Submission No 24

ELECTRIC BUSES IN REGIONAL AND METROPOLITAN PUBLIC TRANSPORT NETWORKS IN NSW

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Electric buses in regional and metropolitan public transport networks in New South Wales

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Table of Contents

The University of Queensland

For more than a century, The University of Queensland (UQ) has maintained a global reputation for delivering knowledge leadership for a better world. UQ has won more Australian Awards for University Teaching than any other university. This commitment to quality teaching empowers our 52,000 current students, studying across UQ's three campuses, to create positive change for society. Our research has global impact, delivered by an interdisciplinary research community of more than 1500 researchers at our six faculties, eight research institutes and more than 100 research centres. The most prestigious and widely recognised rankings of world universities also consistently place UQ among the world's top universities.

The University of Queensland is a leader in the adoption of sustainable technologies. By 2020, we are set to become the first major university in the world to offset 100 per cent of our electricity usage through our own renewable energy assets. We have already installed three solar-powered electric vehicle (EV) fast chargers – designed and built in Australia by Tritium, an EV technology company founded by UQ graduates. We also have several electric cars and vans in our fleet, host a car-sharing scheme, and have halved our vehicle fleet since 2016.

Through our research at UQ we have observed that most vehicle manufacturers are rapidly electrifying their vehicle portfolios due to the associated energy efficiency gains, low operating costs, simpler manufacturing requirements, and zero tailpipe emissions. These emission reductions are particularly important given that each year, in Australia, 40 per cent more premature deaths occur due to motor vehicle pollution than in road vehicle accidents.

In tandem with the electrification of vehicles, UQ has also been investigating how automated vehicles, and the shift from private ownership to the sharing economy, will affect how individuals choose to travel from A to B.

The dawn of shared, autonomous, and electric vehicles (SAEVs) may signal the decline of private vehicle ownership, opening the door for the creation of innovative transport business models. Transport operators overseas are already offering subscription services, similar to mobile phone plans, where fixed monthly fees provide unlimited public transport, a set number of taxi trips and even car rental - with plans to include SAEV services in these plans once they become available in the near future. This emergence of SAEVs also highlights the importance of reducing the cost of public transport to remain competitive with these new services. Electric buses provide an immediate avenue for reducing these costs.

More broadly, all electric vehicles have the potential to be much more than simply a vehicle. At UQ we are currently investigating how electric vehicles could act as mobile battery packs, providing backup power to communities during blackouts, and supporting the uptake of renewable energy through smart bi-directional vehicle-to-grid charging.

Through our research efforts at UQ, we aim to position Australia as a leader in future transport technologies, and through leading by example, continue to motivate staff, students and the broader community to drive transport innovation forward.

Summary and recommendations

Electric vehicles – including electric buses - have the potential to deliver a wide range of benefits to Australia. This technology presents an economically-viable pathway for reducing transport emissions and operating costs, whilst supporting the uptake of renewable energy, improving grid utilisation, and increasing climate resilience. Electric vehicles also present an opportunity to eliminate tailpipe emissions, and in turn, reduce the estimated 1,700 premature deaths that occur due to motor vehicle pollution in Australia each year (40% more than road accident fatalities).

Recommendations outlined in this document are:

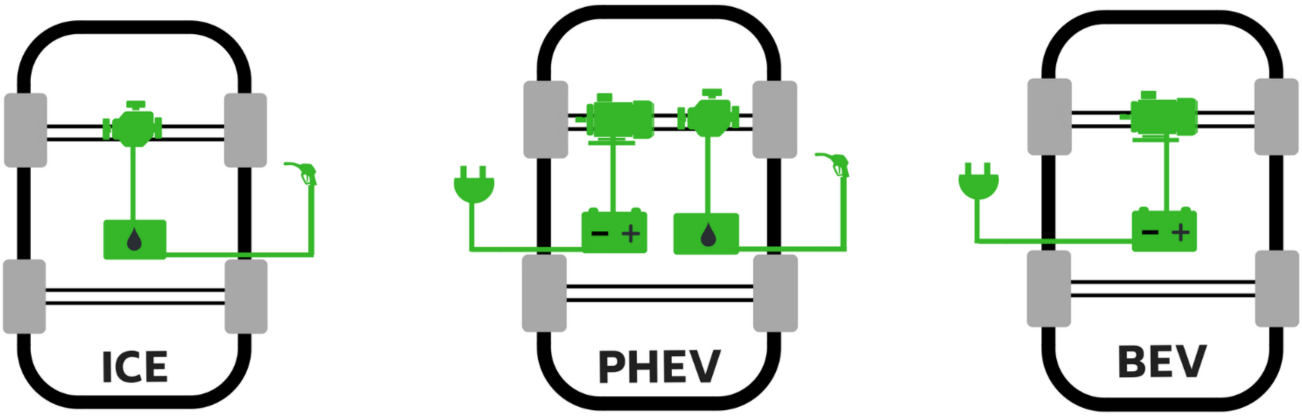
1. The NSW Government should support a transition towards electric buses in order to capitalise on the significant economic, environmental and social benefits associated with this innovative transport technology.
2. The NSW Government should work with the Federal and other State Governments to develop a national electric vehicle policy, which includes support measures for the uptake of electric buses.
3. Recognising the significant, and numerous benefits that electric buses can deliver, the NSW Government should support the establishment of several structured pilots of electric buses in the short-term, to inform the State's medium-term bus investment and fleet transition strategies, including a State-level electric bus target for 2030.
4. The NSW Government should work with electricity utilities to develop clear guidelines, and application pathways, for the approval and installation of charging infrastructure for all electric vehicles, including electric buses.
5. Appropriate charging infrastructure for electric bus fleets must be considered on a case-by-case basis – predominantly due to the need to assess local grid capacity. This again highlights the importance of NSW Government establishing clear guidelines and application pathways, for the approval and installation of charging infrastructure for all electric vehicles, including electric buses.
6. Recognise the likely the need for both depot and on-route opportunity charging to support larger electric bus fleets, and the need for standardisation of on-route charging infrastructure.
7. Hydrogen fuel cell buses are an immature technology, still in demonstration, that is unlikely to be economically-competitive until after 2030. As such, NSW Government should monitor the continuing development of this technology, but prioritise initial efforts to focus on electric buses as the technologically mature and economically-competitive option.
8. Given the water and energy intensity of hydrogen production, it should initially be prioritised for use in other economic sectors where it can have a greater emissions reduction impact, including: existing chemical feedstock processes, steel manufacturing, cement clinkering, and long-haul marine shipping.

Thank you for the opportunity to provide a submission to the New South Wales Legislative Assembly Committee on Transport and Infrastructure's inquiry into *Electric buses in regional and metropolitan public transport networks in New South Wales.*

What is an electric bus?

For the purpose of this submission, an electric bus (EB) is defined as a buse that is solely propelled by one or more electric motors, exclusively uses electricity, and can be plugged-in to charge.

Electric buses differ from other buses, such as internal combustion engine (ICE) buses and hybrid buses, as they can be directly charged using electricity, and operate solely using electricity. This shift from liquid fuel to electricity can deliver significant emission and operating cost reductions, given electric buses emit no tailpipe emissions and are highly energy efficient to operate.



Plug-in hybrid, conventional hybrid, hydrogen fuel cell, and other electrified drivetrains, are not treated as electric buses in this submission, given that the major environmental, economic and social benefits of electric vehicles are generated through the direct and sole use of electricity for transport. In some responses to the terms of reference in this submission, some comparisons have been made to these alternative drivetrains.

Brief market overview

The global electric bus market is rapidly evolving, with new announcements seemingly occurring on a weekly basis. As of 2018, market analysis suggested that the majority of the electric bus market was dominated by standard 12-metre and 18-metre articulated buses[1]. Moving into 2019, a 27-metre articulated bus was launched by the leading Chinese electric bus manufacturer, BYD[2] - see Figure 1.

Figure 1 - The BYD K12A is an electric bus capable of carrying up to 250 passengers, with a driving range of 300 kilometres. Source: https://newatlas.com/byd-world-longest-electric-bus-k12a/59179/

China currently dominates the global electric bus market, with 98% of the close to 500,000 electric buses globally as of the end of 2018[3]. 23% of all new bus purchases in China were electric buses in 2018. It is also forecast that China will surpass 1 million electric buses by 2023, and reach 1.3 million electric buses by 2025[4].

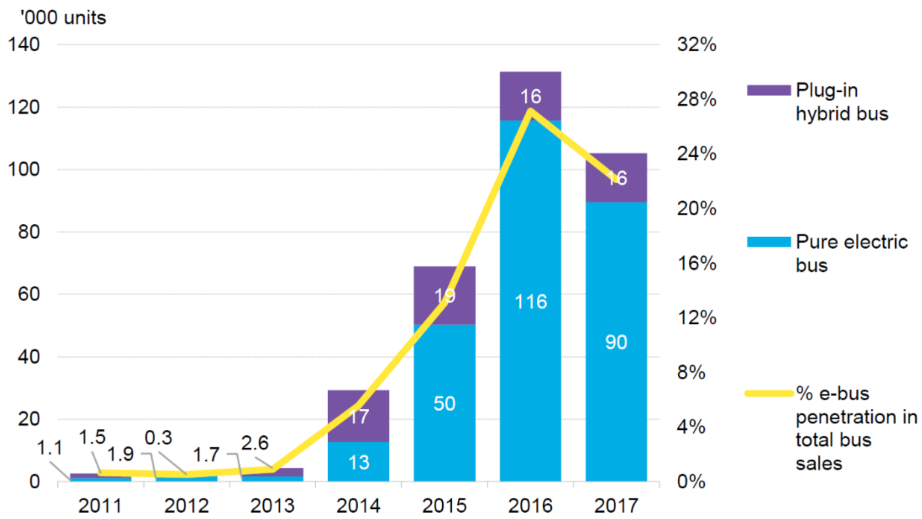


Figure 2 - Total electric bus sales in China: 2011-2017. Source: https://about.bnef.com/blog/e-buses-surge-even-faster-evs-conventional-vehicles-fade/

[1] https://www.cambridge.org/core/journals/design-science/article/design-of-urban-electric-bus-systems/1C0E4AA05F6E1FBF8A545E13F6A8D2DE/core-reader
[2] https://newatlas.com/byd-world-longest-electric-bus-k12a/59179/
[3] https://www.iea.org/reports/global-ev-outlook-2019
[4] https://www.woodmac.com/our-expertise/focus/Power--Renewables/ebus-landscape-2019/?utm_source=gtmarticle&utm_medium=web&utm_campaign=wmpr_ebus2019

Technological readiness of electric buses

The advantages of electric buses are significant. In addition to being zero emission vehicles, electric buses are inherently energy efficient, can be powered using a diversity of both international and domestically-produced energy sources, and can also be used to provide both transport and energy services. Despite these benefits, the technology faces challenges in terms of capital costs (particularly due to battery costs), the time associated with battery charging, the potential impacts of uncontrolled charging on the electricity grid, as well as the cost and installation of charging infrastructure[5,6,7].

Vehicle cost and charging characteristics are closely linked to battery performance, which in turn depends on battery chemistry. Traditionally, vehicles have utilised four main battery types: lead-acid, nickel-metal hydride (NiMH), lithium-ion (LIB) and sodium nickel chloride (Na/NiCl2). Increasingly, most battery electric vehicles – including electric buses - are using a LIB variant, given their superior energy density, meaning longer driving ranges (see Figure 3), at lower costs, with high efficiency and long lifespans. In fact, even based on existing technology, it would be possible to manufacture an electric bus that could travel more than 1,000 kilometres; it would just come at a high cost given the capacity of batteries required.

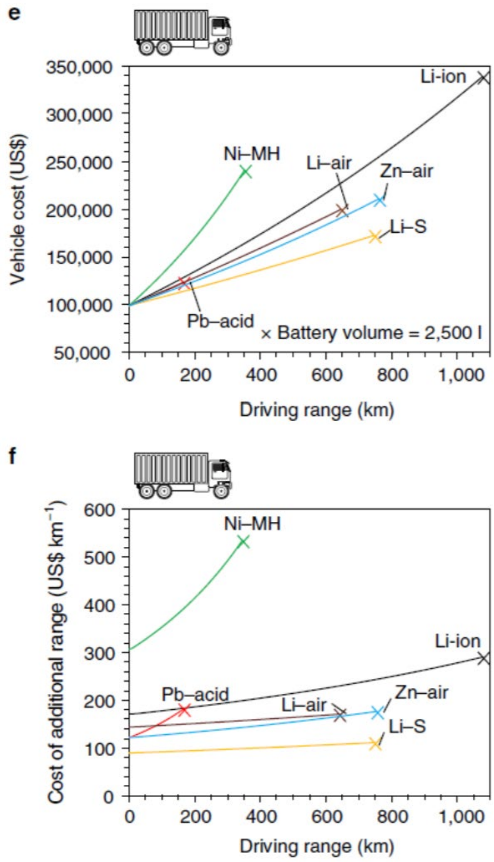


Figure 3 - Heavy vehicle cost, and cost of additional driving range for different battery chemistries.
Source: https://www.nature.com/articles/s41560-018-0108-1

5 https://www.sciencedirect.com/science/article/abs/pii/S1364032117306251
6 https://pubs.rsc.org/en/Content/ArticleLanding/RA/2018/C8RA06458J#!divAbstract
7 https://ieeexplore.ieee.org/document/8320763

There are also a range of new battery chemistries currently under development. These new chemistries could supplement LIBs for certain transport segments, particularly in those requiring longer driving ranges and faster charging times. These chemistries include: Lithium-air (Li-air), Zinc-air (Zn-air), Lithium-Sulfur (Li-S), among others. These chemistries are unlikely to be commercially viable until the early 2030's, and in many cases will be implemented as a secondary battery pack to a primary LIB pack, which is likely to dominate the market for the foreseeable future. It should be recognised that any charging infrastructure installed for today's LIB technology will remain compatible with these future battery chemistries under development.

Despite LIBs competitive advantage over other chemistries, the cost of these batteries is still the predominant factor as to why electric buses attract a price premium compared to conventional ICE buses. These costs, however, have fallen rapidly over the past decade, and are expected to continue to fall over the coming decade – see Figure 4.

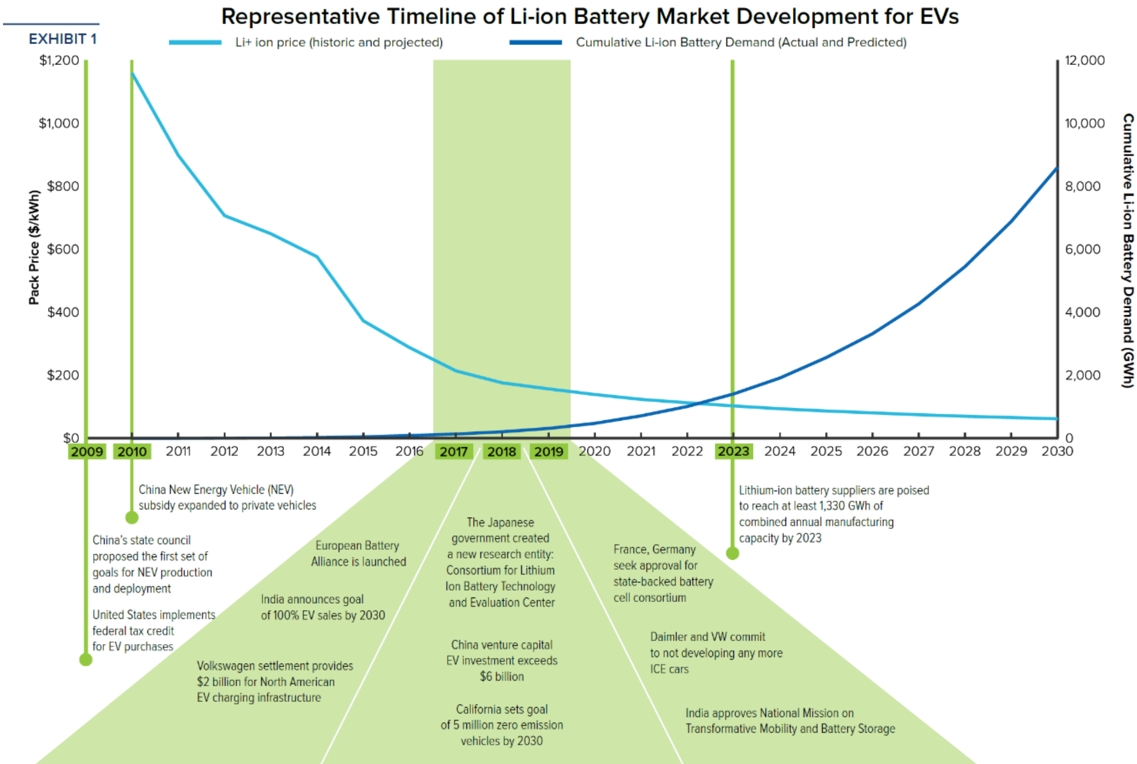


Figure 4 - Timeline of Lithium-ion Battery Market Development, including cumulative battery demand and pack costs. Source: *https://rmi.org/insight/breakthrough-batteries/*

Given the rapid developments in LIBs, there is a certain level of uncertainty in future cost projections, with a general acceleration in forecasts observed over time. These continuing reductions in LIB costs are due to economies-of-scale as the battery market rapidly grows, as well as improvements in battery design, production and manufacturing, along with competition from a range of battery suppliers.

On the basis of these continuing declines in lithium-ion battery prices, it is expected that the capital cost for a 250kWh electric bus (250-300 km driving range) will fall to less than $AU 600,000 by 2030[8].

[8] https://data.bloomberglp.com/professional/sites/24/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf

Terms of reference

1.0 Benefits of electric buses and factors that limit their wider uptake.

Electric buses have the potential to deliver a wide-range of economic, environmental and social benefits for Australia. Electric buses are inherently energy efficient, which leads to lower operating costs, lower foreign energy dependency, and generally lower emissions.

The major potential benefits of encouraging a transition to electric buses include:

- Reducing transport costs
- Improving public health and urban amenity
- Reducing greenhouse gas emissions
- Supporting the uptake of renewable energy
- Improving electricity grid utilization
- Reducing Australia's dependency on foreign oil, and
- Creating new green jobs.

There are also barriers limiting the wider uptake of electric buses, including:

- Lack of national electric vehicle policy and support
- Difficulties dealing with electricity utilities to install charging infrastructure
- A lack of local knowledge due to limited trials

Here we provide further details on each of these key benefits and barriers.

1.1 Benefit 1: Reducing transport costs

Despite Australia's relatively high electricity costs, given the inherent energy efficiency of electric motors, electric buses are still substantially cheaper to operate compared to internal combustion engine buses.

The average diesel bus in Australia currently consumes 28 litres of diesel per 100km[9], resulting in a fuel cost of approximately $34 per 100 km (based on a fuel cost of $1.20 per litre, after fuel rebate). Even at relatively high commercial electricity prices of $0.24 per kWh, this equates to $24 per 100km for an electric bus consuming an average of 100 kWh per 100 km[10]. In reality the diesel bus consumption rates (and costs) are likely greater for city buses, due to high fuel consumption in frequent stop and start traffic. These conditions are advantageous to electric buses, due to their use of regenerative braking, and high energy efficiency at lower speeds, further extending the gap in fuel costs.

The operating costs of electric buses can also be further reduced through the use of off-peak electricity tariffs for overnight charging, or solar charging (when possible) during the day. This means that electric buses can reduce fuel costs by at least 30%. Lower fuel costs lead to lower costs for operators, and in turn, lower costs for public transport users.

[9] https://www.abs.gov.au/ausstats/abs@.nsf/mf/9208.0

[10] Conservative figure based on real-world consumption rates from overseas trial and NSW Nowra Coaches electric bus trial.

Electric buses are also cheaper to maintain compared to other vehicle drivetrains. Electric motors do not require oil changes; most do not have gearboxes; and a significant proportion of braking is performed by the electric motor/s to recouperate energy i.e. regenerative braking. In turn, this means that the main consumables for an EV are the windscreen wiper blades and fluid, along with tyres. The Nowra Coaches electric bus trial in NSW in 2019 observed more than an 80% reduction in maintenance costs for the electric Yutong E12 bus, compared to their diesel bus equivalents[11].

1.2 Benefit 2: Improving public health and urban amenity

One of the major potential benefits of supporting the uptake of electric buses is this technology's ability to improve public health and urban amenity. At present, Australia has no fuel efficiency standards, and inadequate emissions standards. This lack of regulation has led to a situation where Australia has become a dumping ground for some of the world's most polluting motor vehicles. This high-polluting vehicle fleet is leading to a number of major and serious consequence for national public health.

It has been established through several major studies that motor vehicle pollution is linked to respiratory and cardiovascular diseases, including lung cancer, and that the effects of this pollution are particularly pronounced amongst the elderly and young children[12].

The Organisation for Economic Co-operation and Development (OECD) estimates that 1.75 million premature deaths occur globally each year due to motor vehicle pollution[13]. The situation has become so serious locally that recent estimates suggest that 40% more premature deaths occur in Australia each year due to motor vehicle pollution (approx. 1,700 p.a.), compared to road vehicle accidents (approx. 1,200 p.a.)[14]. A significant proportion of these premature deaths can be attributed to emissions from heavy vehicles, including buses.

Considering that many of our children's schools are located on major roads, and are being flooded with carcinogenic fumes from motor vehicles, it would be negligent for the nation to continue to ignore the severity of this issue, and do nothing about it.

Electric buses produce no tailpipe pollution, meaning they have the potential to reduce the premature deaths associated with motor vehicle pollution in Australia by shifting carcinogenic fumes out of urban areas.

1.3 Benefit 3: Reducing greenhouse gas emissions

The transport sector has historically been one of the fastest growing sources of emissions in Australia, with a 48% increase recorded between 1990 and 2013[15]. Transport is also the third largest source of greenhouse gas emissions in Australia, accounting for approximately 18% of the nation's GHG emissions, of which 85% is generated by road transport[16].

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[11] Abel, G., 2019. Electric Bus Trial Route 737. Nowra Coaches Pty Ltd.
[12] https://ama.com.au/sites/default/files/documents/AMA_submission_inquiry_into_health_impacts_of_air_quality_.pdf; https://opus.lib.uts.edu.au/bitstream/10453/12700/1/2009005553OK.pdf; https://www.dea.org.au/images/general/DEA_Policy_-_Air_Pollution_v12-16.pdf; http://jech.bmj.com/content/early/2018/02/09/jech-2017-209948
[13] http://www.oecd.org/environment/the-cost-of-air-pollution-9789264210448- en.htm
[14] https://energy.unimelb.edu.au/news-and-events/news/vehicle-emissions-cause-40-more-deaths-than-road-toll; https://bitre.gov.au/publications/2005/files/wp_063.pdf; https://infrastructure.gov.au/vehicles/mv_standards_act/files/Sub188_Att9.pdf
[15] www.climatechange.gov.au/~/media/climate-change/emissions/2012-12/NGGIQuarteryDecQ2012.pdf
[16] https://www.climatecouncil.org.au/resources/transport-emissions-and-climate-solutions/

Electric vehicles, across all segments, are a promising transport technology given their potential for high emissions reductions. Even when using Australia's current electricity grid, EVs generally produce 30-40% less greenhouse gas emissions compared to equivalent internal combustion engine vehicles[17]. In the case of electric buses, it is expected that they would deliver average emissions reductions similar to the U.S. i.e. 60% less than comparable diesel buses[18]. Importantly, electric bus emissions would continue to decline as the proportion of low-carbon energy increases.

1.4 Benefit 4: Supporting the uptake of renewable energy

Electric vehicle technology has the potential to support the uptake of renewable energy, which in turn supports the transition towards a zero-emission transport sector. Electric vehicles – including electric bues - are essentially mobile batteries, which can transport significant energy stores between locations. If Australia's entire bus fleet was electric, this would provide a potential annual battery storage capacity of approximately 8 TWh[19].

Of course, this energy would also need to be used for transport purposes, however, excess storage capacity could be used during off-peak transport periods/peak electricity periods, to support the electricity grid. The storage capacity also increases climate resilience by providing an opportunity to power buildings, shelters, communications, etc, during grid blackouts and natural disasters. Trials of electric school buses, with these capabilities, are already underway overseas[20].

A recent study in California highlighted the enormous potential of EVs in supporting the uptake of renewable energy through smart charging and vehicle-to-grid (V2G) technologies[21]. The authors of this study found that if California continues to remain on-track for its' target of 1.5 million EVs by 2025 (0.5 million BEVs, 1 million PHEVs), and smart charging capabilities were installed at 60% of homes and 30% of workplaces, the EV fleet could provide the equivalent of 1.0 GW of battery storage, at a small fraction of the equivalent required investment of $US 1.45-1.75 billion in stationary battery storage. Furthermore, if V2G technologies were made available at the same proportion of households and workplaces, the fleet of EVs would provide equivalent services of 5.0 GW of stationary storage, and again at small fraction of the equivalent required investment of $12.8-15.4 billion in stationary battery storage.

The modelling undertaken as part of this study suggests that these EV charging technologies could support California in reaching its 50% renewable energy target by 2030, at a substantially lower cost compared to the equivalent investment required in stationary battery storage.

With similar renewable energy targets being adopted in some parts of Australia, EVs – including electric buses - paired with smart charging and vehicle-to-grid technologies, could provide a lower cost pathway to achieving these goals, whilst improving grid reliability and increasing climate resilience.

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[17] Calculated by comparing fuel lifecycle emissions of comparable electric and internal combustion engine vehicles, as listed in the Federal Government's Green Vehicle Guide e.g. Renault Zoe @ 121 g CO_2 per km vs. Hyundai i30 @ 205 g CO_2 per km; Mitsubishi Outlander PHEV @ 122 g CO_2 per km vs. Mitsubishi Outlander Petrol @ 198 g CO_2 per km.
[18] https://blog.ucsusa.org/jimmy-odea/electric-vs-diesel-vs-natural-gas-which-bus-is-best-for-the-climate
[19] Approximate calculation on the basis of 84,000 electric buses in Australia, with an average battery storage capacity of 250 kWh i.e. 250km driving range, with the ability to fully discharge once per day.
[20] https://ww.electrek.co/2019/08/23/electric-v2g-school-bus-pilots-grow/
[21] http://iopscience.iop.org/article/10.1088/1748-9326/aabe97

1.5 Benefit 5: Improving electricity grid utilisation

Australia has one of the highest penetration rates of rooftop solar in the world, and is also a global leader in regards to the uptake of stationary battery storage[22]. The increasing uptake of these distributed energy resources, by households and businesses, is leading towards a decline in reliance on the electricity grid. In the longer-term, this reduction in grid utilisation could have serious economic implications for those businesses and households that cannot afford to invest in distributed energy resources. As a major electrical appliance, electric buses can help to stabilise grid utilisation through an increase in demand for electricity. That said, it should be recognised that a 100% electric bus fleet would result in increase in national electricity consumption of 2.3 TWh p.a. – representing less than 1% of total national annual electricity generation[23].

1.6 Benefit 6: Reducing Australia's dependency on foreign oil

The existing vehicle fleet in Australia is highly dependent on imported oil and refined oil products to meet its' energy needs. This dependency on foreign oil exposes local businesses and households to volatile global oil pricing, and the prospect of oil shortages in the event of an international oil crisis.
The transition to EVs provides a pathway towards reducing Australia's dependency on oil, and supports the use of locally-produced energy, including renewable energy resources.

1.7 Benefit 7: Creating new green jobs

A number of world-leading EV technology companies already call Australia home, including charging infrastructure supplier, Tritium[24]. Australia also has many of the critical minerals required to support battery production[25]. Given electric buses will redirect foreign fuel spending to domestic energy, this will also support the creation of local jobs. A recent analysis found that high EV uptake in Australia could increase net employment by 13,400 jobs, whil increasing real GDP by $2.9 billion[26].

1.8 Key Barriers

There are three key barriers limiting the local adoption of electric buses:

- A lack of national electric vehicle policy and support
- Challenges in dealing with electricity utilities for installing charging infrastructure, and
- A lack of local knowledge due to limited trials.

Given electric buses are a new technology that may require some changes in operational practices, in addition to the installation of new infrastructure for charging, it is important that Government implements supportive policy to facilitate this transition. While the upfront capital costs of electric buses are currently higher than diesel bus equivalents, purchase prices are rapidly falling. Additionally, as is outlined later in this submission, the total cost of ownership for electric buses is already at parity with diesel buses in some circumstances.

Nonetheless, Government should set a target for electric bus uptake in the fleet, such that this target is incorporated into fleet investment and transition planning, to ensure the State can capitalise on the significant economic benefits of this technology as soon as possible.

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[22] https://www.capgemini.com/news/capgeminis-world-energy-markets-observatory-report-2017/
[23] https://www.energy.gov.au/publications/australian-energy-statistics-table-o-electricity-generation-fuel-type-2017-18-and-2018
[24] https://www.tritium.com.au/ourstory
[25] https://www.australianmining.com.au/features/batteries-included-how-australia-is-charging-up-for-a-revolution/
[26] https://electricvehiclecouncil.com.au/wp-content/uploads/2018/11/Recharging-the-economy.pdf

Besides upfront costs, charging infrastructure – particularly in terms of installation – is a major barrier to electric bus uptake. In the first instance, there have been limited local trials of the technology to outline the process of installating charging infrastructure; and the charging infrastructure requirements for different sized fleets. In the limited local trials, challenges dealing with the electricity utility, have been cited as a major barrier[27].

Given this, the NSW Government should endeavor to support a number of structured pilots of electric buses across the State to increase local knowledge of the technology, while delivering learnings for the future expansion of electric buses into the State fleet.

Additionally, the NSW Government should ensure that electricity utilities do not act as a roadblock to the installation of charging infrastructure, and that clear guidelines, and application pathways, are put in place to ensure requests for the installation of bus charging infrastructure (and other EV charging infrastructure) can be handled in a consistent, and timely approach.

The NSW Government may also need to consider financially supporting any grid infrastructure upgrades required to support charging infrastructure for electric bus fleets.

Recommendations:

1. The NSW Government should support a transition towards electric buses in order to capitalise on the significant economic, environmental and social benefits associated with this innovative transport technology.
2. The NSW Government should work with the Federal and other State Governments to develop a national electric vehicle policy, which includes support measures for the uptake of electric buses.
3. Recognising the significant, and numerous benefits that electric buses can deliver, the NSW Government should support the establishment of several structured pilots of electric buses in the short-term, to inform the State's medium-term bus investment and fleet transition strategies, including a State-level electric bus target for 2030.
4. The NSW Government should work with electricity utilities to develop clear guidelines, and application pathways, for the approval and installation of charging infrastructure for all electric vehicles, including electric buses.

[27] Abel, G., 2019. Electric Bus Trial Route 737. Nowra Coaches Pty Ltd.

2.0 Minimum energy and infrastructure requirements to power electric bus fleets

There are various considerations and options when examining the charging of electric buses. Electric buses can be charged at depots, at opportunity locations – such as bus terminals – using overhead charging pantographs (on-board bottom up or off-board top-down charging arm), or even potentially while in motion using conductive or inductive electric road pavements. Electric buses can also be powered using overhead powerlines – otherwise known as trolley buses. Battery swapping remains another potential option, although this approach is challenged by a lack of standardisation in battery configuration, chemistry and body placement, across the industry.

Traditional plug-in charging remains the most affordable option for overnight charging at depots. These plug-in chargers can be in the form of slower AC chargers (generally 15 to 25 kW or 15 to 25 km per hour on average) or in the form of faster DC chargers (50 to 500 kW or 50 to 500 km per hour on average). A Australian-built Tritium fast-charger is shown in Figure 5, being used to charge a Proterra electric bus in the United States.

Figure 5 – Autralian-built Tritium DC fast-charger being used to charge an electric bus in the US.
Source: https://www.electrive.com/2019/03/12/india-tritium-signs-deal-with-tata-to-supply-dc-chargers/

Fast DC chargers are more expensive than AC chargers, but less are required given the faster charging times. Multiple AC chargers may be more suitable in order to avoid the need to schedule and circulate buses for fast-charging throughout the night, however, this should be determined on a case-by-case basis. An example layout of plug-in chargers at a bus depot is shown in Figure 6.

Figure 6 – Electric bus charging at a depot in Dordrecht, Netherlands – the second city in the country to convert to 100% electric.
Source: https://www.ebusco.com/charging/

As alternative to traditional plug-in chargers, many electric bus operators overseas are now using overhead pantograph chargers, both at depots and on-route for opportunity charging – see Figure 7. While the cost of this infrastructure is generally higher, it has the added advantage of requiring less space, removes the need for drivers to manually plug-in the bus, and opens up the opportunity for on-route charging to be made available in addition to depot charging. It should be noted that pantograph charging has not yet been standardised, with a split in implementation between bottom-up approach (charging arms sits on bus roof), versus top-down approach (charging arm attached to overhead gantry infrastructure). These two approaches are not cross-compatible.

Figure 7 – Electric buses charging using overhead pantograph chargers at a bus depot in Schiphol in The Netherlands. Source: https://www.aviation24.be/airports/amsterdam-schiphol-ams/europes-largest-electric-bus-fleet-operates-at-and-around-amsterdam-airport-schiphol/

2.1 Choosing the right type of charging infrastructure

The primary determining factors in choosing the right charging infrastructure electric buses are:

- Size of the fleet,
- Route distances,
- Feasible offline time, and
- Site availability/conditions for charging infrastructure.

These factors also influence the size of the battery required for the electric buses, which in turn has major implications in terms of capital cost. Ultimately, operators should aim to maximise flexibility, while minimising total costs – taking into account both vehicle capital costs, as well as infrastructure costs.

According to one analysis of electric bus operations in European cities, most operators have utilised depot charging, rather than solely opportunity charging along the route[28]. It was also found that some correlation existed between higher battery capacities and longer routes - see Figure 8. Interestingly, there was no clear relationship between the choice in battery capacity and route terrain (hilly vs flat).

[28] https://www.toi.no/publications/user-experiences-from-the-early-adopters-of-heavy-duty-zero-emission-vehicles-in-norway-barriers-and-opportunities-article35934-29.html

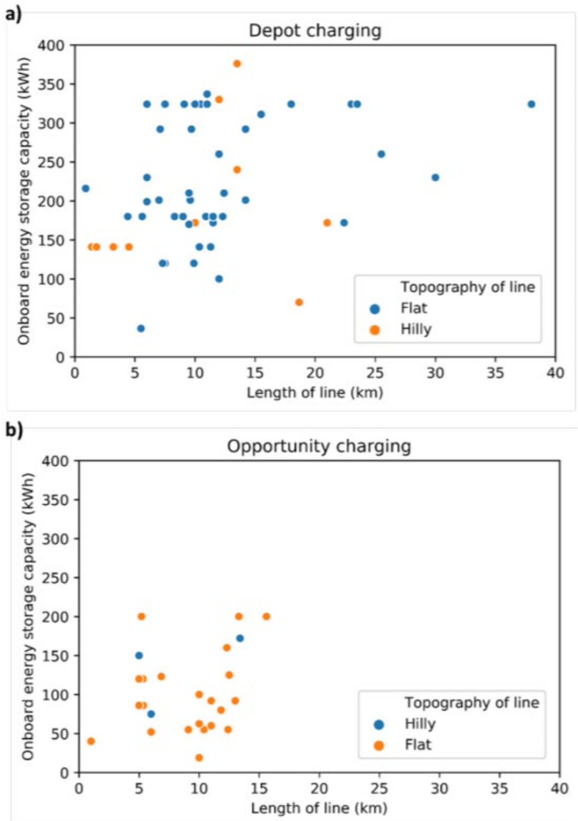

Figure 8 - Length of bus route vs battery capacity for electric bus trials for both flat and hilly routes, divided into (a) depot charging and (b) opportunity charging. Note the colour switches between (a) and (b).
Source: https://www.toi.no/publications/user-experiences-from-the-early-adopters-of-heavy-duty-zero-emission-vehicles-in-norway-barriers-and-opportunities-article35934-29.html

In a detailed breakdown of charging infrastructure utilised in European electric bus projects, Bloomberg New Energy Finance found that while the majority utilised only slow, overnight depot charging, this was closely followed by a combination of slow depot and fast terminal opportunity charging – see Figure 9. This same report provided an assessment of costs and feasibility for each of these charging strategies (see Figure 10).

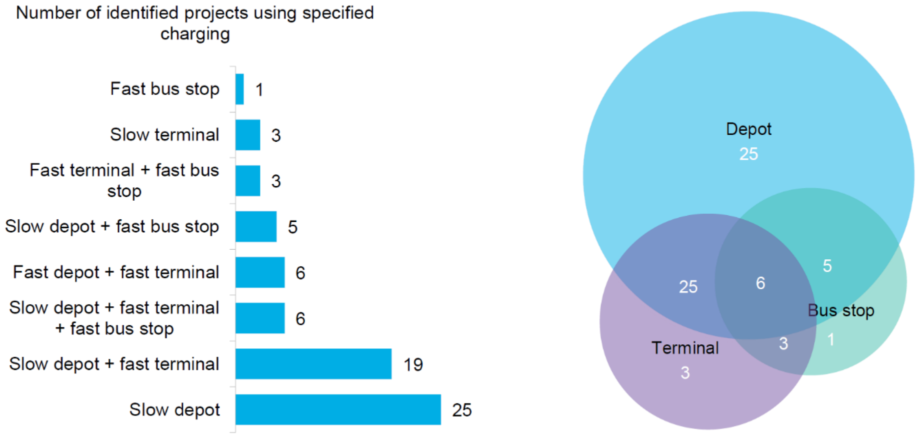

Figure 9 - Different types of electric bus charging configurations for projects in Europe. Data is from the Zero Emission Urban Bus System (ZeEUS) project.
Source: https://data.bloomberglp.com/professional/sites/24/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf

Charging concept	Infrastructure cost	E-bus battery requirements	Overall system cost	Feasibility
Slow plug-in overnight at depot	**Low** – chargers required only at depots, but the charger to bus ratio is high.	**High** – buses using only overnight charging will require higher capacity batteries to be able to cover their routes. Higher costs.	**Medium** – battery prices are the major component today. As prices decrease the overall system cost can be lowered. By using night off-peak tariffs for charging, savings on electricity costs can be significant.	Most popular option today, feasible on a smaller scale when the number of buses is low. On a larger scale, there can be localized problems when charging all the buses at the same time (space, power supply, grid impacts). Risky in places where the depot is far from the bus route. Large batteries mean weight issues and compromises on the number of passengers.
Slow plug-in at depot and fast charging at terminal	**Medium** – two types of chargers required, and in two locations.	**Medium** – buses can top up at terminals in a relatively fast manner, so they can have smaller battery packs.	**Medium** – higher cost of the fast charging system is balanced with savings from a smaller battery. There may still be need for changes in normal bus operations, but in theory layover time can be used for top-up.	Second most popular option today, but issues around parking space at bus terminals may arise. If the number of buses required on the route is steady throughout the day, then a reserve bus can be added for the bus that is charging.
Super-fast charging at terminal and bus stops (wireless / pantograph only)	**High** – pantograph and wireless systems are the most expensive installations today.	**Low** – there is no need for big battery packs as buses charge en route.	**High** – wireless charging is currently very expensive, but requires the least change to normal bus operations. It is, however, dedicated to a single bus route, which limits flexibility. To be the only charging option the installation would need to cover most of the route.	Pantograph charging is becoming more and more popular. The economics improve as the number of e-buses in the fleet rises – more vehicles using the system reduces the cost per kilometer of charging delivered.
Plug-in at depot and pantograph en route	**High** – pantograph systems are still expensive today.	**Medium** – because buses can top up at bus stops, they can have smaller battery packs.	**Medium** – very expensive technology, but costs can be spread over several e-buses. As with the option above, pantograph installations are dedicated to a single bus route, which limits flexibility.	Pantograph charging is becoming more and more popular. The economics improve as the number of e-buses in the fleet rises – more vehicles using the system reduces the cost per kilometer of charging delivered.

Figure 10 - Assessment of different charging strategies for electric buses.
Source: https://data.bloomberglp.com/professional/sites/24/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf

As discussed previously, and again outlined in Figure 10, slow overnight charging at the depot has the lowest cost, but requires a higher charger to bus ratio. Charging costs may also be lower if operators can take advantage of off-peak overnight tariffs, when electricity demand is low. This is the most popular approach today, however, it does require electric buses to be fitted with larger batteries to ensure they can fulfil the entire daily schedule on a single charge. As electric bus fleets grow, this approach can also present challenges in terms of space at depots, as well as localised grid issues if the fleet is not spread out across a number of depots.

This approach contrasts to the most expensive strategy of using pantograph and/or wireless charging systems for opportunity charging on route. The higher infrastructure costs can be offset in part by allowing for smaller batteries, however, there is less flexibility in route schedule as electric buses are restricted to routes where this charging infrastructure is available.

It likely that a combination of slow depot and fast opportunity charging will emerge as a scalable approach for large electric bus fleets which allows for some reduction in battery size, while providing electric buses with the ability to travel longer distances throughout the day.

2.2 Charging infrastructure costs

While it is difficult to put an exact price on each of the chargers outlined above, some indicative figures have been included below, based on a sample of electric bus projects in North America (Figure 11). It should be noted, however, that these costs are not necessarily scalable, and do not always account for potential electricity grid infrastructure upgrades that may be required to support the charging hardware.

These costs align with those reported in the Nowra Coaches electric bus trial in NSW i.e. $74,250 for a depot fast-charger, and an additional $8,700 in installation costs[29].

Deployment Costs	Minimum	Average	Maximum
Depot charging (per charger)	$2,600	$65,000	$130,000
Depot charging installation (per charger)	$2,600	$22,165	$83,200
Depot charging total (per charger)	*$5,200*	*$87,165*	*$213,200*

Figure 11 – Electric bus infrastructure costs for a sample of North American projects in $AU.
Source: https://www.plugincanada.ca/wp-content/uploads/2019/02/25061.pdf

2.3 Other charging infrastructure considerations

Beyond the charging infrastructure itself, it is of critical importance to understand the capacity of the electricity grid at these sites. Bus operators must work closely with local electricity utilities to investigate these issues in further detail, and proactively plan for the future uptake of electric buses.

Necessary charging infrastructure for electric buses may require expansion and investment in grid infrastructure e.g. transformers, substations, etc, which without upgrade could act as a major barrier to electric bus uptake. This information is not readily obtained without local utility input, thus highlighting the importance of their involvement in the early stages of electric bus transition planning.

While grid infrastructure may not pose a problem for limited electric bus trials, it is critical to take a longer-term perspective on the issue to ensure that any infrastructure investments made to facilitate a structured pilot can be leveraged for future expansion of electric buses in the fleet.

A few alternative measures that may also need to be considered in order to minimise any potential burden of electric bus charging on the grid may include:

1. **Implementation of smart charging infrastructure,** where loads can be reduced/delayed during peak demand periods, and charging can be accelerated during off-peak periods when electricity is cheap. Smart charging infrastructure could also be installed to allow energy to be exported from electric buses to the grid/buildings, to provide emergency power during blackouts, or support the grid during potential peak periods where several buses are parked (hot summer evenings).
2. **Installation of alternative power sources at depots**, including electricity generators, or increasingly stationary energy storage (batteries). While early electric bus operators overseas installed diesel generators to provide redundancy for the fleet if the grid was to go offline, increasingly stationary energy storage may play a role in reducing electric bus charging loads on the grid, providing cheaper energy for charging, opening the possibility to trade energy with the grid to further reduce costs, all while providing backup redundancy for fleet charging.

[29] Abel, G., 2019. Electric Bus Trial Route 737. Nowra Coaches Pty Ltd.

3. **Reorganisation of traditional depot structures**, in order to spread charging loads across multiple sites, as opposed to centralising loads in a few sites. Alternatively, it may be necessary to invest in brand new depot sites, which are purpose-built to support electric buses.

4. **Identification of synergies with other electric vehicle operators**, include car-share/ride-sharing fleets, fast-charging operators, and other e-mobility hosts. By partnering with other agencies and businesses that also require charging infrastructure, there is an opportunity to spread grid infrastructure costs across a number of stakeholders. Additionally, if strategically planned, the clustering of several e-mobility opportunities could help to serve public transport demand in the future, particularly if first and last mile e-mobility operators are targeted to form e-mobility hubs, where electric bus opportunity charging can also take place. Given train stations generally have significant grid capacity, and are a complimentary transport mode, these sites offer an immediate opportunity for hosting e-mobility hubs.

Recommendations:

1. Appropriate charging infrastructure for electric bus fleets must be considered on a case-by-case basis – predominantly due to the need to assess local grid capacity. This again highlights the importance of NSW Government establishing clear guidelines and application pathways, for the approval and installation of charging infrastructure for all electric vehicles, including electric buses.

2. Recognise the likely the need for both depot and on-route opportunity charging to support larger electric bus fleets, and the need for standardisation of on-route charging infrastructure.

3.0 Other renewable, emissions neutral energy sources.

This submission considers hydrogen fuel cell buses (FCBs) as distinctly separate from electric buses (EBs) given FCBs generally cannot be charged using external electricity, have significantly different infrastructure requirements, are at a much earlier stage of development, and have substantially higher capital and operating costs compared to electric buses. That said, hydrogen fuel cell buses are another potential zero emission bus (ZEB) technology, and as such, we have included details regarding this technology in the following section of this submission. For the purpose of this submission, it is assumed that FCBs directly use hydrogen, and not biofuels or an alternative hydrogen carrier, such as ammonia.

Fuel cell buses have not yet been commercialised, and as such, it is still too early to determine whether this technology will play a major role in the bus segment. Fuel cell bus technology is considered to currently be in the technology demonstration phase[30]. The high cost of the technology – higher than electric buses – is one of the primary challenges to broader commercialisation. FCBs also face major challenges in regards to fuel cell durability and performance (continuing to fail at meeting lifetime goals[31]), the development of hydrogen infrastructure, along with hydrogen storage and safety considerations[32,33].

FCBs currently cost more than equivalent ICE buses. This is mainly due to the fuel cell component of the drivetrain, however, can also be dependent on the size of battery used to support the fuel cell. Fuel cells are slow to respond to instant power demand. As such, in most FCBs trialled today, a hybrid approach is taken by including a larger battery pack and/or supercapacitor to assist in providing instant power response[34].

The cost of the fuel cell stack is largely due to the material and component costs, manufacturing, and labor[32]. Improvements in the costs of fuel cell materials and components are highly dependent of future technological innovations, and as such, there is a high degree of uncertainty in future cost projections, particularly with an unclear level of market demand.

As shown in Figure 12, while FCB capital costs have fallen over the past decade from around $AU 2.5 million to $AU 1.1 million per vehicle – and are predicted to continue to fall over the coming decade - in order for FCBs to be commercially viable, costs need to fall to below $AU 550,000 years (for a non-articulated single deck bus). Some industry proponents believe that FCB capital costs will only fall to between $AU 800,000 to 1,050,000 in the coming years[35]

Another analysis conducted by a hydrogen fuel cell research collaboration in Europe, predicts that FCB capital costs could fall to between $AU 650,000 to 750,000 by 2030 – if produced at scale (see Figure 13). However, if FCBs remain a niche application, costs are unlikely to fall below $AU 800,000 before 2030. Note that electric buses are expected to fall to less than $AU 600,000 over the same period[36].

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[30] https://www.nrel.gov/docs/fy19osti/72208.pdf
[31] https://www.sciencedirect.com/science/article/abs/pii/S0306261918306081
[32] https://www.sciencedirect.com/science/article/abs/pii/S0360319915315810
[33] https://www.toi.no/publications/user-experiences-from-the-early-adopters-of-heavy-duty-zero-emission-vehicles-in-norway-barriers-and-opportunities-article35934-29.html
[34] https://www.sciencedirect.com/science/article/abs/pii/S0360319917306353
[35] http://hydrogenvalley.dk/wp-content/uploads/2018/04/11_FCB-OSLO18_ELEMENT-ENERGY.pdf
[36] https://data.bloomberglp.com/professional/sites/24/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf

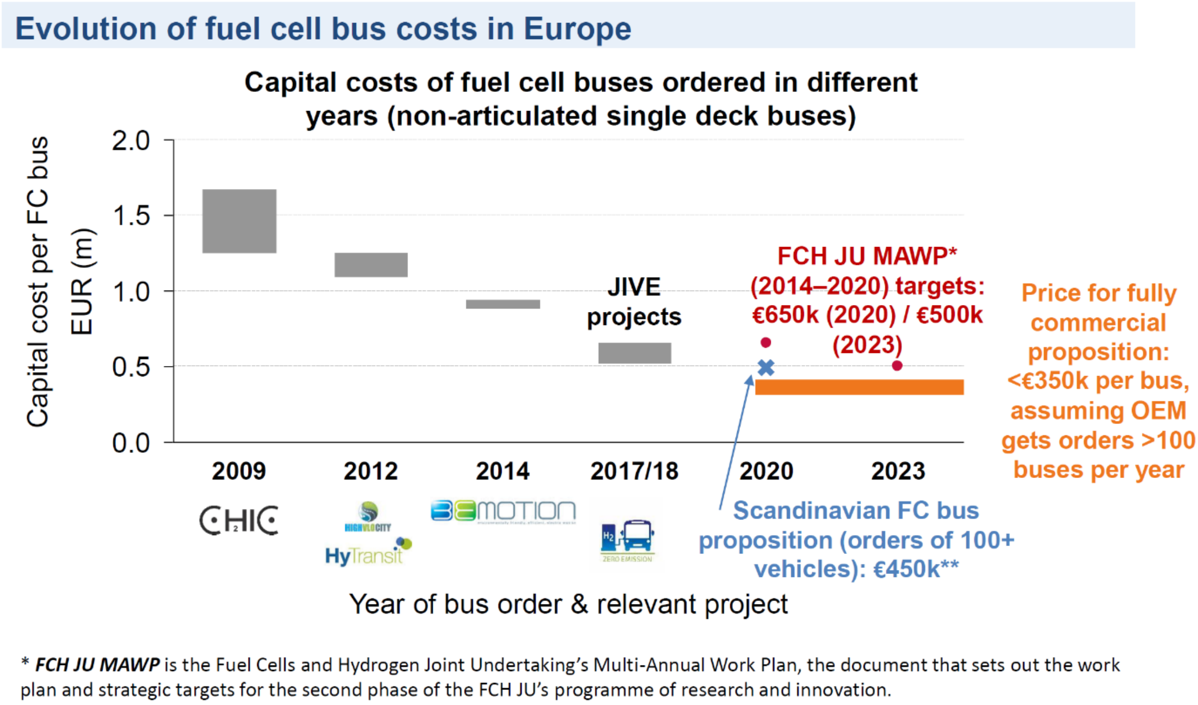


Figure 12 - Projected capital costs of FCBs over the coming years.
Source: http://hydrogenvalley.dk/wp-content/uploads/2018/04/11_FCB-OSLO18_ELEMENT-ENERGY.pdf

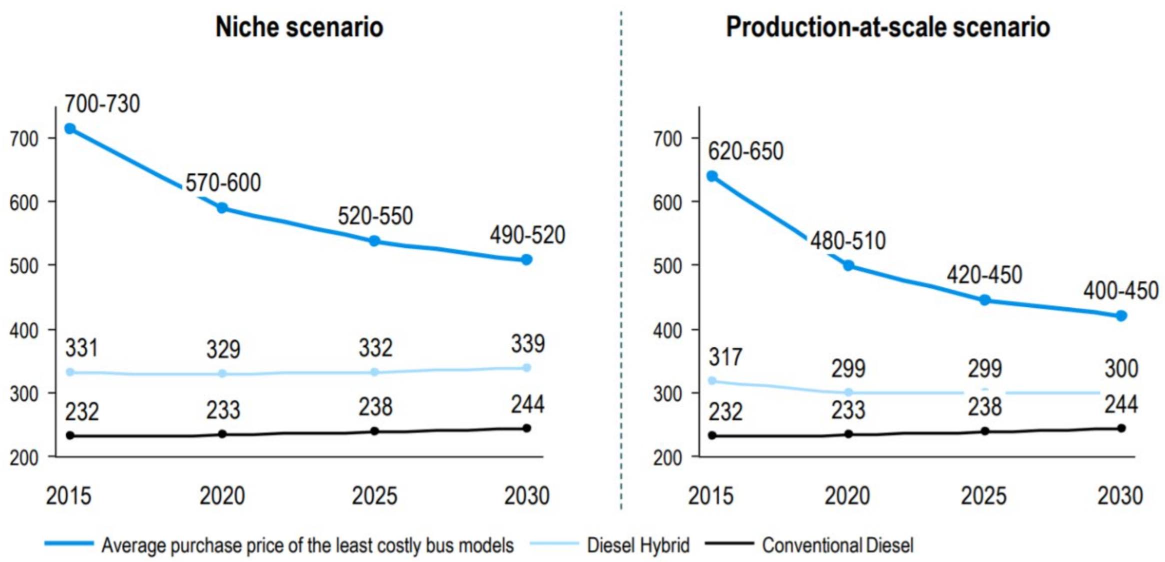


Figure 13 - Capital cost projections of standard FCBs under different uptake production scenarios compared to diesel and diesel-hybrid buses [in EUR '000].
Source: https://www.fch.europa.eu/sites/default/files/150909_FINAL_Bus_Study_Report_OUT_0.PDF

At present, the capital costs for electric heavy vehicles - including buses - are expected to be cheaper than hydrogen fuel cell heavy vehicles up to a driving range of 350 to 400 kilometres. That being said, this comparison does not take into account the relative difference in operating costs between fuel cell and electric buses, which may mean electric heavy vehicles are also more cost-competitive for driving ranges greater than 400 kilometres. It also does not account for the fact that electric buses are likely to be able to store a greater amount of energy, and thus drive further, compared to a hydrogen fuel cell bus, given the volumetric constraints imposed by a large number of hydrogen storage tanks (see Figure 14).

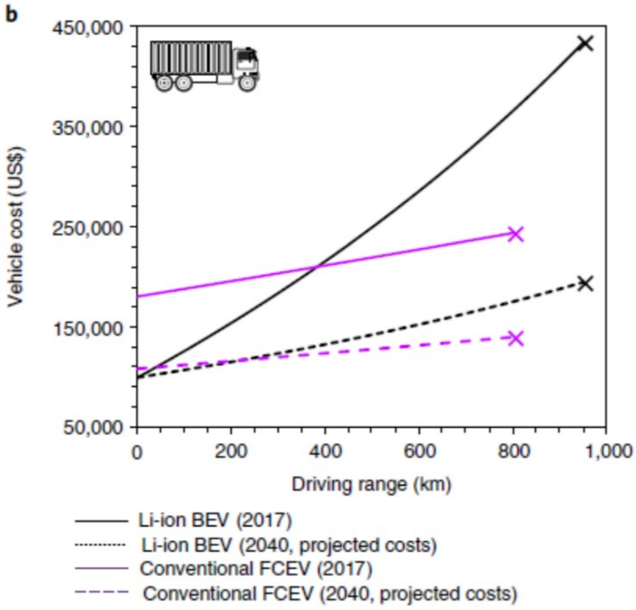


Figure 14 - Vehicle cost as a function of driving range for electric versus hydrogen fuel cell heavy vehicles.
Source: https://www.nature.com/articles/s41560-018-0108-1

Despite the challenges FCBs face, the technology continues to see growing interest from industry, with an expansion in the number of prototypes and R&D trials. These trials have largely taken place in Japan, the United States, and Europe, however, no producers have yet announced plans for series production of these vehicles[33]. While there is still some degree of uncertainly, there is potential for series production of fuel cell buses towards the end of the coming decade[37]. A sample of hydrogen fuel cell buses active in trials of 2018, and their respective characteristics, has been included in Figure 15.

Bus model	**Range, km**	**H_2-storage*, kg**	**Net weight, tonnes**	**Year on the market****
Van Hool A330 (13m)		30-50	16	
Van Hool Exqui.City (18m)		40-45		
Solaris (18m)	250-300	45		2015
Mercedes/Evobus Citario (12m)		35-40	13	2018
VDL/APTS (18m)		40		
Solbus/HyMove (12m)	300+	30		
Wrightbus (12m)	250-300	30	11	2017

Figure 15 - Sample of FCBs available as at 2018.
Source: https://www.toi.no/getfile.php?mmfileid=51698

Total cost of ownership considerations for FCBs, compared to electric and diesel buses, is detailed in Section 7.0 of this submission.

[37] https://www.toi.no/publications/user-experiences-from-the-early-adopters-of-heavy-duty-zero-emission-vehicles-in-norway-barriers-and-opportunities-article35934-29.html

3.1 Infrastructure considerations for hydrogen fuel cell buses

Compared to infrastructure for electric buses – and also conventional diesel buses – refuelling infrastructure for FCBs is relatively complex, and varies depending on how and where the hydrogen is produced. The following section of this submission provides a brief overview of the properties and fuel safety considerations of hydrogen, hydrogen refuelling stations (HRS) components, as well as the costs of HRS.

3.1.1 Properties of hydrogen and fuel safety

It is important to review some of the basic properties and fuel safety issues related to the use of hydrogen. Hydrogen is 14 times lighter than air, and as a result, when released it rises and disperses quickly. Hydrogen is also odourless, colourless, tasteless and considered to be non-toxic.

On a mass basis, hydrogen contains around 2.5 times the energy of petrol. However, given it is the smallest known element, even when compressed to high pressures, it requires more than ten times the volume of petrol to store the same amount of energy.

As is the case with all compressed gases, since they store mechanical energy, if there is an uncontrolled release – such as the rupturing of a storage tank – the tank can be propelled at high speeds, with the potential to cause significant damage, injuries and even fatalities.

Hydrogen also has a wide flammability range compared to most other fuels, with the ability to catch fire and combust. One of the challenges of hydrogen is that when burnt, the flame is invisible in natural daylight, and therefore can be difficult to identify without leakage sensors.

If stored as a liquid – as opposed to pressured gas – hydrogen also carries the risk of causing cryogenic burns and/or lung damage, due to the low temperature (less than -253^{o}C). Hydrogen as a gas occupies around 850 times the volume of liquid hydrogen. Therefore, if even a small amount of liquid hydrogen escapes in an enclosed space, it could vapourise and fill the space in a short amount of time, displacing oxygen and acting as an asphyxiant[38].

As such, the storage and use of hydrogen requires stringent safety measures in order to minimise risks. In particular, ventilation is necessary when working with hydrogen – in gaseous or liquid form. This is of significance when considering the maintenance requirements of hydrogen fuel cell buses. Measures must be taken to minimise the risk to maintenance workers. Some measures that have been taken in overseas FCB trials include:

- Constructing a 2-hour firewall to separate the FCB maintenance area from other sections of buildings;
- Use of high-speed roll-up garage doors which are programmed to open if a hydrogen leak is detected; and
- Depressurisation systems to remove hydrogen from FCBs prior to maintenance sessions.

Examples of the costs incurred to implement some of these measures, based on a series of FCB trials in the US, have been included in Figure 16. The significantly lower costs achieved by SunLine were due to the use of a 'canvas tent' for maintenance, that allowed hydrogen to escape through gaps in the material.

[38] https://www.mjbradley.com/reports/fuel-cell-bus-life-cycle-cost-model-base-case-future-scenario-analysis

Transit Agency	AC Transit [17]	BC Transit [18]	SunLine [19]	Santa Clara VTA [20]	Columbia, SC [21]
Facility Cost	$1.5 million	$680,000 (CAD)	$50,000	$4.4 million	Not provided
Type of modification	Partial modification of existing building	Modifications included in design of new facility	New naturally ventilated 'tent' built	New 2-bay maintenance facility and car wash	Added lift to car wash canopy
Defueling Required?	Max 600 psig pressure	Not reported	No	No	No

Figure 16 - Summary of maintenance facility upgrades required for hydrogen FCB trials in the US. Source: https://www.mjbradley.com/reports/fuel-cell-bus-life-cycle-cost-model-base-case-future-scenario-analysis

While hydrogen is transported in large volumes across the globe, with a low record of safety incidents, it is nonetheless critical to consider, plan and manage these potential risks if using FCBs. This also applies to managing hydrogen refuelling infrastructure (HRS), with lessons still to be learnt in regards to those stations which have suffered recent explosions, including a recent HRS explosion in South Korea that resulted in two fatalities[39], and another recent HRS explosion in Norway[40]. Building codes relevant to the safe handling of hydrogen are not yet well developed, leading to some level of uncertainty in regards to the modifications required to safely implement FCB projects.

3.1.2 Hydrogen refuelling station (HRS) components

Hydrogen fuel cell buses are reliant on the development of widespread and convenient refuelling infrastructure if they are to play more than a niche role. There are four main components of hydrogen refuelling infrastructure (see Figure 17):

1. Supply & Delivery: on-site hydrogen production versus off-site production
2. Compression: to achieve pressure required for economic stationary and vehicle storage
3. Storage: liquid versus gaseous
4. Dispensing: connection between hydrogen refueling station (HRS) and vehicle.

The technological and economic development of each of these components continues to be developed.

Most existing HRS globally today have been designed to refuel less than 250 kilograms of hydrogen per day, on average. This would be enough to support up to approximately 15 city buses. For FCBs to be a viable option in the future, HRS need to support the refuelling of 100+ buses per day, implying a fuel requirement of more than 1,500 kilograms per day.

39 https://markets.businessinsider.com/news/stocks/fatal-explosion-slams-south-koreas-hydrogen-future-1028558222
40 https://qz.com/1641276/a-hydrogen-fueling-station-explodes-in-norways-baerum/

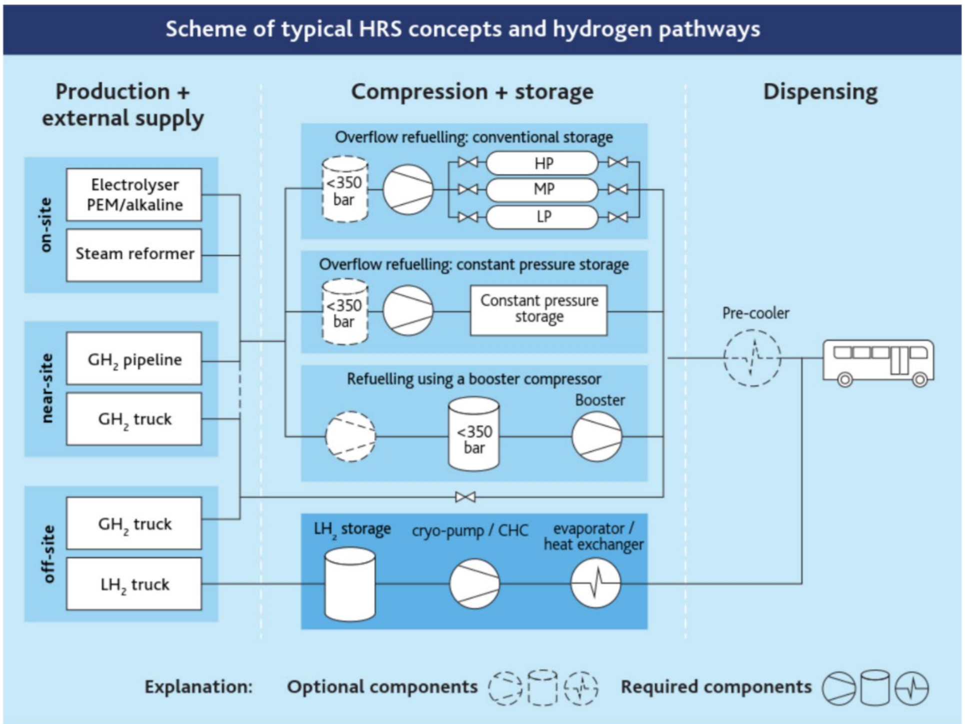


Figure 17 - Schematic overview of typical hydrogen refuelling station components.
Source: http://newbusfuel.eu/wp-content/uploads/2017/03/NewBusFuel_D4.3_Guidance-document-for-large-scale-hydrogen-refuelling_final.pdf

A summary of HRS costs, compiled by ICCT, 2017[41], suggests that at a capacity of 600 kilograms of hydrogen per day, the capital cost (excluding capital costs for on-site hydrogen production) of a single HRS would be approximately $US1.8 million. A HRS producing 1,000 kg of hydrogen per day, including on-site hydrogen generation, is expected to cost approximately EUR 16 million to construct[42] – see Figure 18. These costs do not include the maintenance and operatings costs associated with a HRS of this capacity.

[41] https://theicct.org/sites/default/files/publications/Hydrogen-infrastructure-status-update_ICCT-briefing_04102017_vF.pdf
[42] http://newbusfuel.eu/wp-content/uploads/2017/03/NewBusFuel_D4.3_Guidance-document-for-large-scale-hydrogen-refuelling_final.pdf

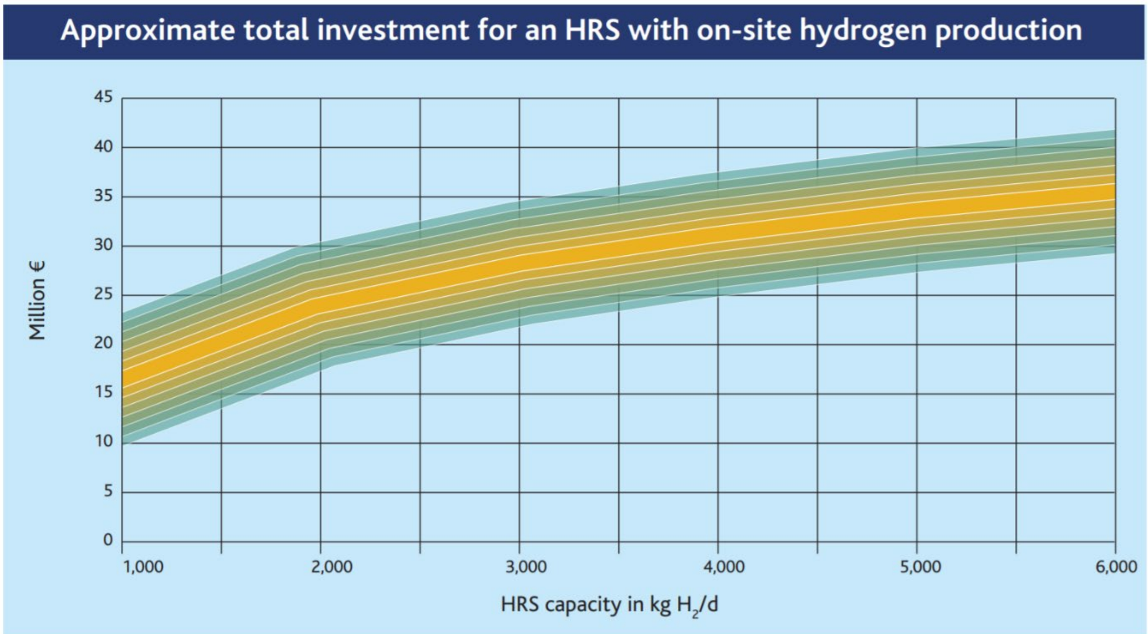


Figure 18 - Forecast of HRS costs, including on-site hydrogen production.
Source: http://newbusfuel.eu/wp-content/uploads/2017/03/NewBusFuel_D4.3_Guidance-document-for-large-scale-hydrogen-refuelling_final.pdf

The dispensed cost of hydrogen is highly correlated with scale of production and the cost of electricity - when produced using water electrolysis – see Figure 20. As such, the economic competitiveness of hydrogen fuel cell buses is highly dependent on increased volume of production, as well as securing low-cost, ideally renewable electricity.

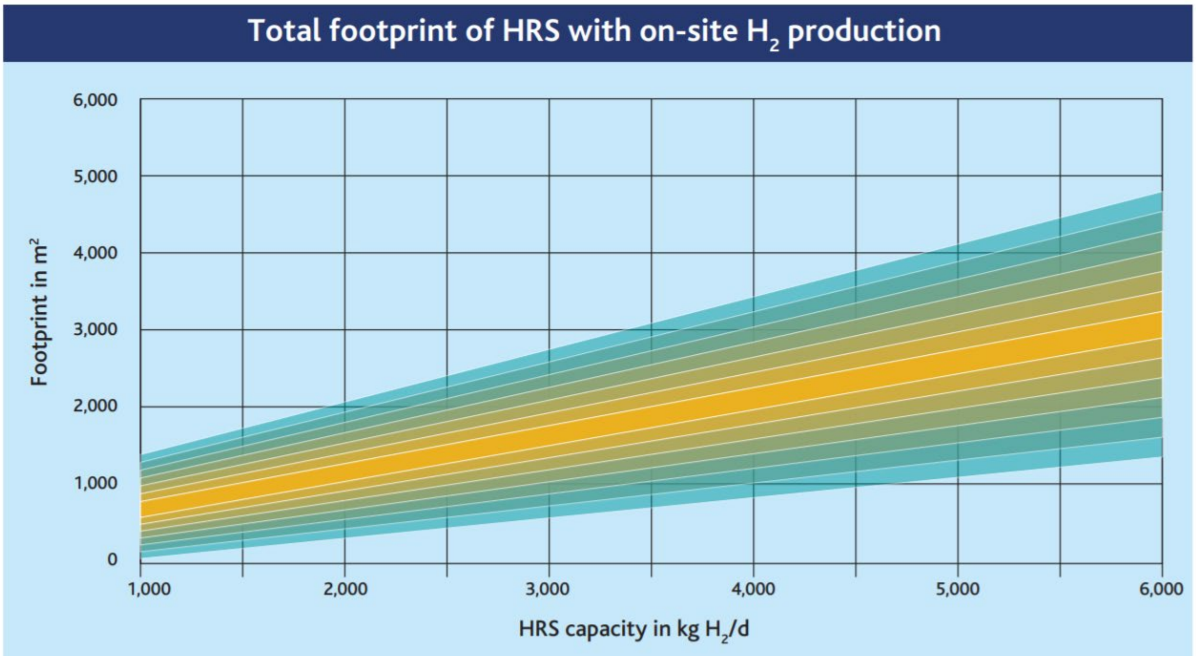


Figure 19 - Relative footprint of HRS for on-site versus off-site hydrogen supply.
Source: http://newbusfuel.eu/wp-content/uploads/2017/03/NewBusFuel_D4.3_Guidance-document-for-large-scale-hydrogen-refuelling_final.pdf

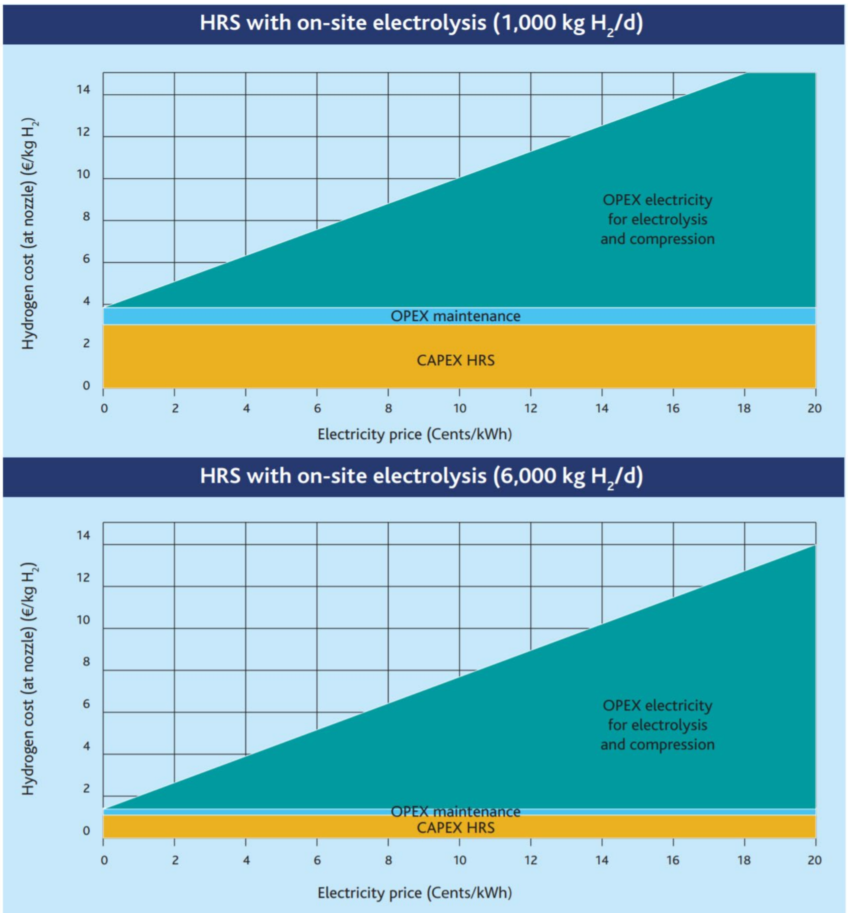


Figure 20 - Modelled HRS capital, maintenance and operating costs when including on-site hydrogen production. Source: http://newbusfuel.eu/wp-content/uploads/2017/03/NewBusFuel_D4.3_Guidance-document-for-large-scale-hydrogen-refuelling_final.pdf

Even with optimistic improvements in the future, the capital investment in HRS required for fuel cell buses to become economically competitive, and convenient, will remain significant. Given the significant footprint required for HRS infrastructure, and the linear relationship between this footprint and capacity, some depots will also be challenged with having sufficient land space to support HRS with adequate capacities for FCB fleets[43].

Given the current stage of economic and technological maturity of fuel cell buses, it is recommended that greater effort is put towards transitioning the segments of fleets where electric buses are likely to always dominate i.e. <300 kilometres per day, given electric buses are a more mature technology, that is economically competitive today. This is not to say that the uptake of electric buses should be mutually exclusive to hydrogen fuel cell buses, but that a more pragmatic approach should be to see how fuel cell bus technology develops internationally over the coming decade, prior to substantially investing in HRS infrastructure, which may later be found to be redundant.

[43] http://newbusfuel.eu/wp-content/uploads/2017/03/NewBusFuel_D4.3_Guidance-document-for-large-scale-hydrogen-refuelling_final.pdf

It should also be noted that there are other sectors of the economy where the use of hydrogen technology should be prioritised, given the limited zero emission alternatives, including:

- Existing chemical feedstock processes
- Steel manufacturing
- Cement clinkering
- Long-haul marine shipping.

Given hydrogen is both energy and water intensive to produce[44], compress, transport and store, Australia should be strategic in where it is used in order to maximise emissions reductions. Arguably, given the existing capabilities of electric buses today, the use of hydrogen in bus fleets should be a far lower priority, compared to the other, more critical hydrogen applications outlined above.

Recommendations:

1. Hydrogen fuel cell buses are an immature technology, still in demonstration, that is unlikely to be economically-competitive until after 2030. As such, NSW Government should monitor the continuing development of this technology, but prioritise initial efforts to focus on electric buses, given they a both technologically mature and economically-competitive.

2. Given the water and energy intensity of hydrogen production, it should initially to be prioritised for use in other economic sectors where it can have a greater emissions reduction impact, including: existing chemical feedstock processes, steel manufacturing, cement clinkering, and long-haul marine shipping.

[44] Current water electrolyser technology available for sale in Australia is stated to use 55-60 kWh of electricity and 20 litres of water per kilogram of hydrogen – excluding considering of water and energy consumption/losses due to water extraction, and subsequent hydrogen compression, transport and storage.

4.0 Ways to support manufacture and assembly of electric buses in NSW

Not addressed in this submission.

5.0 Experience with introducing electric bus fleets in other jurisdictions

A series of electric bus case studies – and the learnings from these case studies – has been included in the following section of the submission. While many new electric bus projects have started in 2019, it is too early for these initiatives to be fully evaluated. Additionally, a high-level overview on a range of electric bus trials in Europe can be found here: https://zeeus.eu/uploads/publications/documents/zeeus-ebus-report-2.pdf

5.1 Antelope Valley Transit Authority, California, United States

The Antelope Valley Transit Authority (AVTA) provides public transport services for Palmdale, Lancaster and North Los Angeles, in the United States. Starting in 2014, AVTA set a goal to be the first public transport operator in the US to fully electrify their fleet[45]. As of 2019 they are on track to reach this goal by the end of the year[46], which includes a total of 89 electric buses supported by 89 plug-in depot chargers, and 13 on-route 50 kW inductive (wireless) chargers.

The fleet conversion and infrastructure rollout for AVTA's electric bus program has been supported through a range of local, state and federal grants, including most recently a $AU 12.6M grant from the Trump Administration an additional 20 electric buses – and associated charging equipment[47].

An overview of some of the first electric buses AVTA purchased are included in Figure 21, noting these were 2014 costs. As shown, AVTA paid $AU 1.1 million for each bus, $AU 108,000 for depot charging infrastructure (including installation), and $AU 875,000 for on-route wireless charging (including installation).

BEB fleet size (OEM)		2 - 40′ (BYD)
Total fleet miles accumulated per month		11,581
Total months in operation		37
Number of depot chargers		1
Number of on-route chargers		2 (50 kW inductive/wireless)
Average route length (mi) – BEB Fleet		21 miles
Daily range requirement – BEB Fleet		185 miles
Average BEB route speeds		17
BEB cost		$770,000
Depot Charger cost	Equipment (per charger)	$19,000
	Installation (per charger)	$55,000
On-route Charger cost	Equipment (per charger)	$350,000
	Installation (per charger)	$250,000
Funding sources	LA County grant, Antelope Valley Air Quality Management District, LA Metro Call for Projects	

Figure 21 - Characteristics of electric buses used in AVTAs fleet [in $US].
Source: http://www.trb.org/Main/Blurbs/177400.aspx

45 http://www.trb.org/Main/Blurbs/177400.aspx
46 https://www.greenbiz.com/article/electrifying-miles-and-milestones-antelope-valley-transit-authoritys-buses
47 https://www.avpress.com/news/local_news/million-awarded-for-transportation/article_d4074f96-05d9-11ea-b0ba-5fc97467141c.html

The depot chargers were supplied as part of the electric bus purchase. These were the primary infrastructure used for charging the electric bus fleet overnight, with the wireless chargers installed at layover locations to support opportunity charging during the day. AVTA have more recently installed additional wireless chargers with a capacity of 250 kW[48], meaning they can provide a top-up charge of around 60 km during a 15-minute layover.

The wireless chargers were installed for two reasons:

1.) Daily distance travelled on some routes required opportunity charging to extend driving range
2.) Some of the local government areas in which AVTA operates restrict the construction of overhead power, and therefore a pavement-based solution was required.

In order to support AVTA's long-term goal of a fully-electric bus fleet, the agency planned in advance for the total power requirements that would be necessary to support this transport. They had sufficient physical space at the depot to install a plug-in charger for every bus, however, there were obstacles encountered regarding the scale of power supply required to support simultaneous charging of the fleet. By working closely with the local utility, AVTA was able to support the installation of the necessary grid infrastructure to charge their fleet. Their initially estimated a full electric fleet would require up to 18,000 amps in instantaneous load (i.e. around 2,000 kW), however, by implementing a smart charging management system, and separating the depot into four electrical zones, they were able to decrease this down to 5,000 amps (i.e. 550 kW)[49].

In addition to grid infrastructure, AVTA needed to work closely with the local electricity utility to secure a tariff structure that would support their transition to electric buses. The local utility was supportive of AVTAs electrification efforts and assisted in designing an appropriate pricing scheme. It is noted that AVTA found it much easier to accommodate growth from 0 to 50 electric buses, than from 50 to 89 ELECTRIC BUSs, given the challenges in scaling up electricity infrastructure. One critical lesson learnt is to install electrical wiring capacity (without chargers) from the beginning to support the long-term electric bus fleet target, as this reduces costs significantly compared to having to retrofit as the fleet expands.

In terms of vehicle performance, it is worth noting that AVTA found significant variations in vehicle efficiency depending on driving style. As such, driver training and incentives were a critical factor in encouraging more efficient driving techniques to minimise charging requirements.

In addition to charging infrastructure, AVTA also has a 1,500 kW backup diesel generator on-site to provide emergency power in case of a grid emergency – noting there could be more value recognised today from an equivalent on-site battery storage system which could support charge, provide redundancy, and reduce electricity costs by trading in the national electricity market. AVTA also has on-site solar PV parking structures, which are not directly linked to the electric buses charging infrastructure, but designed to reduce the depot's overall grid electricity consumption.

[48] https://www.masstransitmag.com/bus/vehicles/hybrid-hydrogen-electric-vehicles/press-release/21091577/wave-inc-wave-supports-antelope-valley-transit-authority-to-be-the-first-fully-electric-fleet-powered-by-wireless-chargers
[49] http://www.trb.org/Main/Blurbs/177400.aspx

5.2 King County Metro, Washington, United States

King County Metro (KCM) is located in Seattle, Washington, in the United States, and operates the 10th largest fleet in the country at around 1,600 buses[50], and the largest hybrid fleet in the country[51], carrying 122 million passengers per year[52]. The agency currently has 185 zero emission buses, including 174 electric trolley buses that use overhead wires and 11 electric buses (see Figure 21). The electric buses have a range of up to 225 km, which is sufficient to cover 70% of their routes. KCM plan to order a further 120 electric buses in 2020 based on the evaluation of the initial 11 electric buses[50], adding a further 250 electric buses by 2025, and another 250 electric buses by 2030, towards the target of a 100% zero-emission fleet by 2040 (including electric buses and electric trolley buses)[50].

Figure 22 - One of KCM's electric buses using an overhead, fast-charger during a layover.
Source: https://www.seattletimes.com/seattle-news/transportation/coming-to-south-king-county-battery-powered-buses-and-a-big-new-base/

The costs and characteristics associated with the initial electric buses purchased in 2016, are included in Figure 23. The electric buses cost $AU 1.1 million each, with on-route overhead (pantograph) fast-charger costing $AU 1.2 million (including installation).

KCM has taken a different approach to AVTA, and instead relied predominantly on on-route opportunity charging using overhead pantograph fast-chargers. While this approach avoids the need for major electricity infrastructure upgrades at the depot, it introduces separate challenges, particularly in terms of scheduling charging. If one bus is delayed due to traffic, it can have a cascading impact when the fleet is solely reliant on opportunity charging. If a driver leaves a bus charging during a terminal layover, this can also lead to delays for subsequent buses waiting to charge. These learnings have led to KCM planning for the establishment of a brand-new electric bus depot, with both slow and fast overhead pantograph chargers installed at the depot, to support the ramp up of its electric bus fleet[53]. Combined with opportunity charging, this approach provides greater flexibility and redundancy.

[50] https://kingcounty.gov/depts/transportation/metro/programs-projects/innovation-technology/zero-emission-fleet.aspx
[51] http://files.metro-magazine.com/images/top100-2017.pdf
[52] https://www.seattletimes.com/seattle-news/transportation/coming-to-south-king-county-battery-powered-buses-and-a-big-new-base/
[53] https://kingcounty.gov/~/media/depts/transportation/metro/accountability/pdf/2019/metro-facilities-master-plan-operational-capacity-report.pdf

BEB fleet size (OEM)		3 - 40′ (Proterra)
Total fleet miles accumulated (per month)		100,000
Total months in operation		12
Traction battery size		105 kWh
Number of depot chargers		1
Number of on-route chargers		1 (overhead conductive)
Average route length – BEB Fleet		18.3 miles
Daily range requirements – BEB		181 miles
Average route speeds (mph)		15.7 mph
BEB cost		$797,882
Depot charger cost	Equipment (per charger)	$60,000
	Installation (per charger)	included
On-route charger cost	Equipment (per charger)	$600,000
	Installation (per charger)	$241,510
Funding sources	TIGGER and local funds	

Figure 23 - Characteristics of initial electric buses used in KCMs bus fleet [in $US].
Source: http://www.trb.org/Main/Blurbs/177400.aspx

Figure 24 - One of KCM's articulated electric buses.
Source: https://seattle.curbed.com/2018/11/21/18106811/king-county-metro-electric-bus-test

In helping to build a business case for the long-term planned transition to electric buses, KCM also includes the environmental and health benefits/costs of buses in its evaluation. In the case of its' electric buses it determined that the total societal lifecycle cost of a standard diesel bus is $AU $180,000, with electric buses able to reduce this by $AU 150,000[54].

[54] https://www.transit.dot.gov/research-innovation/zero-emission-bus-evaluation-results-king-county-metro-battery-electric-buses

5.3 Shenzhen, China

Starting in 2009, the national government of China started to promote the adoption electric buses through demonstration projects and supportive grants. Capitalilsing on this support, Shenzhen – home to 12 million people - developed a strategy for the uptake of "new energy buses" – including electric buses – in the same year (see Figure 25). This strategy was principly aimed at controlling air pollution that plagued the region.

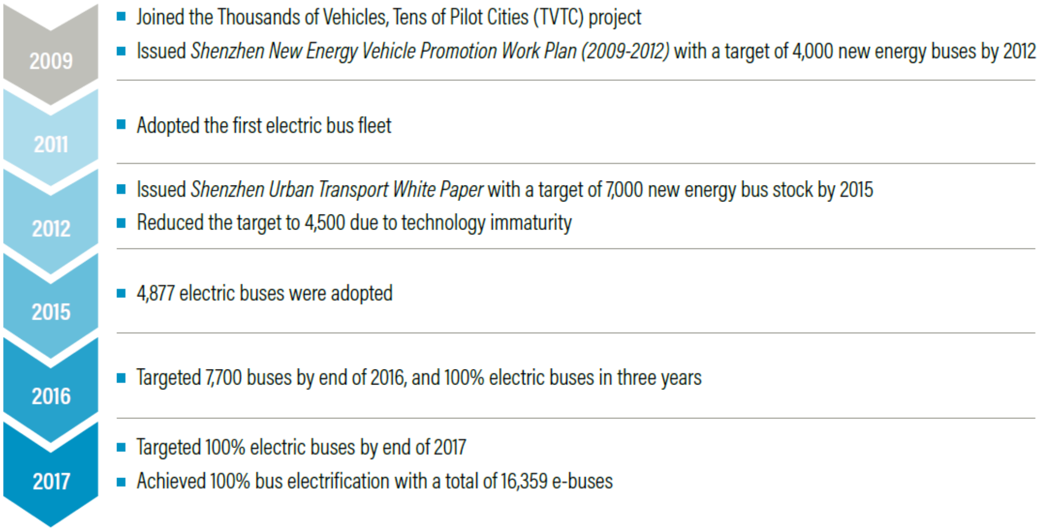


Figure 25 - Progression of battery electric bus adoption in Shenzhen.
Source: https://www.wri.org/publication/how-enable-electric-bus-adoption-cities-worldwide

By 2017, Shenzhen became the first city in the world to achieve a 100% electric bus fleet. Today, the city remains a global leader in electric bus adoption, with over 16,000 electric buses in the fleet[55] - see Figure 25. This achievement was only made possible through systematic planning for the rollout of supporting charging infrastructure, as well as financial support from the federal government.

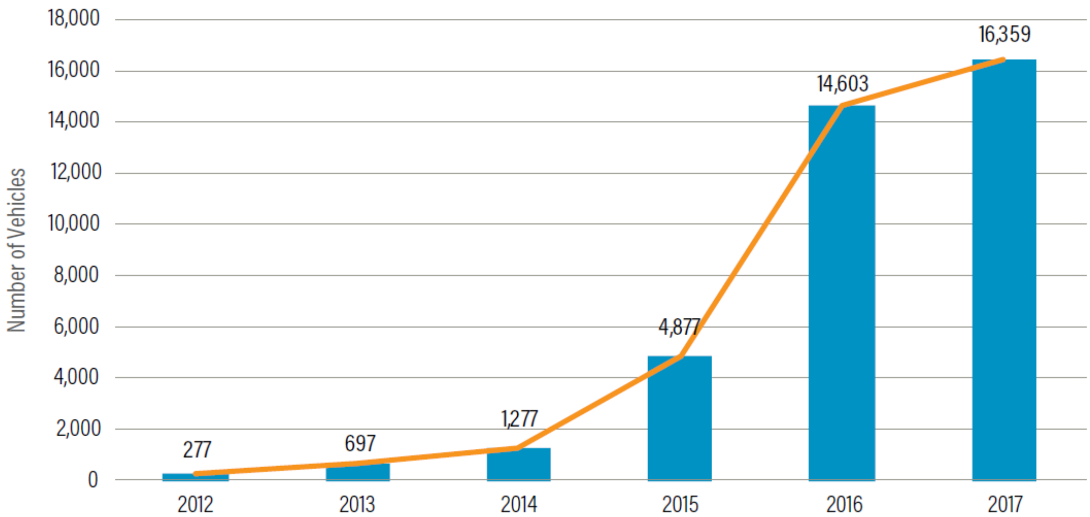


Figure 26 - Battery electric bus fleet evolution in Shenzhen: 2012-2017.
Source: https://www.wri.org/publication/how-enable-electric-bus-adoption-cities-worldwide

[55] https://www.wri.org/blog/2018/04/how-did-shenzhen-china-build-world-s-largest-electric-bus-fleet

The Shenzhen electric bus fleet primarily relies on slow-charging at depots. A number of depots have been purpose-built to support the charging of this fleet, in addition to the region's extensive electric taxi fleet, see Figure 27. Further information continues to be sought to undertake a more comprehensive evaluation of this case study.

Figure 27 - Electric buses and electric taxi's charging at purpose-built depot in Shenzhen.
Source: https://qz.com/1169690/shenzhen-in-china-has-16359-electric-buses-more-than-americas-biggest-citiess-conventional-bus-fleet/

5.4 Schiphol, The Netherlands

In early 2018, 100 electric buses were introduced to the area around Schiphol Airport in Amsterdam, The Netherlands. To date this remains the largest electric bus fleet in Europe, and is let to increase to more than 250 electric buses by 2021[56].

Schiphol is one of the busiest transport hubs in the nation's public transport network, providing a great opportunity for travellers to experience an electric vehicle. The electric buses used in the region have a battery capacity of 170 kWh, a driving range of approximately 100 km, and operate 24 hours a day, 7 days per week[56]. The electric buses are charged using a combination of slow and fast overhead pantograph chargers – see Figure 28. The fast chargers can deliver up to 450 kW, resulting in a total charge time of 15 to 25 minutes. This charging is primarily used during the day between trips. Slower charging is carried out at 30 kW, and happens overnight at the bus depot[57]. Given this project is relatively recent, detailed evaluation of the project is yet to be made public.

Figure 28 - Electric buses at Schiphol charging using overhead pantograph chargers.
Source: https://www.schiphol.nl/en/schiphol-group/page/europes-largest-fleet-of-fully-electric-buses/

[56] https://www.schiphol.nl/en/schiphol-group/page/europes-largest-fleet-of-fully-electric-buses/
[57] https://aviationbenefits.org/newswire/2018/03/europes-largest-electric-bus-fleet-operates-at-and-around-schiphol/

5.5 New South Wales

In one of the few local electric bus trials, Transport for NSW (TfNSW) and Nowra Coaches operated a Yutong E12 electric bus on route 737 between Bomaderry Railway Station and Kiama Railway Station in New South Wales from February to June, 2019[58]. The primary objective of this trial was to gain better insight into the operational capabilities of electric buses under Australian conditions, particularly in a regional area. Further details on the electric bus, charger, and route, are included in Figure 29 and Figure 30.

Bus Details

- Make — Yutong E12
- Model — 2K613HG
- Year — 2019
- Registration — CS12YF
- Registered Use — B RBUS
- Seating — 41 inc Dvr
- Standing — 30
- GVM — 18000
- Tare Weight — 13240
- No. Batteries — 12
- Total battery kwh — 374
- Current Price — 655,000 + gst

Charging Station

- Produced by Yutong
- Certified to EU Standards
- Now recognized by NSW regulators
- Max operating amps = 230
  - able to charge 2 buses in approx. 40 mins at that setting
- Adjusted to 93 amps for our operation
  - charging from empty to 100% approx. 7 hours at this setting
- Easy operation pertaining to charging and retrieval of data
- Current Price = 67,500 +gst

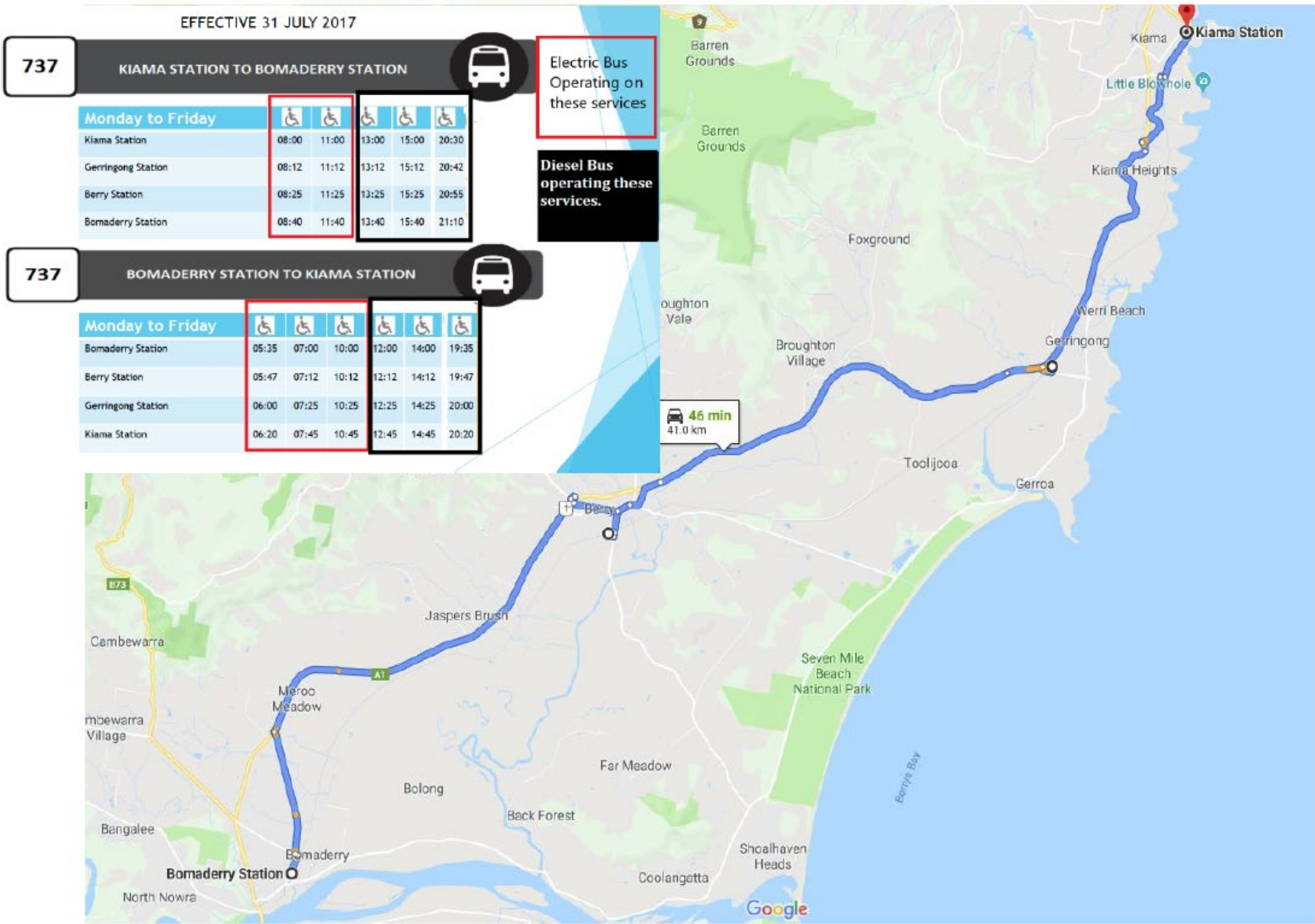
Figure 29 - Electric bus and charger details for the NSW trial.

[58] Abel, G., 2019. Electric Bus Trial Route 737. Nowra Coaches Pty Ltd.

Route Details

- TfNSW contracted route 737
- Bomaderry Station to Kiama Station via Berry and Gerringong return
- Approx 40km one single trip - 80km per return trip
- Approx 45 minutes per single journey
- Majority highway operation (100kph speed limit)
- Operating times of electric bus 5am to 12md

- 737 operates
  - 6 return trips Monday to Friday
  - EB completes 3 x return journeys per day (app 240km) plus relocation
  - Diesel bus completes 3 return trips per day (app 240km) plus relocation



EFFECTIVE 31 JULY 2017

737 KIAMA STATION TO BOMADERRY STATION

Monday to Friday					
Kiama Station	08:00	11:00	13:00	15:00	20:30
Gerringong Station	08:12	11:12	13:12	15:12	20:42
Berry Station	08:25	11:25	13:25	15:25	20:55
Bomaderry Station	08:40	11:40	13:40	15:40	21:10

737 BOMADERRY STATION TO KIAMA STATION

Monday to Friday						
Bomaderry Station	05:35	07:00	10:00	12:00	14:00	19:35
Berry Station	05:47	07:12	10:12	12:12	14:12	19:47
Gerringong Station	06:00	07:25	10:25	12:25	14:25	20:00
Kiama Station	06:20	07:45	10:45	12:45	14:45	20:20

Figure 30 - Route details for NSW electric bus trial.

Overall, this electric bus trial was deemed to be a success, with significantly lower operating costs observed for the electric bus, compared to equivalent diesel buses (Figure 31). Drivers were also impressed with the buses performance, particularly in terms of acceleration up hilly terrain. Passengers were also found to be positive towards the technology[59].

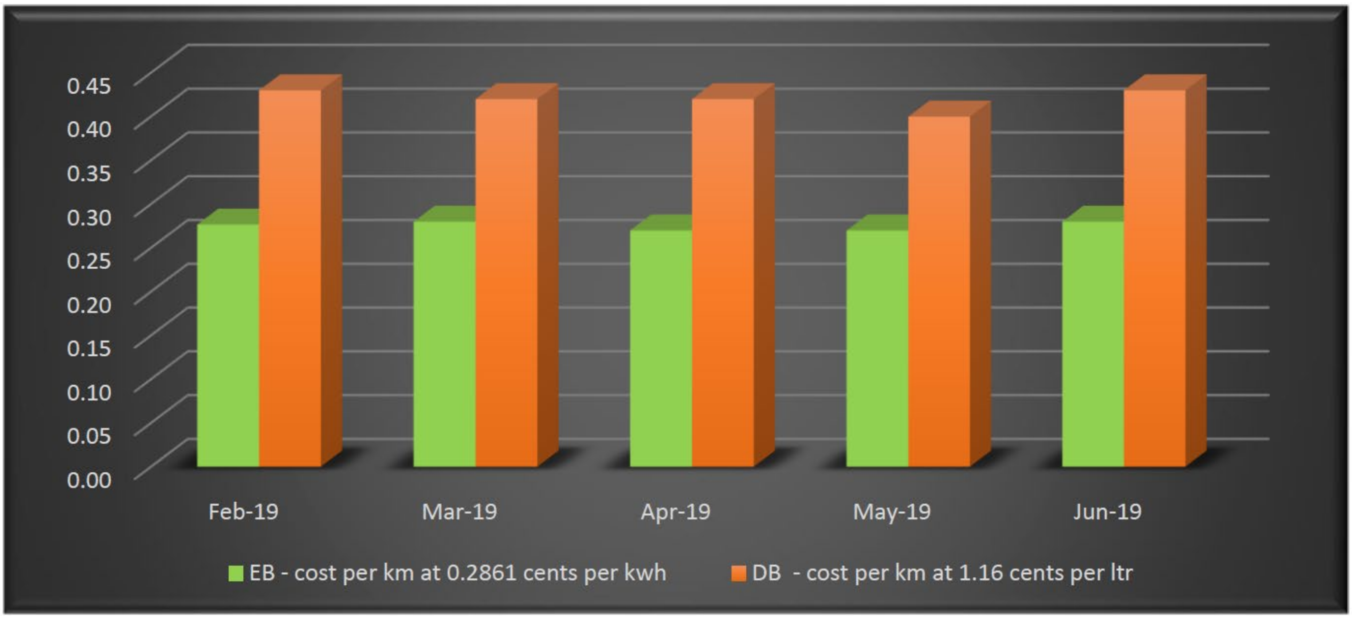


Figure 31 - Operating cost comparison between NSW trial electric bus and comparable diesel buses.

In terms of challenges encountered during the trial, this primarily pertained to the installation of the charging infrastructure. In particular, the lack of local experience in installing this kind of infrastructure led to uncertainties in costs, as well as delays. There were also significant challenges in dealing with the local electricity utility to negotiate grid infrastructure upgrades to support the charging infrastructure. Ultimately a decision was made to reduce the charging rate of the hardware, to avoid the need for grid upgrades, however, this is not a sustainable option for increasing electric buses in the fleet, which will in turn require additional charging infrastructure.

The potential grid infrastructure upgrade costs was highlighted as a major barrier to the future uptake of electric buses, highlighting the need for Government to proactively support these upgrades by working with electricity utilities to develop clear application procedures, and financially supporting these upgrades – where appropriate.

[59] Abel, G., 2019. Electric Bus Trial Route 737. Nowra Coaches Pty Ltd.

6.0 Opportunities and challenges of transitioning the entire metropolitan bus fleet to electric

This issue has been addressed elsewhere in this submission.

7.0 Any other related matters

To provide further insight into the total cost of ownership (TCO) of electric buses, estimates have been included in this report, calculated based on a review of costs experienced in trials overseas, as well as in Australia. The TCO estimates are for electric buses in 2020 and 2030 compared to diesel and hydrogen fuel cell buses, for both an average daily distance travelled of 100 and 200 km per day – see Figure 32.

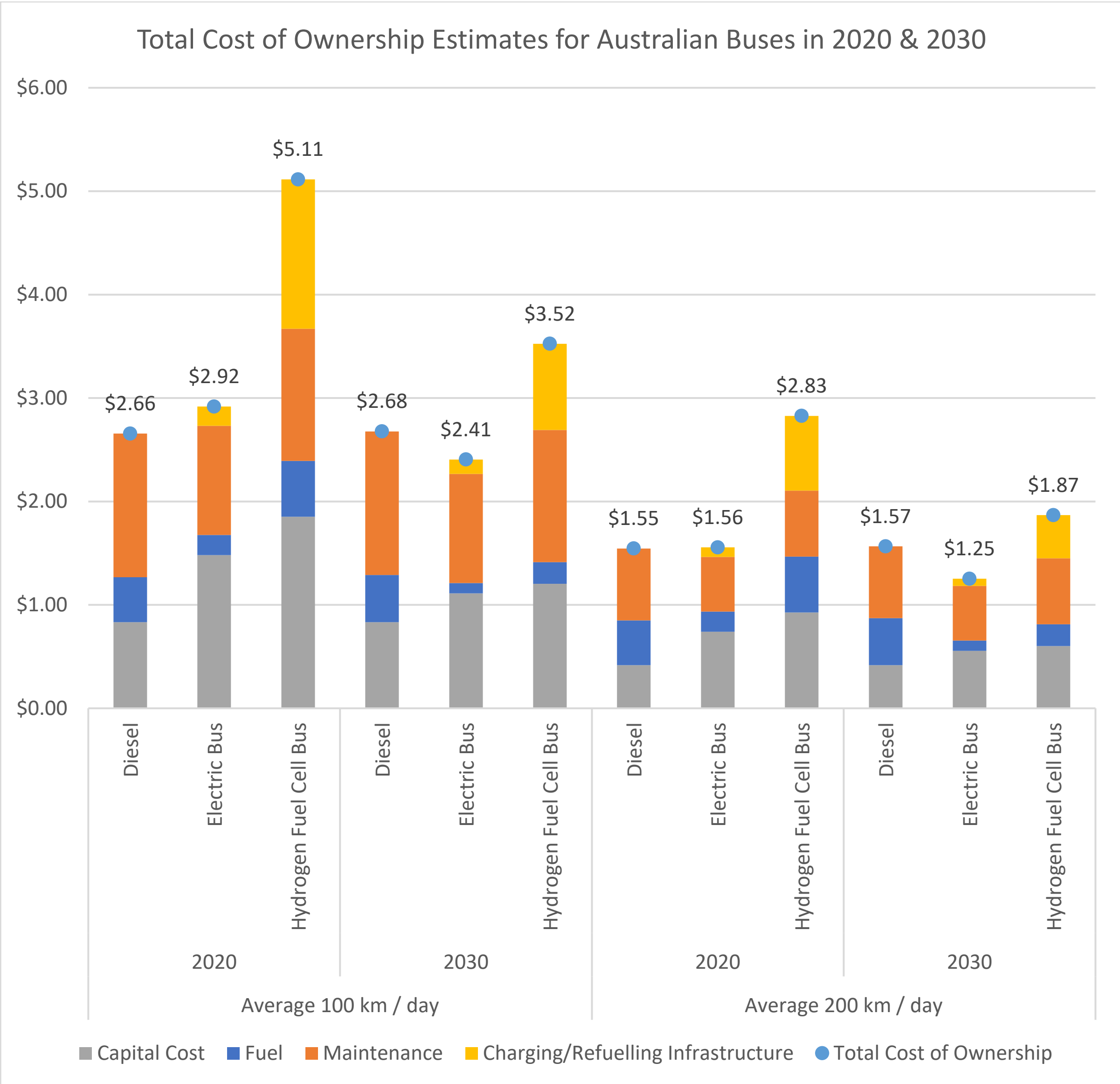


Figure 32 - Total Cost of Ownership Estimates for Australia. See Appendix A for a list of assumed values.

As shown in Figure 32, on the basis of assumed values, the total cost of ownership for electric buses is expected to be competitive with diesel buses driven an average of 200 kilometres per day, and will be even cheaper by 2030. For buses with a lower utilisation rate of 100 kilometres per day, electric buses are likely to be more expensive today, but cheaper than diesel buses by 2030. It should be noted that the assumed electric bus capital cost for these calculations is actually higher than the cost of the electric bus used in the NSW 2019 electric bus trial, and as such, the electric bus TCO estimates are conservative.

The assumptions used to calculate the TCO estimates have been included below. Allowances have not been made for reduced battery size (and capital cost) for electric buses only travelling 100 km per day.

Daily average distance travelled of 100 kilometres per day:

Bus Attribute	2020			2030		
	Diesel	Electric Bus	Hydrogen Fuel Cell Bus	Diesel	Electric Bus	Hydrogen Fuel Cell Bus
Lifetime	15 years					
Annual Distance	36,000 km (average of around 100 km / day)					
Vehicle efficiency	28 L / 100 km	1.3 kWh / km	9 kg / 100 km	26 L / 100 km	1.0 kWh / km	7 kg / 100 km
Fuel Rate at the nozzle/charger*	$1.55 / L	$0.15 / kWh	$6.00 / kg	$1.75 / L	$0.10 / kWh	$3.00 / kg
Charging/Refuelling Infrastructure** (per bus)	$0	$100,000	$780,000	$0	$75,000	$450,000
Upfront Bus Cost	$450,000	$800,000	$1,000,000	$450,000	$600,000	$650,000
Annual Fuel Cost	$15,624	$7,020	$19,440	$16,380	$3,600	$7,560
Annual Maintenance Cost	$50,000	$38,000	$46,000	$50,000	$38,000	$46,000
Total Cost	$1,434,360	$1,575,300	$2,761,600	$1,445,700	$1,299,000	$1,903,400
TCO components:						
Fuel per km	$0.43	$0.20	$0.54	$0.46	$0.10	$0.21
Maintenance per km	$1.39	$1.06	$1.28	$1.39	$1.06	$1.28
Capital per km	$0.83	$1.48	$1.85	$0.83	$1.11	$1.20
Infrastructure per km	$0.00	$0.19	$1.44	$0.00	$0.14	$0.83
Total TCO per km	$2.66	$2.92	$5.11	$2.68	$2.41	$3.52
Total TCO per year	$95,624	$105,020	$184,106	$96,380	$86,600	$126,893
excludes infrastructure costs **includes on-site H2 production						

Daily average distance travelled of 200 kilometres per day:

Bus Attribute	2020			2030		
	Diesel	Electric Bus	Hydrogen Fuel Cell Bus	Diesel	Electric Bus	Hydrogen Fuel Cell Bus
Lifetime	15 years					
Annual Distance	72,000 km (average of around 200 km / day)					
Vehicle efficiency	28 L / 100 km	1.3 kWh / km	9 kg / 100 km	26 L / 100 km	1.0 kWh / km	7 kg / 100 km
Fuel Rate at the nozzle/charger*	$1.55 / L	$0.15 / kWh	$6.00 / kg	$1.75 / L	$0.10 / kWh	$3.00 / kg
Charging/Refuelling Infrastructure** (per bus)	$0	$100,000	$780,000	$0	$75,000	$450,000
Upfront Bus Cost	$450,000	$800,000	$1,000,000	$450,000	$600,000	$650,000
Annual Fuel Cost	$31,248	$14,040	$38,880	$32,760	$7,200	$15,120
Annual Maintenance Cost	$50,000	$38,000	$46,000	$50,000	$38,000	$46,000
Total Cost	$1,667,720	$1,680,600	$3,053,200	$1,691,400	$1,353,000	$2,016,800
TCO components:						
Fuel per km	$0.43	$0.20	$0.54	$0.46	$0.10	$0.21
Maintenance per km	$0.69	$0.53	$0.64	$0.69	$0.53	$0.64
Capital per km	$0.42	$0.74	$0.93	$0.42	$0.56	$0.60
Infrastructure per km	$0.00	$0.09	$0.72	$0.00	$0.07	$0.42
Total TCO per km	$1.55	$1.56	$2.83	$1.57	$1.25	$1.87
Total TCO per year	$111,248	$112,040	$203,547	$112,760	$90,200	$134,453
excludes infrastructure costs **includes on-site H2 production						