Transitioning Victoria's bus industry to zero emission buses

Handbook for operators

BusVic
Bus Association Victoria

MONASH University

Prepared by Monash University, Mobility Design Lab for
the Bus Association of Victoria
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Preface

Governments all around the world are transitioning bus fleets from fossil fuels to renewable technology, representing a fundamental and transformational change to the way bus operators, and all those in the supply chain do business. The transport industry as a whole is going to need to 'unlearn' what it has always done and adopt new safe, and efficient methods to deliver viable, sustainable and enduring bus and coach services using these new technologies.

This is why BusVic commissioned Monash's Mobility Design Lab to produce this guide for operators. To show them what needs to be considered to transition the fleet to zero emission bus technology. This volume is designed to be a tool to support operators in their decision making in this regard.

We trust operators find this guide useful, and of value as they endeavour to reduce transports share of greenhouse gas emissions.

Chris Lowe
BusVic Executive Director
December 2021

Introduction

The Victorian State Government has committed to net-zero carbon emissions by 2050, and that all public transport bus purchases will be zero emission by 2025[1]. More recently, the Australian Federal Government has committed to net zero emissions by 2050. Both overarching policies are in response to the rapid change in earth's climate caused by human activity[2] and the need to keep global temperature rises to a minimum lest we risk very serious global consequences.

While the policy, ambitions and the underlying need for action are clear, the process of transitioning Victoria's bus industry to Zero-Emission-Buses (ZEB) has barely begun, and guidance for Victoria's bus operators is needed.

This handbook aims to present non-technical guidance to the bus industry on the transition from fossil fuels to renewable energy and zero-emission operations. The challenges and opportunities for this transition are upon us in Victoria. In studying guidance from other jurisdictions we the research team have determined that although our situation in Victoria is highly relatable to international experience, there are also unique local elements to this transition. For example, while issues such as technology selection and the impacts of changing from one energy source to another are broadly similar worldwide, for Victoria's bus operators it is the manner in which we undertake the transition that provides scope for transitioning in a way that works for you. This handbook calls on a variety of sources from around the world such as guidance written to a global audience, local examples and experiences from operators and transport authorities in different global regions, as well as specific reports and papers on energy, transport and infrastructure from governments and university research.

In section one, we present the outcomes of our research which has studied the Victorian bus and coach industry through survey and interview methods. In section two, we present a range of non-technical guidance for industry, in which we include the range of issues identified in the literature. Some of these issues may be known to you, while some may not. The guidance aims to provide all Victorian operators with a more consistent level of knowledge and preparedness for the zero emission transition such that we are better equipped to undertake it.

[1] "Transport sector emissions reduction pledge," Victorian Department of Transport, 2021, https://transport.vic.gov.au/our-transport-future/climate-change/transport-sector-emissions-reduction-pledge

[2] IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Geneva, 2014), https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf

Method

This book is the result of a research project commissioned by the Bus Association Victoria (BusVic) in which we aimed to determine what guidance was needed for Victoria's bus and coach operators. Our process for determining this was first, looking at reliable up to date guidance from internationally reputable sources. Second, conducting an industry survey and series of interviews with Victorian operators, and then third, comparing the difference between international examples and local knowledge.

The comparison between international and local examples was not undertaken to score or measure Victorian bus operators' level of preparedness for the zero emission transition but rather to determine how the transition would or could be carried out. Part of this was asking operators what their concerns were, how prepared they felt, and asking them about the specific factors we discovered in the literature. We have used what we discovered from the survey and interviews to help us translate the guidance in section two from generic and international, to more specific and local. In it, we call on information provided by bus and coach operators.

The survey and interview process was undertaken with approval from the Monash University Human Research Ethics Committee, project number 30118.

Key Terms and Abbreviations

Net zero emissions

This term is used to describe Australia's and Victoria's emissions targets by 2050. It identifies the approach whereby some emissions will still be made, but must be accounted for by capturing an equal amount.

ZEB - Zero Emission Bus

This refers to a bus with zero tailpipe emissions. In the context of reducing overall emissions, it is important to consider where the energy comes from, for example the vast difference between sourcing electricity from brown coal, or renewable sources.

BEB - Battery Electric Bus

This refers to Zero Emission Buses (ZEBs) that operate on electricity which is stored within onboard batteries that can be recharged from an external electric supply. See diagram on p24.

FCEB - Hydrogen Fuel Cell Electric Bus

This refers to Zero Emission Buses (ZEBs) that operate on electricity which is stored onboard a vehicle as hydrogen fuel and converted using fuel cells to power an electric motor. See diagram on p25.


E-BUS
VOLGREN

Section 1
Victoria's Bus and Coach Operators

Survey

We conducted a survey with BusVic members to capture the current level of concern, understanding, and readiness for transitioning to ZEBs in Victoria.

113 responses were recorded, 67 of which responded to all key questions. The majority (58%) of these responses came from small businesses, particularly those with 1-4 employees (39%), representing the significant number of smaller operators in Victoria's bus industry.

Respondents indicated that they had already considered a number of factors relating to the transition to ZEBs prior to this survey. Considerations relating to energy infrastructure, vehicle technology and finances were at the top of the list.

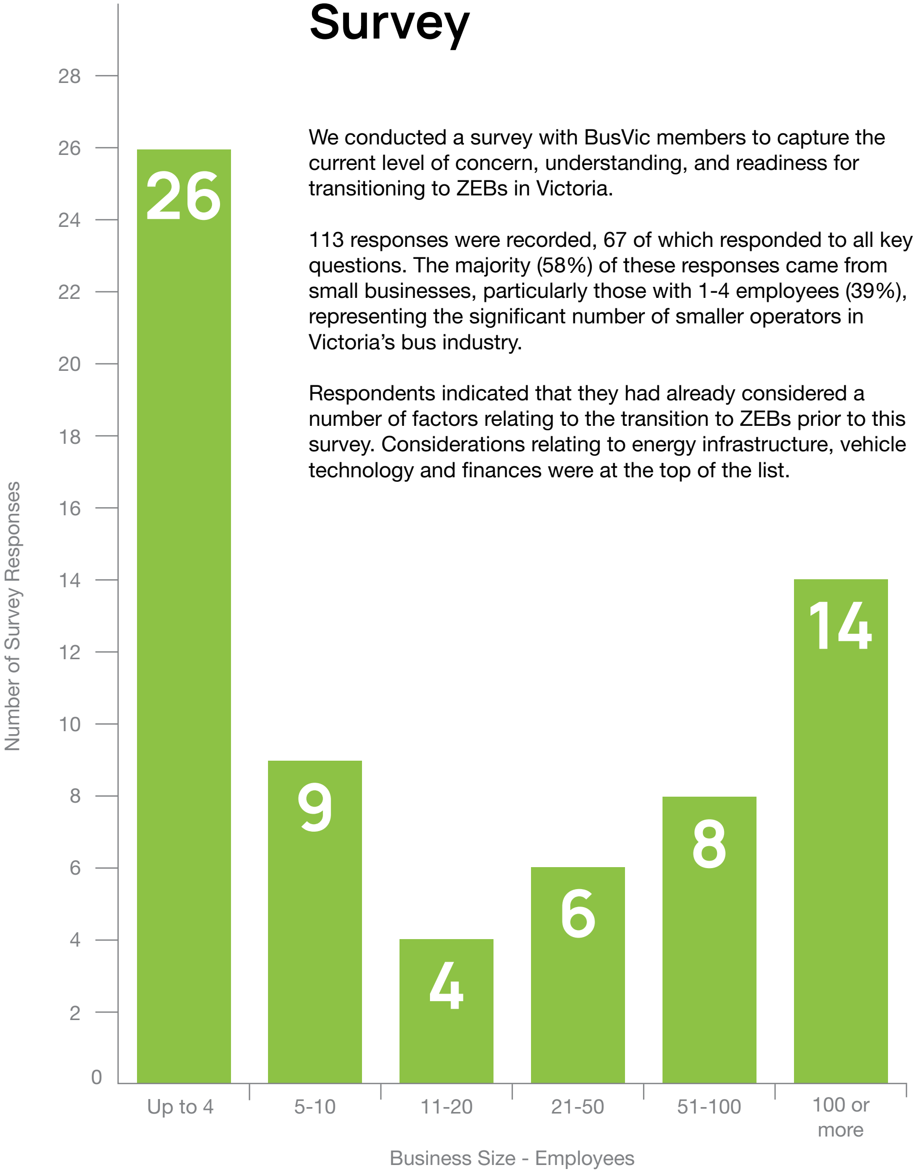


Figure 1. Survey respondents by business size

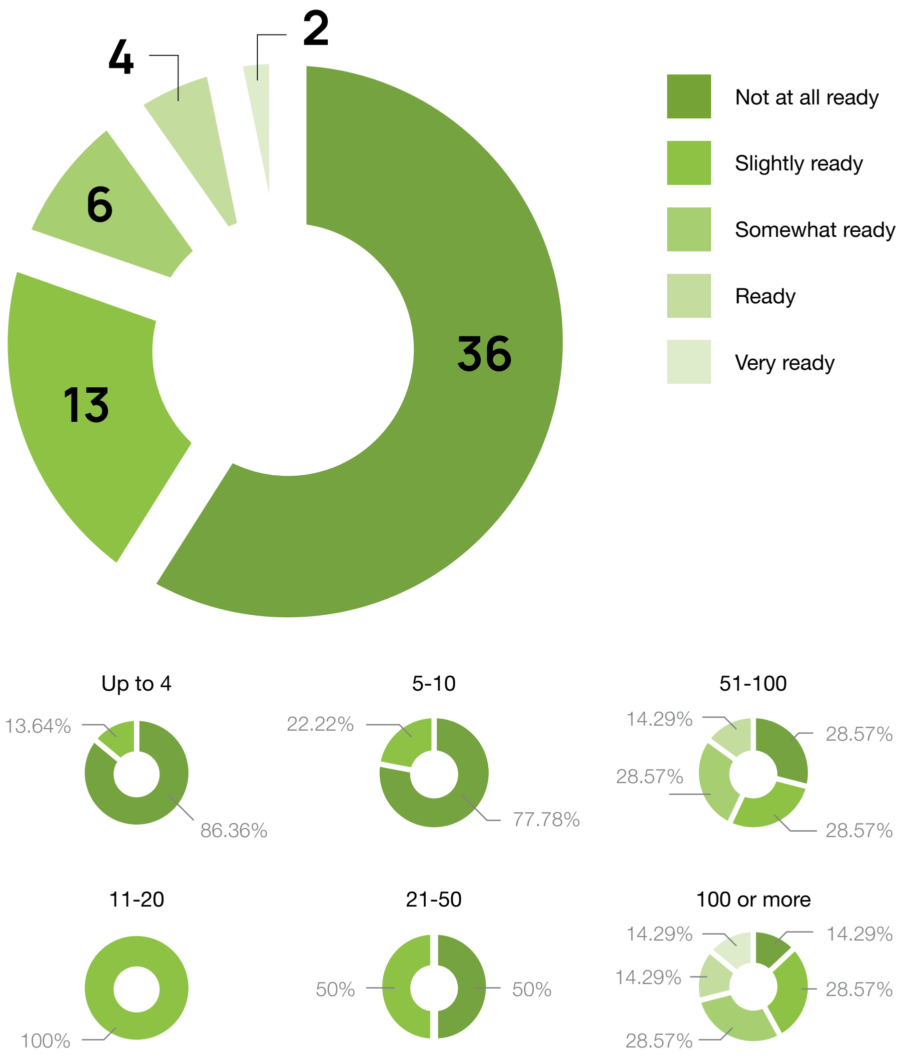


Figure 2. Transition readiness broken down by business size

The majority of respondents stated that based on their understanding, they were either ‘not at all ready’ or only ‘slightly ready’ for transitioning to ZEBs. In general, small operators feel less prepared when compared to large operators, which was evidenced by the proportion of small operators who reported a lack of readiness. In contrast, large operators with 51-100 or over 100 employees showed a more diverse mix of responses stating they were ‘somewhat ready’, ‘ready’, and ‘very ready’.

We asked BusVic members to name factors of the transition to ZEBs that were of least, and most concern. Questions were in a short-answer format allowing participants to openly elaborate on their responses.

Factors that repondents found least concerning about transitioning to ZEBs were the commercial availability (not viability) of vehicle options and also their own capabilities to operate them. These responses suggest that many operators believed ZEB technologies would soon reach a level of commercialisation that made them accessible to the Australian market and that they would have the capability to implement them.

12% of respondents stated that they were concerned about everything, which is represented by the 'none' category and supported by the large number of operators who saw themselves as unprepared for the ZEB transition.

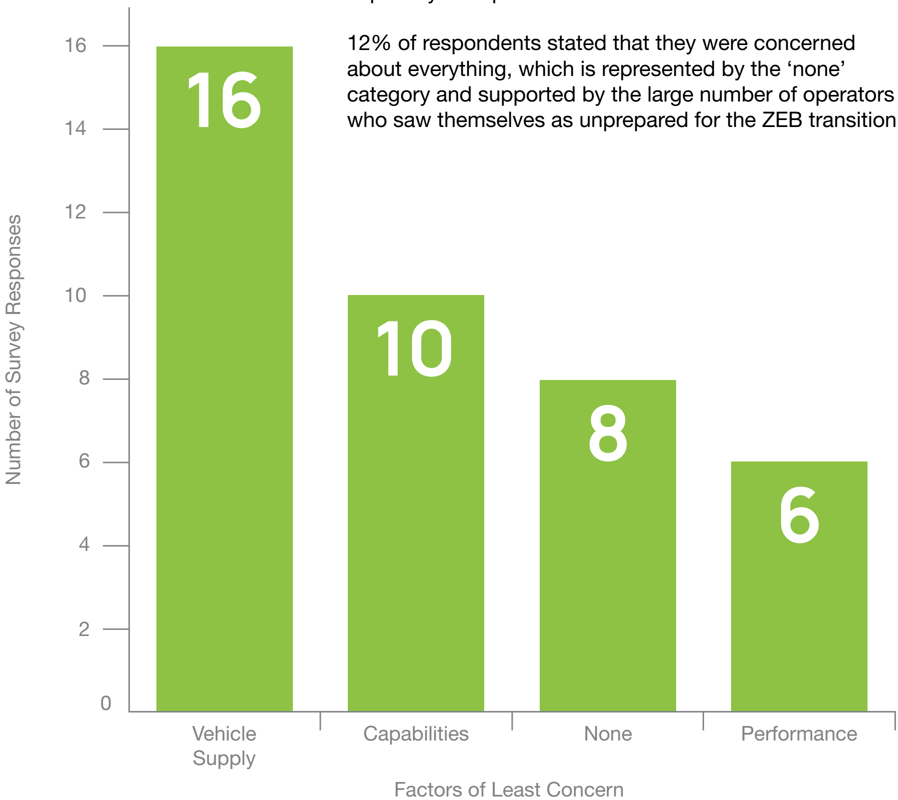


Figure 3. Factors of least concern

Operators were most concerned about establishing energy infrastructure, the cost and commercial viability of ZEB technologies, and their own capabilities to successfully operate, charge and maintain ZEBs. When these responses were cross-referenced against business size and transition readiness, infrastructure and cost were most consistently reported as the major concerns across businesses of all sizes and levels of readiness. Confidence in internal capabilities, which was reported as both a concern and non-concern, correlated with an operator's perception of transition readiness. Those who saw themselves as the most ready were also the most confident in their capabilities; however, this was not always related to business size as respondents from both small and large businesses reported being concerned about their capabilities. The majority of non-responses came from small operators who also reported feeling unprepared for the transition. This suggested that although small operators were concerned about being unprepared, they lacked the necessary information to identify specific areas for concern. Those operators who have broad ranging but unnamed concerns could stand to gain the most from this handbook.

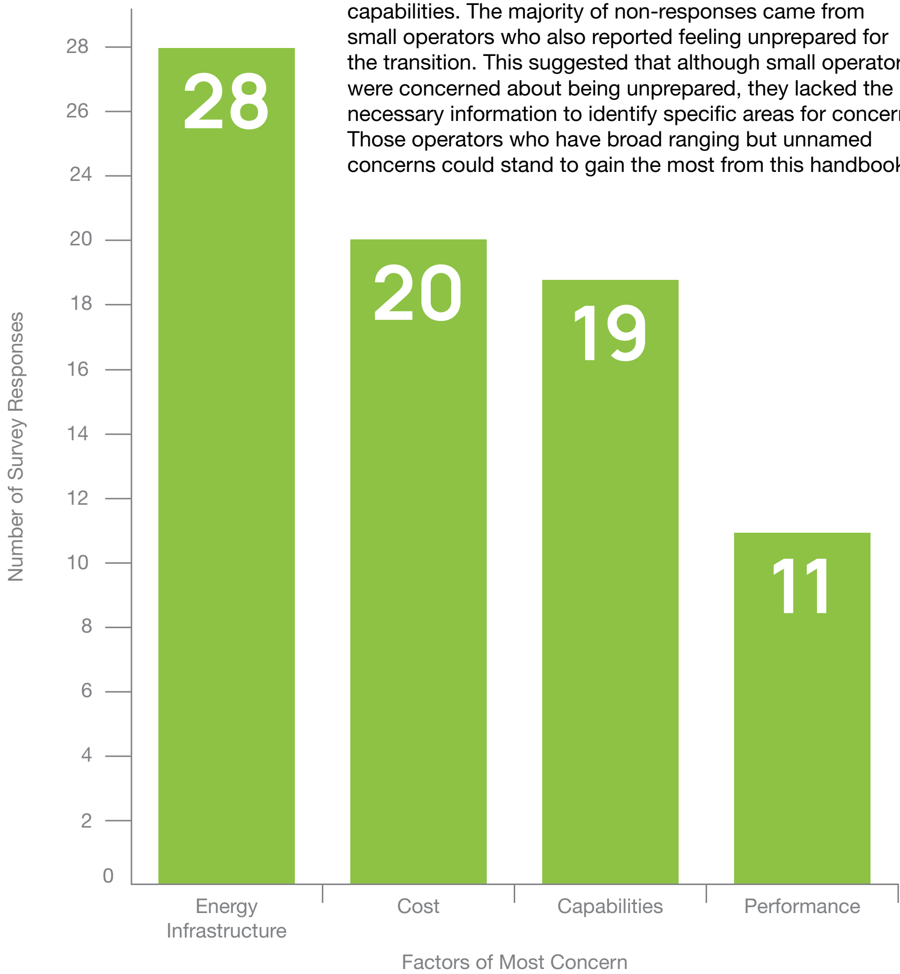


Figure 4. Factors of most concern

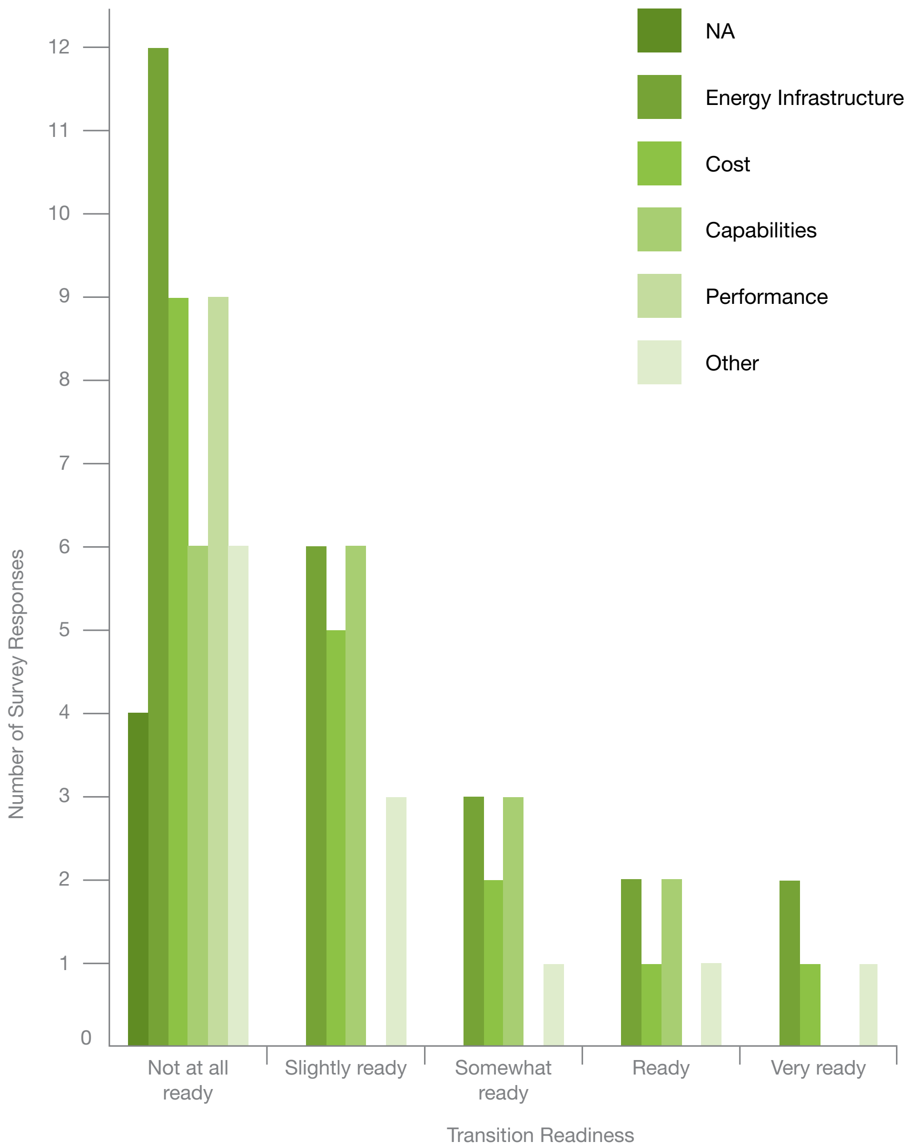
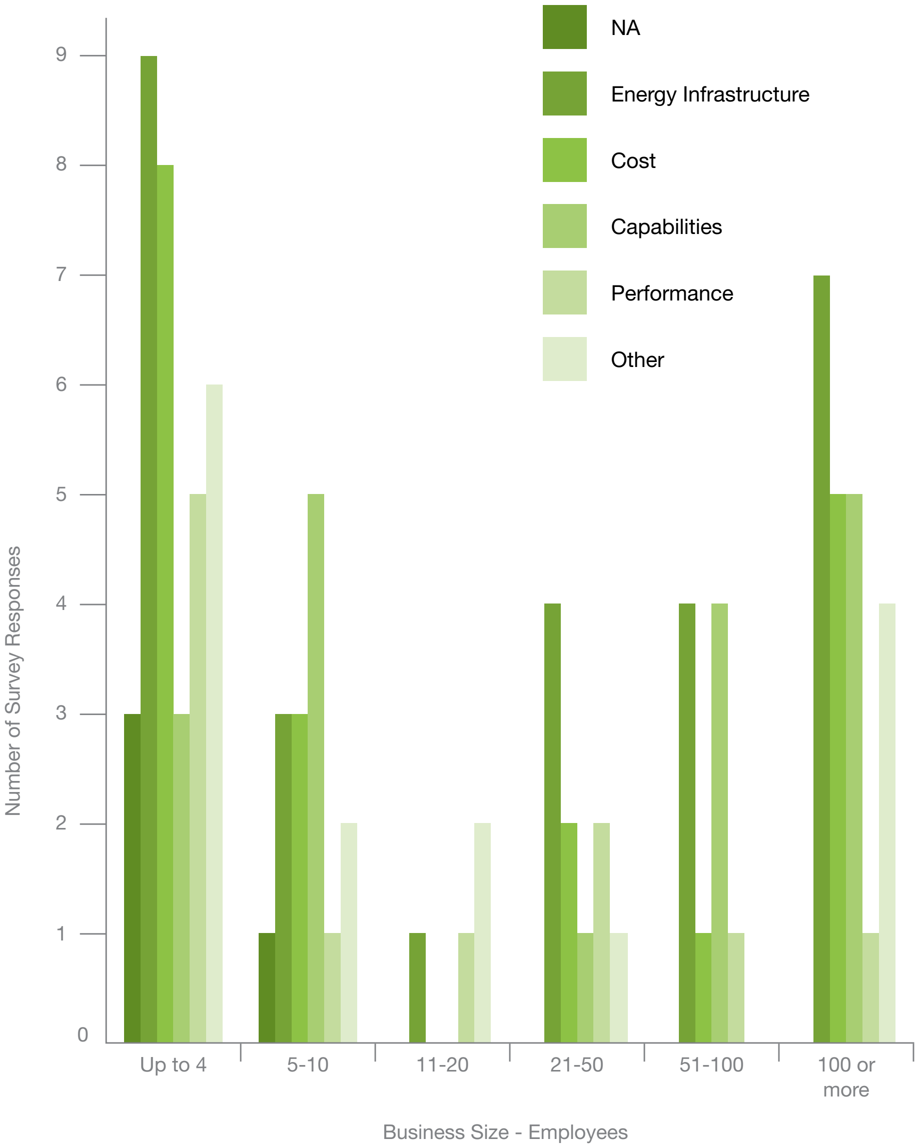


Figure 5. Factors of most concern by transition readiness and business size


NA
Energy Infrastructure
Cost
Capabilities
Performance
Other
Number of Survey Responses
0
1
2
3
4
5
6
7
8
9
Up to 4
5-10
11-20
21-50
51-100
100 or more
Business Size - Employees

Interviews

> **Our overall strategy is to watch. It's to observe the government contractors implementing this ahead of time and seeing what works and what doesn't. And then seeing what the market offers up that will, or won't fit our commercial business.**

Following the survey, BusVic made a call for operators throughout Victoria to participate in interviews. From eight responses, seven interviews were conducted. The interviewees represented bus and coach operator businesses from metropolitan Melbourne, regional centres and country towns. These businesses spanned the different types of operations in Victoria from PTV route services, scheduled coach services such as VLine, private and government school contracts, and charter. As is typical in Victoria, some participants ran multi-generational family businesses, and the business sizes varied from around 40-200 employees.

The purpose of the interviews was to discover in depth the attitudes, knowledge and preparedness of the operators for the zero emission transition. While the results are generalisable to an extent, we also acknowledge that a self-selection bias is highly likely: the operators who responded to the call for interview participants are likely to be at least actively curious, interested, or concerned about the ZEB transition. No interviewee suggested that they had no, or little interest in the transition.

Attitudes towards the transition tended to be optimistic, but cautious. All interviewees identified positive aspects of the transition, but also highlighted concerns and potential risks. For example, in transitioning away from diesel one operator identified the opportunity to generate some of their energy on site; at a higher level several operators noted that the transition would help them meet their company’s emission reduction objectives and also to be a leader in sustainable technology in their local area. Interviewees cited positive experiences with OEMs in hybrid vehicles as grounds for optimism, specifically identifying the technical support and training from their vehicle suppliers as being part of what helped to transition their business to include hybrids.

A near universal concern raised was that of technology selection and concerns about “backing the wrong horse” technologically. Interviewees identified different “starting points” for their transition to ZEBs; for some this was defined as the purchase of a new bus, for others it was the planning prior to such purchases. Although universally raised, regional and country operators had greater concerns regarding the availability of energy from the electricity grid.

Operators we interviewed had taken the time to read some of the materials on zero-emission technology, for example that provided by the Union Internationale des Transports Publics (UITP). They also cited BusVic maintenance conferences as a source of information and several had travelled to Europe with OEMs for technology demonstrations. As noted in the self-selection bias, operators we interviewed were interested in zero emission technology more broadly. An example of operator knowledge is direct experience with battery electric vehicles such as private electric and hybrid cars, hybrid diesel-electric buses in their business, or experiences with solar energy and off-grid technology in their own homes or at their depots.

> **I think you are going to see businesses really specialising in route and using electric buses in one area and those that are wanting to do the long haul and using different energy sources in a different area.**

Operator preparedness showed similar results to the survey - with most operators stating that they were not completely prepared for the transition but had commenced some level of planning. Preparation activities ranged widely from on-site technical factors such as energy sourcing and depot space, through to consideration of changes in business models. Operators noted that some aspects of their business would be impacted in different ways to others - for example government contracts being a different exercise to transition than private school bus contracts. This also highlights the current state of technology; that a battery electric bus for urban route service will have very different energy needs to long-haul coach services. Operators who had participated in the Victorian Government’s Department of Transport bidding process for the electric bus trial program reported that this activity had stimulated planning for the transition in their business.

Based on their experiences outlined above, operators generally perceived battery electric buses as being the next logical step in technology selection, but also noted that hydrogen fuel cell technology is of interest and may be necessary for coach and charter work.

Conclusion
Section One

Aside from a minority of bus operators in Victoria who report a high level of readiness for the ZEB transition, we found that the industry has little direct experience operating or planning for ZEBs. Within this majority, the concerns of operators are spread across a variety of factors, and while some operators perceive the business side of the transition to be easier than the technological side, others perceive it in the opposite way. This reflects, and may be caused by most operators reporting a variety of formal and informal inputs to their thinking, ranging from advice from suppliers to their business, industry and mass media publications, or participation in events.

While there are exceptions, we generally found that the larger operators perceive themselves as more ready for the ZEB transition. In line with this, these larger operators report fewer concerning factors about the transition, as well as fewer concerns overall. Factors of most concern to all respondents tended to be those outside of their control, for example the reliance on a new external energy source.

Section 2
Guidance for Industry


Electric Bus
VOLGREN
VOLGREN

Introduction

In this section we provide guidance to bus operators. First, our review of guidance from other organisations and places who are faced with the same ZEB transition. Some of these places are more advanced than Victoria in the transition, and the advice from organisations such as the UITP is aimed at bus operators at any, or all, stages of the transition. There are many possible approaches and outcomes to the ZEB transition, and as such we have brought together - synthesised - where possible the advice that is applicable to Victoria, using our research into Victorian bus operators through the survey and interview process as a basis for this.

Each section is named for the topic it provides guidance on, however the topics are somewhat interlinked. So while a reader is welcome to look up specific points, the broader context of the transition will be clearer when the guidance is taken as a whole. As our survey and interviews revealed, knowledge about the ZEB transition is varied across the state, so you can expect to find guidance on topics that you already understand. This section is organised into three parts - vehicle technology, energy infrastructure, and operations.

Recommended first actions

The following is a list of recommended actions, some of which you may have already done. This list is selected from the guidance and contains items which are both important, and relatively easy to carry out. They do not require significant investments in time, and the information you glean from doing them will provide a basis on which to plan your ZEB transition.

1. Identify buses that are closest to end of life and cluster together on either one or more routes.
2. Calculate per-vehicle energy requirements to service that route. This will determine a vehicle's energy storage based on operational requirements.
3. Calculate power demand to charge number of ZEBs to determine power demand on the local electricity grid.
4. Contact energy provider to discuss implementation and identify need for upgrades.
5. Determine charge station distribution across one or multiple locations such as depot or en-route charging. Done in consultation with energy provider.
6. Contact vehicle manufacturers to determine options.
7. Rank your routes finding those more suitable for BEB / FCEB.
8. Talk to your local council to see if you have any similar goals in energy and emissions.

Guidance
Vehicle Technology Options

Introduction

Uncertainties around technological development and vehicle capabilities are highlighted as some of the key concerns for transitioning to ZEBs in Australia[3]. ZEBs are currently developed in two main technological variants: BEBs and FCEBs.

[3] International Association of Public Transport Australia/New Zealand (UITPANZ), 2020 Zero Emissions Bus Forum, report and key findings, (2021) https://cms.uitp.org/wp/wp-content/uploads/2021/02/UITPANZ-ZEB-Forum-Report-2021.pdf

Technology development

BEBs are currently at a greater state of development and commercial viability when compared to FCEBs due to the number of manufacturers across Europe, Asia and North America who have invested in bringing them to market. In 2017, BEBs made up 82% of Europe's ZEB market, while FCEBs were only 1%[4]. A survey of European operators indicated that this trend will continue based on responses forecasting BEBs as the dominant transition technology choice over the coming decade making up around 40% of Europe's total bus market. Comparatively, FCEB uptake was forecast to be significantly lower, making up only 5% of Europe's total bus market in the coming decade[5]. As Victoria's bus industry is heavily reliant on European technologies and vehicles, these trends will undoubtedly filter through to our local markets over the coming decade.

Greater development has increased the commercial viability of BEBs when compared to FCEBs. Upfront costs for both technologies are currently higher when compared to diesel buses; however, the cost of batteries–the most high-cost component of BEBs–has dropped significantly over the past 10 years and continues to become cheaper as technology uptake increases. As a result, it is now suggested that BEBs are on par with, if not cheaper than, diesel buses when considering the total cost of ownership including fueling and servicing[6].

FCEB systems are still in their early stages of commercial development and have not seen the same cost reductions from market uptake. Reports from FCEB trials in Japan suggest that the vehicles were around four-times more expensive to implement than diesel buses[7]. Nevertheless, a number of manufacturers including Toyota, Solaris, Alexander Dennis, and Mercedes-Benz have all invested efforts into developing FCEBs. In the majority of these cases, FCEBs are targeted for long-range operation, such as interstate coaches and marketed as a complimentary offering to BEB technologies.

A further factor to consider for Victorian implementation is that electricity infrastructure already exists in many parts of the state and while this will need to be upgraded, and extended in regional areas, it is a known technology. The infrastructure to make, distribute and store hydrogen is only just emerging. It requires more investigation and trials to establish the necessary knowledge base prior to commercial implementation.

[4] Transport & Environment, Electric buses arrive on time: marketplace, economic, technology, environmental and policy perspectives for fully electric buses in the EU, (2018), https://www.transportenvironment.org/wp-content/uploads/2021/07/Electric-buses-arrive-on-time-1.pdf

[5] International Association of Public Transport (UITP) Transport Economics Committee, Large-scale bus electrification: the impact on business models, (Brussels, 2021), https://cms.uitp.org/wp/wp-content/uploads/2021/07/Large-scale-Bus-Electrification-KB-Final.pdf

[6] Alana Aamodt, Kamyria Coney, and Karlynn Cory, Electrifying Transit: A guidebook for implementing battery electric buses, (Washington, DC: National Renewable Energy Laboratory, 2021), https://www.nrel.gov/docs/fy21osti/76932.pdf

[7] Robin Harding, "High costs dog Tokyo's hydrogen buses", Financial Times, July 23, 2021, https://www.ft.com/content/2b9dd655-6b64-416c-a83f-1fe1002da7d5

Technology selection

An electric drive system is at the heart of both of these BEBs and FCEBs, though the way that electricity is stored and supplied to the drive motor varies. These variations make each alternative more suited to certain types of operation. Factors such as driving distances, infrastructure access, route topography, and regional climate, which influences heating, ventilation and air-conditioning (HVAC) energy usage, are all important to consider when implementing ZEB technologies[8]. The following two sections provide an overview of each option.

[8] International Association of Public Transport: Transport Economics Committee, Large-scale bus electrification: the impact on business models, (Brussels, 2021), https://cms.uitp.org/wp/wp-content/uploads/2021/07/Large-scale-Bus-Electrification-KB-Final.pdf

[9] Alana Aamodt, Kamyria Coney, and Karlynn Cory, "Electrifying Transit: A guidebook for implementing battery electric buses", National Renewable Energy Laboratory (NREL), 2021, https://www.nrel.gov/docs/fy21osti/76932.pdf

Battery-electric buses

BEBs store electrical energy in batteries that, much like a portable electronic device can be recharged from an external power source such as the power grid or solar panels.

Batteries are available in a range of sizes that can be specified according to the amount of driving a vehicle must complete between charges. Batteries store and provide electricity directly to the bus's drive motor (or motors) through a wired connection to move the vehicle. This connection works in both directions as the drive motor can also provide electricity back into the batteries through 'regenerative braking', which is when the motor runs in reverse to slow down the bus and generates energy as a byproduct. Utilising regenerative braking increases efficiency and prolongs a BEBs driving distance by generating additional energy in between charges[9].

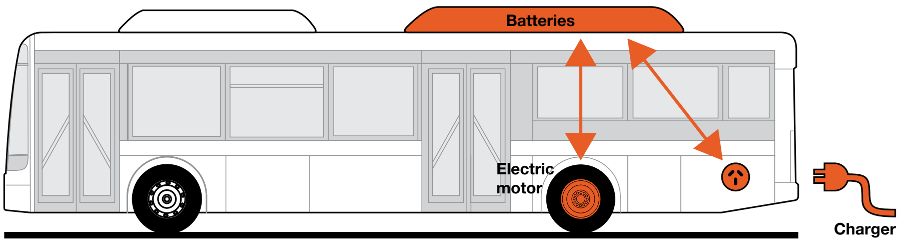


Figure 6: Battery-electric bus (BEB) system overview

An advantage of BEBs is the system's simplicity and flexibility with fewer mechanical components than diesel, and a direct wired connection between batteries and motor. This reduces energy conversion losses associated with mechanical components and multiple energy transfers,[10] such as the energy lost as heat from diesel engines that we are familiar with. The system's flexibility also means that batteries can be distributed throughout the bus. This reduces requirements for areas such as the engine bay and opens up the bus's interior for greater passenger accommodation. As batteries can both give and receive electricity, this allows them to connect back into the power grid through a bidirectional charger to trade their electricity with other consumers, such as the depot, other BEBs, or private homes[11].

Disadvantages of BEBs are primarily due to the battery weight and the time it takes to recharge them. Storing enough electricity for a day's operation requires large batteries that can weigh around 4-5 tonnes, which presents a selection trade-off as large batteries can reduce a bus's passenger carrying capacity while smaller batteries may not store enough energy to fulfil operational requirements[12]. Batteries also take a long time to fully recharge, which increases with their size and can leave a bus out of service for extended periods of time.

When considering BEBs, it is critical to factor in battery size and charging requirements to ensure that batteries are appropriately sized for operation without reducing passenger capacity, and that they are charged with enough electricity to do so. Charging infrastructure and recharge time allowances are both important aspects of BEB implementation. These considerations make BEBs more suited to metropolitan and suburban operation due to availability of electricity infrastructure and the relatively short distances that vehicles travel in between stops.

[10] Volvo Bus Australia, "Electric buses in regional and metropolitan public transport networks in NSW", Parliament of New South Wales, 2019, https://www.parliament.nsw.gov.au/ladocs/submissions/66908/Submission%20-%204.pdf

[11] Chunhua Liu, KT. Hau, Diyun Wu, and Shuang Gao, "Opportunities and challenges of Vehicle-to-Home, Vehicle-to-Vehicle, and Vehicle-to-Grid technologies", Proceedings of the IEEE 101, No. 11 (2013): 2409 – 2427, https://doi.org/10.1109/JPROC.2013.2271951

[12] Robbie Napper, Ilya Fridman, and James Reynolds, "Balancing level of service for a battery-electric university intercampus shuttle bus", paper presented to the Australasian Transport Research Forum (ATRF) 2017, 27 – 29 November 2017, Auckland, New Zealand, https://www.australasiantransportresearchforum.org.au/sites/default/files/ATRF2017_006.pdf

Hydrogen fuel-cell buses

FCEBs are powered by hydrogen fuel that is stored in tanks that can be refilled from a hydrogen pump, much like current diesel pumps. Hydrogen fuel is made from a combination of water and electricity. When electricity is required to propel FCEBs, hydrogen is transferred into fuel cells (FCs) that split it back into water and electricity. Electricity is then used to power a drive motor while water vapour is expelled from the exhaust as a byproduct. Batteries are also often required onboard FCEBs in order to store any additional electricity and take advantage of regenerative braking, which improves operational efficiency.

The multiple energy conversion points in FCEBs make it a hybrid system, similar to those currently powered through a combination of diesel and electricity. The system complexity of FCEBs means that they are less efficient when compared to BEBs due to the losses each time energy is converted from electricity to hydrogen and back to electricity. Because of these, it is suggested that FCEBs cannot currently compete with BEBs from an energy efficiency or energy cost standpoint[14].

[13] Alan Finkel, "Getting to zero: Australia's energy transition", Quarterly Essay 81, 2021.

[14] Volvo Bus Australia, "Electric buses in regional and metropolitan public transport networks in NSW", 2019, Parliament of New South Wales, https://www.parliament.nsw.gov.au/ladocs/submissions/66908/Submission%20-%204.pdf

Hydrogen fuel-cell bus (FCEB)

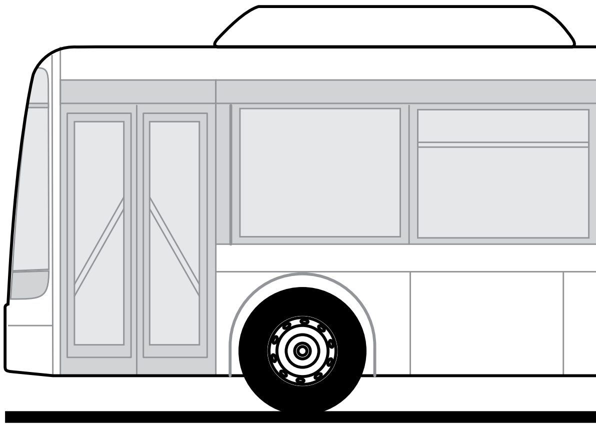


Figure 7: Hydrogen fuel-cell electric bus (FCEB) system overview

An advantage of FCEBs is related to the amount of energy that hydrogen tanks can store and a refilling speed that is faster than battery charging. This provides an advantage over the BEB for long-range applications such as interstate coaches where large amounts of energy storage are required and access to charging is limited or would be too slow[15]. Our interviews with Victorian operators revealed that several operators are considering waiting for FCEBs to become more mainstream before transitioning coaches from diesel.

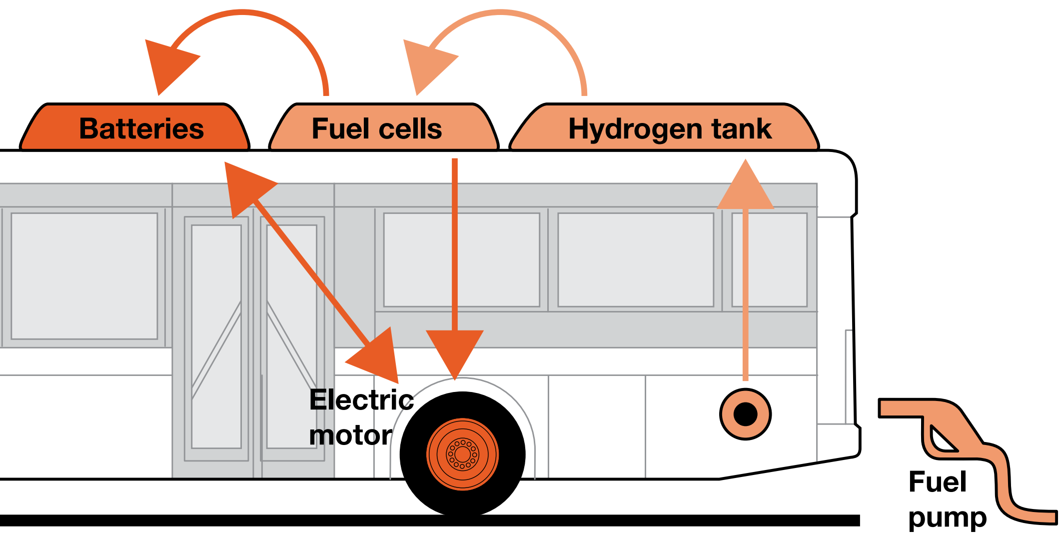
With regard to metropolitan and suburban applications, hydrogen systems are suggested to be more commercially viable for countries or regions that have little available land area for renewable energy generation[16]. This is supported by FCEB uptake in cities such as Tokyo which launched FCEBs into service during the Tokyo Olympics[17] and London where FCEBs have operated for nearly two decades[18] and a double-decker version was recently launched into service[19].

[15 16] Alan Finkel, "Getting to zero: Australia's energy transition", Quarterly Essay 81, 2021.

[17] Tess Joosse, "The 'Hydrogen Olympics' lit a torch for the clean fuel's future", Scientific American, July 30, 2021, https://www.scientificamerican.com/article/the-hydrogen-olympics-lit-a-torch-for-the-clean-fuels-future1/

[18] Shanta Barley, "Hydrogen bus launched on London tourist route", The Guardian, December 10, 2010, https://www.theguardian.com/environment/2010/dec/10/hydrogen-bus-london

[19] "Mayor launches England's first hydrogen double decker buses", Greater London Authority, 2021, https://www.london.gov.uk/press-releases/mayoral/englands-first-hydrogen-double-deckers-launched



Manufacturing

There are five pathways for implementing ZEBs in Victoria, which relate to how buses are manufactured and can influence local job creation.

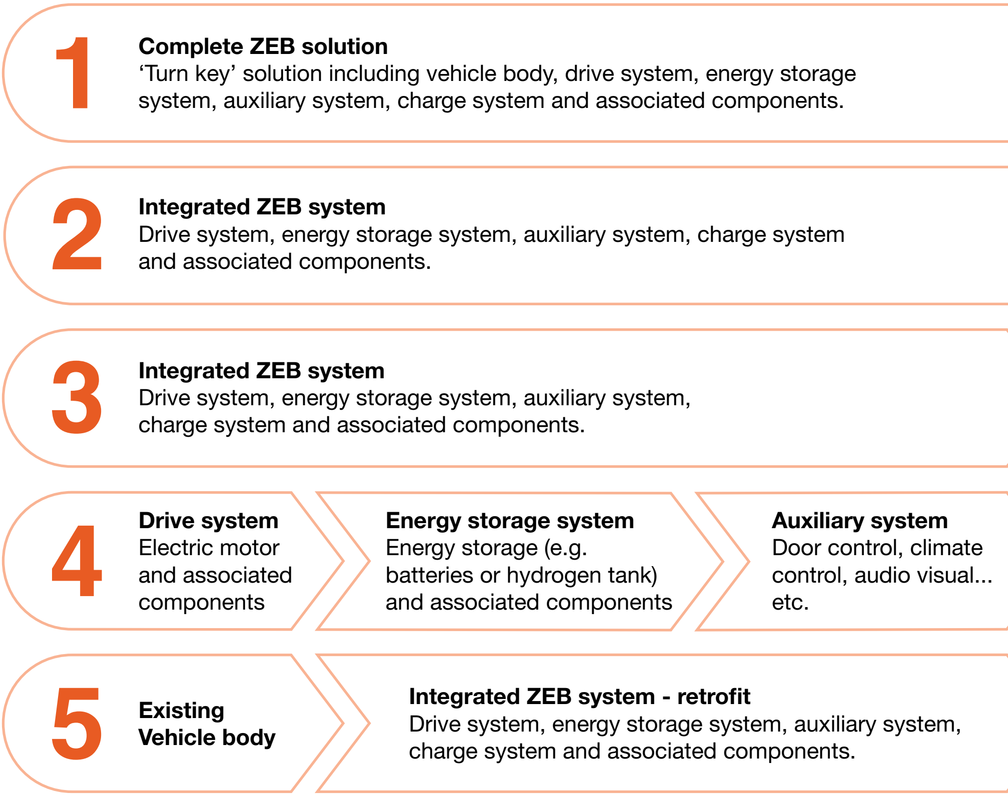
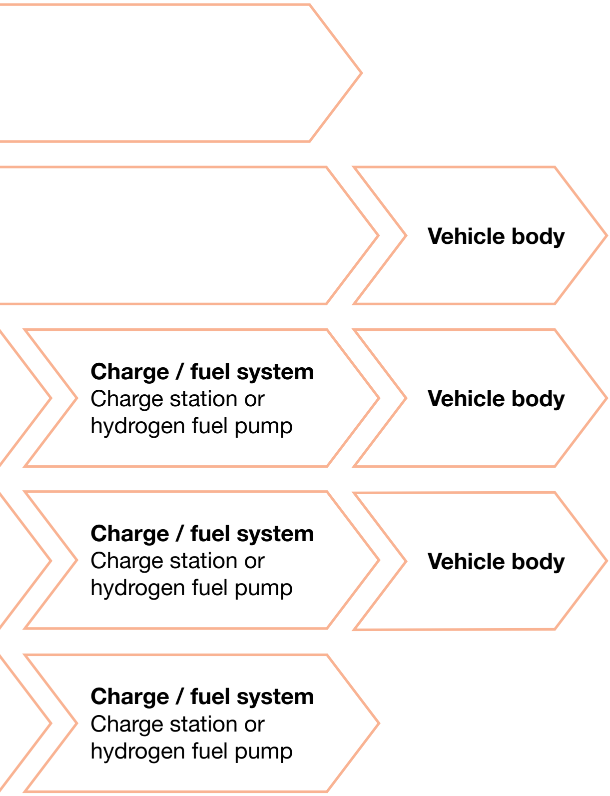


Figure 8: ZEB manufacturing pathways



As shown in Figure 8, the first pathway involves purchasing a complete ZEB 'turn-key' solution from a manufacturer. This will most often include the manufacturer's charge solution as either depot or en route chargers depending on specification. ZEB manufacturers are typically located in either Europe, Asia or North America as this is where technological development is concentrated. Operators choosing this pathway must ensure that implementation support is provided by manufacturers as this may be complicated by distance and other international considerations.

The second and third pathways involve integrating a ZEB system from an international manufacturer into a locally built bus body. ZEB manufacturers may provide their own charge solution (pathway 2) or an alternative charge solution from another provider (pathway 3). In these scenarios, local manufacturers communicate with the international manufacturers to ensure they build a suitable bus body and have technical support throughout the process. For the operator, this means that there is a local point of contact to support implementation.

The fourth pathway involves constructing custom ZEBs using a combination of components from various international or local suppliers for drive motors, batteries, and charge solutions. These are then combined with a locally built vehicle body. This would allow for greater specification flexibility, though require a high level of technical support to ensure that components were properly integrated as part of a cohesively functional drive system. Operators or local manufacturers selecting this pathway would need to allocate appropriate resources to develop technical expertise and allow for experimentation.

The fifth pathway involves retro-fitting existing buses by removing the internal combustion engine and associated mechanical components. Then incorporating new ZEB alternatives. Third party providers typically offer these types of upgrades through coordination with equipment manufacturers to ensure that components are properly integrated as part of a cohesive system. Operators may choose this pathway for transitioning existing bus fleets to ZEB technologies as a cost-effective alternative to retiring buses before their end of life.

These five pathways represent a general overview of approaches to ZEB manufacturing. In reality, implementation may involve mixes of them as operators may purchase a complete turnkey solution initially, though upgrade elements such as charge infrastructure or battery packs as required.

Phase out of diesel buses

As Victoria's operators transition over to ZEB technologies, diesel buses will be phased out with fleets and assets being decommissioned in the process. If allowed to proceed at a natural pace, then the diesel bus phase out will depend on when the latest buses were purchased prior to the government's stipulated ZEB transition starting point in 2025. With an expected service life of 20 years, and sometimes longer, the phase out of diesel fleets may continue all the way through to 2050.

If an operator, or a government, seeks to phase out diesel buses before the end of their functional life then it is important to consider the financial and environmental implications of this approach. 'Replacing existing bus fleets completely with new electric vehicles is neither economical nor sustainable'[20]. ZEBs are 'considerably more expensive than a conventional diesel bus' and early vehicle retirement could unnecessarily waste large amounts of embodied energy used in its manufacture[21]. In Victoria, the used vehicle market is also important to consider as many operators rely on selling and purchasing used buses.

Retro-fitting existing vehicles with ZEB technologies can minimise the financial and environmental implications of phasing out diesel bus fleets prior to the end of their service lives. This has been successfully demonstrated in Europe where the ZEB transition is further advanced. Third-party suppliers can convert existing buses by swapping out diesel technologies for ZEB alternatives[22]. This extends the vehicle's life as older components are swapped out for new ones. It also reduces the environmental impact of unnecessarily wasting the embodied energy of current bus fleets and may be a beneficial option for the used vehicle market.

[20] [21] Andreas Hager quoted in Fabian Cotter, "Diesel-to-electric bus conversion kit debuts at UITP, 2019", Australasian Bus and Coach, July 21, 2019, https://www.busnews.com.au/industry-news/1906/diesel-to-electric-bus-conversion-kit-debuts-at-uitp-2019

[22] UTM Editorial, "Retrofitting instead of new-built: conversion from diesel to electric buses". Urban Transport Magazine, December 5, 2019, https://www.urban-transport-magazine.com/en/retrofitting-instead-of-new-built-conversion-from-diesel-to-electric-buses/

Fleet size impacts on transition

The size of an operator's bus fleet will have practical implications on how they transition to ZEBs. When considering BEBs, the number of buses as well as the size of their batteries will influence infrastructure upgrades required to recharge them[23]. A smart charge strategy may need to be considered for BEB fleets to ensure that all vehicles are not charging at one time, which would overload the local energy grid. This also applies for FCEBs with onboard batteries that may need to be recharged prior to leaving the depot.

Vehicle age can further inform appropriate transition approaches. If a number of vehicles are close to retirement, then these could be grouped together on a route, at a section of a depot, or as a whole depot to be replaced with ZEB alternatives in a cluster[24]. Focusing technological transition at either a route or depot level can be financially beneficial in the long term as it ensures that infrastructure investments are distributed across multiple vehicles rather than only being planned one vehicle at a time[25].

[23] Volvo Bus Australia, "Electric buses in regional and metropolitan public transport networks in NSW", Parliament of New South Wales, 2019, https://www.parliament.nsw.gov.au/ladocs/submissions/66908/Submission%20-%204.pdf

[24] [25] Element Energy, "A study of the impact of electrification of Auckland's bus depots on the local electricity grid", C40 Cities Finance Facility, 2018, https://cff-prod.s3.amazonaws.com/storage/files/goYZtMAiNeyBnqOAapgYh4IzuGpDjIkK0XylzEyO.pdf

Conclusion
Vehicle technology options

It is important to consider the suitability of technology options when transitioning your fleet to ZEBs. Hydrogen fuel-cell and battery-electric are two different technological variants that can be used to power ZEBs. Both come with their own advantages and disadvantages making them suited to different operational contexts. Selecting an appropriate technology requires consideration for the type of service that needs to be performed and the location where the bus will operate. Access to infrastructure and recharge or refuel opportunities will influence this decision as they determine the size and type of energy storage required.

Transitioning to zero-emissions requires the phase out of existing diesel buses. With multiple options to manufacture, purchase and implement ZEBs, the decision to take a specific pathway will depend on the size and age of your fleet. Older buses may be phased out and replaced with brand new ZEBs, while newer diesel buses can be converted to ZEB technologies by exchanging their drive system and energy storage system. The number of vehicles in your fleet will further influence these decisions as investments can be made more effectively when distributed across multiple vehicles.

These vehicle-related factors are also closely linked to other aspects of the transition such as infrastructure and operational approaches. They will determine what type of zero-emissions technology you invest in and how you approach the transition.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Guidance
Infrastructure changes

Introduction

Once the routes have been assessed to identify your fleet requirements, it is time to determine the future of your depot infrastructure. This may require upgrading both the charging and the energy infrastructure.

ZEBs need specific equipment to support the charging process. In the case of BEB, they will require enormous amounts of electricity, making the local grid capacity a critical issue. In the case of FCEB, even though it is charged in a similar way, the particular features of hydrogen require special tanks and handling. As this infrastructure could be as expensive as the fleet, the assessment must always integrate both vehicle and infrastructure elements. Making a decision on a particular vehicle type may have direct and non-negotiable implications on infrastructure, and vice-versa.

The energy and charging infrastructure sizing and selection involves strategic decision-making, technology and economic aspects, and operational issues. In this section, the infrastructure issues that you may face in the future are addressed by identifying the considerations of infrastructure, charging alternatives, energy supply infrastructure, and what your depot will look like during and after the ZEB transition.

How much energy does a bus use?

The energy used by a ZEB will vary based on many factors, for example running time and distance, air conditioning load, mountains, stops, and whether it is operating a dense route bus service, a long distance coach service, or charter. Nevertheless, it is useful to look at a basic case to provide some numbers as an estimate based on urban route service[26]. These are provided for illustrative purposes, and should be replaced when you're ready, by numbers based on your own operations.

For comparison, but also depending on a variety of factors such as seasons and appliance types, an average Victorian household consumes 15v of electricity per day[27].

[26] Zhiming Gao, Zhenhong Lin, Tim J. LaClair, Changzheng Liu, Jan-Mou Li, Alicia K. Birky, Jacob Ward, Battery capacity and recharging needs for electric buses in city transit service, Energy, Volume 122, 2017.

[27] "Typical house energy use", CSIRO, 2013, https://ahd.csiro.au/other-data/typical-house-energy-use/

Energy per km	Day's running	Energy per day, per bus
Low case: 1.24kWh	100km	124kWh
	300km	372kWh
High case: 2.48kWh	100km	248kWh
	300km	744kWh

Energy infrastructure decision-making

A major change will take place in your facilities as a consequence of upgrading them for ZEB. There is no one-size-fits-all solution, so decisions on technology, location, size, and usage patterns must be comprehensively assessed. Therefore, analysing the context in which your business is immersed may provide relevant hints to get the most out of it. Operators we interviewed noted taking different approaches to PTV route services than school bus services, for example.

Internal factors should reflect the current and future requirements of your operation. The slowest possible approach to the transition will be based on replacing diesel buses with ZEBs at the end of life, but there may be advantages or incentives for transitioning sooner. For example, it may be uneconomical to keep a small number of diesel buses once the majority of your fleet is transitioned. Having a clear decommission and transition plan will allow better planning of infrastructure requirements. Moreover, ZEB and their charging stations are long-lasting equipment; therefore, establishing a long-term planning perspective is necessary, including future operational context such as the foreseen ZEB fleet and route scheduling.

On the other hand, external factors will set the scene in which this change is occurring. In this case, the existing charging technology options, either for BEBs or FCEBs, will be the central element of the discussion. The feasibility of using such infrastructure at your depot may lead to considering grid upgrades or even location changes. Collaboration with infrastructure stakeholders will play a relevant role in this upgrade, such as technology suppliers, energy companies, other operators, and the local government.

Finally, as for any strategic decision, you may assess different scenarios: analyse various capacities and configurations of technology, compare different suppliers, look at different electricity rates, among others. You should compare the overall life cycle cost of the alternatives, including up-front, operation and maintenance costs.

[28] Mehmet Efe Biresselioglu, Melike Demirbag Keplan, and Barbara Katharina Yilmaz. 2018. "Electric mobility in Europe: A comprehensive review of motivators and barriers in decision making processes". Transportation Research Part A 109, Elsevier: 1-13. https://doi.org/10.1016/j.tra.2018.01.017

[29] Alana Aamodt, Kamyria Coney, and Karlynn Cory. 2021. "Electrifying Transit: A guidebook for implementing battery electric buses". National Renewable Energy Laboratory (NREL).

[30] Angé Anczewska, Will Griffiths, Andrew Hooley, Franziska Korte, Joey Schaasberg, Andre Tibyrica, and Evan Walker. 2021. "2020 Zero Emissions Bus Forum, report and key findings". International Association of Public Transport Australia/New Zealand (UITPANZ), L.E.K. Consulting and ARUP.

Infrastructure for battery electric buses

Due to range limitations of battery-electric buses, charging may occur either at a bus depot or en-route. The charging needs are closely linked to the operational schedule of your fleet: number of BEBs, their size, the capacity of their battery, their routes and its frequency.

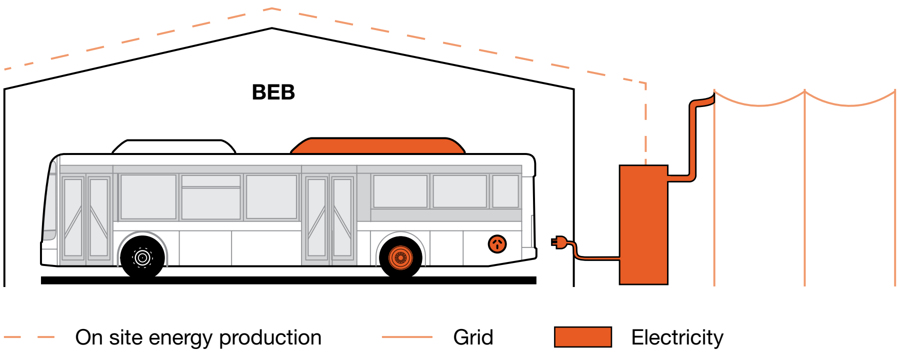
Depot charging often uses slow charging infrastructure (50 - 200kW per charger), considering the buses are expected to stay there for an extended period, minimising the cost impact on charging and electricity infrastructure required. A 50kW charger may charge a bus in 4 to 6 hours, while 200kW chargers will reduce the charging time to 1 to 1.5 hours. Chargers that use a plug or overhead pantograph are available, but plug-in chargers, similar to residential EV chargers, are the most common solution for depots due to their cost-effectiveness. Note that depot chargers should have enough capacity for a fully-charged start every day.

En-route charging typically considers fast charging (> 200kW) as buses are not expected to stay long periods on those stops, therefore maximising the capability to deliver energy into the bus battery. Solutions for en-route are more varied, with pantographs currently the most common alternative, while wireless charging may provide advantages for a more flexible system. As we establish ZEB routes and services, a trade off becomes apparent: between large, long range, expensive batteries on one hand, and the cost of installing off-depot charging which provides more flexibility and backup. Nonetheless, en-route stations require high levels of industry coordination to efficiently allocate their usage. Identifying relevant stakeholders interacting on your routes is essential to benefit from public or shared en-route infrastructure. En-route chargers come at a substantial additional cost, however their use in high density situations might be offset by smaller batteries in buses.

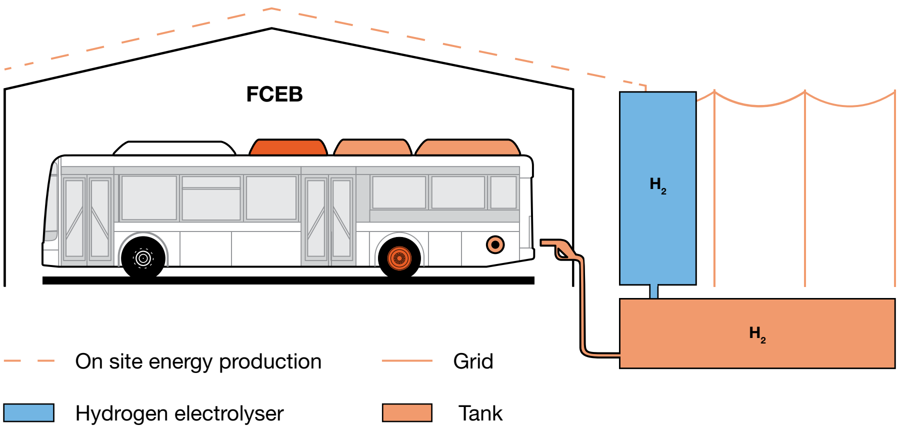
[31] Alana Aamodt, Kamyria Coney, and Karlynn Cory. 2021. “Electrifying Transit: A guidebook for implementing battery electric buses”. National Renewable Energy Laboratory (NREL).

Figure 9: BEB depot schematic

Battery-electric bus (BEB)



Hydrogen fuel-cell bus (FCEB)



Electrical grid upgrade for battery electric buses

As the mass transition of Victorian buses to BEB will be sourced from your electrical plugs, it will impose significant requirements on the electrical grid infrastructure. New charging stations either at depots or en-route will require grid upgrades. These will concern both the energy distributor and retailer,. To determine the peak demand your charging might place on the grid, multiply the charger capacity by how many will be in use at a time. So 10 buses plugged in to 50kW slow chargers would require 500kW of energy. To determine the quantity of energy, multiply it by hours of use. Using the above example for 2 hours would consume 1000kWh of energy (otherwise known as 1 megawatt-hour).

Increasing your depot's electric capacity comes with an impact on the local grid. The more electricity you demand, the more robust the local grid needs to be on your street. Therefore, before renovating the depot, you must check if the energy distributors and retailers will be able to cope with your capacity increment. Consider early-stage coordination with your Distributed Network Service Provider (DNSP) to identify constraints and analyse the alternatives, either in the current or a new location[34]. If you consider a new site, note that the proximity to an electric substation will highly influence the cost of the upgrade.

Inside the depot, the existing plugs, wires, switches, and other equipment will likely be unable to supply electricity to BEBs. Consequently, the bus stations will need an increment in the internal electricity infrastructure capacity consistent with the forecasted demand by renovating the operator infrastructure. Even if you are considering onsite electricity generation, such alternatives may also be constrained by the local grid. Getting in touch with electrical contractors providing details of your requirements to size the technical and financial details of this upgrade will help you to kick off this analysis.

[32] Alana Aamodt, Kamyria Coney, and Karlynn Cory. 2021. "Electrifying Transit: A guidebook for implementing battery electric buses". National Renewable Energy Laboratory (NREL).

[33] Mehmet Efe Biresselioglu, Melike Demirbag Keplan, and Barbara Katharina Yilmaz. 2018. "Electric mobility in Europe: A comprehensive review of motivators and barriers in decision making processes". Transportation Research Part A 109, Elsevier: 1-13. https://doi.org/10.1016/j.tra.2018.01.017

[34] Angé Anczewska, Will Griffiths, Andrew Hooley, Franziska Korte, Joey Schaasberg, Andre Tibyrica, and Evan Walker. 2021. "2020 Zero Emissions Bus Forum, report and key findings". International Association of Public Transport Australia/New Zealand (UITPANZ), L.E.K. Consulting and ARUP.

Infrastructure for hydrogen buses

The charging process for hydrogen-based buses is relatively similar to the charge of conventional diesel buses. The time required to fuel an HFCB is approximately 10 minutes per bus, while a full hydrogen bus tank may last up to 18 operation hours, depending on the specific model[35,36]. Therefore, in contrast to BEB, HFCB usually considers depot filling stations only, as their higher range makes installing en-route stations unnecessary.

Similarly to diesel buses, the charging station of an HFCB consists of pumping the fuel from a large storage tank located on the depot to smaller tanks in the buses. The main difference lies in the fuel features: hydrogen is delivered in a gaseous state and, due to its properties, high-pressure hydrogen storage at both the station and the buses is required. This factor makes the charging infrastructure and supply chain relatively inefficient[35].

[35] Angé Anczewska, Will Griffiths, Andrew Hooley, Franziska Korte, Joey Schaasberg, Andre Tibyrica, and Evan Walker. 2021. “2020 Zero Emissions Bus Forum, report and key findings”. International Association of Public Transport Australia/New Zealand (UITPANZ), L.E.K. Consulting and ARUP.

[36] “Hydrogen vehicles powered by Transit Systems”, Transit System Pty Ltd, n.d., 2021, https://www.transitsystems.com.au/hydrogen-bus-new

Change in energy demand behaviour

With a diesel fleet under operation, scheduling your real-time energy demand was never an issue so long as your diesel tank was full enough. In order to ensure reliable and affordable supply, the diesel storage level is regularly checked to define whether a fuel refill was required at the depot. Nevertheless, this is not the situation with electricity.

The electricity supply chain has a unique feature: supply and demand need to be matched instantaneously. Even though energy storage technologies are becoming more affordable, they will never be as cheap as a fuel tank. For this reason, among others, it is common to see electricity contracts having time-of-use, demand-based and flexible tariff structures. The bigger the demand, the most critical it becomes to the electric operators. The key example of this in Victoria is the ability of our aluminium smelter to adjust energy use on high-demand days.

Providing certainty to the electric operations regarding your charging hours and the expected demand during those periods allow better coordination of their resources. It may be possible to negotiate discounts in your energy supply based on this type of coordination. To better manage your demand on the grid, charging patterns and schedules become fundamental. This includes not only charging at the cheaper times but also spreading the charging process during that period, flattening your demand patterns. Matching your infrastructure with your fleet needs should also consider those patterns, as the operational cost can be highly impacted. The spot price for electricity can fluctuate significantly over the course of a day[37], so discussing your energy demand with your energy supplier can help to find mutually agreeable situations.

[37] "AEMO Data Dashboard: Dispatch Overview", AEMO, 2021, https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/data-nem/data-dashboard-nem

Sourcing electricity and collaboration

In a diesel operation, electricity may be seen just as a utility service bill to be paid. Yet, the transition to zero-emission buses will convert it into a strategic resource that needs to be managed. The electricity market is dynamic and has varied supply offerings. As in any market, demanding more gets you into a better position for negotiation. On the one hand, electricity retailers may be keen to increase their market share by adding your new BEB demand to their portfolio. On the other hand, your consumption behaviour will play a relevant role in this negotiation, as demand response incentives may be introduced[38]. Therefore, collaborating with your supplier by committing to a charging schedule, ideally making use of the low-price hours, is undoubtedly a win-win opportunity.

To get the most out of the collaboration, consider assessing the different alternatives available in the market, such as retailer alternatives, Power Purchase Agreements (PPA), and self-generation projects.

Retailers tariff alternatives consider time-of-use, demand and flexible tariff structures that can be negotiated. Businesses with large electricity demand usually undergo a PPA getting better contract conditions by committing to long-term consumption. A PPA may have several financial schedules and supply structures. In short, it allows you to negotiate your conditions, such as price scheme and contract term. We encourage you to analyse a 100% renewable PPA to make an effective zero-emissions transition. For smaller scales, partnering with other companies is an alternative to aggregate demand and underwrite a joint PPA as an aggregated buyer group[39].

Finally, consider assessing the installation of renewable energy technologies such as solar PV if you have a roof or land area available in your depot. Several operators we interviewed have, or are installing, such systems. Those projects can be developed as self-generation projects or behind-the-meter PPAs. The first one is procuring the system for your business, incurring an up-front investment. In the second option, a third party pays for and installs the system on your site so that you purchase the electricity during a long-term contract period, acquiring the ownership of the equipment at the end of the agreed period[40].

[38] Angé Anczewska, Will Griffiths, Andrew Hooley, Franziska Korte, Joey Schaasberg, Andre Tibyrica, and Evan Walker. 2021. “2020 Zero Emissions Bus Forum, report and key findings”. International Association of Public Transport Australia/New Zealand (UITPANZ), L.E.K. Consulting and ARUP.

[39] Chris Briggs, Finnian Murphy, and Jonathan Prendergast. 2019. Corporate Renewable Power Purchase Agreements: State of the Market 2019. Business Renewables Centre-Australia (BRC-A).

[40] “Accessing Solar Panel Systems”, State Government of Victoria, 2021, https://www.energy.vic.gov.au/renewable-energy/solar-energy/accessing-solar-panel-system

Depot upgrades

Removing a diesel tank is a common thought when we asked operators about changing their depot to accommodate ZEBs. Operators also noted that for the transition period both battery charging and diesel refuelling would need to be carried out in the one depot. This brings up the consideration for some operators of transitioning a whole depot in one go - vehicles and all. A lot of local factors will impact whether this is actually possible; such as your fleet age, depot location, and the types of bus and coach operations that your business runs. Bus operators with experience in running hybrid vehicles have provided an early insight into this process, effectively running "hybrid depots" which support both the electric and fossil-fuelled aspects of hybrid buses. OEM support was cited by these operators as being critical to the success of hybrid vehicles; we expect that OEM support will continue or increase in importance in a transition to ZEBs.

Although there are some major and obvious differences between diesel and electric buses, zero emission buses will still have tyres and suspension requiring the usual scheduled maintenance and inspection. When introducing new vehicle technologies however, there will likely be a requirement to introduce new tools to your depot. These may range from new mechanical tools to specific diagnostic equipment which helps you maintain new motors and batteries.

Finally, it is relevant to note that strategic location decisions may trigger the migration into new depots. With the transition to ZEB, new technical constraints added would also influence the depot location, such as new access to a higher electricity grid capacity, location of opportunity charge stations, or the need for a bigger space and infrastructure to sustain a hybrid fleet.

Charging, hydrogen and the grid

Dr Roger Dargaville

Zero emission transport including buses will be a critical part of net zero carbon targets. Buses are ideal as they can be decarbonised either with battery or hydrogen powered drivetrains and can carry large numbers of passengers making them more cost effective than individual cars. Challenges arise as electric buses draw significant power when charging, so need to be connected to the grid in an optimal way to maximise use of renewable energy and minimize negative impacts of the grid. For hydrogen buses the challenges are perhaps greater, given that hydrogen refuelling stations are not yet commonplace, but could be a solution as they can be refuelled faster than the battery powered bus. Monash researchers are examining various aspects of these solutions, from onsite hydrogen generation and storage, high capacity chargers with optimised charging patterns, and advanced battery technologies to extend the range of electric vehicles in general. Monash sees its campus as a living laboratory where novel and inventive solutions can be developed and tested before they become mainstream.

Roger Dargaville is Deputy Director of the Monash Energy Institute and Senior Lecturer in Renewable Energy at Monash University.

Planning charge stations as a network

As anticipated by operations, the transition to a zero-emissions public transportation system comes with relevant challenges for the infrastructure requirements and the operation schedule. It is particularly relevant for BEBs to operate as a network rather than individuals as it currently occurs with diesel buses. This is due to the need of balancing the utilisation of the fleet - you will want your buses to be operating as much as possible, with the range restrictions of BEB, since 320km of range within one charge[41] may not last for the entire daily schedule.

From a network perspective, the charging infrastructure must be designed to provide fueling service to the transport network. Therefore, the planning of charging nodes should consider not only depots stations but also in public spaces that have passenger interchanges and therefore some dwell time; such as shopping centres or university campuses. This situation brings a new dimension of opportunities on how to plan the charging infrastructure and even for trading electricity between your buses and the electric grid, accompanied by challenges related to the collective complexities of scheduling and splitting responsibilities on shared infrastructure. These issues are set out in more detail in the next section: operations.

[41] "The Verdict's Still Out on Battery-Electric Buses", Aron Levy, Bloomberg CityLab, 2019, https://www.bloomberg.com/news/articles/2019-01-17/battery-electric-buses-yield-mixed-results-for-cities

Conclusion
Infrastructure Changes

In the transition to ZEB, your depot will undergo significant changes adding the infrastructure required to manage and operate the new technologies. One of them is the way you charge your fleet. BEB creates a new dimension on sizing and managing the charging station. Meanwhile, despite hydrogen being more similar to diesel charging, the infrastructure will require an update. In both cases, the infrastructure used to supply energy needs to be defined to ensure a reliable and smooth operation, whether it is electricity, hydrogen or a combination of both.

Energy supply was identified as one of the elements that operations consider difficult in the ZEB transition, and the reason is clear: although bus operators know how the transport business of diesel buses is managed, changing the source of energy will affect the core of the daily activities. Early stakeholder coordination will trigger actions to initiate the transition and get prepared for the next steps.

Guidance
Operations

Introduction

The previous vehicle and infrastructure sections presented considerations of the material things and energy to run them. This section presents operational factors of the ZEB transition that concern what you do as a bus and coach operator. While the technology and energy changes are profound, operational changes might be less disruptive, though still require consideration.

The provision of transport to customers will still be a focus and while a driver's task will largely be the same as before the transition, the way a ZEB is driven and refueled (recharged) will be different. In this section, we present ZEB considerations that will impact on how you operate routes and charter, purchase and maintain vehicles, negotiate contracts and relate to governments.

Passenger experience

A zero emission bus will almost certainly be electric drive, and so offers passengers a different experience. This is felt on board as a quieter ride with less vibration and fewer smells from fuel and exhaust. These same benefits are shared with people on the street who aren't on board the bus. For both of these reasons, the passenger and community experience of ZEBs is noted by the Victorian Government as a benefit of the transition from diesel. Passenger experience is a factor that might be reflected in a contract of operation, as it is already explicitly reflected in contracts for PTV route services. It may also be assumed, or important but not measured in other types of operation such as school bus services. In the case of school buses, talking to the school about the benefits of ZEBs should be part of contract discussions, so that they can understand the benefits to their students and community.

Harmonisation of standards

When we consider the adoption of new technology, one of the big challenges can be deciding which to select. Within this selection, the role of standards and industry norms influence our decisions. As ZEB technology becomes more available and new players enter the market, regulators must strike a balance between being open to foster innovation, while also imposing standards to ensure that the available choices operate to a minimum level of performance. This is also the chance to achieve economies of scale, often through ensuring cross-compatibility.

How Australian standards harmonise with other global regions is also important - as these other regions make up the majority of our supply chain. Australian Standards are actively harmonised with ISO standards so consider this as part of the decision making process, especially any consideration of non-ISO parts and technologies.

Driver training

> **Dirt cheap to run in comparison to a diesel and a lot of fun to drive.**
>
> *- Victorian Bus Operator*

Early adopters who we interviewed reported that the driving characteristics of a ZEB are fundamentally similar to a diesel bus. This means that a small amount of training is needed to translate good diesel driving to good ZEB driving to ensure a safe and comfortable service. The subtleties of a ZEB, such as driving to conserve and regenerate energy and the availability of peak torque at zero speed mean that drivers with more experience behind the wheel of a ZEB could realise more benefits from a ZEB system - be they financial, environmental or human benefits. Changing driving style to recover more energy from the stopping process is one example of this.

Depot crew training

Support from vehicle suppliers such as chassis and body OEMs are important factors in how you prepare your maintenance and repair team for the transition to ZEBs. Consider the changing role of auto electricians. A transition to electric drive will see this role changing focus from the electrical systems in a bus, to almost the entire traction system as well. Operators we interviewed noted that it was easy to identify workshop staff who did, and did not, have interest and capacity in upskilling such as this. High voltage work enters the frame, and may be specifically ruled out by vehicle OEMs for work in your depot because of safety considerations. Training and upskilling your maintenance team will need consideration in consultation with your vehicle suppliers.

In addition to your team who work directly on the vehicle, the way in which you schedule refuelling will change considerably with the introduction of batteries or hydrogen. While eventually the task of diesel refuelling will disappear, it will be replaced by new tasks to get energy stored in your vehicles, and this will have knock-on effects throughout your depot such as moving vehicles around during charging periods or consideration of weather and air conditioning loads. As one operator reflected in the interview, the depot team consisted of a few “early adopters” whose success and interest in new hybrids stimulated interest from the rest of the team:

> **Engaging the ‘correct’ staff is important in early transition stages. You need to find people who were interested in driving the new technology or servicing it. Then others became more interested and wanted to also get involved.**
>
> *- Victorian Bus Operator*

Infrastructure maintenance

Charging infrastructure is used intensively, and so like a bus requires general and periodic maintenance to ensure its long-term operation. Regular maintenance involves checking that plugs are securely placed on their slots, the condition of the different parts, and cleaning the equipment. The equipment manufacturer often delivers periodic maintenance, including a deeper check of electric and electronic (and gas in case of hydrogen) components[42]. It is also relevant to understand the scope and responsibilities of the warranties provided since failures may occur due to technical malfunction, instal issues, incorrect operation, or site host problems (e.g. electrical grid disruptions).

[42] "Charging infrastructure operation and maintenance", U.S. Department of Energy. n.d., Accessed August 29, 2021, https://afdc.energy.gov/fuels/electricity_infrastructure_maintenance_and_operation.html

Contracts of operation

Contracts for bus and coach operations are likely to be an important part of transitioning and may reflect some of the constraints of this major change in energy source. The differences between public transport route services, contracted school services, charter and long distance coach services each have their own contract duration. They also have different characteristics such as daily distance, refuelling/charging opportunities, and how much the market is willing to pay for the service. In some situations, the higher upfront cost and lower life cycle cost of a ZEB to a diesel bus will need to be figured into your business planning and perhaps even into contract negotiations. Some contracting parties might be willing to pay more for a zero emission service if it aligns to their own business objectives, whereas others might not. This will also be impacted by policies at all levels of Government as they pursue emission reductions.

Route and run characteristics

Adding energy considerations to transport planning is taking an already complex task and making it even more so. The storage capacity of batteries and hydrogen tanks on a bus, and the availability of top-up energy during shifts could require changes to some routes or common charter runs. Long distance charter and regular long distance coach services have unique energy needs too - namely that there are longer distances to travel between possible recharging points. This will impact your choice of technology. At present, hydrogen seems more appropriate for long distance, however the technology is still not widely adopted or widely available.

Route operations in metro or regional centres have an advantage in that the route distance and daily runs are known and planned, so charging can be scheduled in ways that might be similar to driver breaks. An important consideration when thinking about route or run length in terms of energy needs is to factor in the varying energy needs of air-conditioning, which in seasonal extremes can demand as much energy per hour as traction[43].

[43] Göhlich, Dietmar, Tu-Anh Fay, Dominic Jefferies, Enrico Lauth, Alexander Kunith, and Xudong Zhang. "Design of urban electric bus systems." Design Science 4 (2018).

Roles of government

One of the problems with an industry transition like this is that it will be affected by the decisions and policy of all three levels of Government. Governments can be observed to use non-technical means such as policy and regulation to increase uptake of the technical solutions; such as our present situation with ZEBs. While we can't predict the future with certainty, it would be useful to consider that new policies, requirements, and support are likely to appear in the next few years.

Nationally we have seen emissions trading schemes introduced and then stopped as governments change. At the time of writing this advice, the current Federal Government has committed to net zero emissions by 2050, but the manner in which this will be achieved remains unclear.

At the state level, it is clear that the Victorian government's announcement to purchase only zero-tailpipe-emission vehicles for public transport routes from 2025 is having an effect on future planning for the industry statewide, as well as for individual businesses. State controlled factors such as transport, energy, business, education and training as well as contracts of operation for bus and coach services mean that the Victorian Government has a direct role in the transition.

Locally, many of the ZEB transition changes will require input, collaboration and approval. Bus depots can be large sites which mean that bus operators play an important role in all communities whether urban, regional or country. Since transport is so closely connected to our communities, we can expect that local governments will be interested in ways that a ZEB transition can, for example, enhance quality of life in light of how it will also necessitate changes to infrastructure. Local governments were some of the first among all levels of government to introduce emission targets and indeed are well placed practically to achieve them.

[44] Moriarty, Patrick, and Damon Honnery. "Greening passenger transport: a review." Journal of cleaner production 54 (2013): 14-22.

Local councils as a key partner

Professor Michael Kennedy OAM

As the level of government closest to the people, local councils have for many years been playing a practical leadership role in addressing climate change, across Victoria and across the world, responding to the aspirations of their local communities. Councils have not just talked about it, they have gotten on with it. Purchasing sustainable energy, facilitating waste re-use and recycling, purchasing electric vehicles, addressing the challenges of extreme weather, bushfires, droughts, flooding and coastal erosion, are just some of the issues that I was involved in addressing, in my years as a local government chief executive, with increasing public transport use and reducing car dependence always a key priority.

Zero emission buses will run on local roads, will be recharged at depots (and potentially shopping centres, schools and other locations) subject to local council controls and, most importantly, they will serve local communities, who are keen to see climate change being addressed. Local councils will be a significant player in the installation of the necessary electric charging infrastructure or in ensuring the future provision is provided for, therefore it will be critical that this is considered when councils design our local projects.

Early engagement and a partnership approach, by bus operators with local government, will develop a shared understanding of the challenges and opportunities, allowing them to be planned for and budgeted for, and for the local community to be a part of what will be a significant and very positive shared opportunity, to do something practical for the future of the planet.

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Roles of institutions

Bus and coach operations are likely to change in some ways, even though there are elements of transport services which passengers would like to keep the same. The technological changes of ZEB operations could have an impact on operational contracts - their content and duration for example. The lifespan of a bus is already a consideration for business, and linked to contracts, but a new factor for consideration is the separate lifespan of a battery, which most often has a shorter time period than the bus chassis and body. Negotiating new forms of leases, purchases, and business contracts will require the support from the industry association. As you start to purchase, and perhaps generate and even sell, substantial amounts of electricity, a new form of energy contract will form a substantial part of a bus operation business.

Victoria is well resourced through connections of BusVic and other associations worldwide, and has local expertise in key issues to the ZEB transition such as transport, energy, business and optimisation through universities, and to training through the university and TAFE sector. Engaging with these institutions will aid the transition to ZEBs as they are equipped to support aspects such as training staff in new technologies. Victoria is also home to industrial expertise in the form of bus body builders and component suppliers.

Finance Structures

When we switch a bus or coach from diesel to electric power, we are entering a new energy market. This has impacts on the bus, depot and charging technology, as well as on how businesses are structured financially[45].

Batteries and hydrogen fuel cells appear to have different lifespans than bus chassis and bodies. This will change how you model total cost of ownership. There is a tendency in ZEB operations to manage them as separate parts, and as such battery leasing has emerged as a possible solution. Much like the investment in a mid-life refit, a battery replacement is a significant undertaking. With this technology change come some new business opportunities such as structuring new businesses as vehicle leasing companies, or renewed maintenance contracts as part of vehicle purchase agreements. Second-life and end-of-life agreements for batteries are a substantial cost and environmental concern and we encourage you to ask any potential supplier about battery replacement, second life, and recycling.

In addition to vehicle and depot costs, there are varying models worldwide for the ownership of charging equipment, as well as different ways to purchase energy. The opportunity to buy electricity at different times of day and indeed to sell it too, could be a new revenue stream for bus operators when we consider the amount of battery power that may be idle overnight, and in the daytime interpeak period. Several bus operators we interviewed stated an interest, and commencement of building their own energy generation facilities, for example large-scale rooftop solar at their depots.

[45] UITP, 2021. Knowledge Brief: Large Scale Bus Electrification, the impact on business models. UTIP Brussels.

Opportunities and challenges for ZEB operation

Professor Graham Currie FTSE

The transition of the bus fleet to zero emission vehicles presents a range of opportunities and challenges to Victorian operators. The opportunities lie in reinforcing the industry's environmental credentials. Addressing climate change is becoming a new priority for all Governments.The bus industry needs to reinforce its environmental social licence to operate by being seen to be as green as electric rail. There are also real ridership benefits; older buses are often perceived as noisy, smoky and smelly while electric buses are quieter and clean with often better ride quality. Another reason operators need to 'get on board' with ZEBs is that they will soon have no choice. Of course there are numerous challenges for implementing ZEBs; the authorities that will mandate them have little practical experience in their implementation and it is bus operators who will have to get them to work in practice. Rescheduling, staffing and resourcing scheduled services for a shorter range vehicle will be one of the many big tasks to achieve a successful transition. There are also significant challenges in implementing recharging infrastructure, in managing battery life and longevity, safety, training and staffing. Operators need to ensure Governments appropriately reimburse them for the electric bus transition since the financial risks are significant.

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Rate and scale of transition

Australia's ambition is to achieve net-zero carbon emissions by 2050[46]. This will involve a near full scale transition of the bus and coach fleet to zero-emission energy sources and might practically be considered a full-scale transition. The way our industry works towards this goal is the issue currently in our hands.

Cities such as Shenzen in China, have completed a transition to ZEBs, and many others, for example Copenhagen in Denmark are well on their way. Unfortunately, most of these example cities are large so they may not serve as perfect examples for Victorian operators in regional and country areas. Likewise, many are large-scale publicly run bus operations and so have different operations to privatised services. Early adopters in the transition have worked through the various risks of being early to market and to a large extent Victoria's relatively late entry to ZEBs means that we stand to benefit from more mature technology. In a global sense, the vast majority of bus operators in Victoria will be "late adopters" of ZEB technology. In a global sense however, there remains the question of how quickly we transition. This needs to be considered at the level of business planning, single buses, groups of buses, and at a depot level. It might be simple enough to implement one ZEB using battery power, though it becomes more difficult when that number grows. Then the organisation of your depot and grid upgrades become more important issues to consider. The precedent for this type of planning is how the industry has progressively introduced more fuel efficient and cleaner EURO5 and EURO6 specification buses - with depots, staff and drivers keeping up with this technology through training.

The rate of transition is also affected by the age of your fleet and vehicle replacement plans; themselves related to whole-of-life cost considerations and any existing plans to invest in mid-life refits. At present there are few Australian market options[47] which can refit a diesel bus as a ZEB, but this may change as this market grows and expertise is transferred from places where the ZEB transition is advanced.

[46] "Australia's whole-of-economy Long-Term Emissions Reduction Plan", Australian Government Department of Industry, Science, Energy and Resources, 2020, https://www.industry.gov.au/data-and-publications/australias-long-term-emissions-reduction-plan
[47] For a European example see: https://www.sustainable-bus.com/news/france-has-now-recognized-the-retrofit-from-ice-to-electric-powered-vehicles/

Fleet obsolescence

Emission reduction targets will have an overarching effect on the lifespan of a bus. The directness of this effect will correlate with the directness of Victorian policy around public transport bus procurement. The current approach to bus retirement is usually a mix of three main views on what determines the “life” of a bus[48]. First, economic life - where a bus is retired at the time which minimises life cycle cost. Second, physical life - where the bus is retired at a point where physical reliability and maintenance become unreasonable for your business. Third, functional life - where for example some buses become obsolete because they no longer meet disability access standards. The ZEB transition is an example of functional life, and although a bus may have some physical and economic life left, it is becoming obsolete with regard to emissions.

Government policy at federal and state levels has a direct impact on the obsolescence of vehicles and associated equipment such as diesel fuel supply. Essentially that is the point of a planned transition; that with a view to anthropogenic climate change and our aim to decrease emissions these vehicles are becoming, or are already, obsolete. When we consider the embodied energy in a bus - the energy used to make the materials and manufacture them into a vehicle - there is also the potential for waste. The rate of retirement and obsolescence will depend on the age of the vehicle, the rate at which we need to achieve ZEB operations, and of course the range of other factors we’ve identified in this report such as cost and skills. The introduction of ZEBs will create a substantial opportunity for the update of rail-replacement standby fleets, which may help to recover costs of an early vehicle retirement from daily duty. The government mandated transition could also accelerate a glut of functionally obsolete, but economically and physically operational buses in the secondhand and scrap markets. There is no single moment of embracing ZEB fleets in Victoria - hence our use of the term “transition”. How you plan to retire your vehicles, or use them in different ways, will be part of this transition and will be different across bus operators.

[48] Vuchic, Vukan R. Urban transit: operations, planning, and economics. John Wiley & Sons, 2017.

Conclusion
Operations

The ZEB transition adds a range of new considerations to something that was already complex. Many of these considerations are new, and while you may have read about them, planning and executing them is the big next step. Our survey and interviews with Victorian bus and coach operators revealed that there are differences in approaches to the ZEB transition across fleet size, location (for example metro, regional, country) and types of transport operations. Beyond these differences, the more individual aspects of your operations such as depot location and the availability of skilled labour in your region will affect how you approach an operational transition to ZEBs.

Summary
Section Two

In this section we've presented the range of considerations from the literature that will provide a well informed starting point for operators at the beginning of the transition, and hope to have provided some new considerations for those already on the way.

The guide is a starting point, although by no means represents everything that the ZEB transition will involve. There are a range of technology options on the market already, and within those, many further options for how they are implemented. Some aspects are still unclear such as whether in the future we will generate our own hydrogen at the depot using electrolysis, or if hydrogen will be available in bulk quantities. Likewise the mixture of battery chemistries on a vehicle to reflect local conditions is not yet determined. Where the chassis, bodies, fuel cells and batteries are manufactured may itself change during the transition.

Infrastructure for ZEBs might be a more obvious change than vehicles, since the phasing out of diesel as an energy source needs to be replaced with new equipment. Filling a bus with energy becomes a different task, which in the case of battery buses will take more time. Depending on operational demands it might make sense to fill buses at night, or in shorter recharge or top-up periods during the day. Electrification of buses, through batteries or hydrogen will place new demands on the existing grid and also require the introduction of a new hydrogen supply chain that is only just emerging as this guidance is being written.

In operations we have presented how the new vehicles and infrastructure are put to work. Although aiming to produce the same service - transport - the manner in which this is planned, contracted, paid for, and maintained will change in line with the hardware. In a global sense, Victoria is late to the ZEB transition, so we stand to learn a lot from our neighbours who have made, or are making, the transition.


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Handbook Summary

Known unknowns

A key issue heading into change of any kind is knowing what may lie ahead. In the case of the ZEB transition, any “unknown unknowns” that we can’t see make it difficult to plan. While the need to transition from fossil fuels to zero emission buses is clear, the manner in which this might be done is less clear. We can expect some guidance, even requirements, to come from regulators, but there are also many decisions to be made within your business. These will vary depending on your circumstances and go well beyond variation in geography, types of services you operate, and the contracts you maintain. To deal with this variation, we have aimed to fill this handbook with information from several sources; first studying similar ZEB guidance from reputable international sources, second, by surveying and interviewing Victorian bus operators, and third by asking experts to add perspectives from their fields as they relate to bus operations.

International guidance and evidence shows that the technology for ZEBs is available, and is either exceeding, or approaching cost parity with diesel. Hydrogen is viable and nearing mass market availability. In some cases, we have found that it is not a question over the availability of technology but rather a question of technology selection and the timeframes for implementation that is of most concern to Victorian bus operators.

In writing the guidance in this handbook, we’ve translated broad guidance to the more specific demands of Victoria where necessary. While there are many issues presented in this book, we know that several operators are well advanced in the transition and are already familiar with them. For readers who have been reminded of considerations they already know, the references provided should offer a starting point for further reading. The main task of this handbook is to reduce the number of “unknown unknowns” and while some of the decisions are large scale and long term, the initial step this handbook aims to provide is to make them “known unknowns”.

BusVic
Bus Association Victoria

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