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BALLARD

INFORMATIONAL

Fuel Cell Electric Buses

An attractive value proposition for zero emission buses in the United Kingdom

Zero–Emission Fuel Cell Electric Buses for the United Kingdom

Executive Summary

There is no doubt that the future of public transportation is going to be zero emission. The bold plan announced by the U.K. Department for Transport to deploy 4,000 zero emission buses within five years represents a significant leading edge of the anticipated rapid growth in zero emission fuel cell-powered buses as we move forward in Europe.

Transit agencies and operators in the UK are being called to find ways to improve air quality in their communities while maintaining quality of service. The choice that faces cities and transit authorities is what technology to deploy. Transit operators can consider two zero emission electric bus solutions: fuel cell electric buses (FCEBs) or battery electric buses (BEBs).

FCEBs are electric buses which offer all the benefits of BEBs while facilitating large scale deployments. FCEBs fuelled with hydrogen are the only zero-emission technology to match diesel fleets with complete route flexibility, short refuelling time and similar depot space utilization.

With more than 15 years on the road and millions of kilometres in passenger service, FCEBs have proven their performance. FCEBs have demonstrated reliable operation long daily drive cycles during all seasons in challenging geographies. Over 2,000 fuel cell buses have been delivered to transit operators around the world. Ballard is currently powering more than 70 FCEBs in Europe. Most recently in the UK, there were 20 FCEBs operating, including buses supplied by Wrightbus and Van Hool and powered by Ballard fuel cells. In the coming years, over 100 new fuel cell electrics buses are planned to be deployed in London, Aberdeen, Belfast, Dundee, Birmingham, Brighton, Liverpool, Glasgow and Dublin.

The potential for growth is immense, with financial incentives available at regional, national and European levels to support the deployment of fuel cell electric buses and hydrogen refuelling stations. Analysis performed by both Deloitte China and McKinsey & Company shows that a number of hydrogen solutions can become competitive by 2030. There is a clear line of site to a positive payback, with fuel cell electric vehicles projected to be less expensive to run than battery electric and internal combustion engine vehicles within 10-years.

Read on to learn more about the benefits of zero-emission FCEBs for public transportation in the UK.

Clean public transit powered by renewable hydrogen will improve air quality in our cities.

Introduction

City councils in the United Kingdom (UK) have recognized the urgent need to take action to address poor air quality in their cities and have also made commitments to reduce greenhouse gas emissions from the transportation sector. Air pollution is the biggest environmental threat to health in the UK, with between 28,000 and 36,000 deaths a year attributed to long-term exposure.[1] Diesel buses and trucks are a major contributor.

Professor Paul Cosford, Director of Health Protection and Medical Director at Public Health England, said "Now is our opportunity to create a clean air generation of children, by implementing interventions in a coordinated way. By making new developments clean by design we can create a better environment for everyone, especially our children."

The UK Government has taken this message to heart, with the Department for Transport (DfT) announcing a 5-year, £5 billion plan to enhance bus and bicycle infrastructure in the country – including new routes, expanded bus lanes, more affordable fares together with deployment of at least 4,000 zero emission buses. Full details of the bus funding program, with its focus on improving and increasing green mobility journeys, is expected to be announced in a National Bus Strategy to be published later in 2020.

Within London, the introduction of an "ultra-low emission zone" ("ULEZ") is one of the steps taken to directly address air pollution from vehicles. Heavier vehicles, including lorries (over 3.5 t) and buses or coaches over 5 t, will be charged £100 per vehicle per day to enter this zone. And the scope of the ultra-low emission zone is expected to be expanded for larger vehicles like buses, coaches and lorries first in 2020, and then expand to all vehicles in all inner London boroughs a year later 25 October 2021.

Emissions targets and regulations mean transit agencies must implement zero-emission bus solutions—fast. The question is which zero emission technology is best suited to meet the needs of a transit operator – battery electric or fuel cell electric.

Now, it's up to cities, transit agencies, and operators to properly evaluate fuel cell electric buses and battery electric buses. While each type has benefits, we believe that, at scale, hydrogen lowers the risk for transit agencies. FCEBs are the only zero emission solution that can meet the performance demands of transit operators without compromise. With millions of kilometres in commercial services and more than fifteen years on the road in different environments, FCEBs have proven to meet operational requirements of transit agencies and bus operators.

[1] GOV.UK

Benefits of Zero-Emission Fuel Cell Buses

FCEBs provide affordable zero-emission transportation with no compromise in vehicle performance. FCEBs are the only zero-emission technology to offer full vehicle capability (gradeability, highway speeds, and long range) in all operating environments.

FCEBs do a complete day's work even on the most arduous routes and allow for a 1:1 replacement for conventional diesel or compressed natural gas (CNG) technologies. This means that FCEBs can operate on all urban bus routes without compromise during long shifts in winter or summer.

Fuel cell electric bus in operation in London

Zero-emission transportation with no compromise in performance or operation.

Performance

FCEBs offer the performance benefits of long range, fast refuelling and full route flexibility, consistent with the internal combustion engine vehicle experience. FCEBs operate over 450 km during an 18-hour shift on the road with a single 10-minute re-filling at night. This is in contrast to the limitations of BEBs that are range-constrained, require long recharge times or roadside recharging infrastructure, and may be limited to certain routes while outside temperature may affect bus performance.

Reliability

The thousands of FCEBs operating around the world have proven to meet operational requirements of transit agencies and bus operators. FCEBs powered by Ballard's fuel cells have travelled more than 20 million kilometres of revenue service, equivalent to circling the Earth 500 times, with fuel cell system availability above 97%.

FCEBs in the UK will benefit from the proximity to our European service centres to ensure increased availability.

Resiliency

Access to public transport is considered an essential service by many, especially in disadvantaged communities. And, in an emergency, buses can play a lifesaving role in transporting the injured or sick.

The question then arises of how BEB fleets will be charged in the event of a prolonged power outage. Hydrogen stored on site at the bus depot will ensure transit agencies avoid this issue, providing multiple refuelling for each bus. FCEBs can also be used as emergency power generators in crisis situations.

Sustainability

BEBs and FCEBs produce zero direct emissions at the tailpipe. This significantly improves air quality in urban areas. However, a higher percentage of their overall lifetime emissions is actually a result of their manufacturing and end-of-life processes.

As a key component supplier, Ballard is engaged in helping reduce the total lifecycle emissions of FCEBs. The manufacturing of a fuel cell electric power train (fuel cell system + battery) generates 75% less GHG emissions than 100% battery power train.

Ballard offers its customers a refurbishment program for end of life fuel cell stacks. Ballard refurbishes the fuel cell stack and recovers more than 95% of platinum for a lower life cycle cost and carbon footprint.

Scalability of Infrastructure

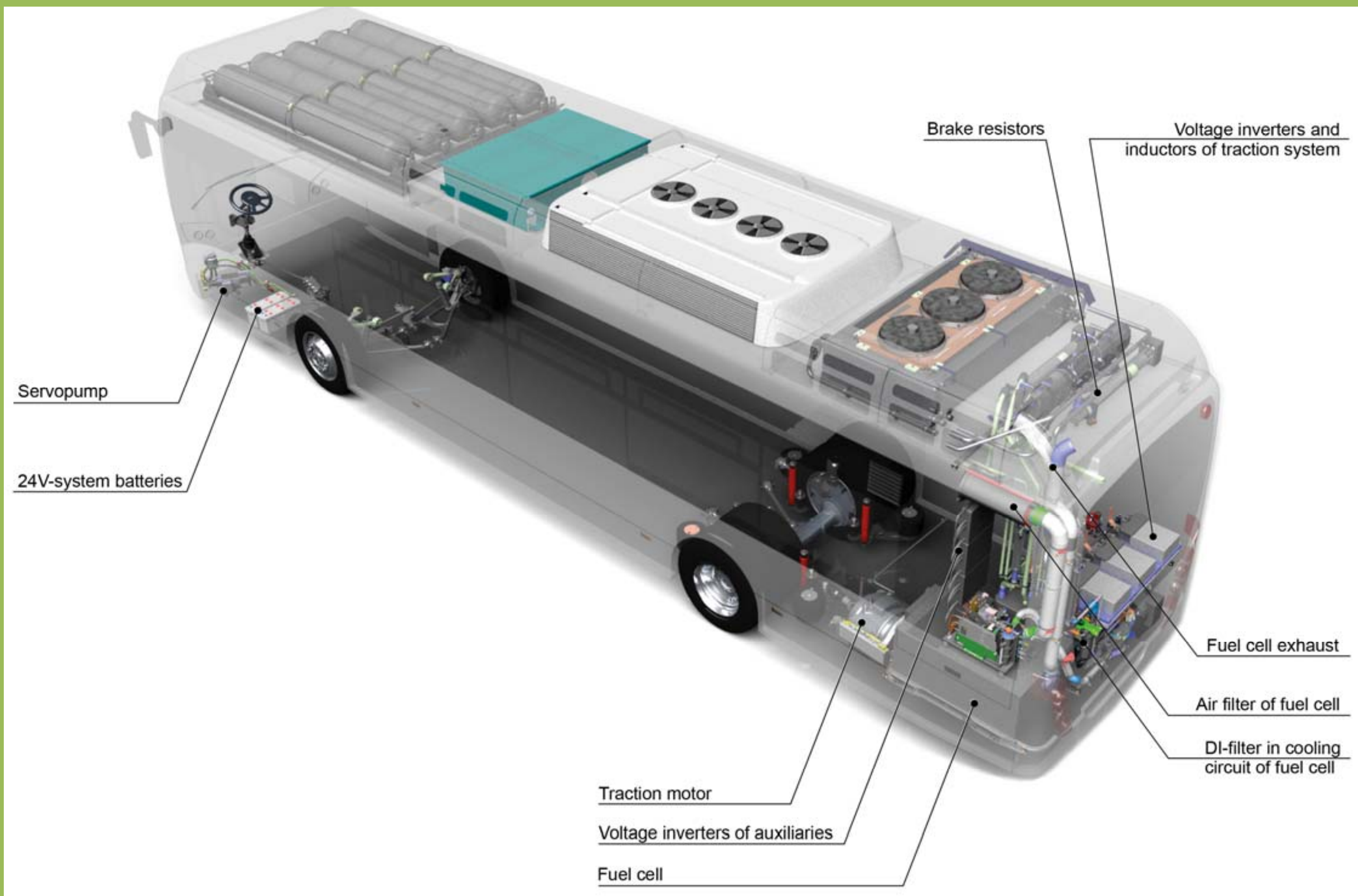
When assessing and comparing TCO across zero emission technology alternatives, a critical cost driver is the cost of infrastructure and how it develops with increasing scale.

The cost of hydrogen fuelling infrastructure for a small fleet of a few FCEBs is initially significantly higher the cost of charging infrastructure for BEBs. However, the infrastructure cost per bus swiftly becomes cheaper for FCEBs with increasing fleet size.

Hydrogen fuelling stations at bus depots are built to be scalable from 10 to 100 buses. An existing station can grow its capacity with minimal incremental cost by upgrading the compression and storage equipment and adding dispensers.

BEB infrastructure costs typically increase as the fleet grows, due to the introduction of fast chargers in the system and grid upgrades (including off-site power substations) that may be required to cover the increased load.

A fuel cell bus is an electric bus with the electricity produced onboard.



Components of a fuel cell electric bus

Fuel Cell Electric Bus

A FCEB is an electric vehicle that includes both a fuel cell and batteries working seamlessly together to provide efficient zero-emission power without compromised range or service requirements. In such hybrid architecture, the fuel cell provides energy to keep the batteries charged, works with the batteries to provide peak traction power, and provides the energy necessary for the bus auxiliary loads.

The fuel cell power module onboard the bus efficiently generates electric energy through an electro-chemical reaction leaving only water and heat as by-products. The electric energy is used to keep the batteries charged and, as a further benefit, the by-product heat is useful as a source of energy for maintaining passenger comfort, to improve vehicle efficiency. The batteries also provide storage for regenerated energy.

There is no need to plug in the bus to recharge the batteries as hydrogen stored in bus provides the entire daily energy need of the bus. The remaining bus elements (chassis, electric drive, etc.) are identical to battery electric buses.

Hydrogen offers much higher energy density compared to electrical storage systems such as batteries. With the addition of a hydrogen fuel cell system, the battery system can be reduced in size, decreasing the overall weight of the propulsion system and provide energy for the bus heating and cooling systems. This improves the fuel efficiency of the vehicle and will allow the vehicle to carry more passengers.

Hydrogen Fuel:
The Zero Emission Solution

Hydrogen Fuelling for Fuel Cell Bus Fleets

Deployments around the world have proven FCEBs can be fuelled with hydrogen safely and efficiently in the depot. Hydrogen is produced in either onsite or trucked in from central production. The ideal solution depends on the amount of hydrogen demanded and physical location of the depot.

Hydrogen refuelling systems are scalable and there are solutions for every hydrogen fuel cell vehicle. It is also possible to upgrade the refuelling station in order to service additional buses as the number increases over time.

Hydrogen suppliers can provide delivered hydrogen at a fixed price dispensed at the pump over, for example, a 5 to 10-year period. This means no investment in infrastructure for the bus operator. The current target price is diesel parity, which is already achievable given scale.

Green hydrogen fueling station in Aberdeen, Scotland.
The facility has three electrolysers to produce zero-emission hydrogen onsite from water.

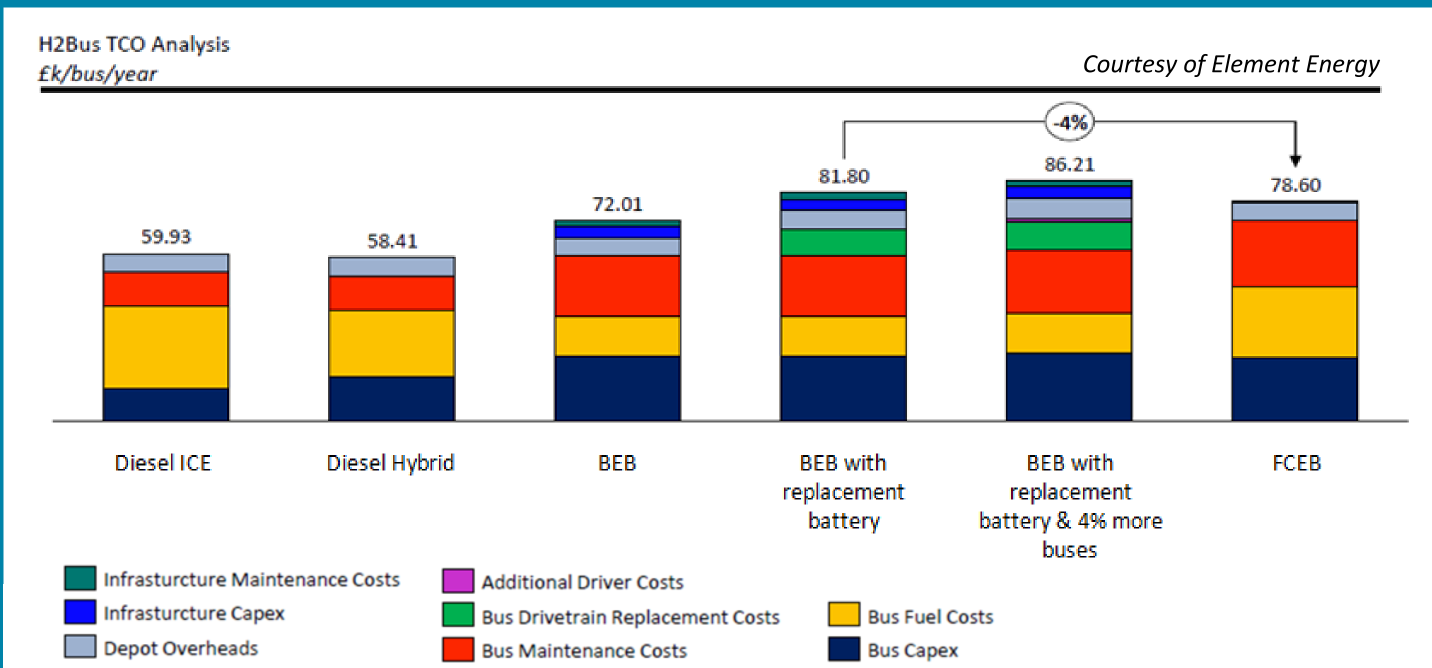
Fuel Cell Electric Bus Total Cost of Ownership

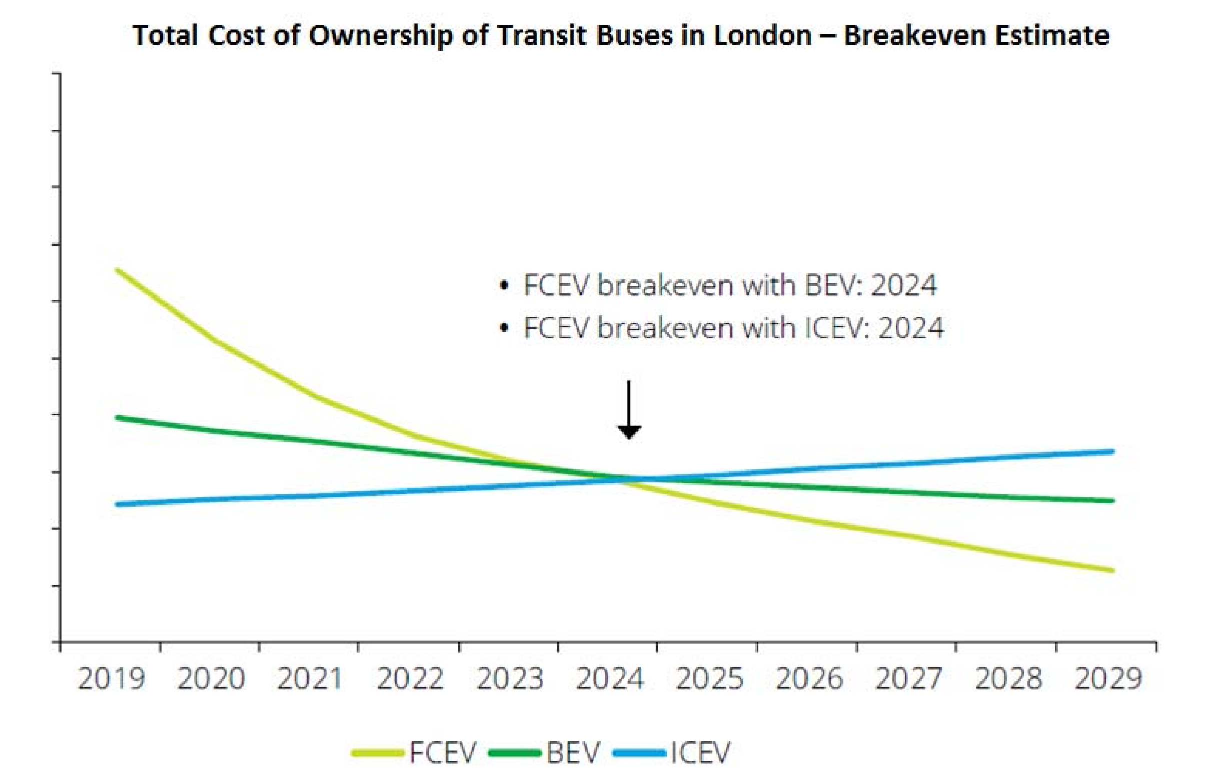
Although FCEBs are currently more expensive to run on a per-kilometre basis than BEBs or conventional ICE buses, they are set to become much cheaper as manufacturing technology matures, economies of scale improve, hydrogen fuel costs decline and infrastructure develops. Indeed, a recent white paper jointly published by Ballard and Deloitte conservatively estimates the Total Cost of Ownership (TCO) for commercial hydrogen vehicles will fall by more than 50% in the next 10 years. The result is that, in Europe, the total cost of owning a FCEB will be less expensive than a BEB by 2024, without subsidies.

Europe has been successfully pursuing a joint procurement strategy for the purchase of FCEBs. This model can be very effective in increasing the demand to where significant price reductions can be achieved, increasing interest from more bus manufacturers and fostering competition in this field.

This chart shows a TCO calculation for transit buses in the UK, supplied by the H2Bus Europe Consortium. This scenario compares the FCEB offer with BEBs in three different scenarios:

- No additional buses or replacement battery
- A replacement battery is required, but no additional buses
- A replacement battery and 4% additional drivers and buses are required





Source: Deloitte

Looking forward, the timeline to reach breakeven for total cost of ownership across technologies is very short. In fact, analysis shows the TCO of fuel cell buses in London would be lower than that of battery buses and ICE buses by 2024.

The total cost of ownership is highly sensitive to local conditions such as costs of electricity or hydrogen fuel, available infrastructure for refuelling, range required, and mileage. The FCEB economics benefit from higher grid electricity cost or requirements for longer range and route flexibility. Ultimately, the optimal technology choice will depend on the fleet operator preferences for flexibility, operational constraints and infrastructure costs.

CASE STUDY: London

Transport for London ("TfL") is the integrated transport authority responsible for the day-to-day operation of the city's public transport network including buses, the undergrounds, light railways and taxis. The authority is a leader in the adoption of green vehicles, committing to purchasing only hybrid or zero-emission buses from 2018.

In December 2003, TfL started its trial of the first generation of fuel cell buses in London to reduce air pollution in the city. This trial was part of HyFleet: CUTE project, which brought together 31 partners from industry and government from across Europe aiming to push the development of hydrogen-based transport systems in Europe, and was funded the European Union and the UK government.

After the successful trial, in 2010, as part of the Clean Hydrogen Cities project ("CHIC"), TfL took delivery of five next generation hydrogen fuel cell electric buses and put them into formal operation serving London citizens on the popular tourist route RV1 between Covent Garden and Tower Gateway. This is the first time a whole route has been fully operated by hydrogen powered buses in the UK.

In 2013, TfL began operating three more hydrogen fuel cell electric buses and expanded the size of the fleet to eight buses. Then in 2018, TfL again added 2 more fuel cell buses to the fleet. The ten zero emission fuel cell buses served London citizens on route RV1 in the city centre of London and route 444. The fuel cell electric bus fleet has travelled more than 2.3 million kilometres in service. Ballard fuel cell modules installed on TfL buses have surpassed 35,000 hours of continuous operation without replacement or repairs, demonstrating a high level of performance together with unsurpassed durability.

Transport for London has ordered another 20 hydrogen fuel cell double-decker buses to expand its zero-emission bus fleet. The 20 hydrogen fuel cell buses will be put into operation in 2020 on routes 245, 7 and N7. These new buses for London represent a tremendous vote of confidence in fuel cell technology for zero emission transportation.

Hydrogen Supply

Most of the hydrogen fuel used in transit bus applications is generated at large scale production facilities, delivered to bus garages and stored as a liquid or compressed gas. In this case, Air Product is the partner of TfL to provide hydrogen fuel to the city's planned fleet of hydrogen buses and to build and maintain the hydrogen refuelling infrastructure. The hydrogen is generated in the Netherlands and then shipped across the English Channel as liquid hydrogen and trucked to the transit bus maintenance facility.

Project Takeaways

The aim of the CHiC project was to show that fuel cell buses can offer a functional solution to decarbonize transport fleets, improve air quality and lower noise levels. This was achieved by deploying 54 hydrogen fuel cell buses, with their associated fuelling infrastructure, across nine sites in Europe, including London and one in Canada.

London also took part in a follow up project 3Emotion with the following aims:

- Integration of latest technologies to lower TCO
- Lower hydrogen consumption (<10 kg/100 kilometre)
- Increase lifetime
- Increase warranties
- Availability > 90 percent
- Reduce bus investment cost

In London, the aims of the projects were either met or an understanding and pathway to reaching or exceeding the goals were established.

The operation of the fuel cell buses in London marked a leap forward for the low emission bus industry. London operated the buses in the same way as a diesel bus, so it was a drop-in replacement. This also extended to the maintenance. Following appropriate training, maintenance was carried out by the operator's technicians. Their maintenance duties included the fuel cell module, proving that the technology is viable in the overall operation of a standard bus depot. Ballard provided second and third line support when necessary, as would be the same with a diesel engine manufacturer.

Workshop procedures were produced and refined over the 9 years of operation to ensure that processes were carried out safely, efficiently and could be controlled as part of the normal daily operation of a bus depot. Management of the project was integrated into normal depot organisation.

London proved the viability of fuel cell buses as an option to zero emission transport. The technology is ready to be scaled up and become part of the everyday low emission bus fleet.

CASE STUDY: Aberdeen

Since 2014, ten fuel cell electric buses provided zero-emission transportation throughout the city of Aberdeen, Scotland. These buses emitted only water vapour, are quieter and run more smoothly than diesel buses. The fleet travelled up to 400 kilometres (250 miles) per day in revenue service, transporting passengers to various destinations throughout the city of Aberdeen.

Six buses were operated by Stagecoach on the X17 Aberdeen city centre to Westhill route, while First operated four buses on the X40 Kingswells to Bridge of Don park-and-ride route. The fuel cell electric bus fleet has travelled more than 2 million kilometres be service ended. In late 2020, fifteen two deck fuel cell electric buses will join the fleet.

The Aberdeen fuel cell bus fleet was funded by Europe’s Fuel Cells and Hydrogen Joint Undertaking (FCH:JU) under the HighVLOCity, HyTransit and JIVE programs.

Hydrogen Supply

The Aberdeen fuel cell buses are part of a sustainable mass transit solution, which includes the use of wind energy to supply power for hydrogen generation through electrolysis. The hydrogen refuelling station, based at Aberdeen City Council's Kitty Brewster depot, is the first fully integrated hydrogen production and refuelling station in Scotland. The commercial scale hydrogen station is owned and operated by BOC, a member of the Linde Group. The facility has three electrolysers to produce the hydrogen on site from water. The hydrogen is then compressed to 500bar and stored ready for dispensing at 350bar. A purpose built hydrogen fuel cell bus maintenance facility is co-located at the depot.

Hydrogen Eco-system in the UK

A strong hydrogen eco-system exists in the UK to support the deployment of fuel cell electric buses.

Hydrogen Production & Distribution	**Ryse Hydrogen** is a UK based hydrogen production and refuelling company dedicated to delivering affordable and low carbon hydrogen for future mobility solutions. Ryse will develop, establish and own the infrastructure for clean production, distribution and dispensing of green hydrogen fuel. **ITM Power Plc** designs and manufactures products which generate hydrogen gas, based on Proton Exchange Membrane (PEM) technology. This technology only uses electricity (renewable) and tap water to generate hydrogen gas on-site and has a product offering capable of being scaled to 100MW+ in size. **Nel** is a global, dedicated hydrogen company, delivering optimal solutions to produce, store and distribute hydrogen from renewable energy. Nel's hydrogen solutions cover the entire value chain from hydrogen production technologies to manufacturing of hydrogen fuelling stations. **BOC** is the largest provider of industrial, medical and special gases in the UK and Ireland. BOC provides innovative hydrogen solutions covering everything from production, storage and distribution to dispenser manufacturing, fuelling stations and infrastructures for fleet applications such as the Aberdeen Bus project. Internationally BOC is a member of The Linde Group.
Bus Manufacturers	**Bamford Bus Company/Wrightbus**, a bus manufacturer from North Ireland, designs and manufactures buses for the United Kingdom and Republic of Ireland. Wrightbus offers fuel cell electric buses in two configurations: 12m single deck and 10.9m double deck. **Optare** is an English bus manufacturer that designs, manufactures and sells advanced single deck and double deck buses for a global marketplace. It is a subsidiary of Indian company Ashok Leyland. **Alexander Dennis Limited** (ADL) is Britain's biggest bus builder and the world's largest manufacturer of double deck buses. ADL is part of global bus and coach manufacturer NFI Group.


Affordable zero emission buses
For public transport operators
H2BUS

H2Bus Europe Consortium

At Ballard we're forming partnerships with European supply chain and ecosystem stakeholders, including bus OEMs and hydrogen equipment suppliers for the production, dispensing, and distribution of hydrogen. Together with our partners, Ballard provides a comprehensive end-to-end solution. The end result is installation and operating efficiencies that make the fuel cell electric bus solution truly cost competitive.

Over 900 new fuel cell electric are expected to be on the road in Europe within the next three years and thousands more in China, Korea and Japan. Fuel cell electric buses are now ready to be deployed in large scale on a commercial basis within the very short time horizon of 2020 and beyond. Large scale deployment projects like the H2BusEurope project (www.h2bus.eu) are being initiated in order to scale up the volume of buses in operation and thus drive down the total cost of ownership of the fuel cell electric buses.

The aim of the H2BusEurope project is to deploy 1,000 fuel cell electric buses by 2023. The H2BusEurope hydrogen fuel cell electric bus solution is expected to be the most cost effective true zero-emission option avail-able, with a target single-decker bus price below €375,000, hydrogen cost be-tween €5 and €7 per kilogram and bus service cost of €0.30 per kilometer.

Conclusion

With millions of kilometres in commercial services and more than 15 years on the road in different environments, fuel cell electric buses have proven to meet operational requirements of transit agencies and bus operators. Fuel cell electric buses offer a 1:1 replacement to diesel buses without performance compromises.

Fuel cell manufacturers, European bus manufacturers, hydrogen suppliers and government agencies are all working together in programs aiming to bring attractive fuel cell electric buses to the United Kingdom's cities and operators. Joint procurements will facilitate volume production, providing an affordable zero-emission transit solution.

Today, fuel cell electric buses are:

Affordable Offering competitive cost of ownership versus an all-battery bus and within 20% of the cost of operating diesel buses.

High Performing Offering the same convenience as a diesel bus for bus operators, without requiring any operational compromises (such as limited range, long charging times or on-route charging).

Zero-Emission Virtually silent, with no emissions of any air pollutant and with no tailpipe emissions of carbon dioxide.

Hydrogen fuel offers a future-proof, scalable refuelling solution well adapted to transit bus operators' requirements. Green hydrogen produced from renewable energy provides a path to true zero emission transit.

The zero emission fuel cell electric bus solution is ready. The technology is ready and sustainable, the price is affordable, and the time is now deploy at scale fuel cell electric buses for public transit.


Now is the time to implement
zero-emission fuel cell buses
in the United Kingdom.

The Other Electric Bus

To learn more about fuel cell electric buses and hydrogen refueling solutions:

Fuel Cell Electric Buses – Proven performance and the way forward

Hydrogen Fueling for Fuel Cell Electric Bus Fleets

Hydrogen at Scale for Fuel Cell Electric Bus Fleets