Birmingham H_2 Bus Fleet Expansion – Techno-Economic Analysis

Inigo Antony Michael Selvam

MSc in Sustainable Energy Systems, University of Birmingham and IIT Madras

Contents

1. Introduction

On the fight towards net zero emissions, decarbonization of transport sector is a crucial step. The UK has drawn plans to reach net zero emissions by 2050 and has deployed various measures across the country to reach it (1). One such measure is the deployment of hydrogen fuel cell electric vehicle (FCEV) technology towards a sustainable urban transport in Birmingham. Birmingham City Council (BCC) (2) has implemented several measures to improve the air quality in Birmingham like the 'Clean Air Zone' and low emission transport alternatives. The 'Clean Air Hydrogen Bus Pilot' trail was kicked off on 2021 with 20 Wrightbus StreetDeck Hydroliner FCEV buses, which emit only water at the point of use (3). These buses are still functional and are being refuelled at the purpose-built Tyseley Energy Park Hydrogen (4). This report is aimed at designing and analyzing the deployment of additional 120 buses and its associated infrastructure.

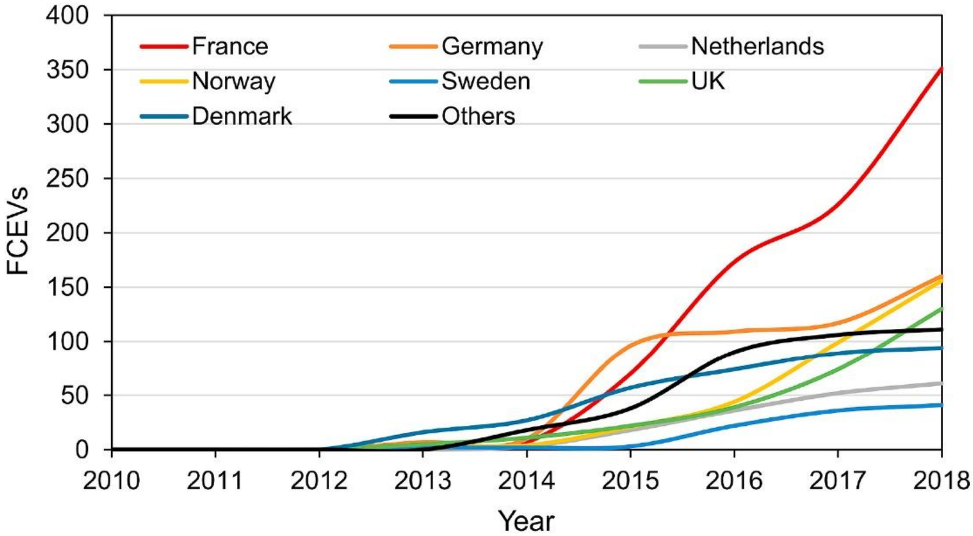


Fig 1: The trend in FCEV vehicle deployment in European countries (5)

The report aims to:

1. Detail the specifications of the operational and planned bus fleet.
2. Estimate the hydrogen fuel demand based on the best available data and clearly stated operational assumptions.
3. Review current Hydrogen Refuelling Station (HRS) technologies, typical sizes, and indicative costs, referencing academic literature and industry examples like Tyseley.

4. Propose and justify a feasible HRS network design for Birmingham capable of supporting the 140-bus fleet, considering station sizing and geographical distribution.
5. Evaluate operational fuel costs, calculate the Well-to-Wheel CO_2 emissions compared to diesel buses.

This report systematically addresses these points, starting with vehicle data and demand, moving through HRS technology and network design, and concluding with cost and environmental analysis.

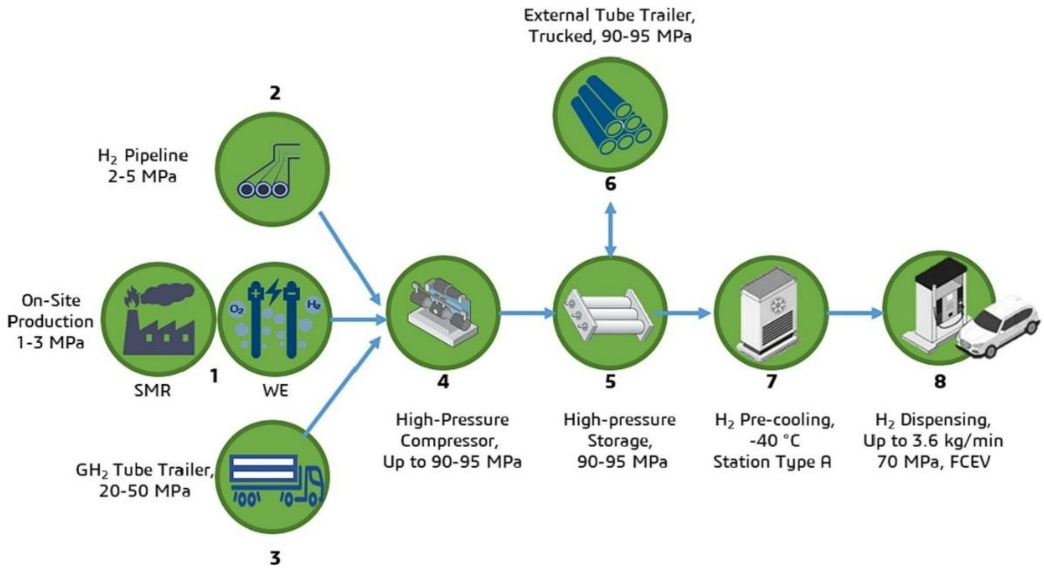


Figure 2: The schematic for gaseous hydrogen refuelling station with cascade system (6).

2. Vehicle data and Hydrogen demand

The current fleet of 20 buses gives us reliable data to analyze and plan the fuel requirements of the expanded fleet of 140 buses. This section provides the analyses of the current bus fleet and extrapolates the hydrogen demand for the complete fleet of 140 busses.

2.1. Birmingham's Current Hydrogen Bus Fleet

Currently, 20 Wrightbus StreetDeck Hydroliner FCEV double-decker buses operated by National Express West Midlands (NXWM) on behalf of BCC, deployed from late 2021 (7) The fuel cell technology in the bus is provided by Ballard (FCvelocity family) (3) It has a range of over 300 miles and fuel tank capacity of 27 kg of hydrogen pressurized at 350 bar. It takes approximately 8 minutes to refuel completely.

Table 1: Specifications of Wrightbus StreetDeck Hydroliner bus (3).

Category	Details
Bus Model	Wrightbus StreetDeck Hydroliner FCEV (double-decker)
Operator	National Express West Midlands (NXWM) on behalf of BCC
Fuel Cell Provider	Ballard (FCvelocity® family)
Fuel Cell Model	FCvelocity®-9SSL
Range	Over 300 miles
Hydrogen Tank Capacity	27 kg
Hydrogen Pressure	350 bar
Refuelling Time	Approximately 8 minutes (complete refuel)

For a theoretical fleet of 140 busses with additional 120 busses, the hydrogen demand can be extrapolated from the current fleet's utilization.

2.2. Hydrogen Consumption and Demand Estimation

Estimating fuel demand requires figures for fuel economy and daily operation. From the specifications of the Hydroliner bus we know that the fuel tank capacity is around 27 kg (3). And it has a maximum range of over 300 miles. From these values we can calculate the fuel economy of the vehicle,

H_2 required per mile = 27 kg/300 mile = 0.09 kg/mile
Fuel Economy = 9 kg/100 km.

The original 2017 Full Business Case used a planning assumption of 8 kg H_2 / 100 km (2). This figure is also referenced in recent academic literature discussing the pilot (6) For this report, we will utilise the 8.5 kg H_2 / 100 km figure, which is an assumption based on potential increase in performance and mileage at the time of deployment. An average daily mileage of 300 km per bus is considered which is also the value quoted in the NX West Midlands website (8). This aligns with the lower end of the potential range, represents a plausible urban operational duty cycle, and allows for schedule variations and potential traffic delays without exceeding single-tank capacity between refuels.

Demand Calculations:

Daily H_2 Consumption = (Daily Mileage / 100 km) * Fuel Economy

Daily H_2 Consumption = (300 km / 100 km) * 8.5 kg H_2 = 25.5 kg H_2 per bus per day

Estimated Hydrogen Demand:

Current Fleet (20 Buses): 20 buses * 25.5 kg/bus/day = 510 kg H_2 / day

Full Planned Fleet (140 Buses): 140 buses * 25.5 kg/bus/day = 3,570 kg H_2 / day

Supply Gap to Meet: (3,570 – 1000) kg H_2 / day = 2570 kg H_2 / day

Annual Demand (140 Buses): 3,570 kg/day * 365 days/year = 13,03,050 kg H_2 / year (approximately 1,303 tonnes per year).

Table 2: Hydrogen Demand Calculations

Calculation	Values
Daily Mileage	300 km
Fuel Economy	8.5 kg / 100 km
Hydrogen demand	25.5 kg H_2 per bus per day
Current fleet demand	510 kg H_2 / day
Full planned fleet demand	3,570 kg H_2 /day
Supply Gap to Meet	2570 H_2 /day
Annual demand of fleet	13,03,050 kg H_2 / year

This estimated daily demand of over 3.5 tonnes necessitates a significant refuelling infrastructure capability beyond the existing Tyseley hub. The following section examines the technologies involved in HRS.

3. Refuelling Infrastructure and Sizing

Hydrogen Refuelling Stations (HRSs) are complex systems designed to safely and efficiently deliver high-purity hydrogen fuel to vehicles. Understanding their components, layouts, and sizing is crucial for network planning (6). HRS can be classified into two types in terms of hydrogen production infrastructure as, on-site and off-site (5). Off-site hydrogen production involves producing hydrogen in purpose-built facilities of large scale that utilize resources efficiently to produce hydrogen in large quantities. The centralized production operation minimizes cost and improves efficiency. On-site HRS system produces hydrogen at the point of consumption. This involves having complex hydrogen production infrastructure on site to reduce transportation costs and difficulties. The production of hydrogen off-site and transporting is much feasible than producing hydrogen on-site due to high capital cost and levelized cost of hydrogen (LCOH) (5,9). In this report, we propose producing hydrogen off-site and transporting it to the HRS location.

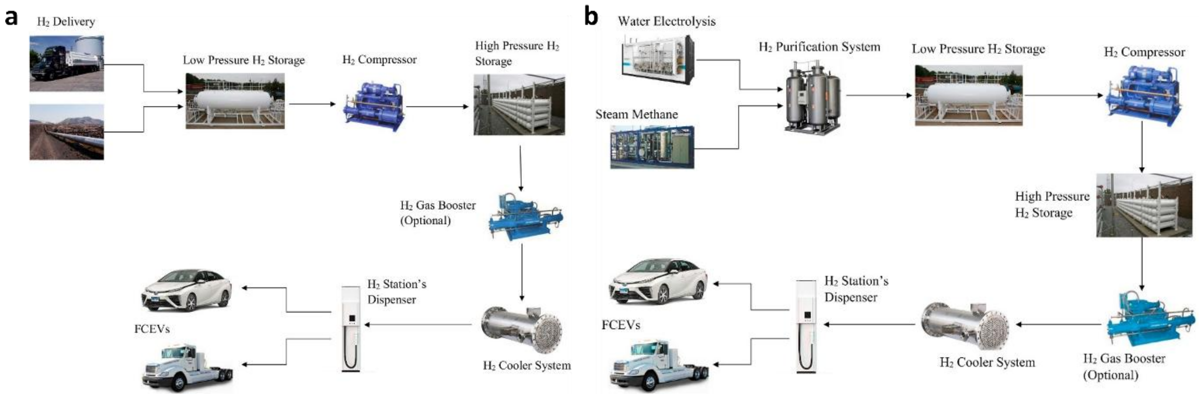


Figure 3: The flow diagram for HRS station with a) off-site production b) on-site production (5).

Moreover, there are two types of hydrogen transportation option namely, liquid hydrogen and gaseous hydrogen transport (5). Gaseous hydrogen (GH_2) can be transported through tube trailers at a pressure of ~250 bar with a load of 500 kg per shift (10). GH_2 can also be transported at highly compressed state at 500 bar pressure in container trailers with 1000 kg per shift. Similarly, liquid hydrogen (LH_2) can also be transported through trailers. At pressures of 1-1.5 bars, ~ 4000 kg of LH_2 can be transported per shift. For maintaining the low temperatures, LH_2 is transported in insulated cryogenic tanks. According to Apostolou and team (5), gaseous hydrogen production and transportation is economically feasible for short and medium scale. The cost of liquefaction is too high for short and medium scale transportation. While, for large scale transportation needs, liquefaction is feasible as transportation and logistics may work against gaseous transport at scale. There are several components present in HRS infrastructure. Each structure and functionality are explained below.

3.1. Key HRS Components and Processes

- **Hydrogen Supply:** Can be via pipeline, tube trailers (compressed gaseous hydrogen - GH_2), liquid hydrogen (LH_2) tankers, or on-site production (e.g., electrolysis, Steam Methane Reforming - SMR) (6) This plan uses centralised electrolysis at Tyseley using renewable electricity with GH_2 delivery.

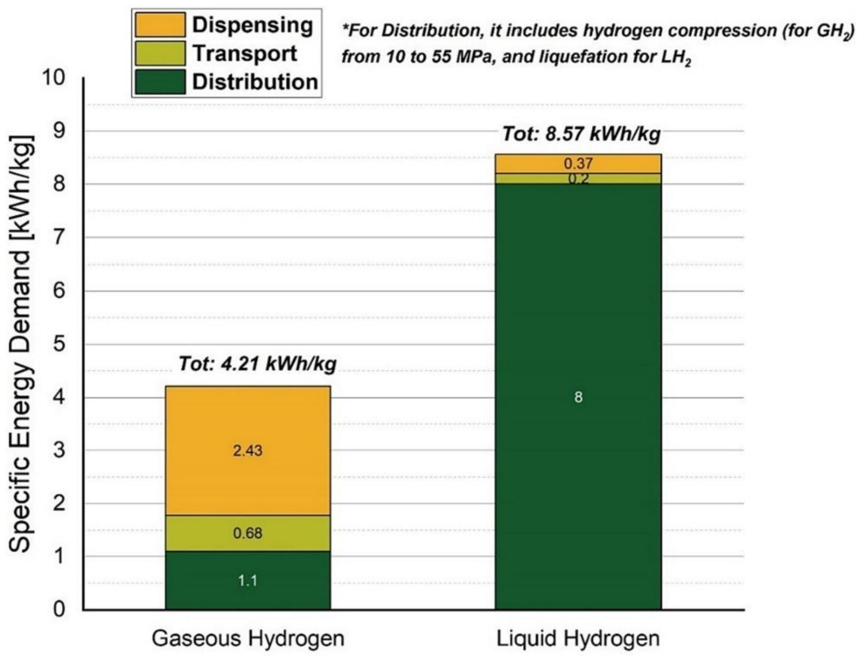
- **Compression:** Hydrogen produced by electrolysis (e.g., ~30 bar) needs compression to ~500 bar for efficient GH_2 tube trailer transport. At the depot HRS, further compression is needed to achieve storage pressures (e.g., ~950 bar for cascade fuelling) or direct booster compression for 350 bar dispensing (6).

- **Storage:** On-site depot storage in high-pressure vessels (Type I-IV composite tanks) buffers deliveries and meets peak demand. Cascade systems (multiple pressure banks) or direct/booster systems (medium pressure bank + booster) are common layouts (6). For this review we are considering a cascade system for storage systems for efficiency and managing multiple simultaneous fills, assuming adequate high-pressure storage.

- **Pre-cooling:** Hydrogen is typically cooled to -20 °C or -40 °C (T40/T20 protocols) before dispensing into 350/700 bar tanks to manage heat generated during filling and ensure a safe, full state of charge (6).

- **Dispensing:** Controls fuel flow, monitors pressure/temperature, ensures safe filling according to protocols (e.g., SAE J2601). Birmingham buses use 350 bar dispensers (3).

- **Safety equipment:** To mitigate explosion and leaks, equipment such as sensors, valves and fire extinguishers are an integral part of the HRS system (6).



3.3. HRS Sizing and Costs

HRS capacity is measured in kilograms dispensed per day (kg/day). Station sizes vary considerably in terms of number of dispensers and hydrogen output (11). The required capacity dictates the scale and cost of equipment, particularly storage and compression. For the particular scenario defined for the report, we select medium sized HRS with two dispensers (2D) configuration that has maximum capacity of 1178 kg/day (11). Data from California in 2015 indicated total installed costs ranging from ~$1.5M – $4.5M (~£1M – £3M) for 770 kg/day stations, with projections suggesting costs could halve by 2025 due to economies of scale and technological learning (12). Operational costs (OPEX) include electricity (for compression and cooling), maintenance, labour, insurance, and the cost of the delivered hydrogen itself (5,6,11).

One of the major hurdles in the transition towards hydrogen powered vehicles is the availability of Hydrogen Refuelling Stations (HRS). This is because of the significant capital investment and market uncertainties pertaining to establishing new HRS (13). The production, distribution and refuelling infrastructure for hydrogen needs to be built from ground up which is a significant deviation from the current reliable fossil fuel infrastructure that people are accustomed to. With an understanding of HRS technology and sizing, we propose a network layout for Birmingham.

4. HRS Placement Strategy

Developing a refuelling network for 140 FCEV buses requires careful planning to ensure sufficient capacity, coverage, and operational resilience. This section proposes a network based on expanding centralised production at Tyseley Energy Park and establishing depot-based refuelling points supplied by GH_2 truck delivery.

4.1. Network Requirements and Strategy

The estimated total daily hydrogen demand for the 140-bus fleet is 3,570 kg/day (Section 2.2). The existing production facility at Tyseley Energy Park, operated by Hygen Energy, has a capacity of producing 1000 kg of H_2/day (4). This leaves a significant production shortfall of 2570 kg kg/day. The chosen strategy involves consolidating all hydrogen production at an expanded Tyseley site and transporting the required GH_2 fuel via truck to strategically located bus depots equipped with HRS facilities. This leverages the existing Tyseley hub while utilising established depot locations for efficient fleet refuelling, typically overnight. Buffer storage at depots will be crucial to manage potential delivery disruptions and ensure consistent fuel availability.

4.2. Centralised Production Expansion at Tyseley

To meet the total 3,570 kg/day requirement (demand plus a small buffer), Tyseley's production needs expanding by 2570 kg/day. Based on the existing 3 MWe electrolyser's output (~267 kg/day/MWe), approximately 11 MWe of additional electrolysis capacity is needed. Given Tyseley Energy Park's focus on hydrogen and energy innovation, installing further PEM electrolyser units is considered technically plausible, assuming sufficient land and grid connection capacity is available. For this report, and additional 12 MW electrolyzer capacity (equivalent to 3204 H_2 kg/day) is proposed to be added to existing Tyesley Energy Park. The additional hydrogen produced can be utilized for retail purposes for vehicles or other use cases.

Based on current industry data, PEM electrolyser system costs for larger installations are estimated to be in the range of $1000/kW (14) Adopting a figure of £750/kW for a 12 MWe system, the core electrolyser package would cost approximately €9 million.

Beyond the electrolyser units themselves, significant additional costs are incurred for the site-specific Balance of Plant (BoP). This includes civil engineering works, water purification systems, power supply and grid connection infrastructure, initial hydrogen compression to 500 bar for tube trailer filling, production-site buffer storage, safety systems, as well as project management, engineering design, and installation labour. These comprehensive BoP and installation costs can be substantial, often adding 50-100% or more to the equipment cost. For this estimate, an additional 75% of the electrolyser system cost is considered for BoP and other expenses, resulting in an estimated €6.75 million.

Therefore, the total estimated upfront CAPEX for the 12 MWe PEM electrolysis expansion at Tyseley Energy Park is projected to be in the order of £15.75 million at an exchange rate of €1.18/£).

Actual CAPEX can vary significantly from real world conditions due to several factors. This upfront capital cost is a key input into the Levelized Cost of Hydrogen (LCOH) calculations discussed in Section 5, where it is amortized over the plant's operational lifetime and output.

4.3. Proposed Network Configuration (GH2 Delivery)

A distributed network of four HRS facilities is proposed, one at the Tyseley hub and three at other major NXWM depots, providing city-wide coverage and resilience.

- **HRS 1 (Tyseley Hub):** Serves as the central production facility (4,000 kg/day total capacity) and includes an 800 kg/day dispensing capability for buses based locally or operating nearby routes.

- **HRS 2 (Perry Barr Depot):** A new satellite HRS with 1,000 kg/day dispensing capacity, receiving GH2 deliveries. This large capacity serves the significant North Birmingham operations and provides network redundancy.

- **HRS 3 (Yardley Wood Depot):** A new 1000 kg/day satellite HRS serving South Birmingham routes.

- **HRS 4 (Acocks Green Depot):** A new 800 kg/day satellite HRS serving East Birmingham routes and providing redundancy for Tyseley/Yardley Wood.

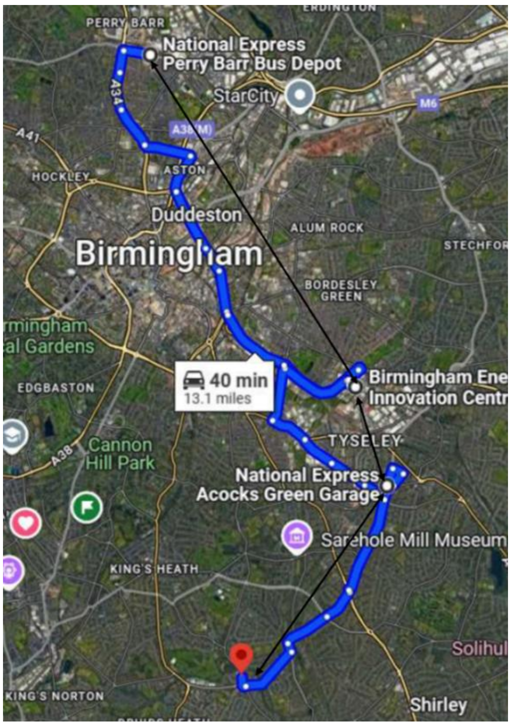


Figure 4: Map illustrating the proposed HRS throughout Birmingham

This configuration provides a total network dispensing capacity of 3,600 kg/day, matching the expanded production and meeting the estimated demand with a slight buffer. The locations provide good geographical coverage, centred on operational hubs (Figure 5). The primary challenge lies in managing the logistics of delivering ~2,700 kg of GH_2 daily via truck to the three satellite depots, requiring at least one delivery each day to each of the stations considering a payload of 1000 kg GH_2 payload at 500 bar.

Capital cost of establishing one station can be derived from Thomas et.al. paper (11), which is around €2.85 million. For 3 new stations, the total capital cost is around £7.25 million. The huge capital cost is a determining factor in the establishment of the HRS.

5. Operation Cost and comparison

The economic feasibility of the hydrogen bus fleet is intrinsically linked to the cost of the hydrogen fuel itself. This section estimates the production and delivery costs based on the chosen pathway: centralised electrolysis at Tyseley and GH_2 truck delivery.

5.1. Chosen Production and Delivery Pathway

The hydrogen is assumed to be generated via PEM electrolysis at Tyseley (preferably sourced from ITM), utilizing low-carbon electricity sourced from the associated waste wood gasification plant or any other renewable energy source with very low net carbon emission. Energy derived from biomass is considered zero or even negative net emissions. But, considering a broader use case of renewable energy sources, an assumption of 35 gCO2e/kWh is made (typical value for off shore wind). After production (at ~30 bar), the hydrogen is compressed to 500 bar, loaded onto specialized tube trailers, and transported by truck to the satellite depots (Perry Barr, Yardley Wood, Acocks Green). At the depots, it's transferred to buffer storage before further compression, cooling, and dispensing into buses at 350 bar.

5.2. Estimated Hydrogen Fuel Cost

The cost per kilogram of hydrogen dispensed includes contributions from various factors. The first thing to consider is the production CAPEX and OPEX. The LCOH calculator is used to estimate this cost which comes out to be €9.69 /kg H_2 for 15 MWe installed power. The second thing that needs to be considered is the transportation costs. Thomas et. al, provide the cost of operating HRS to be €1.22 /kg for HRS with 1000 kg capacity (2 Dispensers at 100% utilization) (11). Therefore, transportation costs can be approximated to €1/ kg H_2. Therefore, the cost of hydrogen at the dispenser is ~€12 per kg which is equivalent to ~£10 per kg. This is majorly an estimation with no subsidies and profit margins being considered for the simplicity of the calculations.

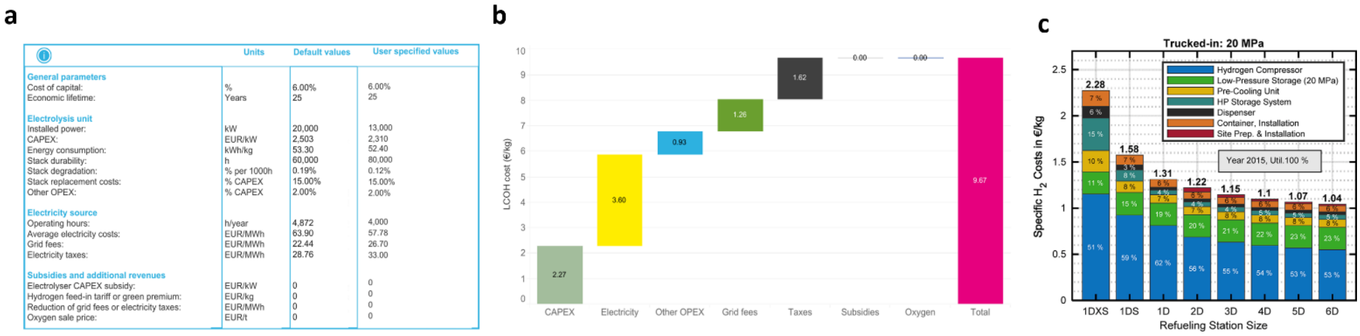


Figure 5: The breakup of levelized cost of a) production and b) HRS (15)(11).

Table 3: LCOH calculations:

Calculation	Values
Cost of Production	€ 9.69 /kg H2
Cost of Transportation	€1 /kg H2
Cost incurred in HRS	€1.22 /kg H2
Total cost of hydrogen	€12 /kg H2
Total cost of hydrogen in GBP	£10 /kg H2

5.3. Annual Fleet Fuel Cost Estimate

Based on the estimated annual demand of 13,03,050 kg and the calculated cost of £10/kg, the total annual operating cost attributable to the production of hydrogen fuel, transportation of GH_2 and HRS for the 140-bus fleet is estimated at approximately £13 million.

5. CO_2 balance and comparison

A key motivation for transitioning to hydrogen buses is the reduction of GHG emissions. This section assesses the Well-to-Wheel (WtW) CO_2 equivalent (CO_2e) emissions of the proposed hydrogen pathway and compares them to the diesel buses they replace. Cost comparison is also done to predict the feasibility of FCEV busses for urban transport.

6.1. Well-to-Wheel CO_2 Emissions comparison

WtW emissions include those from fuel production and delivery. Assuming the use of low-carbon electricity, say off shore wind (35 gCO_2e/kWh) for production of hydrogen, the production and related processes (60 kWh/kg) contributes ~2.1 kg CO_2e/kg H_2 (16,17). Operation HRS involves usage of compressors and other energy consuming activities which (~4.21 kWh/kg total) (6) adds ~0.147 kg CO_2e/kg H_2. Emissions from diesel trucks for GH_2 transport are minimal for short urban distances (~0.027 kg CO_2e/kg H_2)(18). The total WtW emission factor is therefore estimated at ~2.27 kg CO_2e per kg H_2.

Multiplying this factor by the total annual hydrogen demand (13,03,050 kg/year) gives total annual emissions for the 140-bus hydrogen fleet of approximately 2873 tonnes CO_2.
The conventional diesel buses being replaced are stated to have an emission factor of ~900 g CO_2/km (0.9 kg CO_2e/km). For the total estimated annual fleet mileage of 15,330,000 km (140 buses*300 km/day*365 days), the equivalent diesel fleet would emit approximately 13,797 tonnes CO_2e per year.

Table 4: Emissions calculations comparing FCEV buses and Diesel buses.

Calculation	Diesel	Hydrogen
Production emissions	-	2.1 kg CO_2/kg H_2
Transportation emissions	-	0.027 kg CO_2/ kg H_2
Emission pertaining to HRS	-	0.147 kg CO_2/ kg H_2
Total emissions	0.9 kg CO_2/km	2.27 kg CO_2/ kg H_2
Annual demand	-	13,03,050 kg/year
Annual Mileage	15,330,000 km	
Annual emissions	13,797 tonnes CO_2	2957 tonnes CO_2

The comparison, summarised in Table 4, highlights the substantial environmental benefit. The hydrogen fleet, even with grid-connected electrolysis using the specified low-carbon source, offers a potential saving of nearly 10,840 tonnes CO_2e annually, equating to a ~80% reduction compared to the diesel baseline.

6.2. Cost comparison H_2 vs Diesel

We can compare the price of operating FCEV buses with the conventional diesel buses to get an idea about the cost differences. It is evident that FCEV buses are competitive with diesel buses according to the rough calculation attempted in Table 5. But these calculations don’t account for profit margins, subsidies, tax benefits and other unaccounted expenses So, the values could differ slightly from the real-world scenario but still the costs are comparable nonetheless.

Table 5: Cost comparison of Hydrogen and Diesel as fuel source for bus operation per day.

Calculation (diesel)	Value	Cost
Cost of diesel	£1.4/L	£10/kg
Tank size	245 L	25.5 kg
Range	400 km	300 km
Fuel Economy	1.63 km/L	8.5 kg/100 km
Mileage per day	300 km	300
Fuel consumption per day	184.04 L	25.65 kg
Cost of fuel per day	£259.5	£256

7. Summary and Conclusion

This report has evaluated the infrastructural requirements for expanding Birmingham's hydrogen FCEV bus fleet to 140 units. The analysis proposed a network strategy based on significantly expanding green hydrogen production via electrolysis at the existing Tyseley Energy Park hub and distributing compressed gaseous hydrogen (GH_2) via truck to three additional HRS facilities located at key bus depots (Perry Barr, Yardley Wood, Acocks Green). This network provides a total dispensing capacity of 3,600 kg/day, meeting the estimated fleet demand of 3,570 kg/day.

The techno-economic analysis indicated that while this expansion is technically plausible, it requires substantial capital investment, particularly for the ~10 MWe electrolysis capacity increase at Tyseley. The estimated capital cost of establishing the new production facility and HRS is around £24.27 million (£15.75 for production + £8.55 for HRS). The estimated operational cost of hydrogen fuel at the dispenser is around £10/kg. This results in an annual fleet fuel cost baseline approaching £13 million. Logistically, the GH_2 pathway necessitates multiple daily truck deliveries, presenting an operational challenge compared to potentially simpler LH_2 delivery, but avoids the high cost and energy penalty of liquefaction.

Environmentally, the proposed pathway demonstrates significant advantages. Using low-carbon electricity (assumed at 35 gCO_2e/kWh) for hydrogen production, the FCEV fleet's estimated annual Well-to-Wheel emissions are ~2,873 tonnes of CO_2. This represents a ~80% reduction compared to the ~14,100 tonnes of CO_2 estimated for an equivalent diesel fleet operating at 900 gCO_2e/km.

In conclusion, scaling up Birmingham's hydrogen bus fleet via centralised electrolysis and GH_2 distribution offers a viable route to significantly reducing transport emissions. The primary hurdles are the high initial capital costs and the operational fuel cost, which is sensitive to electricity prices. Managing the logistics of frequent GH_2 deliveries is also a key consideration. Achieving long-term economic viability will depend on securing low-cost renewable electricity, realising projected cost reductions in electrolysis and HRS equipment through market growth and technological learning, and potentially supportive policy mechanisms through funding and subsidies.

8. References:

1. Dixon J, Bell K, Brush S. Which way to net zero? a comparative analysis of seven UK 2050 decarbonisation pathways. Renewable and Sustainable Energy Transition [Internet]. 2022 Aug 1 [cited 2025 May 9];2:100016. Available from: https://www.sciencedirect.com/science/article/pii/S2667095X21000167
2. Clean Air Hydrogen Bus Pilot FBC Project Title Clean Air Hydrogen Bus Pilot (CAHB Pilot) Project Code. 2017 [cited 2025 May 9]; Available from: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016
3. Wrightbus First hydrogen fuel cell bus | Double decker bus [Internet]. [cited 2025 May 9]. Available from: https://wrightbus.com/en-gb/hydrogen-bus-streetdeck-hydrolinerFCEV
4. Tyseley Refuelling Station - Tyseley Energy Park [Internet]. [cited 2025 May 9]. Available from: https://www.tyseleyenergy.co.uk/tyseley-refuelling-hub/
5. Apostolou D, Xydis G. A literature review on hydrogen refuelling stations and infrastructure. Current status and future prospects. Renewable and Sustainable Energy Reviews [Internet]. 2019 Oct 1 [cited 2025 May 8];113:109292. Available from: https://www.sciencedirect.com/science/article/pii/S1364032119305003?casa_token=4huQKqhdhsoAAAAA:V1NGD0oz9X8mcIJRL8XcOf6hOP6vNaRXBqouh5Gteyhzuyo13ZKqIKiSQScbYtRqsGg1j5OykA#bib60
6. Genovese M, Fragiacomo P. Hydrogen refueling station: Overview of the technological status and research enhancement. J Energy Storage [Internet]. 2023 May 1 [cited 2025 May 9];61:106758. Available from: https://www.sciencedirect.com/science/article/pii/S2352152X2300155X?via%3Dihub#bb1635

7. Zero emissions buses | NX Bus West Midlands [Internet]. [cited 2025 May 9]. Available from: https://nxbus.co.uk/west-midlands/zero-emissions-buses

8. Zero emissions buses | NX Bus West Midlands [Internet]. [cited 2025 May 8]. Available from: https://nxbus.co.uk/west-midlands/zero-emissions-buses

9. Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California | California Energy Commission [Internet]. [cited 2025 May 9]. Available from: https://www.energy.ca.gov/publications/2022/joint-agency-staff-report-assembly-bill-8-2022-annual-assessment-time-and-cost

10. ENERGY OF THE FUTURE? Sustainable Mobility through Fuel Cells and H 2. [cited 2025 May 9]; Available from: www.shell.de

11. Mayer T, Semmel M, Guerrero Morales MA, Schmidt KM, Bauer A, Wind J. Techno-economic evaluation of hydrogen refueling stations with liquid or gaseous stored hydrogen. Int J Hydrogen Energy [Internet]. 2019 Oct 4 [cited 2025 May 9];44(47):25809–33. Available from: https://www.sciencedirect.com/science/article/pii/S0360319919330022?via=ihub

12. Stetson N, Satyapal S. Title: Hydrogen Fueling Stations Cost Originator: Mariya Koleva and Marc Melaina. [cited 2025 May 9]; Available from: https://afdc.energy.gov/data/10370

13. Nistor S, Dave S, Fan Z, Sooriyabandara M. Technical and economic analysis of hydrogen refuelling. Appl Energy [Internet]. 2016 Apr 1 [cited 2025 May 9];167:211–20. Available from: https://www.sciencedirect.com/science/article/pii/S0306261915013215

14. Electrolyzer prices – what to expect – pv magazine International [Internet]. [cited 2025 May 9]. Available from: https://www.pv-magazine.com/2024/03/21/electrolyzer-prices-what-to-expect/

15. Zealand Banking Group N. HYDROGEN TRANSPORTATION THE ANZ HYDROGEN HANDBOOK VOL II.

16. Wang S, Wang S, Liu J. Life-cycle green-house gas emissions of onshore and offshore wind turbines. J Clean Prod [Internet]. 2019 Feb 10 [cited 2025 May 9];210:804–10.

Available from:
https://www.sciencedirect.com/science/article/pii/S0959652618334310?casa_token=M-gNQ14Mqo8AAAAA:RCTuWCqlJQD4T2dPQSD3XXB7uwIpNA-u574Oy6Q2_DLlsKguqzNyU9nO8a2t5eaDtzdtGVrvNA

17. Abe JO, Popoola API, Ajenifuja E, Popoola OM. Hydrogen energy, economy and storage: Review and recommendation. Int J Hydrogen Energy [Internet]. 2019 Jun 7 [cited 2025 May 9];44(29):15072–86. Available from: https://www.sciencedirect.com/science/article/pii/S036031991931465X?via%3Dihub

18. Emission Factor: Rigid truck 26-32t - Average/mixed load - Diesel | Transport | Road Freight | Europe and South America | Climatiq [Internet]. [cited 2025 May 9]. Available from: https://www.climatiq.io/data/emission-factor/1deb995a-fa97-41f3-930e-6d8fd99b20e0