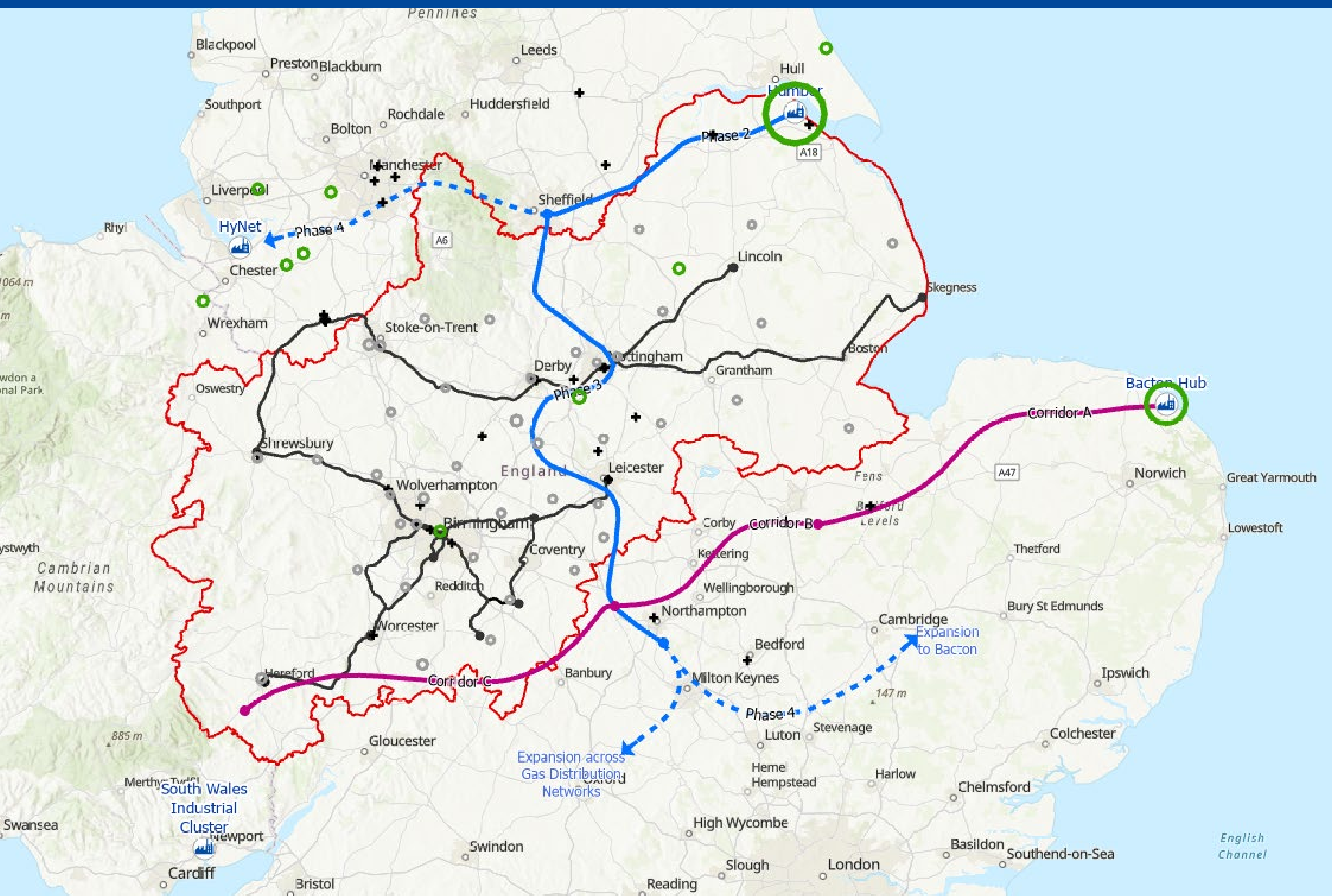
MIDLANDS HYDROGEN RAIL STUDY

Landscaping of Hydrogen Rail Opportunities across the Midlands

2024



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1. Executive Summary

Decarbonising our energy systems presents both a major challenge and opportunity for the UK and its regions. For the Midlands specifically, the Ten Point Plan for Green Growth in the Midlands Engine highlights both net zero transport and low carbon hydrogen as key regional 'green growth' strengths where the region can drive sustainable, inclusive growth and support wider UK decarbonisation. This study brings both these key themes together to outline how hydrogen rail could not only offer a viable decarbonisation solution for certain rail routes, but also how this can help catalyse growth in the wider Midlands hydrogen economy.

The UK is committed to decarbonise its rail sector by 2040 but it is currently running behind other transport sectors. Electrification is the primary solution to achieve this, but it is expensive with elongated timescales and isn't financially feasible on various rail routes. Battery and hydrogen trains therefore offer a critical interim or permanent alternative where electrification isn't affordable either in the near- or long-term future.

The Midlands is key to delivering these zero-emission trains of the future. The Midlands hosts the UK's largest rail industry hub including key battery and hydrogen rolling stock developers such as Alstom, Porterbrook, Eversholt and Siemens. Coordinated by the Energy Research Accelerator and other stakeholders, the region has acknowledged R&D strengths in the development of alternative energy and the decarbonisation of transport, including rail. It hosts 20 rail centres of excellence and Midlands businesses have received 71% of Innovate UK funding for rail since 2005. A large fleet of passenger and freight trains also go from, to and through the region. Many of these are diesel-powered and large sections of the rail network are not yet scheduled for electrification. It is clear the opportunity to rapidly accelerate the development of zero emission rail, including battery, hydrogen and hybrid options, is very important to the region.

Determining which traction power option is most suitable for a rail route depends on many factors, including route length, terrain, train operation speed and frequency, stopping pattern, fleet size and diagramming, and electricity and fuel supply capacity. The present report identifies four routes that seem to have an appropriate blend of these factors for a hydrogen train trial in a commercial setting, utilising the existing hydrogen supply chain in the region:

- Nottingham to Skegness
- Worcester Foregate to Stratford-upon-Avon (via Birmingham Snow Hill)
- Birmingham New Street to Shrewsbury
- Birmingham New Street to Kings Norton (the Camp Hill line)

Hydrogen train trials on a pilot route would be beneficial for UK rail's decarbonisation journey, particularly for hard-to-electrify routes. But hydrogen trains will ultimately only make up a small proportion of our future zero-emission rail stock. Whilst the trials will help prove technology readiness levels, the key question will be whether appropriate market readiness and commercial viability can be achieved. If the pilots prove successful operationally and commercially, then the next question could be how hydrogen train R&D in the Midlands can support the wider hydrogen economy.

A further key question on commercial viability will be whether hydrogen fuel will be competitive and available, especially in the form of green hydrogen. The Midlands hosts the UK's largest hydrogen refuelling station with on-site green hydrogen production (Tyseley), the largest inland hydrogen cluster (East Midlands), and will soon have the biggest fleet of hydrogen buses in the Western world in and around Birmingham. Already, local hydrogen production in the region could theoretically supply the average daily hydrogen consumption of a train across the modelled routes. And by providing long-term, consistent hydrogen demand, a hydrogen rail route could provide early market confidence for the emerging regional business ecosystem of hydrogen generators and off-takers.

There is clearly an urgent need to get on with answering these important questions, which would benefit from further exploration through hydrogen and/or battery train trials in the Midlands. This could inject momentum into a faltering UK rail decarbonisation effort. But more importantly for the Midlands green economy effort, it could create regional economic growth: firstly, by securing the future of the Midlands rail manufacturing industry and unlocking larger commercial opportunities from deploying hydrogen and battery trains across the wider UK; and secondly, by catalysing growth of the overall Midlands hydrogen economy.

Key next steps are:

- Work with regional stakeholders on a more detailed exploration of technology and commercial viability to help understand key building blocks needed for an investment case for delivering a pilot for battery and/or hydrogen within the Midlands.
- Work with key stakeholders in the region, including train operators, train developers, hydrogen suppliers, RSSB, local and national government bodies and research and innovation centres to quantify the full economic, commercial and financial case for a hydrogen rail programme utilising the strengths of the Midlands.
- Ask regional stakeholders to raise with government challenges associated with the current rail landscape inhibiting the development, procurement and roll-out of new zero-emission rolling stock, including hydrogen trains.
- Ask Midlands Connect and the Energy Research Accelerator to engage government departments, including DfT, to co-develop a Midlands rail decarbonisation strategy.
- Seek Government support to encourage developments of UK compatible rolling stock and develop hydrogen train refuelling infrastructure that exploits the region's strategic, central location.

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2. Introduction

2.1 Low Carbon Rail Opportunity

To support the UK's decarbonisation objectives, a transition to zero emission fuel sources will be required for critical power generation, energy intensive industries and heavy transport. In particular, the UK rail industry faces several challenges to achieve their ambition of having no diesel-only trains operating on the UK rail network by 2040.

Affordability: considering key events over the past few years – the UK's decision to leave the EU, the global pandemic, the ongoing environmental crisis to address climate change and the global security crisis sparked by Russia's invasion of Ukraine – the UK Government faces unprecedented fiscal challenges. The effect of which has already been felt in the rail sector with the Network Rail Traction Decarbonisation Network Strategy's (TDNS) recommended expansion of electrified network being deemed unaffordable (Shirres D, 2022).

Pace of change: recent studies by the Great British Railways Transition Team (GBRTT) indicate significantly elongated timescales for electrification, with phased upgrades over the next 40 years. This lengthened upgrade plan could result in net-zero targets being missed. This is reinforced by the recent audit of the Transport Decarbonisation Plan progress highlighting that Rail is significantly behind in its decarbonisation commitments compared to other transport sectors with only 5 out of 8 commitments partially met (Nilson P, 2023).

Technology choices: as already demonstrated in Europe, the deployment of battery and hydrogen rolling stock is emerging as critical interim and permanent solutions to achieve complete decarbonisation of rail. They can act as direct replacements to diesel trains with minimal enabling rail infrastructure changes required. In Italy, 20 "tribrid" (battery-electric-diesel) trains are running across Italian routes (Smithsonian Magazine and Kuta S, 2023). In Germany, whilst 14 hydrogen trains were successfully deployed in Lower Saxony, the regional transport authority LNVG has opted to replace the remaining diesel fleet with 102 battery Electric Multiple Units (EMUs) (Railtech, 2023).

Hydrogen and battery technologies offer an alternative to overhead electrification enabling decarbonisation of hard-to-electrify routes. Both will play important roles in decarbonising the national rail sector. However, determining the most suitable technology for a region or a route is dependent on many factors, including route length, terrain, train operation speed and frequency, stopping pattern, and electricity and fuel supply capacity. These factors will have contributed to the decision deeming battery EMUs as the most cost-effective solution for routes in Lower Saxony. However, considering some route lengths, fleet size, operational speeds, challenging terrains, and lack of electrification in the UK and the Midlands, hydrogen is a viable solution to decarbonise certain routes in the region.

2.2 Hydrogen Economy in the Midlands

The Midlands has played an important role in the development of the hydrogen economy to date and hosts a vast range of hydrogen expertise largely resulting from key hydrogen assets, companies, programmes and university expertise located in the region. These include:

- The UK's largest green hydrogen production and refuelling facility: ITM Motive's 1 tonne/ day hydrogen production at Tyseley, providing zero-carbon hydrogen for buses and HGVs (Hydrogen Central, 2021)
- The Horiba-MIRA hydrogen refuelling facility located amongst a growing cluster of hydrogen automotive businesses.
- The West Midlands' fleet of 144 hydrogen buses which is to be the largest in the Western World (West Midlands Combined Authority, 2022).
- The HyDeploy hydrogen blending programme which undertook the first UK trial in the gas network at Keele University.
- 'East Midlands Hydrogen' which is poised to become the UK's largest inland hydrogen cluster with a hydrogen demand forecast of 10 TWh by 2040 across 70 industrial sites and low carbon hydrogen production forecasts of up to 650MW.
- The Humber Industrial Cluster which could meet 30% of the UK government's hydrogen production target by 2030 (Midlands Engine, 2022b).
- Hydrogen infrastructure may also support the decarbonisation of smaller industrial clusters in the region. For example, hydrogen infrastructure may support the Black Country Industrial Decarbonisation Programme to decarbonise the 3000+ energy-intensive manufacturing businesses based in the region (West Midlands Combined Authority, 2021).

Considering the rail industry specifically, the Midlands is also home to companies including Alstom, Siemens and Porterbrook, with expertise developing hydrogen technologies and renowned for developing hydrogen passenger trains; Alstom's Coradia iLint (Alstom, 2018), Siemens Mobility's Mireo Plus H (Siemens, 2023) and Porterbrook's HydroFLEX (Porterbrook, 2023). The latter collaborated with the University of Birmingham to develop the demonstrator showcased to the world at the 2021 COP26 Climate Summit in Glasgow.

The Midlands is also a key location of commercial innovation associated with hydrogen and is home to industry-leading businesses with international reach as outlined in Table 1.

Table 1: UK hydrogen businesses based in the Midlands (Midlands Engine, 2022a)

Hydrogen boilers and heating solutions	Worcester-Bosch, Baxi & Vaillant
Gas Distribution Network	Cadent
Fuel Cells	Intelligent Energy, Ballard Power Systems & Adelan
Hydrogen Storage	Luxfer Gas Cylinders
Hydrogen Trains	Porterbrook, Alstom, Siemens & Vanguard Sustainable Transport Solutions
Hydrogen Vehicles	Toyota, Tevva, Bosch, Horriba Mira, JLR
Heavy Vehicles	Caterpillar, Faun Zoeller & JCB
Hydrogen Generation	ITM, Progressive Energy, SSE, Engie, Siemens, Uniper

Coordinated programmes, like HyDEX, aim to accelerate the development of the hydrogen sector and engage relevant companies and education institutions. The region can also draw on the insights, advocacy and coordination of the Midlands Engine exemplified by the Midlands Engine Hydrogen Technologies Strategy (2022) developed to crystallise and champion the pivotal role the Midlands can play to achieve government ambitions to expand the UK hydrogen economy and drive sustainable growth. The region's collective and diverse expertise, along with strategic coordination by HyDEX and Midlands Engine creates a very promising opportunity to develop new skills, services, and products to unlock economic growth in the region.

As part of an integrated regional economy, hydrogen crucially presents the potential to support the decarbonisation of key sectors in the Midlands, including Transport and Industry which collectively account for two thirds of all emissions in the Midlands (Transport: 33.4%, Industry: 32.5%) (Midlands Engine, 2021). The 2022 Rail Infrastructure and Assets report (Office of Road and Rail, 2022) showed that a high proportion of passenger trains operating in the Midlands are diesel – West Midlands Trains (22%), East Midlands Railway (77%) and CrossCountry (89%) – highlighting a significant decarbonisation challenge. Hydrogen is thus a potential solution for the sector.

Transport: Supported by its location and rich heritage in transport-related research and development, the Midlands is a major transport hub at the centre of the UK's freight network and transport infrastructure. The region hosts 20 rail centres of excellence, 16 of the world's top 20 automotive suppliers, the busiest train station outside of London and two international airports (Midlands Innovation, 2019) – including the UK's largest dedicated air-cargo operation at the East Midlands Airport. The area also has an acknowledged strength in the research and development of alternative energy and the decarbonisation of transport through academic and industry research, and coordination of the Energy Research Accelerator and other partners.

The region hosts the UK's main rail cluster with the largest number of rail supply chain manufacturers located in Derby and 47% of £100m+ turnover rail companies having a Midlands location. 71% of Innovate UK funding for rail since 2005 has also gone to businesses in the region (Midlands Engine, 2023). With 45% of British rail and 33% of heavy road freight going to, from or through the Midlands (Midlands Innovation, 2019), and the large proportion of emissions from the transport sector, the opportunity to rapidly accelerate the development of zero emission rail, including hydrogen, is very important to the region. There is also a catalytic effect of the HS2 investment connecting Birmingham to London and the rest of the network, bringing new infrastructure for rolling stock manufacture and better access to engineering supply chains.

Industry: The presence of a decarbonised rail network, including hydrogen-fuelled routes, also provides an opportunity to catalyse the decarbonisation of other industries across the Midlands. Figure 1 highlights large CO_2 point source emissions in the Midlands for the highest emitting industries that, due to the associated energy requirement, are some of the most challenging and unrealistic to electrify. Consequently, hydrogen is likely to play an important role in these industries to meet net-zero targets, and a means of sustainably transporting the hydrogen will be required.

Industry	CO_2 emissions (tonnes of C eq.)
Major power producers	3887862
Iron & steel industries	1290449
Processing & distribution of petroleum products	822095
Cement	517588
Lime	321762
Waste collection, treatment & disposal	267223
Other mineral industries	159057
Chemical industry	133974
Food, drink & tobacco industry	120965

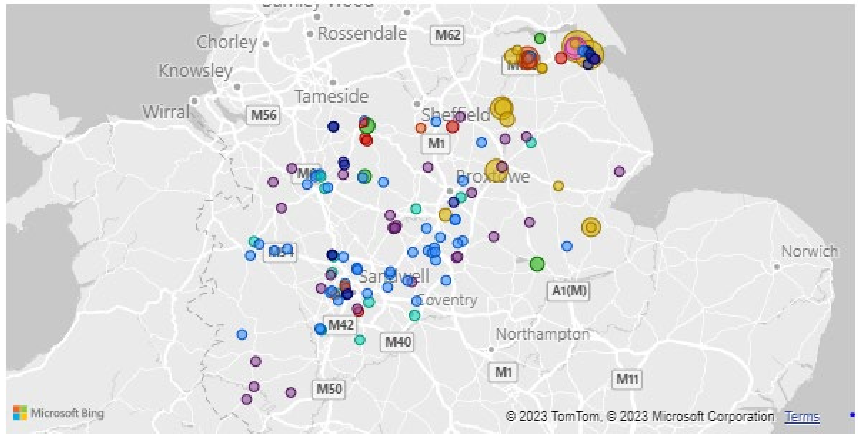

Figure 1: Midlands Large Point Source CO_2 Emissions (National Atmospheric Emissions Inventory, 2020)

To unlock this opportunity and accelerate the decarbonisation of primarily and subsequently the transport and industry sectors respectively, the following factors need to be considered.

Local Generation and Import of Green Energy & Hydrogen: Green hydrogen production plants using electrolysis have been developed in several Midlands locations including Tyseley Energy Park, Keele University and MIRA Technology Park, which combined could provide an estimated 1500 kg H_2 each day. To provide context, the average daily hydrogen consumption of a train across the modelled routes, outlined in later sections of this report, was 230 kg H_2. Theoretically therefore, local hydrogen generation already has the potential to run trains in the region.

The local hydrogen generation is also anticipated to increase. National Grid's Distribution Future Energy Scenarios outlines the potential for local supplies from Hydrogen Electrolysis within the Midlands to supply ~100,000 kg H_2 each day by 2050. This potential could be further improved considering proposed redevelopments of former coal power station sites. As demonstrated by the proposed 5 MW Green Hydrogen Production Plant at the High Marnham Site (JG Pears, 2022), these sites could encompass large-scale hydrogen production. Most notably, the Ratcliffe site could offer a 500 MW combined capacity (Uniper, 2023) by 2030 which could supply 134,000 kg H_2 to the region each day. There is also the possibility of generating hydrogen from solar and wind renewables at rural locations. Additionally, a waste to energy plant in Cannock has been recognised as a potential large-scale producer of hydrogen, with other towns including Loughborough, Melton Mowbray, Rugby and Warwick identified as potential sites for production. Consequently, there exists a substantial local opportunity which could significantly bolster the local generation and supply. As a result, by 2030 approximately 4% of predicted hydrogen generation from the region could enable a selected rail route in the region to be entirely operated by a fleet of hydrogen trains if the economics were demonstrated to be viable.

The centrality of the region is equally advantageous due to the excellent connectivity it brings, particularly to coastal clusters within and outside the Midlands which have the most large-scale plans for hydrogen production. This is demonstrated well by planned hydrogen infrastructure developments which in the next 10+ years could secure the region significant amounts of hydrogen from coastal clusters. These include the East Coast Hydrogen development and phased pipeline expansion due to extend throughout the Midlands bringing hydrogen from the Humber (Cadent, 2021), National Gas Transmission and Cadent's Hydrogen Valley proposal to bring hydrogen into the region from coastal industrial clusters in East Anglia (Net Zero East, 2023) and Cadent's ambition to develop a 'hydrogen for heating' network (Cadent, 2022). There will also be a requirement to deliver hydrogen to southern regions of the UK which will naturally require a route that passes through the Midlands, as outlined by National Gas' Project Union. Hydrogen production from the Bacton and East Coast Hubs alone could supply over 3 million kg H_2 by 2030 and over 5 million kg H_2 by 2040 which the Midlands will be perfectly located to benefit from.

Energy Network Capacity: Renewable energy transmission through the electrical network is essential for the local production of green hydrogen. However, the electrical network faces its own significant challenge due to the current operational strain on the existing network. Considering the "Best View" from the Midland's Distribution Network Operator – National Grid Electricity Distribution – 85% of substations will have no headroom available for increased demand and 49% will have no headroom for increased generation by 2050 (National Grid, 2022b). As a result, significant network reinforcement, which itself is already suffering significant delays, will be required to facilitate further power demand from and supply into the network. However, hydrogen production plants can be co-located and directly connected to renewable energy generation sites or on sites with lower network capacity constraints, alleviating the pressure on the electrical network. Hydrogen then can be transported to refuelling sites via tube trailers or pipelines.

Rolling Stock Technology: The range of the rolling stock and subsequent recharging/refuelling time could place a significant constraint on the technology choices suitable for certain rail routes. Routes need to be analysed to determine the best and most effective technology to deploy for decarbonisation. Hydrogen offers the potential to operate on longer rail routes with lower train frequency matching distances and operations that traditional diesel trains achieve on a single tank (Hirschlag A, 2020). The first UK hydrogen-powered train, HydroFLEX, is currently under development for commercial use, and the German Coradia iLint alternative has demonstrated capability to run for 600 miles on a single tank. In contrast, premium battery technologies – like Vivarail – offer ranges of 60 miles on only-battery power with a 10-minute recharging time (Railtech, 2020). Whilst overhead electrical lines could be tactically positioned along the route to provide the required recharging for battery trains, hydrogen could present a reliable and affordable alternative (in comparison to electrification) in particular for longer rail routes with hilly terrain and low frequency service.

3. Hydrogen Rail Potential in the Midlands

3.1 Potential Hydrogen Routes

3.1.1 Route Selection

For the purposes of this study and as shown in Table 2, 11 example routes in the Midlands were identified and modelled to assess the feasibility of hydrogen technology. It should be noted that this is not an exhaustive list of possible routes in the region, and the same methodology could be used to analyse further routes across the region. The methodology considered three main factors as outlined below:

Assessment of Route Intensity: The term "headway" refers to the time interval between successive trains on a route. Routes with heavy traffic and short headways (less than 20 minutes) are considered more suitable for electrification and were therefore discounted from potential hydrogen routes.

Existing Plans for Electrification: Routes identified by Network Rail or government documents for electrification have lower potential for adopting hydrogen technology and were therefore also discounted.

Rolling Stock Procurement Strategy: Routes served by rolling stock expected to be replaced in the next 5 to 10 years were considered as candidates for hydrogen technology adoption. However, routes with recently acquired new diesel-powered multiple units (DMUs) are less likely to transition to hydrogen trains, as retiring or relocating relatively new rolling stock would be less feasible due to their high cost and challenges around OEM depot locations and servicing infrastructure.

Table 2: List of potential hydrogen routes identified for modelling

Birmingham New Street to Kings Norton (Camp Hill Line)
Worcester Foregate Street to Birmingham Snow Hill to Leamington Spa
Worcester Foregate Street to Birmingham Snow Hill to Stratford-upon-Avon
Shrewsbury to Crewe
Nuneaton to Coventry to Leamington Spa
Birmingham New Street to Leicester
Derby to Lincoln
Crewe to Stoke-on-Trent to Derby
Birmingham New Street to Shrewsbury
Birmingham New Street to Hereford
Nottingham to Skegness

3.1.2 Route Modelling

Routes were modelled using the University of Birmingham's Single Train Simulator (STS). STS employs a discretisation method to break down the rail journey into a series of equal-distance increments to determine key parameters such as acceleration, velocity, power demand and time over each constant displacement step. The train power demand is divided between two sources: the traction battery and the fuel cell. The specific balance between fuel cell and battery power depends on the supervisory control strategy employed. In the basic scenario used in this study, the fuel cell provides the mean power for the entire journey at a relatively constant output, while the traction battery supplements power during high-load situations, such as acceleration. The battery can also recover energy during regenerative braking. The simulator has been validated using real data from the HydroFLEX train trial and adapted to model more realistic trains, which are expected to have regenerative capabilities for efficiency gains.

The simulation results include the amount of hydrogen consumed, expressed in kilograms per kilometre over the journey, as well as the state of charge of the battery system.

Table 3 summarises the main modelling results for each route.

Table 3: Potential hydrogen routes modelling summary

Rail Routes	Route Electrification %	Train for Simulation	Return journey H_2 consumption (kg)	Return journey distance (km)	Return journey time (hr)	No. return journeys per day	H2 for whole day (kg)	Min Rolling stock units required	H_2 for whole fleet (kg)
Birmingham New Street to Kings Norton (Camp Hill Line)	18.4	Class 150	5.66	22.59	0.64	18	90.05	4	360.18
Nuneaton to Coventry to Leamington Spa	9.3	Class 150	21.61	62.98	1.39	8	152.90	4	611.62
Birmingham New Street to Shrewsbury	34.8	Class 196	40.60	133.95	1.71	6	215.49	4	861.95
Worcester Foregate Street to Birmingham Snow Hill to Leamington Spa	0	Class 172	83.03	199.62	2.79	4	293.80	4	1175.21
Birmingham New Street to Leicester	4.7	Class 170	67.02	126.94	3.24	4	237.13	3	711.39
Birmingham New Street to Hereford	22.0	Class 196	66.77	176.72	3.09	4	236.26	3	708.77
Worcester Foregate Street to Birmingham Snow Hill to Stratford-upon-Avon	0	Class 172	103.34	189.58	4.95	2	182.83	4	731.31
Derby to Lincoln	0	Class 170	82.25	159.01	2.91	4	291.04	4	1164.17
Nottingham to Skegness	0	Class 150	69.36	257.86	3.73	3	184.06	4	736.23
Shrewsbury to Crewe	4.5	Class 170	73.74	105.76	1.92	6	391.37	4	1565.47
Crewe to Stoke-on-Trent to Derby	29.6	Class 170	87.85	162.21	2.71	4	264.87	4	1059.47

3.2 Rolling Stock Review

3.2.1 Existing Train Fleets

The routes identified in this study are operated using a variety of Diesel-Multiple-Units (DMUs). The DMUs currently in use on these lines can, broadly, be separated into three categories:

Second generation DMUs, built between 1984 and 1993 for use by British Rail. These units are now generally considered to be end-of-life. E.g., Class 150, 155, 156, 158, 159.

Third generation DMUs, built between 1998 and 2011 by *Adtranz and Bombardier Transportation* for use by various private Train Operating Companies (TOCs). These units are generally considered to be mid-life. E.g., Class 168, 170, 171, 172.

Fourth generation DMUs, built between 2017 and 2023 by *Construcciones y Auxiliar de Ferrocarriles* for use by various TOCs. These units are considered to be beginning-of-life. E.g., Class 195, 196, 197.

3.2.2 Available H_2-powered Rolling Stock, and Conversion Donor Vehicles

Currently, the only hydrogen-powered rolling stock project in the UK suitable to enter regular, mainline passenger service is a Class 799/2. This unit, built by the rolling stock leasing company, *Porterbrook*, is a bi-mode unit, adapted from a Class 319 Electric Multiple Unit (EMU) under the HydroFLEX project. The existing 25 kV electric traction system has been retained, with a hydrogen fuel cell–battery hybrid traction system introduced, allowing the unit to be operated away from overhead line electrification equipment.

Given the precedent set by Porterbrook and Arup/Ballard Motive Solutions during their respective HydroFLEX and Scottish Hydrogen Train projects, converting an existing EMU to use a hydrogen fuel cell-hybrid traction system presents a feasible pathway to introduce hydrogen-powered trains into passenger service in the Midlands. This would likely be a more cost-effective, and rapid way to introduce a hydrogen-powered train into service rather than procuring a new fleet of trains (Arup, 2023b).

The Siemens *Desiro* fleet of EMUs were built between 2004 and 2014 and are generally considered to be mid-life. Despite this mid-life status, some *Desiro* fleets and sub-fleets will soon be off lease, to be replaced with newer Bombardier/Alstom *Aventra* EMUs. This generation of *Desiro* units was designed and built before the development of newer wheel/rail interface requirements, which has seen a generation of EMUs with lighter vehicles and bogies. This impacted both the energy consumption and track access charges of the units which are key contributors to their replacement.

Extensive pre-engineering feasibility work has been carried out assessing the prospect of converting a Siemens *Desiro* unit to a hydrogen-electric bi-mode unit (Arup, 2023b). This report concludes that this conversion would be technically feasible, and would enable a faster, cheaper pathway to introduce hydrogen-powered trains into service in the UK. Table 4 shows the current state of Siemens *Desiro* fleets operating in the UK. It is expected that 203 *Desiro* units (15.5%) will be off lease within the next five years and could therefore be available for hydrogen conversion.

Although the conversion of existing rolling-stock is a viable option, it is strongly recommended that a full economic comparison is made with the purchase of new purpose built rolling-stock before a final decision is made.

Table 4: Current state of Siemens Desiro fleets in the UK

Class	Current Operator	Units	Owner	Vehicles per Unit	Total Vehicles	Expected to be unused/off lease within 5 years
350/1	West Midlands Trains	30	Angel Trains	4	120	No
350/2	West Midlands Trains	37	Porterbrook	4	148	Yes
350/3	West Midlands Trains	10	Angel Trains	4	40	No
350/4	West Midlands Trains	10	Angel Trains	4	40	Yes
360/1	East Midlands Railway	21	Angel Trains	4	84	No
360/2	N/A	3	Global Centre of Rail Excellence	5	15	Yes
380/0	ScotRail	22	Angel Trains	3	66	No
380/1	ScotRail	16	Angel Trains	4	64	No
444	South Western Railway	45	Angel Trains	5	225	No
450	South Western Railway	127	Angel Trains	4	508	No

3.2.3 New H-EMU Products

Based on discussions with OEM Rolling Stock Suppliers, new UK-specific Hydrogen Electric Bi-Mode Multiple Units (H-EMUs) are being developed and can be available for delivery by 2028-29. However, developing a UK compatible hydrogen train requires significant investment and OEMs require government support for the development and assurance of sufficient demand to build the business case for the development.

In addition, development is ongoing for B-EMU (Battery – Electric Bi-Mode) and H-EMU (Hydrogen – Electric Bi-Mode) variants of the following OEM train platforms:

- Alstom *Aventra*
- Siemens *Desiro Verve*
- Stadler *FLIRT* UK

Many rolling stock leasing companies operating in the UK have expressed their desire to support H2 trials on suitable branch lines by financing new rolling stock.

3.3 Infrastructure

3.3.1 Rail Refuelling Infrastructure Requirements

Current hydrogen rail development is focused on gaseous compressed hydrogen, with on board storage and fuel cells used to generate power for propulsion. Specifically designed hydrogen refuelling depots will be required to accommodate: 1) Hydrogen production and delivery to site; 2) Hydrogen storage and compression; 3) Hydrogen dispensing.

Large scale, stationary refuellers are still in their infancy for the volumes of hydrogen that will be required for trains. However, it is anticipated that depots can leverage the advances made in road transport applications utilising components and systems that have been developed and refined to date. Therefore, there is an opportunity to trial its use on specific applicable routes.

In order to support hydrogen train deployment, medium to large scale refuellers (>500 kg/day capacity) will be required. For instance, to transition a rail route with a fleet of 4 trains and hydrogen demand of 250 kg/day per day, a large scale 1000 kg/day hydrogen refueller is needed, along with on-site storage for in the range of 2000 kg to allow for operational contingency.

3.3.1.1 Hydrogen Production

Hydrogen production can either be on-site production, via electrolysis, or sourced from off-site production plants. To estimate the hydrogen supply that could be accessible to the Midlands, production was grouped into four main sources.

Local Supply: green hydrogen production for each local authority in the Midlands was estimated using National Grid's *Leading the Way* Distribution Future Energy Scenario (National Grid, 2022a). Due to the significant potential for hydrogen production at the Ratcliffe Power Station site, this supply has also been considered. For the purposes of this study, it was assumed that the initial 100 MW electrolyser is in operation by 2030, and the subsequent scale-up to 500 MW is in operation by 2040 (Uniper, 2023).

Bacton Hub Supply Cluster: data taken from a study undertaken by Hydrogen East which details different scenarios of blue hydrogen production and the phased development of green hydrogen in the region (Hydrogen East, 2021). The most cost-effective blue hydrogen scenario was used for the purpose of this study, but it should be noted that the possible production capacity could be significantly higher to meet demand as required.

East Coast Hydrogen Hub Supply Cluster: data taken from analysis undertaken by Arup for the East Coast Hydrogen project.

Net Zero Hydrogen Fund (NZHF) Projects: data obtained from published updates on the NZHF projects. Whilst only one of these projects is based within the Midlands, the others listed are in proximity and could offer additional hydrogen supply sources. It was assumed that each of the remaining shortlisted projects will be in operation by 2025 as per the condition of funding (Department for Business, Energy and Industrial Strategy, 2022).

For all green hydrogen sources, the daily hydrogen production was estimated considering the load factor of the electrolyser (BEIS, 2021), the process efficiency required to produce fuel cell grade hydrogen (Arup, 2023b) and Hydrogen's Higher Heating Value (Engineering Toolbox, 2003). An estimated timeline of daily hydrogen production potentially available to the Midlands is summarised within Table 5. To provide context, 1565kg of hydrogen each day would be sufficient to operate a fleet of trains on the route with the highest hydrogen consumption from those analysed in this study. These supplies are plotted alongside proposed pipelines as shown in section 3.3.1.2.

Table 5: Daily Hydrogen Production Capacity in the Midlands

H_2 Source	H_2 Source Location	Daily Hydrogen Production, kg			
		2025	2030	2040	2050
Local	West Midlands (Green H_2)	761	8,980	21,800	61,100
	East Midlands (Green H_2)	2,580	5,250	10,500	41,000
	Ratcliffe Power Station (Green H_2)	0	22,800	124,000	134,000
	Total	**3,340**	**37,000**	**156,000**	**236,000**
Cluster	Bacton Hub (Green H_2)	0	0	248,000	269,000
	Bacton Hub (Blue H_2)	0	0	1,560,000	1,560,000
	East Coast Hub (Green H_2)	140,000	578,000	578,000	578,000
	East Coast Hub (Blue H_2)	0	2,750,000	2,750,000	2,750,000
	Total	**140,000**	**3,330,000**	**5,140,000**	**5,160,000**
NZHF Projects	Green hydrogen 2	1,630	1,710	1,860	2,010
	Chesire Green Hydrogen, Progressive Energy Net Zero	6,090	6,380	6,950	7,520
	Green Hydrogen Winnington & Middlewich, Statkraft	1,090	1,140	1,240	1,340
	Green Hydrogen St Helens, PUKL	1,090	1,140	1,240	1,340
	Trafford Green Hydrogen, Carlton Power	4,350	4,550	4,960	5,370
	H2 Production Plant at High Marnham, JG Pears	1,090	1,140	1,240	1,340
	Aldbrough Hydrogen Pathfinder, SSE Thermal	7,610	7,970	8,690	9,400
	Total	**22,900**	**24,000**	**26,200**	**28,300**
Total		**167,000**	**3,390,000**	**5,320,000**	**5,420,000**

3.3.1.2 Hydrogen Delivery

Delivery of hydrogen to refuelling sites from the production sources will be through a combination of hydrogen pipelines and tube trailers.

Short-Medium Term: The Midlands will be reliant on tube trailers taking hydrogen from production sites to demand points. Reducing the mileage of tube trailer journeys will be essential to drive efficiencies and reduce the cost of hydrogen.

Long Term: Phased pipeline expansions, including the East Coast Hydrogen and Hydrogen Valley pipelines, will deliver hydrogen from key hubs through the Midlands. Off-take locations along these proposed routes will provide the opportunity to optimise and reduce the distance that tube trailers will have to travel to deliver the hydrogen. It should be noted that the timeframe for the pipeline proposals is not fixed but is currently estimated to be in operation in the Midlands by around 2040.

Figure 2 summarises the hydrogen supply points and potential hydrogen pipelines across the Midlands by 2050.

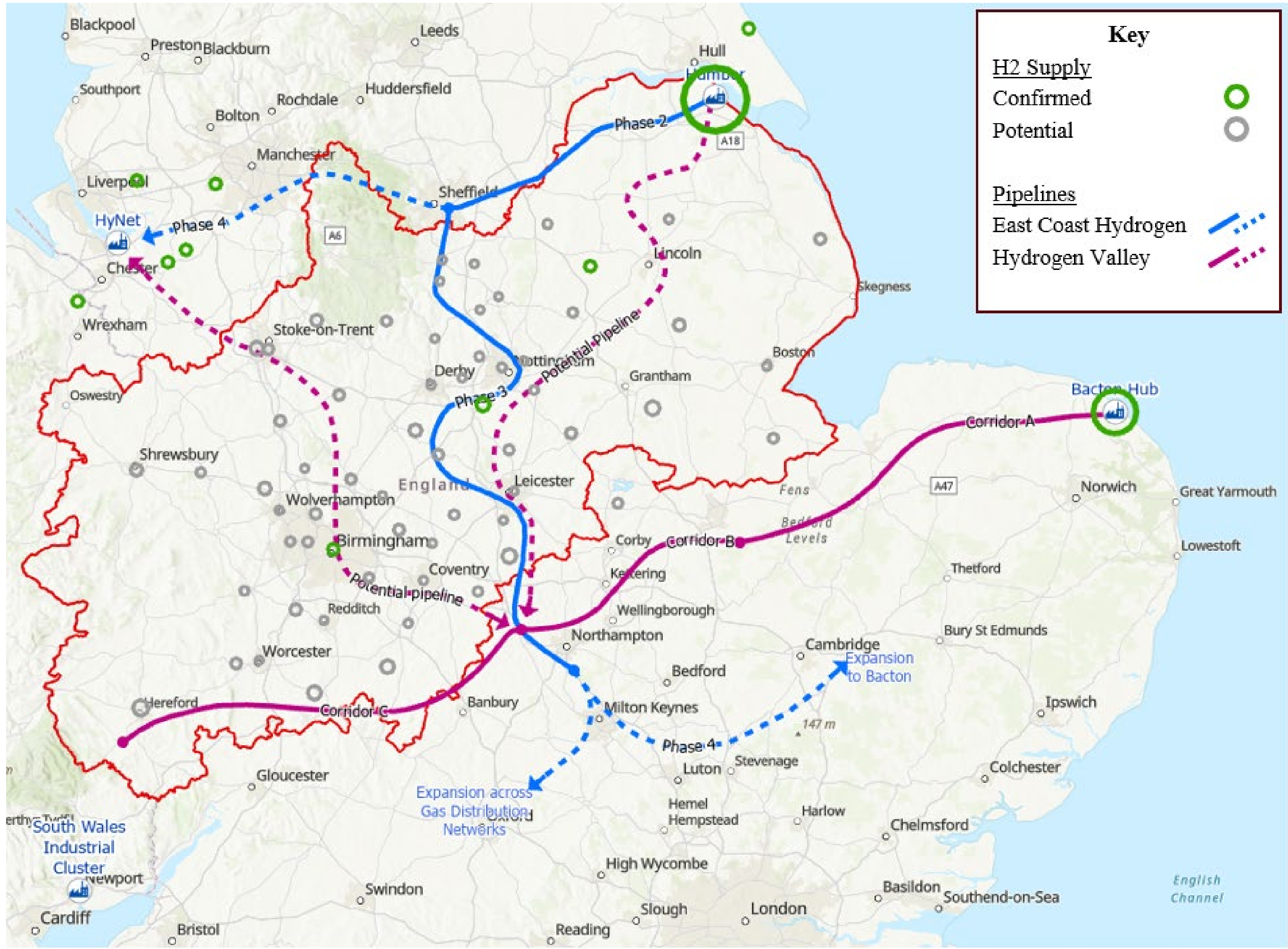

Figure 2: Hydrogen Supply Points and Pipelines across the Midlands by 2050

3.3.1.3 Hydrogen Storage and Compression

Storage of hydrogen on site will be necessary to allow the refuelling site to function as intended. Compression and potentially purification of hydrogen will also be required to get the hydrogen to the required specifications for the trains, ensure fuel cell grade hydrogen purity and increase the hydrogen pressure to 500 bar to enable pressure balance refuelling if refuelling at 350 bar. The storage capacity is determined based on the amount of hydrogen required to be dispensed back-to-back.

3.3.1.4 Hydrogen Dispensing

Hydrogen dispensers will also be required to deliver the hydrogen from the storage tanks to the on-board storage tanks on the trains. The dispensers also act as an interface and monitors the refuelling process to ensure safe delivery of hydrogen.

3.4 Hydrogen vs Electrification Economic Comparison

A high-level economic analysis was conducted to compare the costs associated with using hydrogen-powered railway traction and electrification for the routes investigated as part of this project. This utilised the route modelling data and various assumptions to compare upfront capital costs and through-life system costs as outlined below. Table 6 provide a comparison for the train operation considering a 25-year lifetime operation.

- **Rolling Stock Costs:** H-EMU vs conventional EMU (Office of Rail Regulation, 2015)
- **Infrastructure Costs:** Hydrogen (Tyseley Energy Park, 2021) vs electrification (Arup, 2023a)
- **Through-life System Costs:** Hydrogen fuel (University of Birmingham, 2022) vs electricity for traction (Network Rail, 2023)

Table 6: Route Hydrogen System vs Electrification Comparison

Route	Cost for Full H_2 System (£M)	Cost for Full Electrification (£M)
Birmingham New Street to Kings Norton (Camp Hill Line)	80	59
Nuneaton to Coventry to Leamington Spa	105	108
Birmingham New Street to Shrewsbury	130	148
Worcester Foregate Street to Birmingham Snow Hill to Leamington Spa	162	272
Birmingham New Street to Leicester	104	169
Birmingham New Street to Hereford	104	186
Worcester Foregate Street to Birmingham Snow Hill to Stratford-upon-Avon	117	245
Derby to Lincoln	161	231
Nottingham to Skegness	118	313
Shrewsbury to Crewe	202	189
Crewe to Stoke-on-Trent to Derby	150	182

While this analysis offers valuable insights into the relative costs, it is recommended that further, more comprehensive work be undertaken to explore these costs in greater detail. This extended analysis should encompass a full net present value economic evaluation and project appraisal, adhering to established industry standards within the rail sector. Nonetheless, the preliminary results do offer a strong indication of situations where hydrogen may be cost-competitive with electrification systems, highlighting its potential as a decarbonisation solution for rail transport.

3.5 Summary

1. With a high percentage of rail operations in the Midlands fuelled by diesel, vehicle-based decarbonisation technologies such as hydrogen and battery are required to be deployed to meet the 2040 no diesel-only trains in the UK target.
2. Currently two projects in the region are supported by the Net-Zero Hydrogen Fund (NZHF). The East Midlands Hydrogen cluster could act as a catalyst for hydrogen economy development in the region.
3. Whilst the Midlands will be an importer of hydrogen from regions with high production potential, small to medium scale developments could enable early hydrogen off-take and infrastructure development in the region.
4. Current hydrogen train technology could be deployed on rail routes in the Midlands utilising locally produced hydrogen to replace diesel trains with clean, zero-emission hydrogen trains. Routes can be assessed for suitability for hydrogen based on the route length, fleet size, terrain, frequency of service, line speed and fuel supply availability.
5. Hydrogen supply to the Midlands will be primarily from the Humber Industrial Cluster and Bacton Hub's via pipeline. However, the timeline for development is 2035-2040. Therefore, there will be a requirement to utilise tube trailers to deliver hydrogen to the region in the shorter-term, and reducing tube trailer mileage will be important to drive efficiencies and reduce hydrogen cost.
6. A high-level economic comparison across the Midlands rail routes considered highlights the potential whole life cost benefits of adopting hydrogen technologies over full electrification on these routes.

4. Midlands Hydrogen Rail Opportunities

4.1 Opportunity Ranking Methodology

Whilst all routes were selected due to their hydrogen rail potential, it was important to rank and prioritise the routes to maximise the success of a future trial. A multi-criteria analysis that utilised six weighted criteria was used to evaluate each route. Due to the anticipated phasing of the trial – outlined below – and the associated gradual transition from existing to hydrogen rolling stock, each criterion was given an overall importance weighting (w = 1: Low, 2: Medium, 3: High) that was subjectively allocated to ensure existing train services during the trial are maintained whilst considering other possible technologies and optimising operational considerations. The modelled routes were then evaluated against each criterion based on the criteria outlined in Table 7.

- Phase 1: replace an existing train on the route with a hydrogen alternative.
- Phase 2: gradually replace remaining trains in the fleet with retrofitted H2 trains.

Criteria 1 – Tube trailer requirement (w = 2: Medium) (A = Daily no. tube trailers required)

Using the daily H_2 requirement of each train on the modelled route and the minimum number of rolling stock units that would be required to run the service, the total fleet hydrogen requirement was estimated. Assuming the worst-case scenario that all trains on a route would require refuelling from the same depot and that each trailer could deliver 300 kg H_2 at a time, each route was scored assessing the number of tube trailers that would be required.

Criteria 2 – Route operating speed (w = 3: High): (B = Peak route operating speed, mph)

Porterbrook have reported that HydroFLEX has reached speeds of over 80 mph during mainline testing (Porterbrook, 2023). For the purposes of this report, it was assumed that it has capability of operating at 90 mph which was therefore used as the upper limit for scoring, with routes operating under 75 mph deemed optimal for an initial trial.

Criteria 3 – Train Storage Capacity (w = 3: High): (C = Daily H_2 requirement per train, kg)

Comparing the modelled daily hydrogen requirement per train on each route against the storage capacity on each train, facilitated a definitive assessment of each route. Further insight from the HydroFLEX train was used to inform this critical limit (277 kg) for the purposes of the initial phase of a future trial. This limit is expected to increase for future rolling stock development.

Criteria 4 – Train Class Replacement Requirement (w = 1: Low): (D = Current Train Class)

Considering the existing train class currently operating, or proposed to operate, on each route, an assessment of the likely requirements to replace each train class was made. This considered decarbonisation requirements, the future lifespan of each class and the suitability of retrofitting each class during future trials.

Criteria 5 – Route Battery Train Potential (w = 2: Medium): (E = Scaled recharge time, min)

Comparing the scaled total time each route passes through electrified sections against the capabilities of current premium battery train technologies (Railtech, 2020), allows a high-level battery suitability assessment to be undertaken. Although a detailed investigation is required to understand whether battery trains could operate on remaining routes, this is a simple method of identifying routes where battery trains cannot provide the decarbonisation solution and where hydrogen technologies will be vital.

Criteria 6 – Electrification Cost Comparison (w = 2: Medium): (F = Elect. Cost Factor)

Comparing the total costs if each route adopted a full hydrogen system (rolling stock, fuel, H_2 infrastructure) against a full electrification system (rolling stock, EC4T, route-wide electrification) – as outlined in Section 3.4 – allows a high-level assessment of long-term electrification suitability to be considered. An electrification cost factor was generated by dividing the costs of adopting a full hydrogen system by the costs of adopting a full electrification system on each route.

Table 7: Route Opportunity Scoring Criteria

Score	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Criteria 6
5	A <= 2	B <= 75	-	-	-	F <= 0.8
4	A = 3	75 < B <= 80	-	-	-	0.8 < F <= 0.9
3	A = 4	80 < B <= 85	-	D = 150	-	0.9 < F <= 1.1
2	A = 5	85 < B <= 90	C <= 277	D = 170 or 172	E > 10	1.1 < F <= 1.3
1	A > 5	B > 90	-	D = 196	-	F > 1.3

For the purposes of this study, these were deemed the critical factors to differentiate between each route's feasibility for an immediate future hydrogen rail trial. Additional operational considerations, (e.g. distance from hydrogen supply locations, distance from maintenance depots, space availability at depots for hydrogen storage and refuelling) should be explored in greater detail in subsequent phases of assessment to understand trial practicalities.

It should also be noted that the importance of these factors will vary when assessing routes for longer-term hydrogen rail deployment. For example, as the hydrogen technologies and infrastructure developments advance, the importance of current operational constraints (e.g. route speed or tube trailer requirements) will significantly reduce whilst other factors (e.g. distance from hydrogen supply or availability of space at depots to accommodate hydrogen storage and refuelling) will increase. Therefore, the methodology to identify and select routes suitable for hydrogen technologies will update over time.

4.2 Opportunity Ranking Summary

Table 8 summarises the results of the multi-criteria analysis. It is clear from the scoring that the top four routes present the best opportunities to implement an immediate hydrogen trial considering the current technology that is available and the limited decarbonisation options for each. A Red-Amber-Green (RAG) status has been assigned to each to prioritise those that should be investigated further for an initial trial. The route numbering aligns with the labelled route map shown in Figure 3.

Table 8: Ranking Summary of Modelled Routes

Route	C1 Score	C2 Score	C3 Score	C4 Score	C5 Score	C6 Score	Overall Score	RAG Status
Nottingham to Skegness (1)	4	5	2	3	2	5	46	Green
Worcester Foregate Street to Birmingham Snow Hill to Stratford-upon-Avon (2)	4	5	2	2	2	5	45	Green
Birmingham New Street to Shrewsbury (3)	4	5	2	1	0	4	38	Green
Birmingham New Street to Kings Norton (Camp Hill Line) (4)	5	5	2	3	0	1	36	Green
Birmingham New Street to Leicester (5)	4	1	2	2	2	5	33	Amber
Birmingham New Street to Hereford (6)	4	1	2	1	0	5	28	Amber
Nuneaton to Coventry to Leamington Spa (7)	4	1	2	3	0	3	26	Amber
Worcester Foregate Street to Birmingham Snow Hill to Leamington Spa (8)	3	1	0	2	2	5	25	Red
Derby to Lincoln (9)	3	1	0	2	2	5	25	Red
Crewe to Stoke-on-Trent to Derby (10)	3	1	2	2	0	4	25	Red
Shrewsbury to Crewe (11)	1	2	0	2	2	3	20	Red

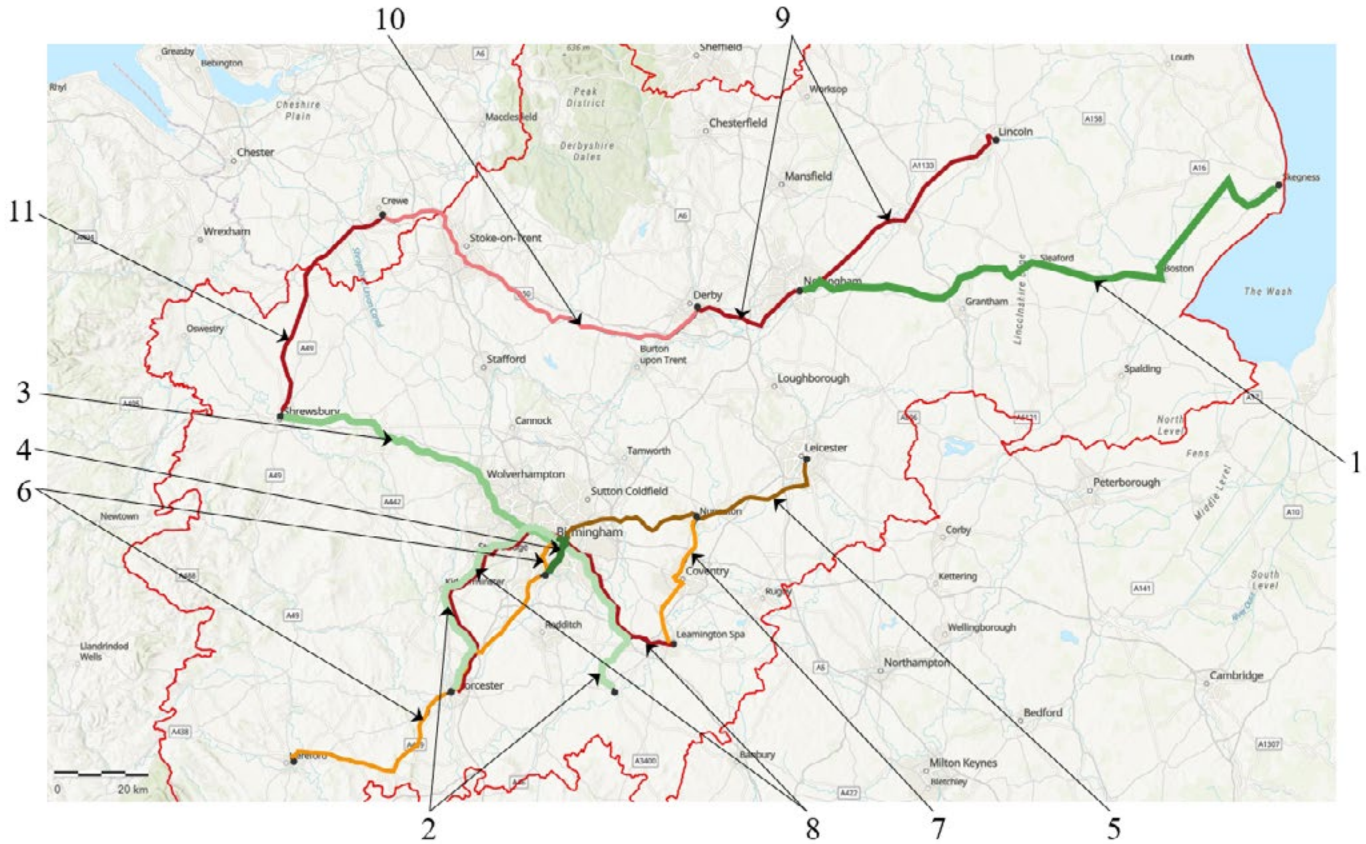

Figure 3: Labelled Map of Ranked Rail Routes

4.3 Key opportunity 1: Nottingham to Skegness

Figure 4: Nottingham to Skegness Route

Nottingham to Skegness has been identified as the prime candidate in the Midlands for adopting hydrogen trains as part of the proposed trial. Fundamentally, current hydrogen technologies can store the daily hydrogen quantity that is required, can operate at the required operating speeds, and can therefore meet the existing service requirements.

To date there is currently no electrification that has been undertaken on the route. Considering the absence of potential recharge time, the route length and the required line speeds, battery-powered trains are less feasible as an option. The high-level cost estimates also indicates that the cost to electrify the route could be 2 to 3 times more expensive than the hydrogen alternative over a 25-year period (£313M vs £118M). Therefore, hydrogen technologies will likely offer the most cost-effective solution for decarbonisation.

The route is located close to the redevelopments at the High Marnham and Ratcliffe-on-Soar power station sites which could provide hydrogen supplies within the next 2 and 7 years respectively. With the East Midlands Cluster also being in proximity, the route is ideally located to benefit from the potential catalytic hydrogen investments that may follow.

Considering all these factors, this route presents a strong candidate for undertaking an initial trial within the immediate future (2-3 years) with subsequent scaling of a trial aligning with the time required to procure a fleet of hydrogen trains (5-6 years). This timeframe would also align with the need to replace the current Class 150 trains that are currently in operation on the route.

4.4 Key opportunity 2: Worcester Foregate Street to Birmingham Snow Hill to Stratford-upon-Avon

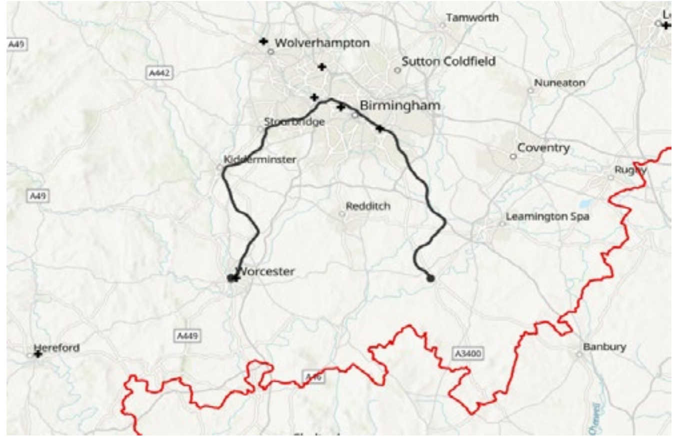

Figure 5: Worcester Foregate Street to Birmingham Snow Hill to Stratford-upon-Avon Route

The Snow Hill line that runs between Worcester and Stratford-upon-Avon also shows significant prospects for conversion to hydrogen operation in the not-too-distant future. Fundamentally again, current hydrogen technologies can comfortably operate the route and maintain existing services. The stopping pattern alternates between sustained high-speed sections (well within hydrogen train capabilities) and frequent stops (which hybrid trains can use to recover energy). The interface of the route with highly populated regions in Birmingham, lends this route as an attractive prospect to gain local support to remove harmful emissions (particulates, noise etc) for residents and commuters.

There is also no electrification that has been undertaken across the route which again rules out battery technologies considering the route length, absence of recharging and required line speeds. The high-level cost comparison also shows that full route electrification could cost up to twice as much as adopting hydrogen technologies (£245M vs £117M). Therefore, hydrogen rail again offers the best decarbonisation option.

This route would likely utilise the Tyseley Depot in Birmingham for maintenance. Another key attractive consideration of this option is the proximity of this depot to the Tyseley electrolyser hydrogen refuelling site which is less than 1 km away. This refuelling site can currently generate 1000 kg hydrogen each day which is sufficient to meet the hydrogen requirements of all four trains in the fleet.

Due to the current presence of hydrogen supply in the area, there is potential for this route to utilise existing hydrogen retrofitted rolling stock in the immediate future (1-2 years) with a subsequent scaling of the trial aligning with the time required to procure a fleet of new hydrogen trains (5-6 years).

4.5 Key opportunity 3: Birmingham New Street to Shrewsbury

Figure 6: Birmingham New Street to Shrewsbury Route

The Birmingham New Street to Shrewsbury route is the third key opportunity to adopt hydrogen rail technologies in the Midlands. Whilst currently hosting a newer class of diesel trains, the Class 196, the route operating speed and daily hydrogen storage requirements are well within the current hydrogen rail technologies that are available. Hydrogen rolling stock could therefore replace the current diesel units and free them up for use on alternative routes in the region.

To date, approximately one third of the route has been electrified. Whilst the sequencing of such electrification should be investigated in more detail, a high-level estimate of the total recharge time available indicates that there is potential for battery-powered trains to operate on the route. However, current battery technologies would not be able to reach the line speeds required on the route and could not therefore maintain the current operational service. When comparing the estimated cost to electrify the remaining route against adopting a fleet of hydrogen technologies, hydrogen again could offer significant savings (£148M vs 130M) and presents a strong option to support decarbonisation.

Similarly, the maintenance of this route is likely to be undertaken at the Tyseley Depot in Birmingham and therefore will also benefit from the proximity to hydrogen supplies. The current capacity of which would again be sufficient to operate all four trains in the fleet.

It is therefore recommended that procuring a fleet of new-build or retrofitted hydrogen powered trains would be suitable for decarbonising the Birmingham to Shrewsbury route. This would be dependent on provision of supplies of hydrogen being available and the installation of refuelling equipment at the base depot of this fleet (Tyseley). This could be achieved in a 5-to-10-year time frame.

4.6 Key opportunity 4: Birmingham New Street to Kings Norton (Camp Hill Line)

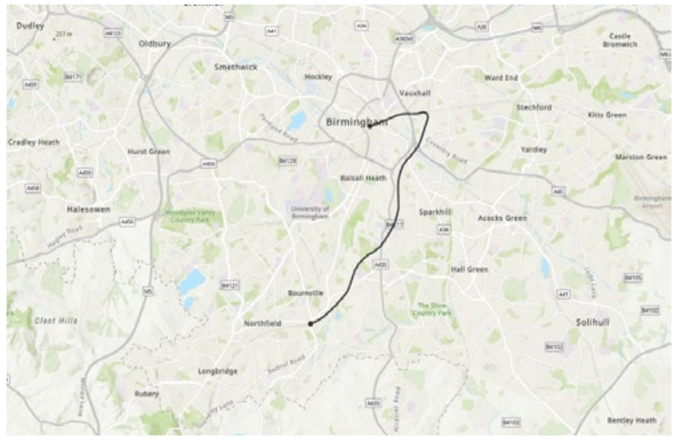

Figure 7: Birmingham New Street to Kings Norton (Camp Hill Line) Route

The Camp Hill Line runs between Kings Norton and Birmingham New Street. Currently, stations are being constructed to allow re-instatement of stopping passenger services on the route for the first time since 1942 and is expected to be in operation by the end of 2024 (Kanaris S, 2023). Due to the smaller route length and slower speeds, it would be a very comfortable route to adopt current hydrogen technologies as a relatively low amount of hydrogen would be required, simplifying logistics. Likewise, these considerations make this route a prime candidate for adopting battery technologies.

With nearly two fifths of the route electrified and considering the slower operational speeds, short route length and flat terrain, battery technologies will likely play a crucial role in replacing the current Class 150 in operation and decarbonising this route in the short-medium term. It is also estimated that full electrification will be cheaper rather than adopting hydrogen technologies (£59M vs £80M). These factors contribute to the route scoring worse on the multi-criteria analysis than the other key opportunities.

Although the long-term credentials of the route do not point towards hydrogen technologies, the route could play a crucial role in gaining hydrogen support from both the UK government and the public, particularly demonstrating the technology and safety case of hydrogen rail to the public.

The route benefits from also being maintained at the Tyseley depot in Birmingham adjacent to the Tyseley electrolyser and refueller where approximately 10% of the generation each day would be sufficient to operate a hydrogen train.

With hydrogen vehicles being ordered directly into services across Europe and other counties, the rolling stock manufacturers are well past the demonstration phase. This route provides the UK and the Midlands with the opportunity to utilise available hydrogen rolling stock to operate a regular hydrogen service and champion the long-term decarbonisation of the rail sector – rather than current proposals to operate a Class 150 on the highly anticipated route due to be reopened.

5. Creating a route to market – next steps

This report highlights the important role hydrogen trains can play both in supporting decarbonisation of certain rail routes in the Midlands and catalysing the wider hydrogen economy. It also suggests routes that could be suitable for hydrogen train deployment, and presents both the technical and the economic benefits of hydrogen over electrification. Hydrogen trains have been demonstrated in the UK during the COP26 and the HydroFLEX development. The next step is to trial hydrogen trains in commercial real-life operation.

The Midlands has all the key ingredients for a successful trial of hydrogen trains, from a strong and established rail industry with hydrogen experience, to hydrogen supply chain and refuelling infrastructure, to suitable rail routes for hydrogen trains. A successful trial of hydrogen trains will unlock a larger commercial opportunity of deploying hydrogen trains in the UK and enable the development of new skills, services, and products from the Midlands, creating economic growth in the region.

Government support and collaboration between the key stakeholders will be essential to enable the trial that helps to better understand the technology, commercial and market readiness levels and so encourage further investment in the sector. The following next steps should be considered for realising a hydrogen train trial in the Midlands:

- Conducting a feasibility study on the train routes considered favourable for hydrogen trial.
- Developing the business and safety case for hydrogen train deployment on the selected route/s.
- Obtaining engineering change approval under the operators Safety Management system. This requires identifying the rolling stock and hydrogen refuelling infrastructure for the trial, obtaining hydrogen rolling stock approval, conducting mainline testing and training operational and engineering staff.

Further action is also required to realise the long-term potential of hydrogen rail in the UK, this includes:

- Working with key stakeholders in the region, including train operators, train developers, hydrogen suppliers, RSSB, local and national government bodies and research and innovation centres to quantify the full economic benefits for a hydrogen rail programme based within the Midlands.
- Developing policy proposals that incentivise train operators to consider hydrogen and battery trains over diesel trains for any new procurements.
- Seek Governmental support to develop hydrogen trains refuelling infrastructure and encourage developments of UK compatible rolling stock.
- Engaging government departments, including DfT, to co-develop a Midlands hydrogen rail strategy.

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