THE ROLE OF HYDROGEN IN DECARBONISING THE STEEL INDUSTRY: UPSTREAM AND DOWNSTREAM IN THE UK AND ONTARIO

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ABSTRACT

Currently the iron and steel industries are a significant contributor to global carbon emissions due to their reliance on fossil fuel powered processes. Use of technologies exploiting hydrogen as a fuel have gained prominence as a potential route to decarbonise the sector. This research offers a hitherto under-explored understanding of the enablers and barriers to industry adoption of hydrogen technologies, using the context of the steel industry in the UK and Ontario, Canada as case studies. Through thematic analysis of semi-structured interviews with key businesses and stakeholders across the steel network, we build a causal map which explicates the decision-making underpinning adoption of hydrogen technologies in the processing and production of steel. The outcomes will inform priorities for technological development and policy to support decarbonisation of steel manufacturing, a problem of international importance.

Understanding the interdependency between decisions, uncertainties and goals are essential for informing effective strategy development in such a socio-technical problem. Causal mapping provides a means to visually represent the cause-effect relationship between relevant factors within a system. We explore issues with goals such as carbon emissions and 'net-zero', uncertainties related to carbon taxes, government policy, and hydrogen colour classification, as well as hydrogen embrittlement, costs and technology replacement in relationship to hydrogen adoption. The corresponding policy-facing causal map interprets this understanding into a decision-making tool to assist the journey to net-zero. We adopt an inductive reasoning approach by firstly analysing data gathered from the UK industry, developing a concurring hypothesis and testing this on the Canadian industry. Our paper presents the preliminary data and findings, and argues that the three main barriers to hydrogen technology adoption in the UK steel industry are: (1) Cost; (2) Supply; (3) Knowledge.

This project is in collaboration with the National Manufacturing Institute Scotland (NMIS). NMIS have formed a conglomerate of industrial partners from the UK forging industry and furnace companies to develop hydrogen powered furnace technology.

Keywords: hydrogen furnace, steel, barriers, enablers, sustainable transition, net-zero

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1. Introduction

Steel forming and forging is a global, carbon-intensive industry; the World Steel Association (2021) found that 1,860 million tonnes of steel were produced in 2020, which was accumulatively responsible for 2.6 billion tonnes of carbon dioxide (CO2) emission, and represent between 7% and 9% of global anthropogenic CO2 emissions. Annually, the UK produces approximately 7 million tonnes of steel which emits 11.6 million tonnes of CO2 (UK Steel, 2022). In comparison, in 2019, the three largest steel plants in Ontario, Canada, had a production capacity of 10.4 million tonnes of steel and emitted 12.37 million tonnes of CO2 (Canadian Steel, 2019; Ontario Ministry of the Environment, Conservation and Parks, 2021). The steel sector in the UK and Ontario are therefore somewhat equivalent and provide an appropriate basis for valuable analysis. This is further exampled by the sector's employment levels in their respective countries; the UK iron and steel industry bore approximately 33,400 jobs in 2019 (House of Commons, 2021). In contrast to this, Ontario's primary metal manufacturing industry (46.7% of which is upstream steel production, and 16.3% is downstream steel processing) employed 29,231 in 2021 (Government of Canada, 2022). This equates to around 18,416 steel-specific jobs and accounts for around 50% of the industry's employment in the country. Though Ontario's steel industry has a lower employment rate than the UK, the Government of Canada (2022) have specifically outlined their expectation of moderate growth in employment levels as a result of direct investment in clean steelmaking within the region.

Industrial decarbonisation is a priority for both the UK and Canada, both of which having outlined their commitment to achieving net-zero emissions by 2050. Nonetheless, the Government of Canada (2021) and UK Steel (2022) have emphasised that the policy environment is critical in encouraging, rather than disincentivising, decarbonisation, which is often a costly transition. Policy intervention is the key enabler to achieve these ambitious targets, whilst maintaining the industries' international competitiveness (UK Steel, 2022).

The UK Parliament (2022) identify three main pathways to decarbonise the steel industry: (1) increased use of electric arc furnaces which are typically used to recycle scrap steel and encourage a circular economy (the UK has an abundance of scrap steel which is commonly exported (UK Steel, 2022)); (2) employing carbon capture and storage (CCS) technology, and (3) direct reduced iron (DRI) using renewable (green) hydrogen.

This paper focuses on the third option: the use of green hydrogen. We investigate the barriers and enablers of introducing hydrogen furnace technology to decarbonise the steel industry, in the UK and Ontario. This research approach includes semi-structured interviews which are being analysed through an inductive coding method and thematic analysis.

This project had been divided into two phases: (1) the UK; (2) Ontario, Canada. At the time of writing, data collection is almost complete in the UK, with this phase expected to be finalised in May 2023. Interviews have been completed with a range of stakeholders including furnace engineers, senior policy advisors and hydrogen business strategists. Phase 2 of the project (data collection in Ontario) will then commence in June 2023. The project will be complete in Autumn 2023.

The key deliverable of this project is the policy-facing decision model (in this case, a causal map) which will be constructed through synthesis of the identified themes. Unsustainable practices are often a result of incoherent and inconsistent policies; improving policy coherence requires better integration of economic, environmental and social outlooks (OECD, 2001). A causal map is a useful tool in understanding the interdependency between decisions, uncertainties and goals which is critical in informing effective strategy development in a socio-technical problem such as the one at hand, and encouraging the required integration. As acknowledged by the UK Government (2021), supporting technology through policy developments is critical in successful industrial decarbonisation, thus validating the importance of this output.. This is widely agreed amongst literature, much of which suggests that an effective carbon pricing policy is often successful in the implementation of climate policies and encouragement of sustainable transitions (Edwards et al., 2021; Dominioni, 2022). However, recent studies have emphasised hydrogen as an emerging technology, with hydrogen strategies becoming more prevalent within the policy focus of countries including the UK, Ireland and the USA (Hammond, 2022; Martins & Carton, 2023).

An analysis of existing literature has found that prior research regarding hydrogen is largely focused on its capability as an alternative energy source, it's subsequent role in industrial sustainable transitions, and case study research which, like this study, identifies the barriers and enablers of sustainable transitions. For example, Rynikiewicz (2008) and Wesseling et al., (2017) found that the production structure of the steel industry is both energy and capital intensive which makes technological innovation high-risk and costly, and develops resistance towards transitions. Combined with aforementioned policy findings, this suggests that companies, governmental agencies and knowledge institutions (Critical stakeholders recognised by Wralsen et al., (2021)) should collaborate to drive the hydrogen-based sustainable transition within the complex steel industry; these sources identify policy as the critical enabler of this collaboration, further validating the relevance and importance of this research.

The distinctive nature of this research is that it is an empirical study with UK and Canadian stakeholders. Existing literature fails to consider the decarbonisation strategies within industry across different geographical contexts and from the perspective of the industrialist. This is important; the OECD (2022) highlight that the decarbonisation of the steel industry is a global challenge that requires a collaborative response among countries. This view is further supported by Richardson-Barlow et al., (2022) who recognise the importance of international emissions goals and progress, and argue that industrial decarbonisation is of little use if not implemented on a wider, collaborative scale. The comparative nature of this study will not only offer assistance in policy-facing decision-making per the UK and Ontario as separate entities, but also offers the potential to identify synergistic strategies to facilitate the 'collaborative response' deemed so critical within literature.

In this paper, Section 2 provides a summary of the methodology employed, Section 3 will outline the study's findings so far (primarily focusing on Phase 1 of the project), and Section 4 will offer a discussion of such findings. Section 5 will outline the next phase of the study (the Ontario-based data collection and analysis). Finally, Section 6 concludes the paper, summarising the key findings so far.

2. Methodology

Qualitative methodological approaches allow for in depth examination of the issue at hand, often through understanding the behaviours of values, beliefs and assumptions (Choy, 2014). By adopting a qualitative approach in our study, we aim to develop deep insights and understandings of the barriers and enablers of hydrogen furnace introduction.

Much of the methodological choices in our work follow that of a comparable study by Ohman et al., (2022), which explored the barriers and enablers of hydrogen furnace introduction to the European steel industry with a particular focus on the success of Sweden. Ohman et al., (2022) used a case study methodology and conducted and analysed twenty qualitative interviews. Their method has provided a benchmark of validity for our study.

Specifically, we gathered the perceptions of key businesses and stakeholders across the steel network through twenty semi-structured interviews with experts in the UK, and plan to follow with twenty semi-structured interviews with experts from the Canadian industry. In this case, an expert has been defined as a person with extensive knowledge and industry practice, which is rationalised by Bolger (2017), and we have selected for experience across four knowledge areas: steel, business, policy and engineering, identified through analysis of key themes within existing literature. Within these areas, we aim to capture a broad range of perceptions and, so far, interviewees have experience relating to sustainable business strategy, operations management, hydrogen-based business transitions, policy advising and furnace engineering. Figure 1, below, demonstrates the breadth of experience offered by a sample of participants, both in terms of their knowledge base and years in industry. On average, each participant offers 14.8 years of relevant experience.

Expert judgement is inherently prone to error and bias, especially when the knowledge analysed by the researcher within an interpretative process, such as that of our causal map. To mitigate such, we have employed grounded theory as a knowledge elicitation technique, which Pidgeon et al., (1991) argue is the most efficient method to systematically analyse semi-structured interview data whilst minimising the application of prior theoretical assumptions and therefore, the impact of researcher bias. This ensures that the study's conclusions are a faithful representation of the qualitative data.

The first stage (Phase 1) of the data collection process is focused on the UK-based experience. Once experts were identified and semi-structured interviews were conducted, inductive coding was applied as the first stage of data analysis. This was subsequently followed by a thematic analysis, which is the present stage of our research. Following the identification of key themes, an initial hypothesis will be developed and the findings translated into a final causal map which embodies the perceptions of key stakeholders in the UK steel industry.

A causal map is a useful tool in understanding of the interdependency between decisions, uncertainties and goals which is critical in informing effective strategy development in a socio-technical problem such as the one at hand. The development of this model remains an iterative process due to the rapid development of hydrogen technology and evolving government policy concerning such (for example, the UK Government's Department of Business, Energy & Industrial Strategy was disbanded part way through this project and replaced by the Department for Energy Security and Net Zero and Department for Business and Trade, both of which had reformed priorities). Some studies, such as that of Pyrko and Dorfler (2018), adopt a relativist approach and create a causal map after each interview, which represents the views of each individual participant. These maps are then merged to create one map with clear interdependencies. However, this study has applied a more interpretivist approach whereby the data is analysed and interpreted within a sole causal map at the end of each corresponding stage of data collection. This is rationalised by a similar method being applied in a comparable study by Penn et al., (2022), who created collaborative causal maps using the perceptions of multiple individuals in the context of transport decarbonisation.

We will then examine the issues within the context of the steel industry in Ontario, Canada (Phase 2). An additional twenty semi-structured interviews will be conducted using experts with similar levels of experience and knowledge as participants in the UK-based data collection process. Our comparative approach will allow us to test our hypothesis in an alternative geographical environment but within the same industry that is also investing in hydrogen-based technology. As before, these interviews will be analysed using inductive coding, and an additional causal map will be produced, this time from the perspective of Ontario-based stakeholders.

Figure 1 – This table illustrates the experience of a sample of interviewees who have been selected due to their breadth of industry knowledge and experience within their roles.

Interviewee	Steel	Engineering	Business	Policy	Experience (years)
1	✓	✓			18
2	✓		✓		28
3	✓	✓			11
4	✓		✓		13
5	✓		✓	✓	10
6	✓			✓	9
7	✓	✓			21
8	✓	✓			10
9	✓	✓	✓		18
10	✓			✓	10
Average	100%	50%	36%	29%	14.8 years

3. Findings so far

Phase 1 of this study is complete, with Phase 2 commencing June 2023. As such, the findings in this paper are solely from the perspective of the UK steel industry.

Preliminary results indicate there to be three main barriers to the UK's introduction of hydrogen technology: (1) Cost; (2) Supply; (3) Skills and knowledge. We expand on each in turn:

Cost: Industrialists widely agree that introducing hydrogen furnaces within steel production is both capital and energy intensive. Firstly, UK furnaces are old and not capable of operating with hydrogen – they must be either refurbished or rebuilt to be able to do so. Despite offering lower costs, a furnace refurbish would be mostly insufficient given the age of UK furnaces; therefore, furnace rebuild is often necessary, yet significantly more expensive. In addition, a rebuild is likely to require a temporary shutdown of operations which has opportunity cost implications in terms of lost profits.

Hydrogen supply: Hydrogen-powered steel furnaces are energy intensive. Interviewees share concerns that the UK does not currently have a sufficient supply of hydrogen to meet the high demands of the country's steel industry. In general, our findings indicate that industrialists, and in particular business strategists, believe that the UK's hydrogen production capability is as of yet unexplored, with government policy instead choosing to prioritise the generation of offshore wind energy. Whilst renewable wind energy is likely to eventually power green hydrogen production, interviewees raised concerns that current hydrogen production remains dependent on both electricity and natural gas. This not only hinders decarbonisation efforts, but is especially concerning given the UK's high electricity costs when compared to that of European countries such as Sweden. This impacts the UK steel industry's international competitiveness and disincentivises investment in hydrogen production, thus is perceived to be a significant barrier when considering the sustainable transition of the UK steel industry.

Skills and knowledge: The UK steel industry is facing a skills gap and shortage of the required knowledge to transition to hydrogen powered furnaces. Our research insights indicate that there is a significant shortage of furnace engineers in the UK which limits the capability of the sustainable transition. In addition to this shortage, the existing workforce does not have the knowledge required to effectively implement the change; an upskill of the existing workforce is critical. However, this is often limited by resistance amongst experienced steelworkers arising from uncertainty. In comparison to other steel intensive European countries such as Germany or the Netherlands, the UK also lacks the technological capability (such as data capture technology) that would enable an efficient transition to hydrogen technology. This also contributes to the uncertainty felt by the existing workforce and demonstrates the interdependency between the barriers and enablers within this issue.

Importantly, existing resources fail to consider the perception of the industrialist in Ontario; these potential findings cannot be considered certain and solely provide an initial basis for discussion.

4. Discussion

The UK steel-industry faces significant barriers to hydrogen furnace adoption. These are primarily cost due to a lack of government funding (in comparison to the Canadian steel industry;) which has subsequently led to a lack of investment in infrastructure (both furnace specific, and infrastructure relating to the storage and transportation of hydrogen). As a consequence of this, UK furnaces are not hydrogen ready, nor are suitable for a refurbish. Instead, industry professionals have suggested that a complete rebuild is required which is both capital intensive and generates an opportunity cost arising from the factory shutdown required. A key influencing factor on this seeming lack of investment derives from steel's position as a highly exported commodity. As argued by the European Parliament (2021), many countries' competitive position in the industry has deteriorated in recent years due to the downward-price trend arising from the oversaturation of the global steel market and under-pricing of steel exports from China, where decarbonisation efforts are minimal. For steel companies, increased investment will have a negative impact on profitability in an environment where their competitiveness is already threatened. Our causal map (an extract of which is seen in Figure 2 below) recognises the influence of the international steel market and proposes increased government-funded investment or subsidies to maintain the UK's competitiveness whilst promoting the decarbonisation of the sector. Competitiveness can be restored by international collaboration measures which encourage the market creation for green steel (Vogl, et al., 2021), which this model considers.

However, the barriers to decarbonisation measures cannot solely be attributed to a lack of government funding. As identified by policy makers, the UK is further disadvantaged by its geography. Canada has vast open spaces where hydrogen infrastructure can be positioned outside of human habitation; 80% of Canada remains uninhabited, though there should be consideration for the Indigenous communities who occupy around 6.3% of total landmass and rely on the tenure of such for sustainable economic development (OECD, 2020). The integration of hydrogen infrastructure is arguably more difficult in a smaller country such as the UK which has around 25% of available land (this excludes greenbelt protected land, and areas with high-risk flood zones) (UK Government, 2022). In addition, policy advisors have argued that citizens are often reluctant to allow such infrastructure close to their homes, especially in the case of hydrogen which has distinctive chemical properties that could endanger life (for instance, hydrogen's flammability and Nitrous Oxide emissions has been a cause for concern to those living locally to a hydrogen pilot (Whitby Hydrogen Village, 2023)). Nonetheless, the data acknowledges potential mitigation methods to limit the impact of this barrier, primarily through offering financial compensation to those affected. As demonstrated by Cadent's hydrogen village, these inherent risks can be assuaged and should not denounce the steel industry's decarbonisation measures, which are critical to achieving the UK's net-zero goals and preserves the industry's global competitiveness.

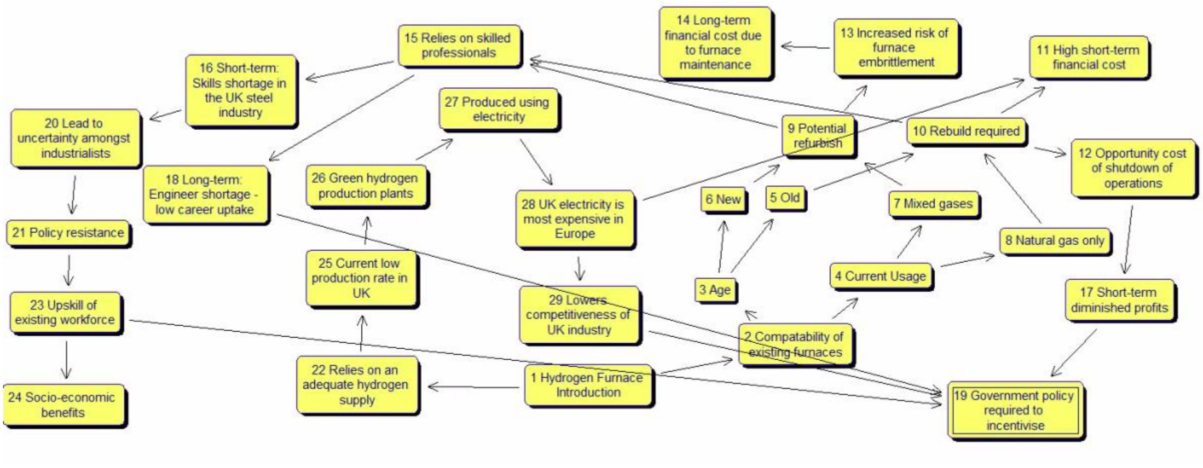
Furthermore, the UK lacks competitiveness from a complementary technology perspective. Interviewees with international experience indicated that technology such as data capture (which, for example, is used elsewhere to measure furnace efficiency) is widely absent in the UK industry. This not only impacts the adeptness of sustainable transitions, the absence of such data encourages uncertainty amongst stakeholders. Combined with a lack of communication from government, uncertainty is rife amongst those interviewed. Business strategists have argued that this uncertainty develops to question the true effectiveness of hydrogen introduction in the UK which, in turn, hinders the efficiency of the sustainable transition of the industry and generates resistance across the industry.

Similarly, the UK faces a skills shortage; young people are not pursuing engineering careers and there is a shortage of training opportunities for current employees. Policy should focus on both incentivising engineering careers, and upskilling the existing workforce. Policy makers have implied a resistance amongst the existing workforce to respond to change in their industry, instead favouring 'tried and tested' steel production in an uncertain environment. In theory, implementing education-based fiscal policies such as local workshops should improve employment rates and encourage growth and social inclusion (Weedon & Tett, 2013). However, this has been contested by some academics who argue that upskilling the workforce will not automatically upskill the work, particularly when the workforce resist (Lewis, 2010). This study finds that whilst policymakers perceive industrialists to be resistant to change, attitudes in industry are the opposite; both engineers and business strategists demonstrated a willingness to engage in skills development despite their uncertainty, and all stated that they would attend an upskilling workshop if presented the opportunity. This further demonstrates the influence of the discord of miscommunication between industry and policy, as is highlighted on the causal map.

As a result of these findings, an initial policy-facing causal map has been drafted; an extract of such is shown in Figure 2, below. As this study found, an influence on the main barriers of hydrogen adoption is the uncertainty felt within the industry. This model will alleviate this uncertainty by assisting decision-making for both industry and government. The main implication of such is a more efficient transition towards using green hydrogen as an energy source in the steel industries of the UK and Canada. Given the carbon-intensive nature of the industry, this will have a profoundly positive impact on the environment and will assist in achieving the countries' respective net-zero goals. From an economic perspective, policy makers will have a clearer viewpoint of the position of industry; as found within the data analysis, a cause of the skills shortage is the poor communication between industry and government. This model will communicate the barriers faced in industry to policy-makers which should lead to more efficient and effective policy measures (for example, more focused investment on education to upskill the existing workforce, an incentive plan for steel manufacturers to produce green hydrogen to address the supply shortage, or improved trade policies which the OECD (2022) argue are essential to underpin the industry's decarbonisation). As was outlined above, the UK steel industry bore approximately 33,400 jobs in 2019 (House of Commons, 2021). Decarbonisation is inevitable; a failure to address the intrinsic barriers within this transition will impact the competitiveness of the UK industry. This could lead to a loss of jobs, which will have a damaging impact on local economies and the wellbeing of constituents. For example, large multinational corporations (such as Tata Steel, who employ around 8,000 people in the UK (Sweney & Lawson, 2022)) would move their operations elsewhere should the UK no longer offer a competitive and profitable business environment.

Overall, as defined by the OECD (2001), unsustainable practices are often a result of incoherent and inconsistent policies; improving policy coherence requires better integration of economic, environmental and social outlooks, all of which are captured within this causal map. Effective policy making and government support will ensure the long-term viability and competitiveness of the industry which will ensure job stability, maintain steel exports and promote economic growth.

Figure 2 – An extract of a draft causal map which has been developed from findings so far. The arrows demonstrate the interdependency between variables.



5. Next Steps

Phase 2 of this project will focus on the perceptions of the Ontario-based steel industries. As such, the findings from the Canadian perspective are yet unknown. However, the Government of Ontario is showing commitment to a hydrogen future, with significant investment from the steel industry in Ontario, Canada via the Low-Carbon Hydrogen Strategy. The strategy aims to propel industry and promote both the production and use of hydrogen energy in steel-making (Government of Ontario, 2022). Over $500 million in loans and grants have been offered to support the move to hydrogen-ready electric arc furnaces (EAF) (Government of Ontario, 2022). We therefore anticipate that cost will be a less significant barrier in the Canadian context in the UK, where there are currently no similar financial mechanisms in place.

The Government of Ontario has also announced a hydrogen innovation fund alongside a Low-Carbon Hydrogen Strategy, with the intention that it will encourage hydrogen production projects and support hydrogen producers. We therefore anticipate that Ontario has a sufficient supply of hydrogen. Instead, the Government of Ontario have acknowledged barriers regarding the flexibility of their regulation (particularly concerning the production and storage of low-carbon hydrogen derived from natural gas) which has led to an effectively unregulated business environment (Government of Ontario, 2022). Thus, it is possible to deduce that appropriate policy has been implemented by local government to minimise the barriers to decarbonisation. Furthermore, as mentioned, Ontario's geography will be explored to determine the space available for hydrogen infrastructure (such as storage plants and transportation), whilst respecting the land of Indigenous communities.

However, these conjectures are preliminary, and further insights will be provided once the next stage of the data collection and analysis has been completed in Autumn 2023.

6. Conclusions

So far, our research indicates that cost, hydrogen supply and the skills and knowledge gap are the three main barriers facing the UK steel industry's hydrogen-technology transition. All three of these can be largely attributed to a lack of investment and lack of focused policy-making directed at UK industry. Due to the capital, resource and skills-intensive nature of the industry, this has had a detrimental long-term impact which has diminished the UK's global competitiveness. To successfully decarbonise the industry, policy should focus on offering investment support to improve the UK's existing furnace infrastructure, consider incentivising hydrogen production within industry (for example, through subsidies), and upskill the workforce by encouraging steel-based careers amongst young people and offering appropriate training courses to the existing workforce.

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