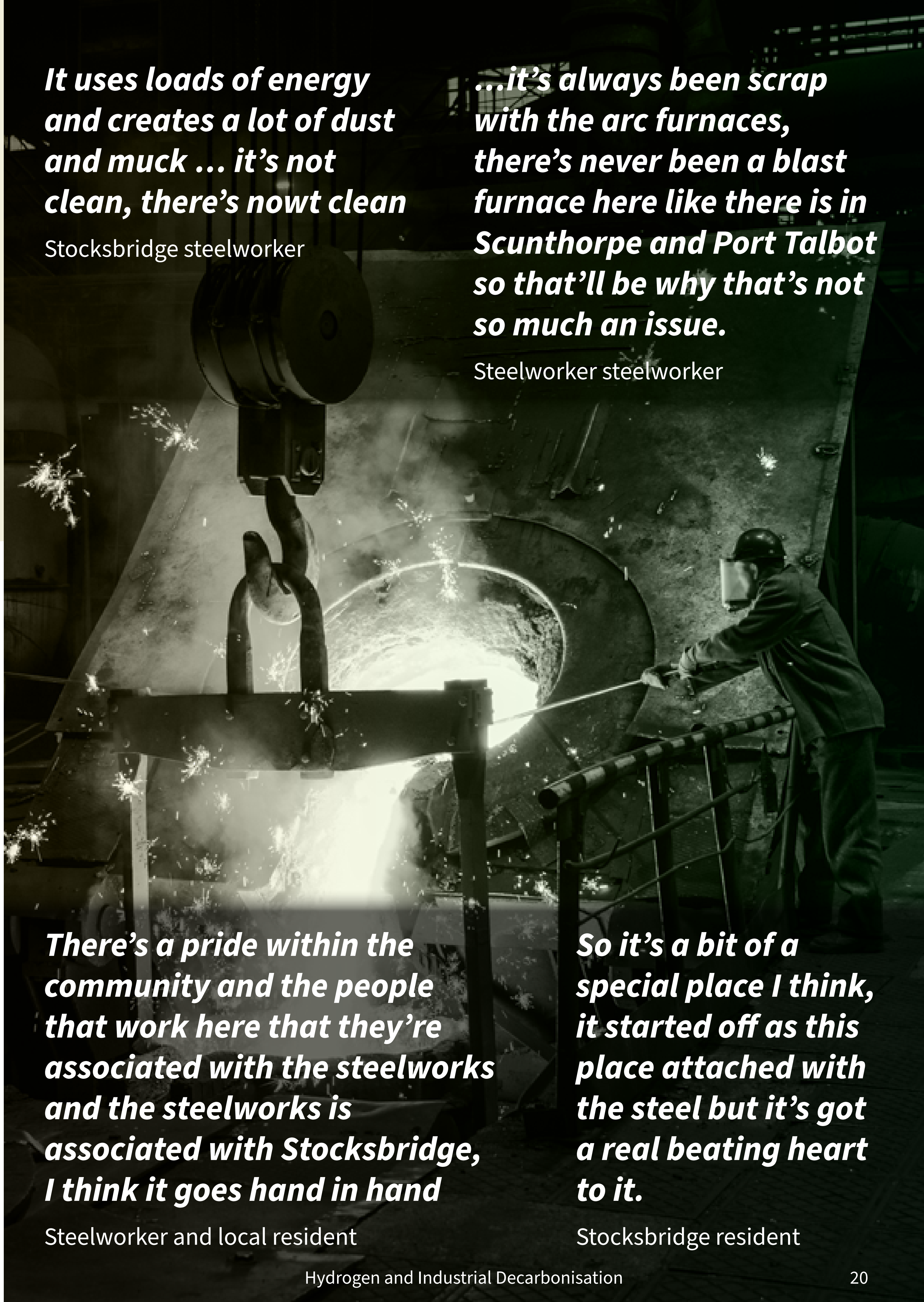
Steel is essential to everyday life. It is used in everything from house-building to surgical tools, from defence to energy systems, and as such is a strategically important industry for the UK. It is also an emission and energy-intensive industry, responsible for 8% of the world's carbon emissions[1] (2.4% of all UK emissions[2]). However, it is also a 'hard-to-abate' industry as decarbonisation potentially requires significant changes to production processes.

Steel decarbonisation can be seen as a phase of restructuring for the industry, in the context of previous phases of industrial change (Figure 1), which also has impacts for workers and communities where steel firms are located.

The development of the steel industry over the late 19th and early 20th centuries led to large concentrations of employment in some places, including communities across South Yorkshire. Those places grew around the industry and the industry often provided social and welfare services to communities. Significant changes to the steel industry since the 1970s have changed its geography, resulting in a relative decline of steel production across Europe and North America. In 1970, 28.3 million tonnes of crude steel were produced in the UK. This declined to 17.8 million tonnes by 1990 and 9.7 million tonnes in 2010[3]. By 2022 production had fallen to 6 million tonnes, almost one-fifth of its 1970 peak[4].

South Yorkshire, an historic heartland of steel production, was particularly hard hit. It is known worldwide for its cutlery production, and more recently specialist steel and advanced metals manufacturing. This is woven through the identity of the region: Sheffield is still known as the 'steel city'; its major sports teams carry this through nicknames 'The Blades' (football) and 'Steelers' (ice hockey). But the steel industry in South Yorkshire has undergone significant change over the last 40-50 years. In 1971, 140,000 people were employed in the steel industry in Sheffield alone. This accounted for half of all the city's jobs. In just over a decade this fell by more than half to 57,000

1 IEA (2023) Tracking Steel.
2 Knight, L and Walker, A (2022) Green Steel. UK Parliament POST Research Briefing Number 672
3 Rhodes, C (2017) UK Steel: Decades of Decline. UK House of Commons Library
4 World Steel (2023) World Steel in Figures.



It uses loads of energy and creates a lot of dust and muck … it's not clean, there's nowt clean

Stocksbridge steelworker

…it's always been scrap with the arc furnaces, there's never been a blast furnace here like there is in Scunthorpe and Port Talbot so that'll be why that's not so much an issue.

Steelworker steelworker

There's a pride within the community and the people that work here that they're associated with the steelworks and the steelworks is associated with Stocksbridge, I think it goes hand in hand

Steelworker and local resident

So it's a bit of a special place I think, it started off as this place attached with the steel but it's got a real beating heart to it.

Stocksbridge resident

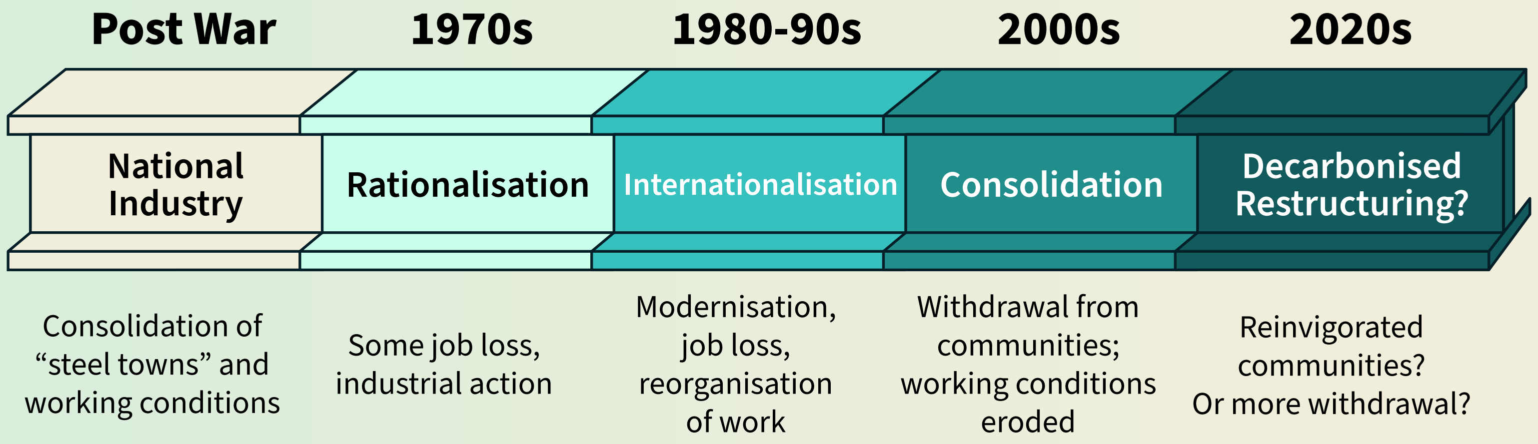


Figure 1: Phases of steel restructuring 1945-2020s

in 1987[5]. This decline in employment numbers continued in the 1990s and 2000s. By 2024 metals production and manufacturing industries were estimated to employ around 15,000 people across South Yorkshire[6]. Despite the decline in the size of the South Yorkshire steel industry, it remains important to the local economy and to national strategic interests. As well as a wide range of metals supply chain and manufacturing businesses, South Yorkshire retains several steel production sites.

Each of these sites are energy intensive and require investment to decarbonise, or risk – in time – production moving elsewhere or ceasing entirely. Decarbonisation also potentially brings opportunities to firms and places that can adapt sooner. As such the low carbon transition brings risks and opportunities for local employment and communities.

To date there has been very little research on how decarbonisation will affect where steel is produced and what the implications of changes to steel production will have on workers and steel communities, despite understanding that previous rounds of industrial change had deep and long-lasting impacts. This was the focus of our research.

Research Response

Our research in South Yorkshire was conducted in collaboration with an international project investigating how steel decarbonisation is beginning to impact on where steel is produced and the implications of these changes for workers and communities[7]. The project included detailed case studies of steel communities in Sweden and the UK. In South Yorkshire we conducted research in Stocksbridge. This research provides detailed understanding of resident and worker experiences of change and perceptions about green steel futures. We sought to understand how present-day experiences and expectations are shaped by historic processes of change. As such our research delved into personal and place-based histories through using oral history techniques and archival analysis. In Stocksbridge we interviewed workers, residents, trade union representatives and other local stakeholders. We also analysed local policy documents, like the Stocksbridge Towns Fund strategy.

The study involved the following methods:

- Document review (company and industry websites, academic and grey literature on the history of UK, Sheffield and Stocksbridge steel)

5 Hudson, R and Sadler, D (1989) The international steel industry: restructuring, state policies and localities. Routledge, Abingdon.
6 Office for National Statistics (2025) Business Register and Employment Survey.
7 For more information see here

- Two tours of the Stocksbridge steelworks (October 2023 and February 2024)
- Visit to Stocksbridge history society archives
- Archival research
- Six focus groups with **20 workers** in total (16 'shop floor'; 4 'management'; all men), and two interviews with senior managers (both men)
- Qualitative oral history interviews with **20 residents** (12 men; 8 women)

Interviews were recorded, professionally transcribed and manually coded using NVivo qualitative data analysis software. Resident interviews lasted approximately 1 hour; focus groups lasted approximately 1-1.5 hours.

Evidence and Outputs

Stocksbridge hosts a Liberty Steel site that has faced continual upheaval since the 1980s. Steel remains central to the town's identity, though employment has fallen from 8–10,000 in the early 1980s to about 650 in 2023[8]. Liberty promotes a "Greensteel" strategy, branding South Yorkshire operations as green due to their reliance on Electric Arc Furnaces (EAFs). However, producing specialist steels at Stocksbridge remains highly energy-intensive, and decarbonisation options remain unsettled. This uncertainty is compounded by wider challenges, including high energy costs and competitiveness concerns for UK steel. Following several years of financial uncertainty, during which most of the company's workers were placed on indefinite furlough, in 2025 Liberty Speciality Steels UK was placed in receivership, under UK government control.

Despite green branding, Stocksbridge's processes—remelting, rolling, and alloying—remain energy and carbon intensive. Decarbonising EAFs might involve renewable energy supplied locally or – more likely given site constraints – via grid-based Power Purchase Agreements. Another challenge is replacing natural gas in reheating furnaces. There are plans to use hydrogen, seen as less capital-intensive than electrification and requiring less reskilling. However, this depends on reliable hydrogen supply, which remains uncertain given that there is no clear timescale for development of 'at scale' hydrogen infrastructure locally.

Worker perspectives[9]

Implications of green steel restructuring were unclear to employees, as no concrete plans existed. Managers were broadly aware of options, but 'shop floor' workers less so. Some referenced job losses at blast furnace sites in Scunthorpe and Port Talbot, although some others believed Liberty's use of electric arc furnaces insulated them from similar challenges. There was also uncertainty about what 'green steel' meant, with some cynicism about whether steel could ever truly be green.

Despite this, and wider challenges for the business, confidence in existing markets for the business remained strong. Participants highlighted demand from renewable energy sectors, such as wind turbines, alongside high-carbon industries like oil and gas and aerospace. This belief, coupled with perceptions that Stocksbridge either already produced green steel or that fully green steel was impossible fostered a belief that jobs would not be significantly affected.

For most research participants, green transition was not a pressing concern. Some managers noted potential challenges, such as reaccreditation for specialist aerospace products. However, ongoing financial uncertainty surrounding Liberty's parent company overshadowed low-carbon transition issues. A few participants linked energy policy and carbon costs to this precariousness, while others cited cashflow problems as barriers to green investment. Moves toward electric steel production elsewhere were associated with job losses, reducing the industry's appeal to new entrants.

Overall, workers viewed Stocksbridge's future in the context of a long trajectory of economic change and job decline over decades. Yet, there was an underlying belief that the steelworks would endure, reflecting a sense of resilience despite uncertainty.

8 All the information and findings in this and subsequent sections are based on our underpinning empirical research. A summary of the Stocksbridge study can be found here.
9 Worker perspectives from Swedish case studies can be found here: Eadson, W., Mukezinovic, D., van Veelen, B., Malmberg, S., Backius, S. (2025) Worker experiences of green steel transitions. Lund University Centre for Sustainability Studies.

I'm not against new development or new ideas at all but I want it to be right for the community and who will be the people who'll work in the offices, are they the kids on the Stubbin estate who would have normally worked in the steelworks?

Stocksbridge resident

Community perspectives[10]

Stocksbridge retains a strong sense of identity, rooted in its steelmaking heritage. Residents described a close-knit community that persists today, with long-standing social connections particularly among those with historic or family ties to the steelworks. Historically, British Steel and its predecessors were central to both economic and social life of the town, providing welfare and community functions. Since the 1990s, this role has diminished, and respondents reflected on the steelworks' decline with mixed feelings. Some mourned its loss, while others highlighted regeneration and Stocksbridge's growing role as a commuter hub.

This shift is not wholly negative. Earlier eras of production reinforced strict gender roles, shaping social life around male workers. Today, reduced engagement by the steelworks and state welfare retrenchment has spurred community mobilisation, supported by strong local ties and the Town Council. These connections, forged through generations, underpin resilience and hope for the future.

Visions for a thriving Stocksbridge varied. Some residents expressed fatalism, while others focused on practical improvements such as housing retrofit, sustainable transport, better amenities, and restored rail links. A recurring theme was the desire for foundational services, connectivity and a future shaped by solidarity. Respondents saw community capacity to organise as vital, rooted in place identity and industrial history. Narratives of independence contrasted with feelings of entanglement in external forces, limiting local control.

Recent developments include the fight to save the town's leisure centre, leading to community management, and a £20m Towns Fund grant in 2023. Official plans emphasise heritage, high street redevelopment, and mixed-use spaces, sparking debate over priorities. While diversification and commuter-town dynamics loom large, respondents stressed that one-off grants and activism cannot replace long-term coordinated efforts. Stocksbridge's future will depend on sustaining its spirit of solidarity amid ongoing economic and political challenges.

What does this mean for the region?

This research highlights a number of key challenges to achieve just transition for the region's foundational industries like steel:

- **Activities to bring about green industrial futures must be sensitive to the fact that industry is tied to worker and community identities**, and that change triggers emotions rooted in lived experiences of previous change. This is especially important when local industrial survival is also seen to be precarious.
- **Local institutions need to reconnect with citizens**. Residents and workers saw local government (Sheffield City Council; South Yorkshire Mayoral Combined Authority (SYMCA)) as distanced from the needs of Stocksbridge.
- **Local and regional stakeholders need to support industrial workers to become active stakeholders in achieving green industrial futures**. This includes access to skills provision and job support where retraining is required, while more broadly providing open communication and engagement around the opportunities and challenges of green industrial futures. Trade Unions can play an important role within this, alongside businesses and policy organisations.
- **Green industrial futures need to encompass community renewal** to overcome fatalism and exacerbating potential 'green backlash'. In Stocksbridge, local community action is strong compared to many similar places but as we know from other research, community action also has its limits and can create challenges/ contestations too; it is not always inherently more 'just', and cannot alone fill the gaps of state and private sector retrenchment.
- **Steel communities' futures are entwined** (especially those directly connected to Liberty Steel at Aldwarke, Brinsworth and Stocksbridge). Changes to operations in Rotherham impact on Stocksbridge and vice-versa. As such it is important that policy solutions recognise these interconnections through a green deal for South Yorkshire steel. This should be at the heart of plans for regional inclusive economic futures.
- **Central government coordination will be critical to low carbon infrastructure provision and regulation**; some of our participants also argued that as a critical industry, steel should be state-owned to provide a just transition and protect the industry. Tata and British Steel have received large subsidies and state intervention to support the conversion to EAFs but at the moment there is no similar offer to support specialist steel producers. The region's leaders need to press for investment in a 'green deal for South Yorkshire steel' or risk further decline and loss.

Next Steps:

We are now working with SYMCA to develop a broader approach to 'inclusive industrial decarbonisation' that seeks to set out a framework for delivering sustainable industrial futures across the region that also addresses key social, economic and cultural challenges. This builds from our work in Stocksbridge along with research on 'green and just' industrial decarbonisation in the UK and internationally[11, 12, 13].

In Stocksbridge, we see opportunity in the current situation of uncertainty for a new community-rooted taskforce to lead community and infrastructural renewal rooted in the town's heritage while working towards a sustainable future. Our research can support development of this. For Liberty Steel, we see an opportunity to work with key stakeholders to support planning for a sustainable steel future working in partnership with workers and communities.

10 Community perspectives from our Swedish case studies can be found here: van Veelen, B., Eadson, W., Melin, Å., Backius, S., Malmberg, S., and Mujezinovic, D (2025) Green steel transitions: impacts on people and places. Lund University Centre for Sustainability Studies

11 Eadson, W and De Leeew, G (2025) Path development politics: contesting regional hydrogen economies in Northern Europe. Geoforum 167

12 Dawley, S., Mackinnon, D., Steen, M and Eadson, W. (2025) State-orchestrated green path development? Industrial decarbonisation in Teesside and the Humber.

13 Eadson, W., Northall, P., Copeman, V. and Ahmad, Z (2023) Humber Industrial Cluster Plan: Societal and Cultural Challenges and Social Innovation Study

HySaaS: Securing Social Licence for Hydrogen Storage and Distribution in South Yorkshire

Project team:
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Project partners:
Hive Hydrogen, Advanced Manufacturing Research Centre, Chesterfield Special Cylinders, Element2

Challenge Statement

South Yorkshire is emerging as a key region in the UK's hydrogen economy, supported by investment across the wider Yorkshire and Humber industrial cluster in production. While hydrogen is widely recognised as essential to industrial decarbonisation, its successful deployment depends not only on technical feasibility and cost reduction, but on societal and institutional readiness. Hydrogen storage and road-based distribution systems will operate within industrial estates, logistics corridors and alongside residential communities. This makes public confidence, emergency preparedness and regulatory clarity critical to delivery. However, the existing evidence base is heavily weighted toward techno-economic modelling and carbon intensity analysis, with comparatively limited research examining multi-stakeholder social acceptance, particularly for storage and transport infrastructure. Existing studies often focus solely on general public opinion and overlook the perspectives of industry actors and emergency responders. This creates a regional evidence gap at a time when South Yorkshire must ensure hydrogen deployment proceeds in a way that maintains trust, supports a just transition and avoids infrastructure resistance that could delay investment.

Research Response

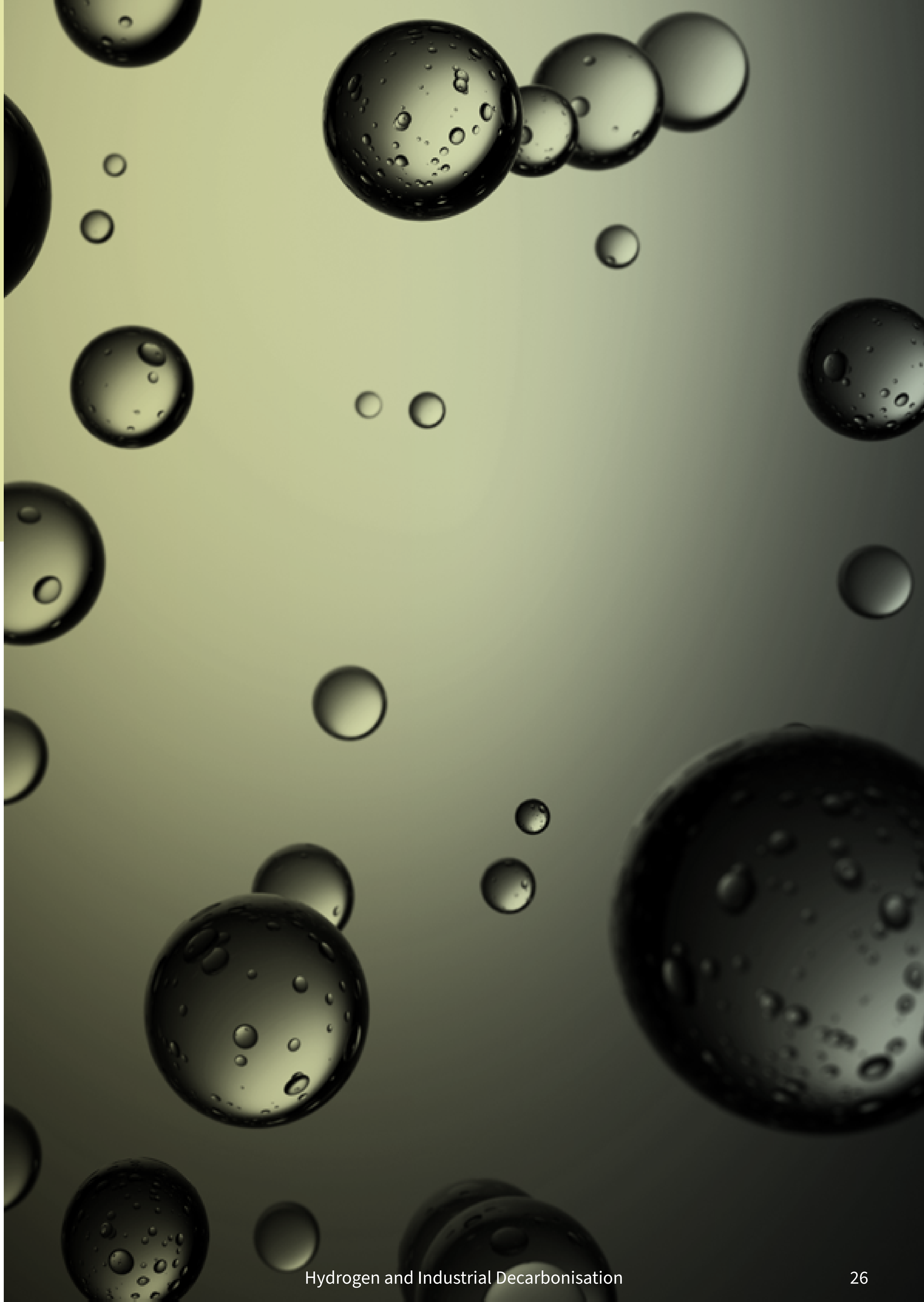
This project responded directly to the regional challenge by providing a structured, multi-stakeholder assessment of social acceptance focused specifically on hydrogen storage and distribution, the parts of the value chain most visible to communities and emergency responders.

Using a mixed-method approach, the research engaged:

- Industry value chain actors
- A nationally representative public sample
- The fire service

The aims were to:

- Assess industry appetite for service-based hydrogen storage models
- Evaluate public attitudes, including the effect of local proximity
- Understand emergency responder



preparedness and information needs

- Generate evidence-based recommendations to support safe and scalable hydrogen deployment in South Yorkshire

Evidence and Outputs

The research found that acceptance of hydrogen storage and distribution is broadly positive but strongly conditioned by perceptions of safety and risk. Across all stakeholder groups, safety emerged as the dominant determinant of acceptance. Industry stakeholders emphasised clear responsibility boundaries between service providers and asset users, regulatory compliance and predictive monitoring systems. Public respondents frequently associated hydrogen with “flammable” and “explosive,” demonstrating that perceived technological risk remains influential despite recognition of hydrogen’s environmental benefits. Fire service representatives highlighted operational challenges including invisible flames and high-pressure systems.

Crucially, all groups responded positively to enhanced monitoring and transparency. More than 80% of public respondents indicated that additional monitoring systems would increase their comfort with hydrogen storage and distribution. This suggests that visible, data-driven safety mechanisms can materially improve acceptance.

Standardisation and clarity also emerged as cross-cutting themes. Industry participants noted that inconsistent design specifications create integration challenges and administrative burden. The fire service emphasised the importance of real-time system data during incident response. Greater standardisation was viewed as enabling smoother deployment and improved safety management.

Important divergences were also identified. Industry actors and emergency responders expressed confidence in regulatory frameworks, whereas public respondents demonstrated persistent technological risk concerns. Support was strongest at national level but declined when infrastructure was framed locally, highlighting proximity-based hesitation. Visual design of transport trailers also influenced public comfort levels.

Key outputs include the Hydrogen Storage as as Service (HySaaS) WP6 Social Acceptance Report, a structured multi-stakeholder engagement framework informed by social life cycle assessment (S-LCA)’principles, and a nationally representative survey dataset.

What does this mean for the region?

The findings suggest that hydrogen storage and distribution can secure social licence if deployment is treated as a governance and trust challenge as much as a technical one.

For South Yorkshire, policymakers should:

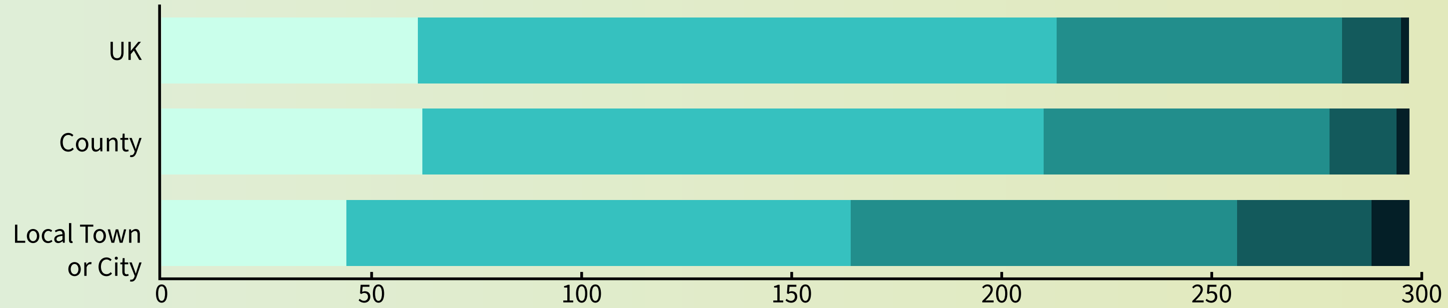
- Prioritise visible and transparent safety mechanisms, including real-time monitoring and clear reporting
- Embed early collaboration with fire and rescue services, including hydrogen-specific training
- Adopt proactive, place-based engagement strategies to address proximity concerns
- Promote standardisation across storage systems and operating procedures
- Ensure clarity in responsibility-sharing within service-based models

South Yorkshire can scale these recommendations through hydrogen deployment demonstrators that combine monitored assets, responder training and community engagement. This approach reduces perceived risk, improves insurability and strengthens the commercial case for hydrogen investment. Lessons learned can be scaled out to other UK regions pursuing industrial decarbonisation.

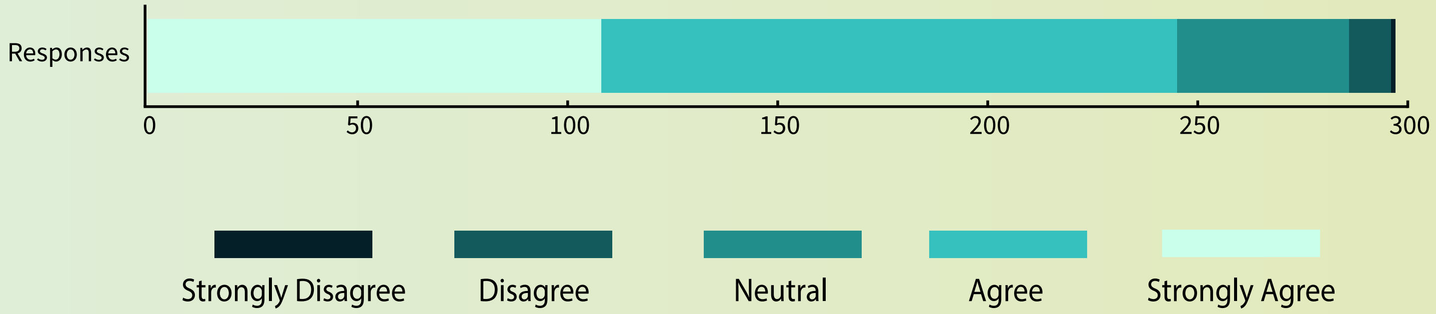
Next Steps:

Further research should track how public attitudes evolve as hydrogen infrastructure becomes more visible and explore how monitoring data can be translated into meaningful public-facing safety indicators. Collaboration opportunities have emerged across emergency services, insurers, planners and infrastructure developers to support an interdisciplinary, durable hydrogen transition.

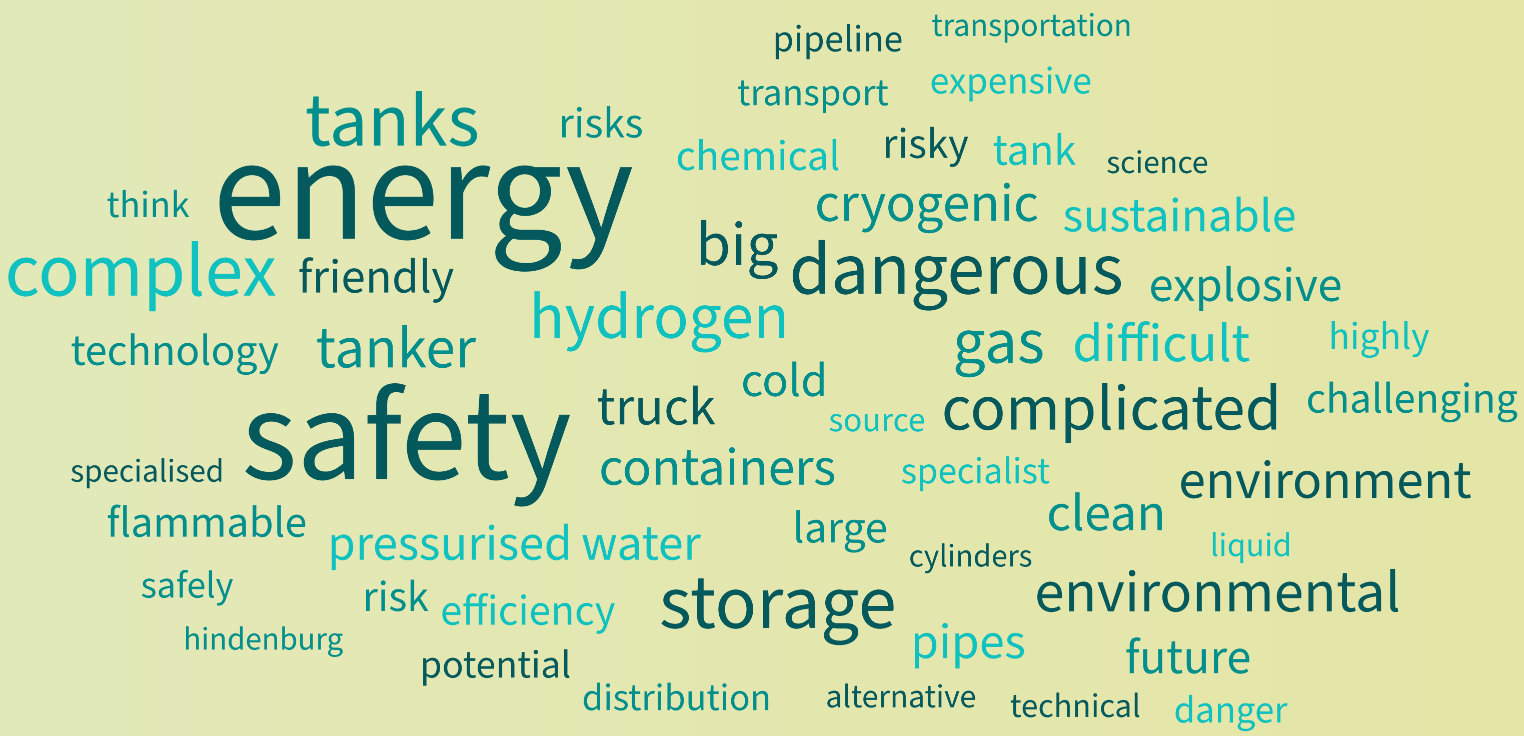
I would support the development and use of hydrogen storage and distribution in the...



I would feel more comfortable with hydrogen distribution and storage if additional monitoring systems were in place to track equipment history, performance and health



Word cloud showing the most common responses to the question: What is the first word/image that now comes to mind when you hear the term ‘hydrogen storage and distribution’?



Towards Net-Zero Aviation: Life Cycle, Resilience, and Decision-Making Evidence for Waste-Derived Sustainable Aviation Fuels

Project team:
University of Sheffield: Prof. Lenny Koh, Eleanor Borrill

Challenge Statement

The UK's Jet Zero Strategy commits to achieving net-zero aviation by 2050, with an interim mandate requiring that 2% of jet fuel demand is met by sustainable aviation fuels (SAF) by 2025. SAFs are a near-term solution for decarbonising aviation because they are drop-in fuels requiring no engine modifications and can be produced from waste resources, supporting both emissions reduction and a circular economy.

Several key challenges remain in advancing SAF development and deployment. Firstly, there is not only a lack of lifecycle data, but also an absence of a comprehensive, comparative evidence base that evaluates all SAF production pathways using waste-derived biogenic feedstocks across key producing countries and energy-mix scenarios. Secondly, evidence on the resilience of SAF supply chains under different feedstock, technology, and trade scenarios is limited. Significant uncertainty exists around the scalability of waste-derived feedstock supplies, potential competition with alternative sectors, and the impacts of geopolitical or logistical disruptions on international trade flows. Thirdly, uncertainty persists over which SAF pathways should be prioritised, as each involves trade-offs among economic cost and scalability, environmental performance across impact categories, technological maturity and conversion efficiency, logistical feasibility of feedstock supply and transport, and broader social and political acceptance.

These challenges have important implications. Without a robust comparative evidence base, policymakers lack the data needed to design effective sustainability standards and carbon reduction policies, while industry faces uncertainty about which pathways deliver the greatest environmental benefits with the fewest trade-offs. Limited understanding of supply-chain resilience constrains long-term investment planning and hinders the design of strategies that ensure both security of supply and progress toward net-zero aviation targets. Moreover, the absence of structured, cross-cutting comparisons between pathways, feedstocks, and national contexts makes it difficult to weigh trade-offs and prioritise sustainable technology-feedstock-country combinations. Addressing these gaps is essential for guiding sustainable SAF investments, improving supply-chain resilience, and informing coherent policy design.

Research Response

Contribution of Research

This project addresses key evidence gaps through three integrated studies. The life cycle assessment (LCA) study provides the first comprehensive, comparative analysis of all SAF technologies certified by the American Society for Testing and Materials that are capable of utilising waste-derived feedstocks[1], measuring environmental impacts across multiple countries and energy-mix scenarios. The supply chain resilience study examines the scalability and stability of SAF production by forecasting feedstock availability, technology adoption, and trade dynamics under various scenarios. The stakeholder engagement and multi-criteria decision analysis (MCDA) study captures stakeholder perspectives across the SAF value chain and translates them into structured evaluations of competing pathways. Together, these approaches generate a holistic evidence base that combines stakeholder priorities, environmental performance, and supply chain feasibility to guide policy and industry decisions.

Evidence and Outputs

Research Findings

A comprehensive assessment of SAF pathways based on waste-derived feedstocks brings together environmental, supply-chain, and stakeholder perspectives to identify the most viable routes toward net-zero aviation. Comparative LCA across key producing countries reveals that environmental performance varies significantly with feedstock type, conversion technology, energy mix, and trade flows. These variations underscore the importance of tailoring SAF pathways to national contexts to maximise greenhouse gas reductions and minimise other environmental impacts.

Building on these insights, scenario modelling links environmental outcomes to supply-chain dynamics, assessing how feedstock availability, technology adoption, and international trade may interact under different future conditions. The results indicate that SAF deployment targets are likely to outpace the sustainable supply of biogenic waste feedstocks, creating potential bottlenecks

1 Borrill, E., Koh, L. and Yuan, R. (2024). Review of technological developments and LCA applications on biobased SAF conversion processes. Frontiers in Fuels, 2.

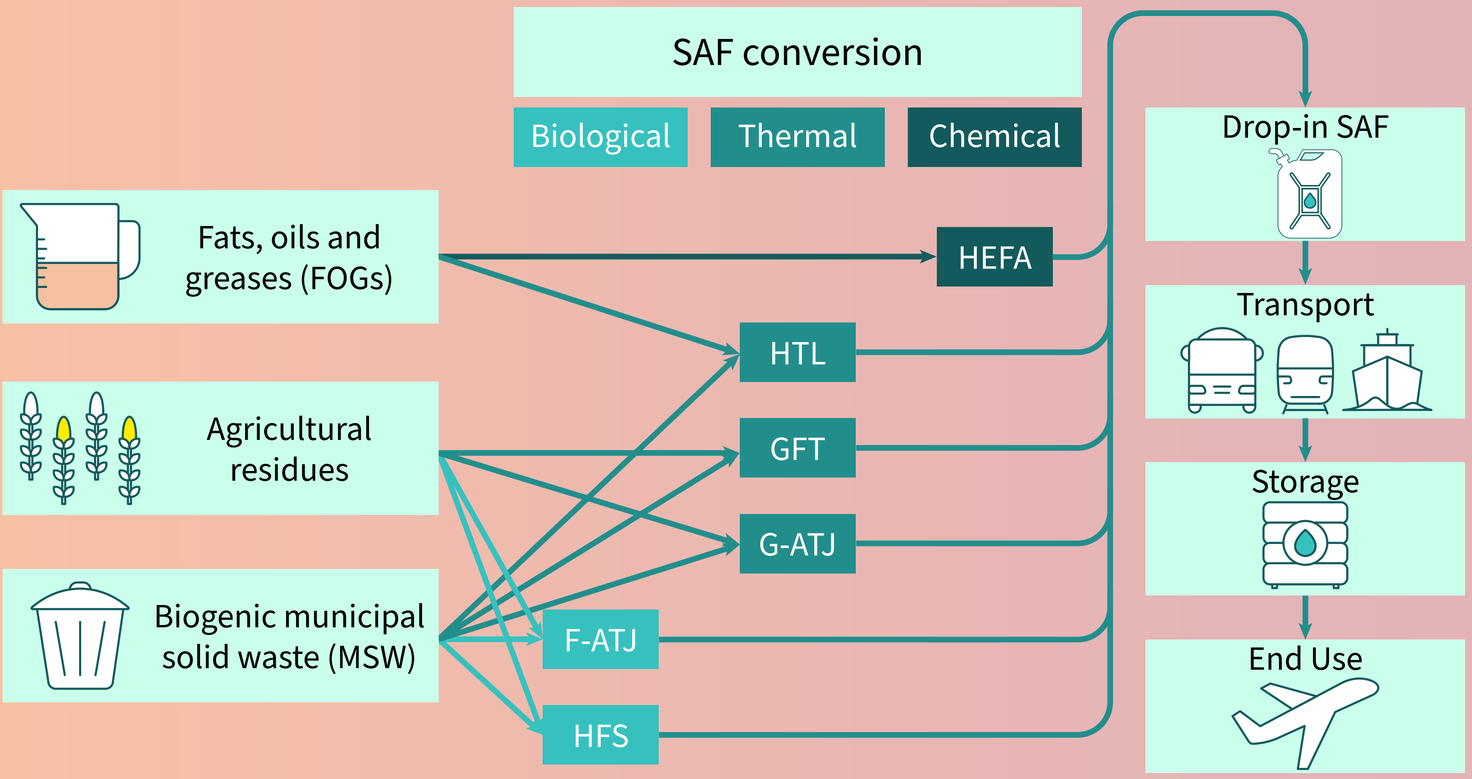


Figure 1: SAF production methods; Hydroprocessed Esters and Fatty Acids (HEFA), Hydrothermal liquefaction (HTL), Gasification with Fischer – Tropsch (GFT), Alcohol-to-Jet (ATJ), Hydroprocessed Fermented Sugars (HFS)

and competition with other sectors. This highlights the need for diversified feedstock sourcing and resilient, internationally coordinated supply chains, integrating both biofuels and synthetic (power-to-liquid) fuels to achieve the necessary scale-up.

To complement these quantitative analyses, stakeholder engagement and MCDA provide an integrated perspective on how different stakeholders, such as feedstock suppliers, fuel producers, airlines, and policymakers, evaluate and prioritise competing criteria such as economic feasibility, environmental sustainability, technical readiness, logistical practicality, and political acceptability. By combining stakeholder preferences with environmental and supply-chain performance data, the MCDA enables a transparent comparison of SAF pathways, identifying which technology-feedstock combinations are perceived as most viable overall and where perspectives diverge.

Together, these integrated analyses provide a robust, evidence-based framework for comparing SAF pathways across environmental, resilience, and socio-political dimensions, supporting more informed decision-making and investment strategies aligned with sustainable, net-zero aviation goals.

Scalability and Commercialisation

For the UK, and South Yorkshire in particular, SAF offers opportunities to integrate local waste resources, advanced manufacturing capacity, and logistics infrastructure into a new green growth sector. South Yorkshire's position as a region with both industrial heritage and research expertise makes it well-placed to participate in SAF supply chains, from feedstock collection to technology development and production.

The proposed re-opening of Doncaster-Sheffield Airport (DSA) further increases the regional significance of SAF. As aviation activity grows, ensuring that operations are aligned with the UK's Jet Zero strategy will be critical. Positioning DSA as an early adopter and distribution hub for SAF could strengthen South Yorkshire's role in sustainable aviation, attract investment, and support the creation of skilled green jobs while demonstrating regional leadership in the transition to net-zero aviation.

Evidence from the LCA and resilience assessments supports targeted scaling of SAF production providing that waste feedstocks and clean energy mixes align, reducing environmental impacts while maximising output potential.

However the below nuances and trade offs should be noted:

- Feedstock competition: Waste-derived feedstocks are also in demand from other bio-based industries (e.g., biogas, chemicals), creating potential conflicts that must be managed through policy.
- Geographical variation: Environmental performance is highly dependent on national energy mixes; countries with fossil-heavy grids may undermine the sustainability of SAF production.
- Technology maturity vs. sustainability: Some pathways with strong emissions reductions face technical or cost barriers, while more mature technologies may offer weaker environmental performance.
- Resilience vs. reliance: Over-reliance on a single feedstock or trade route increases vulnerability to shocks, highlighting the need for diversification.
- Circular economy benefits: SAF from wastes can reduce landfill use and support circularity, but logistics and collection systems must be designed to avoid offsetting emissions gains.

Nuances and Trade-Offs

Recommendations for Industry

For industry, the immediate priority is to use the evidence generated from the MCDA and LCA to determine which SAF pathways present the strongest balance of environmental performance, scalability, and commercial viability. This will enable airlines, fuel producers, and investors to align their resources with the most promising feedstock-technology combinations. At the same time, industry should focus on developing resilient supply chains by building partnerships across feedstock suppliers, technology developers, and end users. Such collaboration can help secure access to consistent waste streams, reduce dependence on imports, and strengthen resilience to feedstock shocks or market fluctuations.

A critical next step for industry is to scale demonstration projects. Pilot and pre-commercial SAF plants should be established both in the UK and internationally, especially for waste-derived pathways that show strong sustainability potential and stakeholder acceptance. Industry actors can also collaborate with local authorities, agriculture, and waste management sectors to embed SAF within circular economy models, turning municipal solid waste, agricultural residues, and other biogenic streams into reliable fuel inputs. Finally, advancing innovation will be essential, in order to improve conversion yields, reduce process energy demand, and accelerate the commercialisation of less mature but environmentally promising SAF pathways.

Recommendation for Policymakers

For policymakers, the research highlights the need for stronger and more targeted incentives. SAF mandates, subsidies, and funding mechanisms should be designed to only favour pathways with the strongest evidence base for environmental sustainability and supply chain resilience. Policymakers should also ensure that SAF is embedded within broader waste and circular economy policies, enabling scalable use of municipal solid waste, agricultural residues, and other feedstocks that can contribute to aviation decarbonisation. Alongside this, national frameworks and international agreements are needed to manage competition for waste-based feedstocks across aviation, energy, and chemicals sectors, reducing risks of scarcity or unsustainable resource allocation.

Policymakers should also support the development of resilient SAF infrastructure, particularly at regional hubs such as the proposed re-opening of Doncaster-Sheffield Airport. Investment in storage, blending, and distribution systems will be vital to enable SAF adoption at scale. On the international stage, the UK should champion harmonised SAF sustainability standards and certification frameworks within International Civil Aviation Organization (ICAO) and related bodies, ensuring market interoperability and building investor confidence in SAF markets. Finally, investment in workforce development is essential. Expanding training and education in SAF technologies, logistics, and circular economy supply chains will ensure that both industry and regions like South Yorkshire have the skilled workforce required to support the transition to sustainable aviation.

Scoping a Hydrogen Network for the South Yorkshire Region using the Network Optimisation Model AENi

Project team:
University of Sheffield: Prof. Solomon Brown, Dr Diarmid Roberts, Dr Victoria Brown, Thomas Cowley, Joseph Hammond

Challenge Statement

The South Yorkshire area has a large number of energy intensive industrial sites, producing a range of products including glass, steel and ceramics. Not all of the processes behind these industries can be decarbonised using electricity, hence there is a need to swap out hydrocarbon fuels for hydrogen, or deploy small scale carbon capture plant. Unlike for electricity, there is no national network for transport of hydrogen or CO_2 that individual emitters may currently tap in to.

The UK government has already provided funding to address this issue, but only for specific larger industrial clusters, such as the Humber Industrial Cluster. As such, there is a lack of research on the feasibility of hydrogen/CO_2 networks in other areas. Additionally, the South Yorkshire area has the challenge of having several large emitters located within an urbanised environment, where routing of networks is considerably more complex than on greenfield sites, or those wholly owned by large industrial companies.

This case study represents a first step toward addressing the industrial decarbonisation challenge in South Yorkshire.

Research Response

Developing shared infrastructure is economically complex, as multiple stakeholders with differing needs and motivations must be catered for. Additionally the development of feasible network routes and modelling of their costs and timescales is complicated and data-intensive, which may prevent industry partners from initiating the research individually. The South Yorkshire Sustainability Centre (SYSC) can act as a central coordinator for multiple industries that may not otherwise share their requirements, and give them collaborative access to researchers and modelling tools.

The specific aims of this research project were to:

- Gather data on notable CO_2 emitters in the South Yorkshire region, and estimate equivalent annual hydrogen consumption.
- Research possible locations for a grid connection large enough to site a hydrogen electrolyser.
- Use the network routing tool AENi to determine a preliminary network route as the first step in assessing feasibility.

Figure 1: Graphic representation of relative CO_2 emission scale of the 21 industrial sites considered in this case study.

Figure 2: Least cost hydrogen network for 21 emitters in the South Yorkshire region, found using routing software AENi. The largest dot represents a hydrogen electrolyser plant sited at the Thurcroft Grid Supply Point (400 kV transmission). Credit Joseph Hammond of AENi.

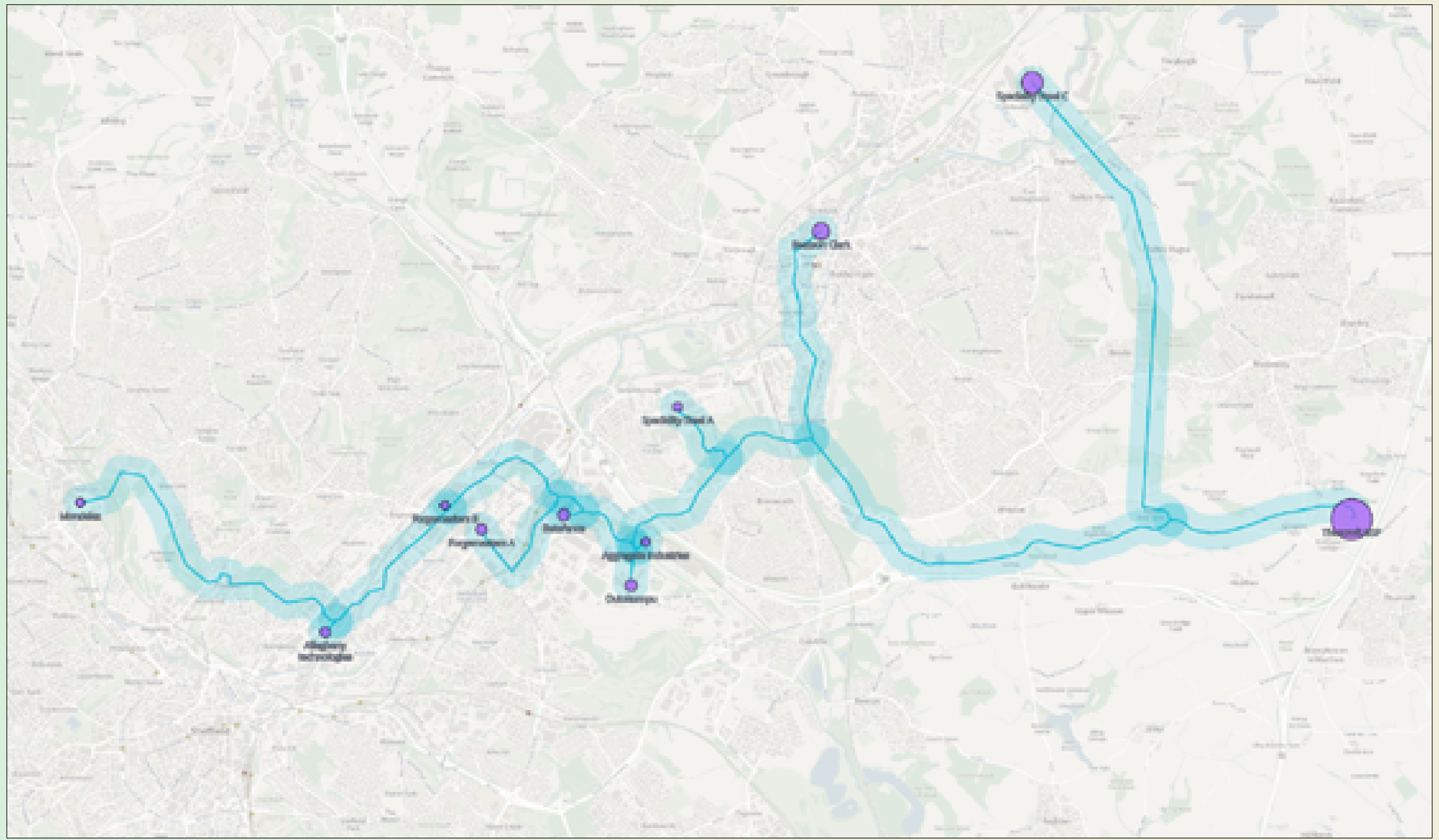


Figure 3: Least cost hydrogen network for 10 emitters in and around the Lower Don Valley area, found using routing software AENi. The largest dot represents a hydrogen electrolyser plant sited at the Thurcroft Grid Supply Point (400 kV transmission). Credit Joseph Hammond of AENi.

Evidence and Outputs

The case study considered 21 large emitters located in South Yorkshire. These ranged greatly in size as shown in Figure 1.

The pipeline routing/sizing software AENi[1] developed as a spin-out from the Brown group at University of Sheffield was used to find a cost optimal network linking these sites to the grid supply point at Thurcroft. The network found is shown in Figure 2. The network shows several notable features, including a tendency to follow existing roads and to take longer detours around built-up areas. The latter is clear to see around Doncaster, at the top right of the image.

A smaller network was then found for a set of 10 emitters in and around the Lower Don Valley (LDV) area[2], as shown in Figure 3.

For the LDV network, the average electricity consumption of the electrolyser was modelled as 70 MW. This is significant, as it is considerably lower than the current headroom of ~200 MW at the Thurcroft grid supply point. The larger South Yorkshire network has an average electrolyser power consumption of 202 MW, which likely cannot be met at Thurcroft. However, the greater challenge for the larger network is the long pipeline distances to parts of the network, particularly to the West.

The representation of the industries in the modelling was crude; it was assumed that all recorded CO_2 emissions were due to burning natural gas, that all of this gas would be replaced by hydrogen, and that hydrogen would be consumed at the same rate throughout the year. These assumptions must be improved upon by further collaboration.

What does this mean for the region?

The findings of the case study are significant in that they provide preliminary evidence that a hydrogen network for industrial sites is likely feasible using existing electrical grid connections. The next step is for policy makers to support more in depth research where partners collaborate more deeply with the researchers to develop network designs that are feasible from an economic and timeline perspective.

The modelling tool used in this case study could easily be applied to other regions with notable industrial activity, such as South Wales.

Next Steps

- Carry out further partner engagement to understand which decarbonisation option they prefer (hydrogen will not be best for all).
- Develop a methodology for analysing the economics of sub-sections of the network to predict the most favourable roadmap for rollout.
- Collaborate with partners in areas where the network cost is lowest in order to develop a more accurate model, and gauge willingness to pay.

1 https://www.runpilot.io/
2 Sheffield City Council (n.d.) Lower Don Valley Master Plan. Part 6 - LDV Districts.