DEPARTMENT OF TRANSPORT AND PLANNING

ZERO EMISSION BUS TRIAL EVALUATION

FINAL

JUNE 2025

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Zero Emission Bus Trial Evaluation Final

Department of Transport and Planning

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WSP acknowledges that every project we work on takes place on First Peoples lands.
We recognise Aboriginal and Torres Strait Islander Peoples as the first scientists and engineers and pay our respects to Elders past and present.

Table of contents

Glossary

Average Service kms per day	The live kms the ZEBs regularly deliver
Average kWh per km	ZEBs efficiency. The less energy (kWh) used per km means the bus is more efficient and therefore cheaper to run.
Average Charge After a Day's Service	The remaining batteries levels after one day's service. Ideally above 20% for maximum asset performance and longevity
Average kWh consumed per Day	The energy usage required to run the ZEBs
BEB	Battery Electric Bus
Charging unit / dispenser	The dispensing unit that connects the charging cabinet to an electric vehicle, including all cabling (i.e., plug-in and pantograph).
DNSP	Distribution Network Service Provider (for example, Powercor)
DTP	Department of Transport and Planning
EV	Electric Vehicle
H_2	Hydrogen gas
HFCBs	Hydrogen Fuel Cell Buses
ICE	Internal Combustion Engine
Lithium-ion battery	Battery technology used in majority of trial BEBs.
OCPP	Open Charge Point Protocol
OEMs	Original Equipment Manufacturers
OPEX	Operating Expense
SOC	State of Charge
Solid state battery	Battery type used in three trial BEBs. Has solid electrolyte instead of the liquid or gel electrolytes utilised in lithium-ion batteries.
ZEB	Zero Emission Bus
ZEV	Zero Emission Vehicle

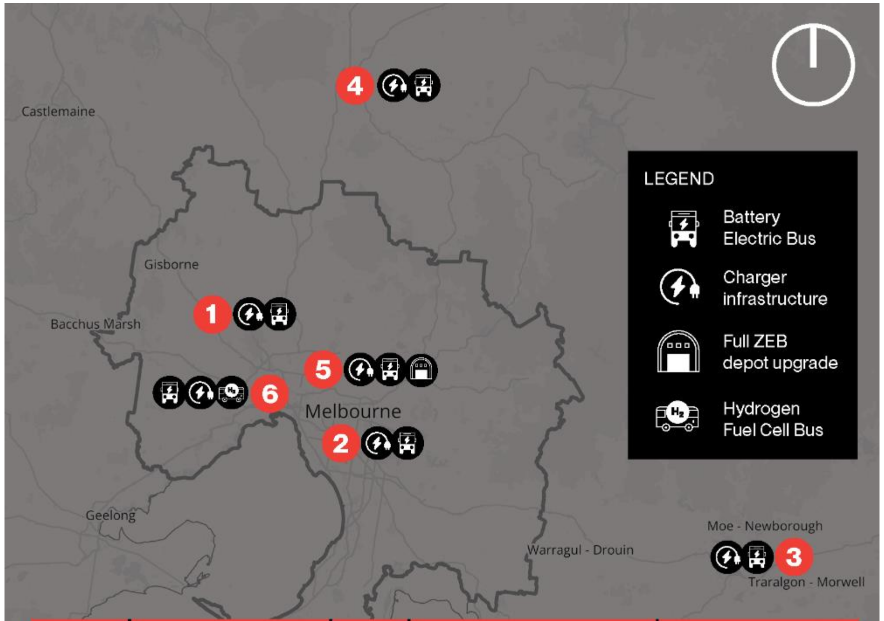
1 Introduction

As part of the Victorian Budget 2020/21, the Victorian Government invested $20 million in a three-year state-wide trial of ZEBs, launched in 2022. Six Victorian bus operators were selected to trial 52 ZEBs on existing routes across the state's metropolitan and regional town bus networks. This is addition to the operation of other ZEBs in Victoria separate to the trial.

Figure 1 provides an overview of the different operators and technologies trialled, covering both metropolitan and regional geographies and service routes.

The main technologies involved were battery electric buses (BEBs) and plug-in charging dispensers installed at depot sites. Additionally, two hydrogen fuel cell buses (HFCBs) with mobile refuelling were also trialled. One depot (Ventura's Ivanhoe) underwent full transition from diesel to ZEB, with other depots subject to necessary infrastructure upgrades to facilitate the trial.

This document collates key findings and data arising from the trial to the end of February 2025. Lessons from the trials are paving the way for the ongoing transition of Victoria's public transport bus fleet to be zero emission technology, providing practical information such as depot charging needs and capacity, infrastructure and energy network requirements, environmental outcomes, customer expectations and commercial arrangements.



	Operator and location	No. of Buses	Zero emission technology & manufacturer	Charger / Refuelling technology
1	Donric - Sunbury	3	BEB - Custom Denning build with solid state battery	ABB Charger
2	CDC -Oakleigh	8	BEB – Volvo chassis	Kempower Charger (w/on-route charging)
3	Latrobe Valley - Traralgon	1	BEB - Volvo chassis	Siemens Charger
4	Seymour - Seymour	3	BEB - Volvo chassis	Siemens Charger
5	Ventura - Ivanhoe	26	BEB - BYD Chassis	Tritium Charger
6	Transit Systems - Footscray	9	BEB - BYD Chassis	Kempower Charger
		2	Hydrogen Fuel Cell – ARCC build	Low powered rental refueller

Figure 1 Overview of trial participants and technologies

2 Key findings

The ZEB trials have demonstrated the viability of ZEB technology in metropolitan and regional towns in Victoria, as well as providing passengers, bus industry staff and the wider community the opportunity to see and use ZEB technology.

Along the way, the trials have also supported the Victorian economy by boosting the transport equipment, manufacturing and electricity supply sectors, driving the local development of skills and innovation and contributing to economies with established bus manufacturers.

Ten key findings are collated below, with more detail shown on the following pages.

1	Trial ZEBs have completed **over 4.1 million kilometres** across a variety of metropolitan and regional town locations, an **average of 130 kilometres per day per ZEB**.
2	Trial ZEBs have **reliably delivered typical metropolitan and regional town route schedules**, returning to the depot with **40-60% charge remaining**. In all cases, recharging has comfortably been achieved between operations, with **charging times as low as 1-2 hours per bus** where high voltage power is available.
3	Trial ZEBs have run efficiently, utilising on **average 1.18kwh of battery power per kilometre travelled**, comfortably within the expected range.
4	Over **1.4 million litres of diesel have been saved**, equivalent to over **4,800 tonnes of greenhouse gas emissions saved**. This is equivalent to the annual emissions of approximately 1,650 motor vehicles.
5	Trial ZEBs have provided similar on time running performance, highlighting there is **no operational impact to passengers**. Furthermore, positive passenger feedback has been received relating to the **level of comfort on board, smooth, quiet running, and lack of noise and fumes** during idling.
6	Trial ZEBs have been shown to be operationally efficient, with trial operators finding **BEBs are cheaper (or at minimum, no more expensive) to operate per km than diesel counterparts**, considering fuel/recharging, maintenance and other operational costs.
7	Average BEB battery degradation (reduction in usable battery capacity) across the three-year trial period is **3%,** a significant improvement on manufacturer provided benchmarks.
8	Two hydrogen fuel cell buses were trialled providing an opportunity to test hydrogen technology in Victoria. An average consumption rate of **6.2kg(H_2) per 100km** has been recorded to date, a slightly higher consumption rate than manufacturer expectations.
9	The ZEB trials have provided upskilling training for at least **310 bus operator staff including 225 drivers, 33 mechanics and 28 other depot-based staff**. Training has also extended to electricity providers, first responders and the wider local community.
10	Insights relating to resolution of common technical issues, ZEB depot upgrades and interoperability will inform the ongoing Victorian ZEB transition.

All data presented is through the end of February 2025, which includes the trial closeout position for Ventura and Transit Systems (50% of trialled buses) and information to date for other operators whose trials will complete later in 2025.

2.1 Vehicle performance

2.1.1 Range and reliability

ZEBs were comfortably able to complete typical service range of their diesel counterparts, with plenty of battery life remaining. ZEBs collectively averaged around 130km per day, with some reaching almost 200km per day as routes assigned required (see Figure 2)[1]. The average range grew steadily throughout the trial, as operators became more comfortable with their ZEBs and assigned them to longer and more varied assignments.

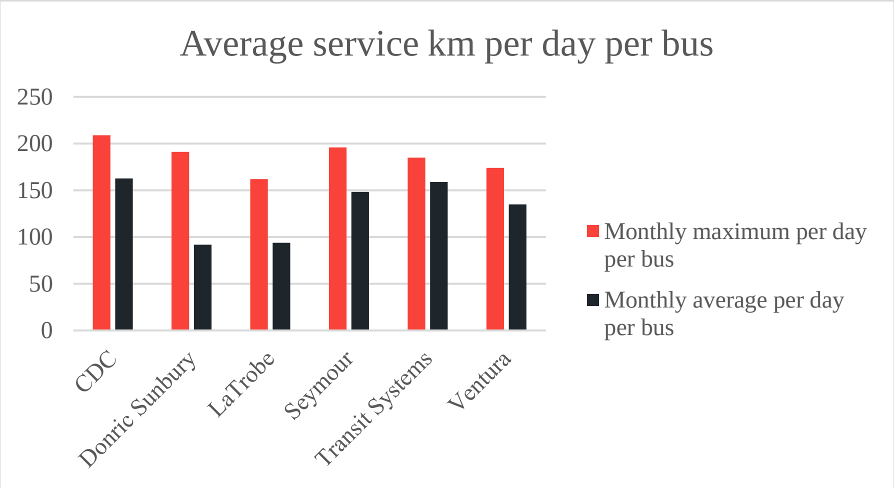


Figure 2 Average and maximum monthly service km per day per bus

ZEBs were trialled on a variety of route profiles, geographic locations and through various weather conditions. None of these factors were shown to significantly impact range or BEB performance.

[1] ZEB models trialled typically have up to 300km range on a full charge

Trial buses returned to the depot with 40-60% charge remaining (See Figure 3). Typically, the lowest desired level of charge upon return is 20%, highlighting a significant amount of range resiliency.

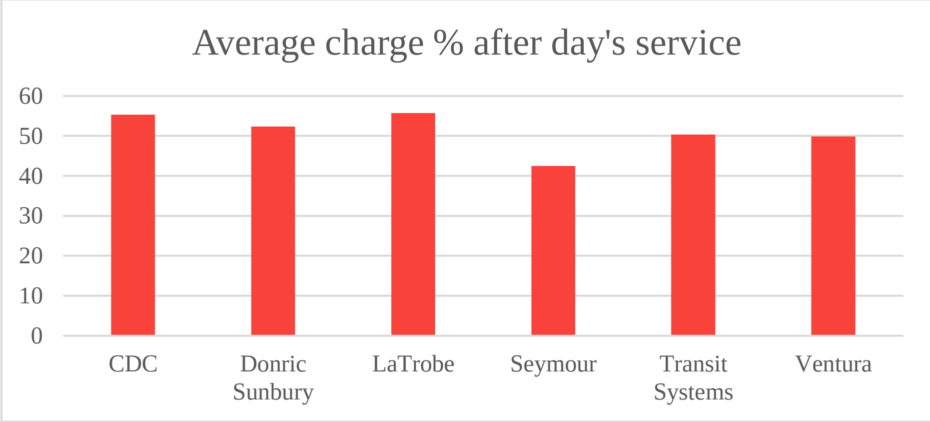


Figure 3 Average monthly average charge (%) after day's service

Figure 4 Siemens charger at Seymour depot

2.1.2 Charging resiliency

Average charging time required per BEB was as little as 1-2 hours for operators where high voltage charging could be provided. Operators typically charged BEBs through the evening and overnight, utilising off-peak electricity rates where possible.

The significant variation shown in Table 1 is linked to differences in electrical capacity at depot locations. For example, LaTrobe's Traralgon depot currently has a low voltage service, which restricted the charging power available to buses. In all cases, charging times did not have an adverse impact on operations or service planning.

CDC utilised top up, on-route charging during bus layover as part of their daily charging strategy, reducing the overnight charging time.

Table 1 Overview of average charging times

Operator	Approximate average Daily Charging Time per bus	Charging power type[2]
CDC	3-5 hours (including on route charging)	Rapid (50-150kW)
Donric Sunbury	7-8 hours	Fast (11-22kW)
LaTrobe	8-12 hours	Fast (11-22kW)
Seymour	2-4 hours	Rapid (50-150kW)
Ventura	1-2 hours	Rapid (50-150kW)

All operators maintained backup options in the event of a power outage or charger issue, in the form of portable chargers, backup diesel buses and utilising charging infrastructure at other bus depots. There were no reports of significant electrical supply issues throughout the trial. Some charger failure instances occurred for the initial installations, which were resolved with support from OEMs (see section 4.1).

2.1.3 Efficiency

2.1.3.1 Battery electric buses

The efficiency of trial BEBs fell within the expected range, with an average of 1.18 kWh of battery power consumed per kilometre travelled (as per Figure 5)[3]. Efficiency is influenced by factors including route topography, average speed and frequency of bus stops, patronage, driver behaviour and use of onboard climate controls.

Operators reported the impact of climate controls reduced battery efficiency by around 10-20%, but they found ways to mitigate this by preconditioning the bus cabin temperature at the depot under mains power.

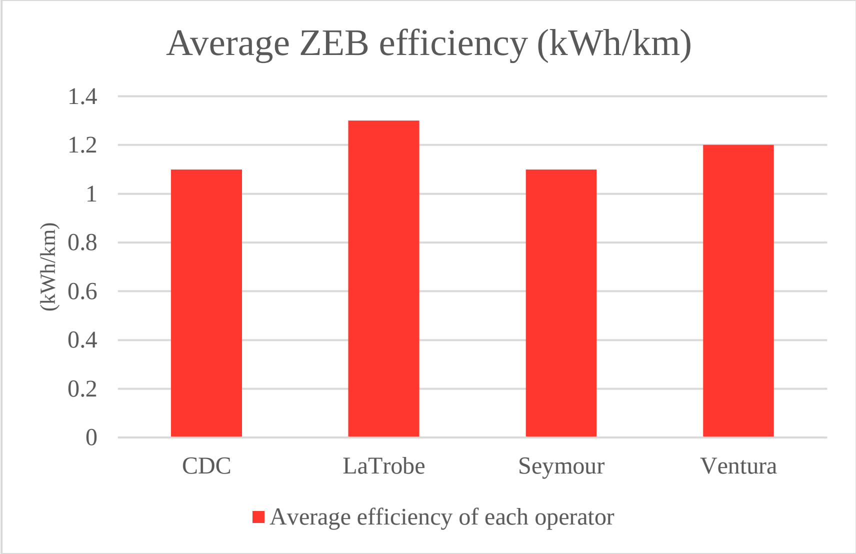


Figure 5 Average monthly ZEB efficiency (kWh/km)

2 Charging power types categorised based on typical average charging power as per Table 1.3, [DTP Battery Electric Bus Guidance Document]

3 Average daily consumption rates for metropolitan operations in Australia are between 0.9 kWh/km and 1.4 kWh/km ([DTP Battery Electric Bus Guidance Document])

2.1.3.2 Hydrogen powered buses

Two Hydrogen Fuel Cell buses (HFCBs) were trialled for a total of 26,987km on a variety of routes from Transit Systems' Footscray depot. Each bus is equipped with a 350 bar H_2 tank system which has 30.8kg nominal storage.

As shown in Figure 6, HFCBs had an average consumption of **6.2kg(H_2) per 100km** during the trial period, which is higher than the manufacturer's benchmark of 4.9kg per 100km[4]. Factors including route profile, hydrogen quality and energy losses influence the observed H_2 consumption rate.

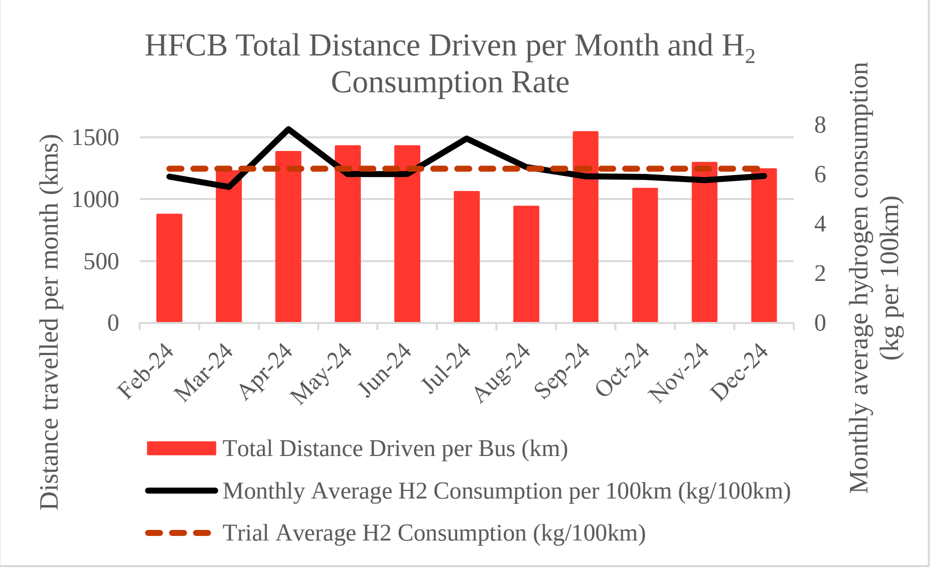


Figure 6 Overview of HFCB monthly distance travelled and consumption rate.

The two HFCBs were typically in operation 3-4 days a week, with an average daily travel distance of 70-110 km. Due to the limited service, the trialled HFCBs only needed one H_2 refuelling each week. Given the average consumption of 6.2kg(H2) per 100km, the buses could achieve a range closer to 450-500km with a full tank.

Hydrogen refuelling has taken around 6-8 hours per bus, based on the use of a low powered refueller (2-3kg H_2 refuelled per hour). While the slow refueller met the HFCB demand during the trial, a more efficient high powered refueller should be explored to accelerate H_2 refuelling in preparation for the wider deployment of HFCBs, which will have higher service demands and longer daily distance travelled in operation.

Efficient hydrogen refuellers can typically achieve refuelling times from 7 to 15-minutes, but this depends on several factors related to compression and high-pressure storage capacity (typically 350 to 700 bar), cooling systems to improve speed and efficiency, dispenser flow rate, and the pressure rating of vehicle's hydrogen tank system.

While the results from the HFCB trial were positive, further testing and evaluation is required on more strenuous routes and with higher pressure refuelling to better understand overall performance.

Hydrogen Fuel Cell Buses at Transit Systems' Footscray Depot

[4] H_2 storage and benchmark consumption data are from [ARCC Longreach Hydrogen Bus – ARCC]

2.1.4 Battery degradation

Over time, degradation reduces the maximum usable energy of the battery. This is a normal and an expected feature of BEBs. Typically, a battery is considered to have reached the end of its useful bus life when it reaches less than 80% of its initial capacity[5].

Of the two operators whose BEB trials have fully completed, Transit Systems and Ventura, degradation testing showed that the remaining BEB battery energy is on average 94% and 99% respectively. These results are a significant improvement on manufacturer provided benchmarks, which projected battery energy to be around 90% of starting energy given the number of charging cycles completed (approximately 300-400). This highlights that battery life may be longer than initially anticipated.

Among remaining operators, current observed battery degradation shows a similar trend, with a total 49 of 50 batteries having over 90% of initial battery capacity. See further discussion on battery technologies in section 4.1.4.

Table 2 Average BEB Battery Degradation

OPERATOR	NUMBER BEBS	AVERAGE CURRENT BATTERY ENERGY (% OF START OF LIFE)
CDC	8	93
Donric Sunbury	2*	97
LaTrobe	1	98
Seymour	3	91
Ventura	26	99
Transit Systems	9	94

*Excluding one battery which failed and is being replaced and recycled under warranty

2.1.5 Environmental impact

By the end of February 2025, the trial has avoided the use of over 1.4 million litres of diesel fuel (Figure 7). This is equivalent to approximately 4,889t of CO_2-equivalent greenhouse gas emissions avoided[6], which is equivalent to the average annual emissions from 1,650 motor vehicles[7].

In the context of 52 buses of a total 4,500 contracted fleet across the state, this highlights the scale of the potential overall environmental benefits of the ZEB transition.

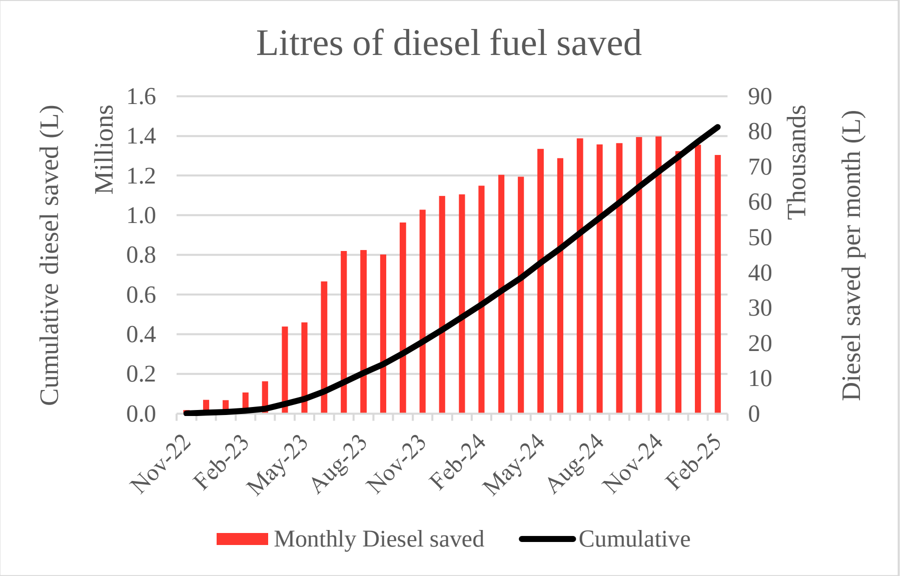


Figure 7 Summary of fuel saved per month and cumulative through trial to date

5 At below 80% of its original capacity, a battery cannot reliably support typical daily bus operations, however can be used for other applications.

6 Emission estimation is based on Section 2.3 of Australian National Greenhouse Accounts Factors.

7 Based on average annual motor vehicle usage in Australia, as per Greenhouse Gas Equivalencies Calculator | US EPA and Survey of Motor Vehicle Use, Australia, 12 Months ended 30 June 2020 | Australian Bureau of Statistics.

2.2 Service

Throughout the trial, positive feedback has been received from customers, drivers and other members of the public interacting with the buses. Common areas of customer feedback relate to the level of comfort on board, smooth and quiet running, and lack of noise and fumes during idling.

Drivers have reported the ZEBs drive well, are comfortable to operate, and offer a reduction in fatigue linked with reduced noise and rattling compared to diesel buses.

As shown in Figure 8, there has been no significant variation in operational performance compared to diesel buses for customers. The minor difference shown in late running is attributed to majority of trial ZEBs running on congested inner-city routes.

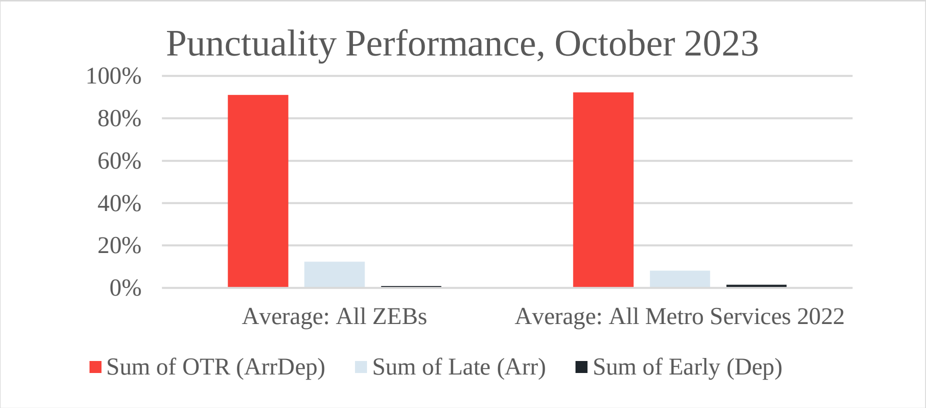


Figure 8 Overview of on time running (OTR) of trial ZEBs compared to diesel counterparts, October 2023 snapshot

2.3 Skills and training

Upskilling training has been provided for at least 310 Victorians including 225 drivers, 33 mechanics and 28 other depot-based staff. Training has also extended to staff from electricity providers, first responders and the wider local community.

ZEB training has provided significant development opportunities for local Victorian staff and supported multiple local jobs amongst trainers, who primarily come from original equipment manufacturers (OEMs) based in Australia.

Key areas of upskilling completed include ZEB vehicle and charging maintenance, software programming, ZEB repairs and maintenance, driving ZEBs, and safety when working with ZEBs including electricity and hydrogen safety. Some training in Battery Electric Vehicle Inspection and Servicing was provided through the Kangan Institute, a TAFE provider in Melbourne.

Training has brought together the bus industry, emergency services, electricity providers and the wider community. The example in Figure 9 shows a ZEB and EV Training Day which brought together emergency services including fire brigades, police and SES to provide information relating to fire and accident safety. Latrobe also organised training with towing and Country Fire Authority (CFA) in case of BEB incidents.

Some operators such as CDC have adopted ‘train the trainer’ approaches, with five drivers initially trained to progressively deliver practical on-road training to the rest of the 140 drivers.

Figure 9 Seymour Passenger Services hosted a CFA ZEB and EV Training Day, attended by over 150 people

Figure 10 ZEB Training Day with Emergency Services held at Seymour in November 2022

2.4 Depot readiness

Varying level of depot upgrades were completed to support the trials. This included charging or hydrogen refuelling infrastructure, power supply upgrades and civil works to support depot infrastructure (e.g. roof raising, or fire life safety related improvements). Often, the combination of the above can alter existing operational arrangements and/or depot layouts.

Some operators, such as Seymour, made minimal adjustments at the depot to run the trial, installing a charging dispenser and working within the existing site electrical capacity. At the other end of the scale, Ventura’s Ivanhoe depot was fully converted to a BEB depot as part of the trial (read more about this in Case Study 3).

Lessons learned relating to ZEB depot upgrades are collated in Section 4.

Figure 11 ZEB charging infrastructure installed at LaTrobe Valley – Traralgon depot

2.5 Operating costs

Trial operators have found BEBs to be cheaper (or at minimum, no more expensive) to run per kilometre than diesel counterparts. Data collated by two operators showed trial operating costs for BEBs to be in the region of 30-35% cheaper than diesel equivalents. This includes consideration of ‘fixed’ BEB related operational costs accrued during the trial including charger and BEB maintenance and charger management software.

A key element of reduced operational cost relates to maintenance. Trial operators have found ZEBs to have a lower maintenance burden, both relating to frequency and cost of repair per maintenance incident. ZEBs have fewer moving parts, reduced wear and tear, and simplified maintenance compared to traditional internal combustion engine buses. Where significant failures occurred, such as one instance of battery failure, replacement was completed offsite by the manufacturer under warranty.

Longer term unknowns including electricity and diesel rates, diesel and ZEB bus purchase prices, and battery & charger maintenance and replacement burden will be key in the determining the overall lifecycle cost competitiveness.

Currently, HFCB operational costs are higher than diesel and BEB equivalents due to the high cost of hydrogen in the current market, however this gap would be expected to close as the scale of hydrogen usage grows and supply and delivery chains mature.

3 Case studies

3.1 Ventura's Ivanhoe depot upgrade

Overview

Ventura trialled 26 BEBs based out of Ivanhoe depot in Melbourne's inner north-east. Ventura's Ivanhoe depot underwent a full transition from diesel to ZEB to support the trials, becoming Victoria's first fully ZEB depot.

ZEBs trialled	26 BEBs
Depot	Ivanhoe
BEB type	BYD chassis
Charger type	Ground mounted plug in - Tritium

Depot upgrade

The depot upgrade took 12 months including site preparation, a major transformer upgrade completed by DNSP Jemena, works to raise the workshop roof, installation of 150kW Tritium pedestal dual chargers, and testing and commissioning.

Depot upgrade works highlighted the need for early engagement with key approval bodies including Council and DNSPs, and the importance of undertaking suitable soil testing and scanning. See more details in Lessons learned section.

Operational performance

The BEB fleet were assigned to the depot's existing mix of metropolitan route services without any need for compromise or adjustments.

Access to a high voltage connection meant charging was rapid, taking 1-2 hours on average per bus. This resiliency meant that even during a period of charger module failure, charging was still comfortably completed between operations.

Battery life has been excellent, with degradation testing showing minimal loss in battery energy after 2.5 years of operation.

No concerns with maintenance have been noted. Overall, Ventura have found electricity to power BEBs to be approximately 30- 35% cheaper when compared to cost of diesel fuel to operate a diesel-powered bus, which over the bus lifetime assists in offsetting higher upfront costs of BEBs.

Customer experience

Customers did not experience any operational impact during the trial. Ventura received positive feedback from customers and drivers relating to the quiet, clean and smooth running of the BEBs.

Figure 12 BEBs charging at Ventura's newly upgraded Ivanhoe depot

3.2 Seymour Town

Overview

Seymour Passenger Services trialled 3 BEBs based out of the Seymour depot in the Goulbourn Valley in regional Victoria.

ZEBs trialled	3 BEBs
Depot	Seymour
BEB type	Volvo chassis
Charger type	Ground mounted plug in - Siemens UC200

Depot upgrade

Seymour completed operations with 3 BEBs within the existing 100kW depot connection, minimising upfront costs and lead in times. A portable charger and diesel bus backup connection was maintained to provide resilience in event of any charger issues or scheduled maintenance, however these were seldom used once initial interoperability issues (see section 4.1.2) were resolved.

BEB features

Seymour worked with various suppliers to install several features to support operations and passenger comfort and safety, including:

- A zone management system, enabling autonomous compliance with special rules and restrictions along the routes (e.g. school zone speed restriction)
- Electric air conditioner heating and cooling unit
- Onboard fire suppression system
- Other on-board features including CCTV, driver display, passenger display and passenger counting.

Operational performance

BEBs have reliably and comfortably completed all assigned regular route patterns of around 150km. Seymour report the BEBs require maintenance less often, which over time will start to show as savings.

Some reduced efficiency has been noted (approximately 10-20%) when climate controls are in operations, however this can be mitigated through preconditioning of the buses in the depot using mains power when this becomes available.

Customer experience

Positive sentiment from the local community, both passengers and local residents, has been recorded linked with lack of noise and emissions from idling diesel buses. Seymour's drivers report less fatigue given the almost total elimination of vibration associated with diesel buses.

Training and community engagement

As discussed in section 2.3, Seymour hosted a number of hugely successful events, bringing together bus operators, emergency services and the local community to enhance knowledge and understanding of ZEB related technology and practices.

Figure 13 Three charging dispensers installed at Seymour depot, operated within existing 100kW electrical capacity

3.3 LaTrobe Valley

Overview

Latrobe Valley Bus Lines (LVLB) trialled one BEB serving several contract service routes in the regional towns of Traralgon, Morwell and Moe.

ZEBs trialled	1 BEB
Depot	Traralgon
BEB type	Volvo chassis
Charger type	Ground mounted plug in - Siemens UC200

Charging

Charging was completed utilising Traralgon depot's existing 100-amp connection (a residential connection), highlighting BEBs can be introduced to a depot with minimal requirement for infrastructure upgrade. The low power connection meant longer charging times of around 9-10 hours, although this was comfortably completed through the evening and overnight between scheduled activities.

Some initial issues were noted harmonising charger, BEB and charger management software, however these were worked through with support of DTP and OEMs (see section 4.1 for more details).

Operational performance

The BEB comfortably completed scheduling up to 220km a day through varied operating conditions and terrain, on predominantly hilly routes. On average, the BEB returned to the depot with over 55% of charge remaining.

Operational cost

Through the trial period, LVLB have found the BEB to be approximately 30-35% cheaper to run per kilometre of service than their diesel equivalent. A key element of this is the significantly lower maintenance requirements for the BEB to date, compared to diesel equivalents.

Customer experience

Phone based feedback received highlights customers enjoy the quiet and smooth nature of the BEB and are excited to see a BEB in service in their area. LVLB's drivers have reported that the bus drives very well and is exceptionally quiet on the road.

Figure 14 LaTrobe Valley's BEB in Traralgon

4 Lessons learned

4.1 Overview

The ZEB trial has provided valuable insights which will inform the next steps of Victoria's ZEB transition. The trials have generated practical information such as depot charging needs and capacity, infrastructure and energy network requirements, environmental outcomes, customer expectations and commercial arrangements.

The trial has also highlighted the value and importance of sharing data and insights across the state and nationally, as the ZEB transition proceeds.

This section provides further discussion and summary of key learnings arising.

4.1.1 Chargers

The trial has highlighted a range of teething issues which can arise during early stages of setting up ZEB charging operations. These included:

— Several trial operators experiencing charger 'handshake' failures, where the bus and the charging infrastructure have not been communicating with each other properly.

— Charger failure, or part failure, requiring fix by OEM.

— One instance of battery failure (replaced by OEM under warranty).

Bus procurement generally includes aftercare arrangements, including timely local maintenance, spare part supply and asset longevity. The trial has highlighted that maintaining similar aftercare arrangements for charger procurement must be considered, importantly including quick, onshore maintenance support.

Many trial operators took on warranty arrangements as part of bus procurement, which de-risk battery failure. Under these arrangements, batteries are replaced at no cost to the operator if they fail or degrade to a point where they are considered 'end of life'.

The trial has significantly increased understanding of how and why charger set up issues occur, such that this would not be expected to be a significant issue for wider rollout.

Lessons learned:

— Early testing of bus charging should be undertaken, with clear responsibilities for any problems.

— Selecting charging hardware and software products which are industry tried and tested.

— Importance of ensuring any warranty and charger aftercare arrangements come with assurances of timely responses to technical issues from locally based technicians.

— Requiring a charger aftercare arrangement in future procurement models may significantly de-risk depot conversions and BEB service delivery.

— Having backup options available such as portable chargers or diesel bus backup to provide resiliency as issues arise.

— Importance of considering battery warranty options as part of ZEB procurement.

— Importance of interoperability (see section below).

Figure 15 Different equipment layouts: Volvo (left) and BYD (right)

4.1.2 Interoperability

The trial reinforced the importance of interoperability, relating to BEBs, chargers and supporting software. Areas where interoperability have been shown to be important include:

— Charging topography at depots (ground mounted, pantographs, or top-down gantries, etc)
— Charger-bus handshakes (hardware and software)
— Hydrogen tank valves/refuelling nozzles/pressures
— En-route charging
— Driver training
— Mechanic training
— Charger aftercare standards
— Safety procedures and signage.

In a key area of success, one trial operator took a BEB to complete charging at all other trial operators' depots, confirming the efficient and effective nature of different charging infrastructure and management systems.

The Open Charge Point Protocol (OCPP) is a communication standard that facilitates communication and interaction between charging dispensers and charging network management systems, regardless of their brand or origin. OCPP is widely adopted by charging equipment manufacturers and is considered the market standard.

Lessons learned:

— Importance of procuring BEBs, charging equipment and management systems which supports interoperability, i.e. Open Charge Point Protocol (OCPP).
— Interoperability is not guaranteed - need to test bus/charger combinations before procurement or procure known compatible combinations.
— Importance of BEB related performance data and insights sharing between DTP and operators. Operators should not enter into confidential agreements that could limit the state's ability to benefit from operator experiences with ZEB

4.1.3 Depot upgrades

The trials have demonstrated that a small number of ZEBs can be operated with minimal depot infrastructure upgrades. For larger depots, the successful conversion of Ventura's Ivanhoe depot from diesel to ZEB provided important learnings for future full depot conversions.

The trial has confirmed that in most cases, the greatest challenges will arise from depot upgrades. This is a process utilising new technology and approaches and bringing together bodies which may not normally work together. Additionally, there are several major risks and infrastructure elements at play, which can significantly impact cost and delivery timelines.

Challenges and issues arose during the Ivanhoe depot upgrade, including:

— Soil contamination and underground objects identified while undertaking groundwork including trenching or laying foundations for new chargers or transformers. This is expected to be typical of many bus depots on old brownfield sites.
— Need for multiple approvals for items such as easements for new transformer (DTP) and adjustments to depot building roofs (Council).
— Manufacturers having limited space for stock. Should delays arise in depot conversion, storage space is required.
— DNSPs have long planning horizons – up to two years – and may not be able to incorporate depot upgrades into their plans at short notice.

Lessons learned:

— Depot conversions can take significant length of time. This needs to be allowed for in scheduling, with sufficient contingency allowed to account for risk items and unforeseen delays.

— Soil contamination is a high project risk for depot conversions – high-quality underground scanning and soil testing (to sufficient depth) should be undertaken early in the process, with clear allocation of responsible parties for contamination liability.
— Clear roles and responsibilities need to be established between different parties including operator, council, DTP and DNSP.
— Requirement for easements and DNSP dependencies must be identified as early as possible.
— Approval related processes should be started early in the process. This may require having a refined depot design available early in the program.
— Bus operators and manufactures should have agreements for BEB storage in case of BEBs being ready before the destination depot has been upgraded.

Figure 16 Aerial view of Ventura's Ivanhoe depot

4.1.4 Battery technology

The three trial BEBs operated by Donric Sunbury used solid-state batteries. These have a solid electrolyte instead of the liquid or gel electrolytes utilised in lithium-ion batteries (the battery technology used in remainder of trial BEBs).

Solid state batteries are still a relatively new technology in early development stages for heavy-duty vehicle applications, with lithium-ion batteries remaining the dominant choice. Solid-state battery technology has several potential benefits for bus operations including higher energy density, improved safety and longer lifespan.

In the trial, solid state batteries were found to be efficient, however concerns around reliability were highlighted. One solid state battery experienced a battery fault and was replaced and recycled by the manufacturer under warranty agreement. At the close of the trial, all solid-state batteries were replaced with lithium-ion batteries to ensure reliability going forward.

Lessons learned:

— Further research and testing is required to enable reliable use of alternative battery technologies in BEBs

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