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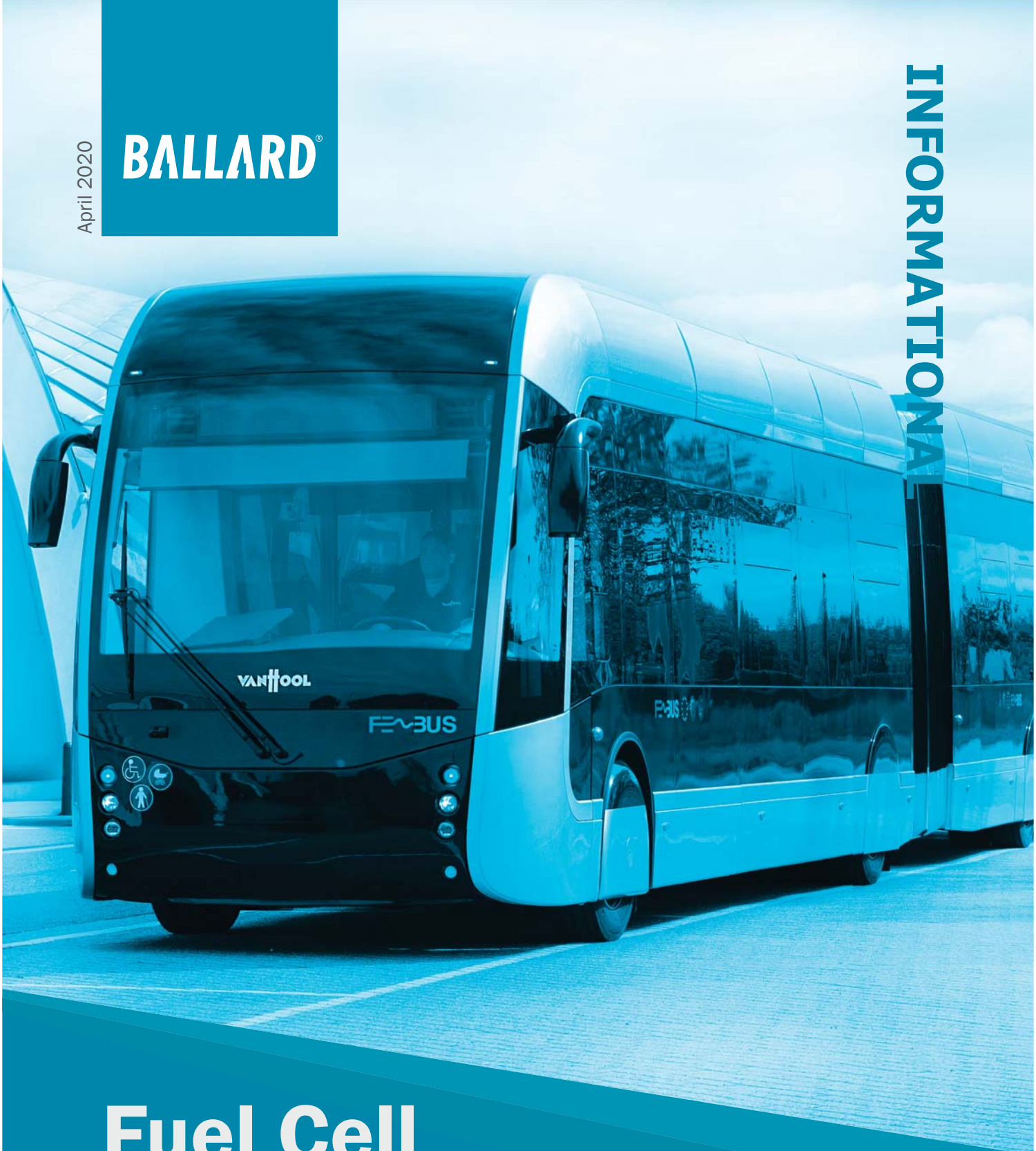


Fuel Cell

Electric Buses

An attractive value proposition for zero emission buses in France

Zero–Emission Fuel Cell Buses for France

Van Hool fuel cell electric buses are in operation between Versailles and Jouy-en-Josas

Executive Summary

France has recognized the importance of sustainable transportation. With the knowledge that mobility is a key contributor to air pollution, there is immense pressure to reduce CO2 emissions. Evidence of this is the ban on diesel and petrol car sales from 2040 and the strategy for clean mobility put forward in the "Loi de Transition Energétique pour la Croissance Verte." French cities are also leading initiatives to reduce local emissions, such as Paris' ambition to ban diesel cars as early as 2023.

There is no doubt that the future of public transportation is going to be zero emission. Transit agencies and operators in France 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 fueled with hydrogen are the only zero-emission technology to match diesel fleets with complete route flexibility, short refueling time and similar depot space utilization.

With more than 15 years on the road and millions of kilometers 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. Today in France, there are approximately 16 fuel cell electric buses operating, including Van Hool buses powered by Ballard fuel cells in Versailles and Pau.

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 refueling 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 France.


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

Introduction

Climate change is one of the most significant issues of our times, demanding action today. Transport is responsible for 30% of CO2 emissions in France[1], while transportation demands are growing. In order to meet the goals of the Paris Agreement, including limiting global temperature rise to well below 2°C, it is vital that transportation be decarbonized.

France has accepted the challenge to transition to zero emission public transportation. In July 2015, the French government set a mandate for French cities to replace polluting diesel buses cleaner alternatives. Regulations are strictest for Paris and the 22 surrounding agglomerations, as well as the centre of other agglomerations containing over 25,000 inhabitants, which must deploy only zero emission buses.[2]

FCEBs are the only zero emission solution that can meet the performance demands of transit operators without compromise. With millions of kilometers in commercial services and more than fifteen years on the road in different environments, FCEBs are proven to meet operational requirements of transit agencies and bus operators.

France's government, recognizing the environmental, operational and economic contributions of hydrogen economy, has set out a hydrogen roadmap. Targets for the deployment of zero emission solutions for transportation include:

- By 2023, 5,000 light utility vehicles, 200 heavy duty vehicles (bus, trucks, trains, boats) and 100 hydrogen refueling stations.

- By 2028, up to 50,000 light utility vehicles, 2,000 heavy duty vehicles and 400 hydrogen refueling stations.[3]

AFHYPAC, Hydrogen Mobility France and UGAP have set an even more ambitious goal with its '1000 Bus Plan', calling for the deployment of 1,000 FCEBs by 2023.[4]

Financial support is available from both the European Union and France. Starting in 2019, 100 million Euros was earmarked for the implementation of France's hydrogen deployment plan.[5] The French government's commitment to supporting the development and deployment of hydrogen infrastructure helps to define a path to the country's low-emission, sustainable future.

SOURCES:

[1] NVG Global News
[2] Strategies for Joint Procurement of Fuel Cell Buses Report
[3] Ministry of Ecological and Solidary Transition
[4] FuelCellWorks
[5] McPhy

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.

Solaris Urbino 12 hydrogen fuel cell electric bus

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

Performance

FCEBs offer the performance benefits of long range, fast refueling 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 traveled more than 20 million kilometers of revenue service, equivalent to circling the Earth 500 times, with fuel cell system availability above 97%.

FCEBs in France will benefit from the proximity to our European service centers to ensure increased availability.

Resiliency

Access to transit 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. Hydrogen stored on site at the bus depot will ensure transit agencies avoid this issue, providing multiple refuelings for each bus. FCEBs can also be used as emergency power generators during natural disasters.

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.

Furthermore, Ballard offers its customers a refurbishment program for fuel cell stacks that have reached the end of life. Ballard's ability to refurbish the fuel cell stack and recover more than 95% of platinum means far fewer waste products end up in landfills, as well as lower life cycle cost and carbon footprint.

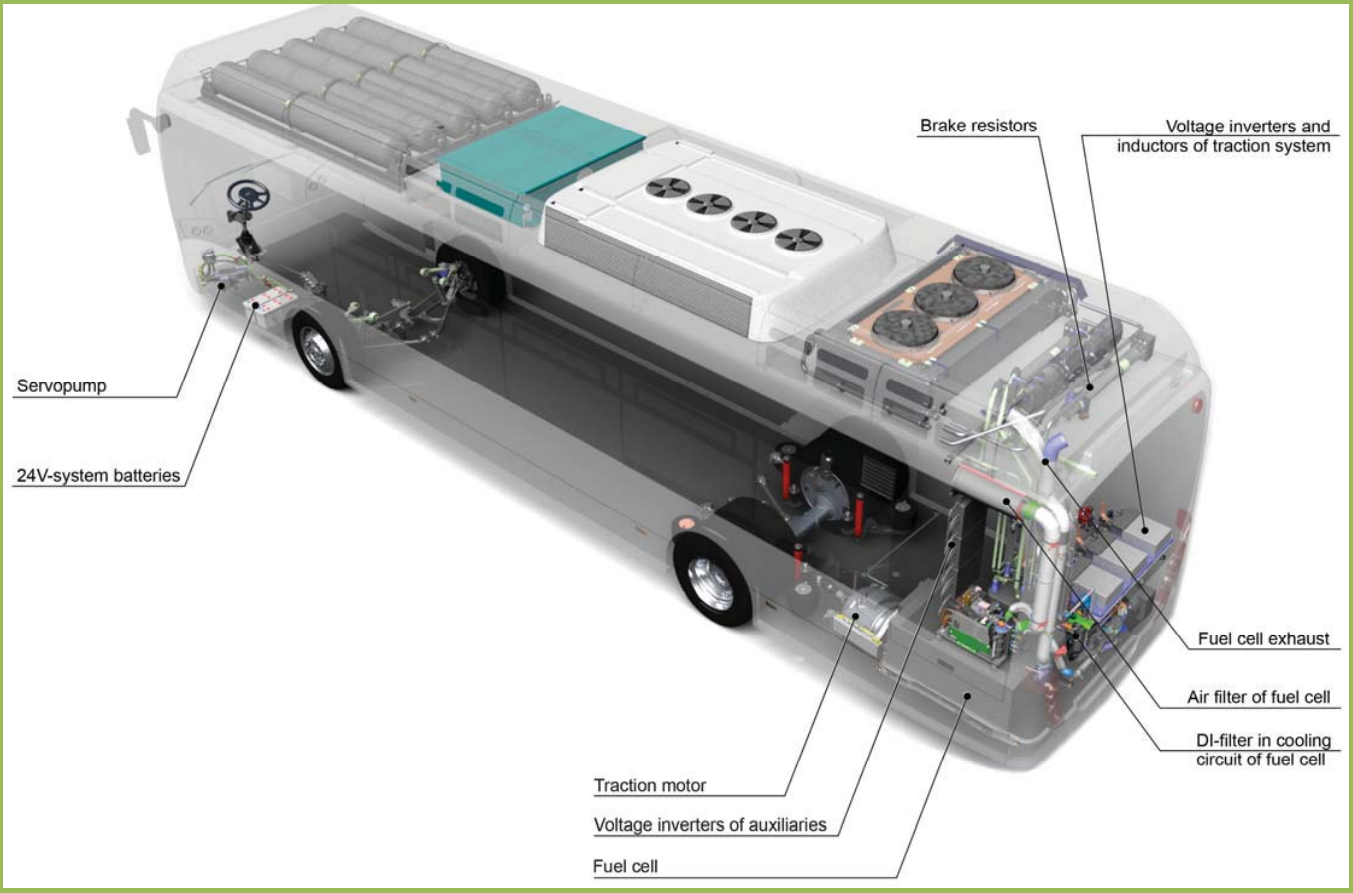
Scalability of Infrastructure

The cost of hydrogen fueling 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 fueling stations at transit 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 power substations that may be required to cover the increased load.

A fuel cell bus is a battery electric bus with an on-board range extender.



Key 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 (glider, 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 fueled 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 refueling systems are scalable and there are solutions for every hydrogen fuel cell vehicle. It is also possible to upgrade the refueling 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 target price is diesel parity, which is already achievable in a few countries worldwide.

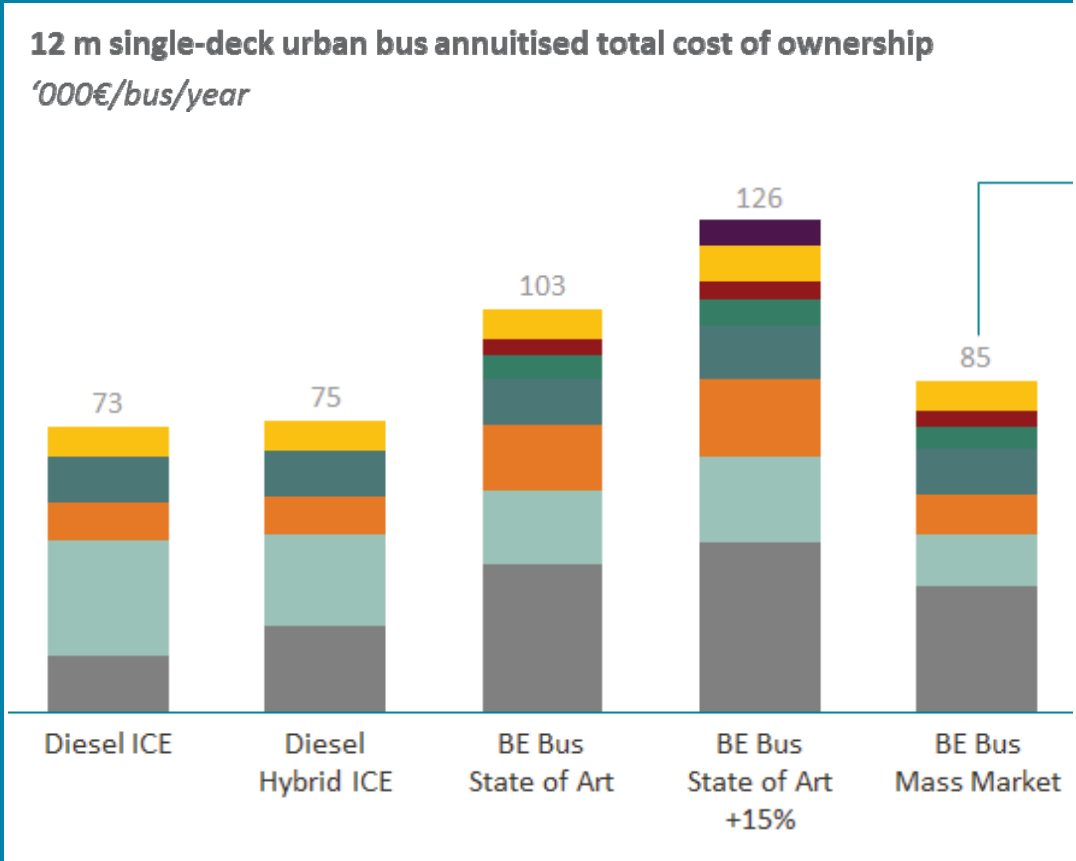
In France today, hydrogen is primarily produced from oil and gas for industrial use. In its energy plan, France aims to decarbonize hydrogen production. Hydrogen produced through the electrolysis of water powered by low-carbon (renewable or nuclear) electricity has the potential to be a low cost, green source of transportation fuel.

Fuel Cell Bus Cost

Bus Technology Comparison

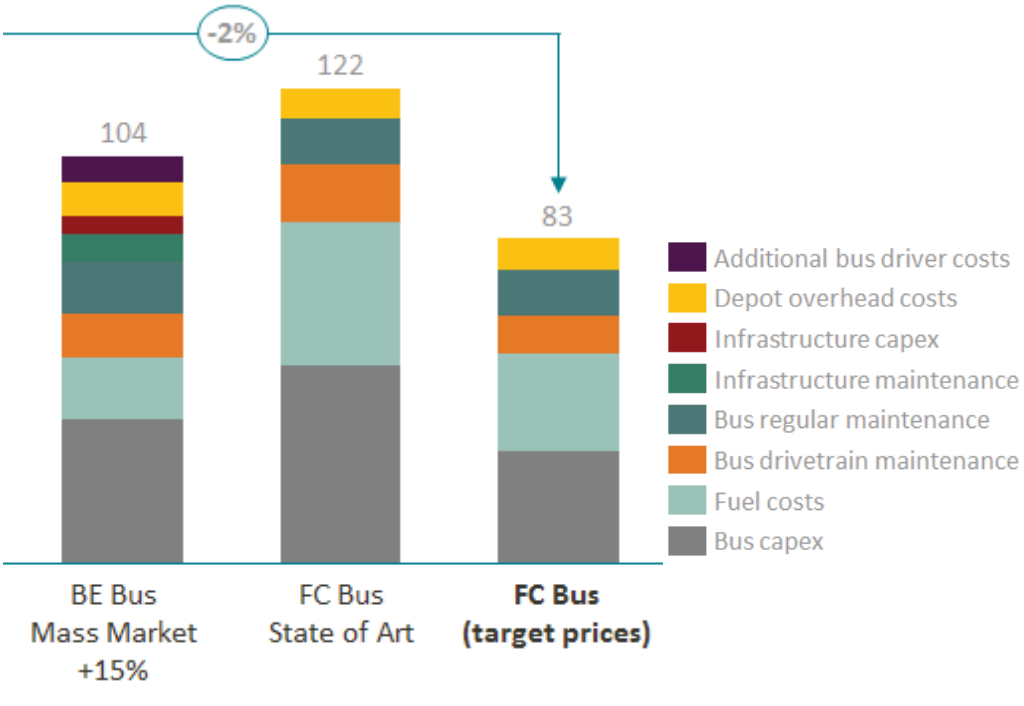
Although FCEBs are currently more expensive to run on a per-kilometer basis than BEBs or conventional ICE buses, they are set to become much cheaper as manufacturing technology matures, economies of scale improve, hydrogen fuel costs decline and infrastructure develops. Indeed, a recent white paper jointly 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.



An example of this is Europe's H2Bus Consortium, whose members are working together to deploy 1,000 zero-emission FCEBs and related infrastructure in European cities at commercially competitive rates. The H2Bus FCEB solution is expected to be the most cost effective true zero-emission option available, with a target single-decker bus price below €400,000, hydrogen cost between €5 and €7 per kilogram and bus service cost of €0.30 per kilometer. As shown in the figure below, the TCO analysis confirms that FCEBs will compete with BEBs.

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.



Hydrogen & Fuel Cell Eco-system

An eco-system of industry partners have come together to support the deployment of FCEB fleets in France.

Hydrogen Production & Distribution	**Engie** and **Air Liquide** are launching the HyGreen Provence project, which is expected to produce annually 1,300 GWh of solar electricity and 10,440 tons of green hydrogen by 2027. **Lhyfe** designs, engineers and operates industrial production sites of green hydrogen. Electrolyzers powered by renewable energy produce hydrogen that is then transported to local refueling stations. **Hynamics**, a subsidiary of EDF, is responsible for offering effective low-carbon hydrogen for industry and mobility. Hynamics creates hydrogen from water, using low carbon production methods.
Bus Manufacturers	Many European bus manufacturers offer FCEBs as a standard product offering. Ballard fuel cells power buses manufactured by **Solaris Bus & Coach**, **Van Hool NV**, **Wrightbus**, and **VDL Bus & Coach**, among others.
Funding	In 2019, the French government made over €90 million in public funding available to accelerate the development of the hydrogen sector in France. New calls for tenders launched in March 2020 support expansion of the program. The **Hydrogen Mobility Ecosystems** call for projects launched by ADEME in October 2018, funded €80 million of projects to deploy more than 43 hydrogen service stations (for a target of 100 in 2023), and 158 heavy goods vehicles (for a target of 200 to 2023).
Financing	**NEoT Capital** is an investment company supporting its customers to make their transition to zero mobility and low-carbon energy. NEoT offers tailor-made financing and service solutions for zero emission buses and refueling infrastructure.

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

Case Study: Fuel Cell Electric Buses for Pau, France

Decision Criteria

The Pau-Béarn-Pyrénées urban community in France has been carrying out an Air Energy Climate Plan for its territory since 2016, which is focused on the priorities of energy management, development of renewable energy, improvement of air quality, and development alternative mobility.

In January 2017, the city of Pau Béarn Pyrénées issued a public tender for the procurement of eight 18m articulated buses to provide environmentally sustainable transportation on its BHNS ('high level of service') bus routes. Both BEB and FCEB solutions were evaluated. The comparison of solutions was not only limited to vehicle performance, but also took into consideration operating constraints, required infrastructure and the level of service expected.

Analysis found that a BEB solution would have required the purchase of more vehicles to service the same routes. To meet the operational requirements would require:

a) 10 BEBs with on route charging,
b) 14 BEB with overnight depot charging, or
c) 8 FCEB with depot refueling.

Considering the number of vehicles and the overall infrastructure cost, the BEB and FCEB solution cost estimates were very similar for both capital expenditure and operating expenses.

In the end, the city of Pau selected FCEBs based on their ability to satisfy the following operational requirements:

- Flexibility to extend the route at certain periods of the year;
- Resilience to potential energy infrastructure failures;
- Securing range margin while under additional energy-demanding constraints such as a particularly cold winter / hot summer.

Fuel Cell Electric Bus Fleet

Van Hool NV was selected to supply eight ExquiCity tram-buses (Fébus), powered by Ballard's FCveloCity®-HD 100-kilowatt fuel cell engines. These first ever fuel cell-powered tram-buses were subsequently delivered to the City of Pau – Communauté d'Agglomération Pau Béarn Pyrénées in 2019 and are being operated by the STAP (Société de Transport de l'Agglomération Paloise).

The clean energy hybrid tram-buses use fuel cells for primary power and lithium batteries for additional power when needed, with the only emission being water vapour. Each tram-bus is over 18 meters (60 feet) long, has capacity for 125 passengers and can operate more than 300 kilometers between hydrogen refuelings. As of January 2020, the fleet had already travelled more than 12,000 km in revenue service.

Awards granted to Fébus

In November 2019, the national jury of the Marianne d'Or, the first civic competition in France, awarded Pau and Fébus its top award innovation linked to Sustainable Development. Fébus was also the 2018 winner of the energy transition trophy in the "Sustainable Transport" category. At BusWorld 2019, Fébus was crowned "best bus in the world," winning the prestigious "Grand Award Bus" as well as the Ecology award.

Hydrogen Fueling

GNVERT, a subsidiary of ENGIE, constructed and operates the hydrogen refueling station for the tram-buses, which will produce 174 to 268 kg of hydrogen a day. Hydrogen is generated onsite from water using an electrolyzer. In the near future, the power for the electrolyzer will be provided by nearby solar panels. With no emissions generated by the production of hydrogen or produced by the buses, this is a truly green transportation solution from well to wheel.

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

Conclusion

With millions of kilometers in commercial services and more than 15 years on the road in different environments, fuel cell buses have proven to meet operational requirements of transit agencies and bus operators. Fuel cell 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 buses to French cities and operators. Joint procurements will facilitate volume production, providing an affordable zero-emission transit solution.

Today, fuel cell electric buses are:

Affordable Offering superior 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 refueling 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 FCEB solution is ready. The technology is ready and sustainable, the price is affordable, and the time is now to deploy FCEBs at scale for public transit.

The Other Electric Bus

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

zeroemissionbus.org

www.fuelcellbuses.eu

www.ballard.com