Victorian Department of Transport and Planning

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Battery Electric Bus Guidance Document

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Battery Electric Bus Guidance Document

Victorian 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.

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Glossary

AC	Alternating Current
BEB	Battery Electric Bus
BESS	Battery Energy Storage System
BMS	Battery Management System
CCTV	Closed-Circuit Television
Charging cabinet	Cabinet containing equipment that manages power supply to feed electric vehicles via a charging dispenser.
Charging dispenser / dispenser	The dispensing unit that connects the charging cabinet to an electric vehicle, including all cabling (i.e., plug-in and pantograph).
Charging System	All charging equipment downstream of the main switchboard comprising the charging cabinet, charging dispenser and other equipment required.
CMS	Charge Management Software
CNG	Compressed Natural Gas
DC	Direct Current
DMS	Depot Management System
DEECA	Department of Energy, Environment and Climate Action
DNSP	Distribution Network Service Provider (for example, Powercor)
DTP	Department of Transport and Planning
EV	Electric Vehicle
FAQs	Frequently Asked Questions
HFCBs	Hydrogen Fuel Cell Buses
HV	High voltage
HVC	High voltage customer
HVAC	Heating, Ventilation, and Air Conditioning
ICE	Internal Combustion Engine
ISO	International Organization for Standardization
LFP	Lithium-ferrous-phosphate
Li-ion	Lithium-ion
LV	Low voltage
MVA	Megavolt amperes
MW	Megawatt

NMC	Nickel-manganese-cobalt
OMS	Operations Management System
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
OPEX	Operating Expense
PV	Photovoltaic Solar
SOC	State of Charge
ZEB	Zero Emission Bus
ZEV	Zero Emission Vehicle

Executive summary

Victoria is transitioning its bus fleet to Zero Emission Buses (ZEBs). From 2025, all new public transport bus purchases will be zero emissions in line with similar programs nationwide and worldwide. Zero Emission Buses (ZEBs) have zero tailpipe emissions, currently achieved by Battery Electric Buses (BEBs) or Hydrogen Fuel Cell Buses (HFCBs).

This document outlines essential information and considerations for a bus operator to successfully transition their fleets from diesel to battery electric buses, which will be the focus of the Victorian ZEB transition in the short term. It has been commissioned by the Department of Transport and Planning and prepared by the Department's technical advisor, WSP, to support and guide all Victorian bus operators in the transition to ZEBs.

The Zero Emission Bus Transition Consultation Paper released by the Victorian Government in August 2023 acknowledged the critical role of the broader bus industry, including operators, in realising the benefits of this transition. Bus operators in Victoria vary in size; around twenty operators with larger fleets across multiple depots run more than 80% of contracted buses in metropolitan and regional centres. In rural and regional Victoria, many smaller operators often operate school bus services and may use public open space or private property to park buses when not in use rather than depots on commercial or industrial land.

Three key physical components of a successful BEB system – facilities, vehicles, and charging infrastructure working together – are illustrated in Figure ES.1, underpinned by people and systems:

1 **Vehicles (bus fleet)**: In this guidance document, BEBs.

2 **Charging infrastructure**: All necessary charging infrastructure at the depot, along with electricity grid upgrades.

3 **Facilities (bus depots)**: Depots where the fleet is maintained, stabled, and charged.

4 **Systems**: All necessary systems including software for managing bus operations.

5 **People**: Including (but not limited to) drivers, maintainers, schedulers and all the other people needed to successfully deliver bus services.

Figure ES.1 Zero emission bus system

Some bus system elements, such as timetabling, ticketing, driver rostering and cleaning, are beyond the scope of this document. This document explores:

— **Battery electric bus 101**: An introduction to BEBs, with essential information on the buses themselves, along with power and charging infrastructure. (Subsequent chapters provide further detail.)

— **Depot conversion:** An overview of the key aspects of a BEB depot and charging infrastructure.

— **Operational considerations:** The transition to BEBs will require operators to consider how they plan, manage, and maintain their BEB fleets.

— **Safety:** Safety considerations that are markedly different for BEBs, including the need for training, risk assessments, and managing the different fire risks that BEBs pose.

— **Timing and staging:** How a risk-based approach to transition planning can identify lead times, and inform a staged approach to transition.

Key guidance includes:

- **Technology type**: Based on the currently available technology, BEBs will best support the initial transition to zero emission buses from 2025. Once the production of green hydrogen is well-established (expected to be a 2030+ horizon), HFCBs may have a greater role in the ZEB transition (see Section 1.2).
- **Interoperability:** Ensuring that BEBs can seamlessly operate just like the buses they are replacing is a key outcome of the Victorian transition. Buses using CCS2 charging will maximise their interoperability (see Section 1.7).
- **Power supply:** The extent of grid upgrade works required depends on available 'spare' capacity in the local distribution network; this will be different from site to site, and can only be confirmed by liaising directly with the relevant electricity DNSP for the area. It typically takes up to two years from the first enquiry's date for upgrade works to be completed, so planning and consultation should begin as soon as practicable (see Section 2.3).
- **Power type**: DC charging is preferred over AC charging in most cases (see Section 2.4).
- **Charging technology/dispenser**: There are four main methods of connecting the bus to a charger, each with their own strengths and weaknesses. Smaller depots, without major space constraints are generally well served by ground mounted plug-in solutions as these are typically the simplest to implement (see Section 2.4).
- **Parking:** As BEBs will typically charge in their parking bays, parking at depots must be formalised, the addition of charging infrastructure will also reduce the space available for parking (see Section 2.7).
- **Range and service planning:** Experience to date in Victoria and New South Wales has demonstrated that start-of-life BEBs have not had range issues. Operators should understand and monitor their BEBs' power consumption to inform service planning, and consider scheduling buses to runs, as well as drivers to shifts, to ensure all services can be delivered (see Section 3).
- **Maintenance:** BEBs have significantly less maintenance requirements compared to ICE buses, and may lead to changes in the depot's maintenance approach (see Section 3.4).
- **Training:** Operators have extensive experience, so training can be focussed on the key points of difference relating to BEBs without requiring operators to change their broader staff-training approach. BEB transitions are taking place nationally and globally, with lessons learned from other jurisdictions emerging and being made available to DTP. DTP will continue to work with its stakeholders, including in other states, as training programs develop and requirements are better understood (see Section 4.1).
- **Fire safety:** The transition to BEBs changes the nature of the fire risk for bus operations. These risks can be safely managed by monitoring buses and batteries, and ensuring bus depots are suitably designed (see Section 4.3).
- **Lead times:** The activities associated with transition have lead times, which must be managed properly to avoid preventable delays (see Section 5.2).

Document focus

This document offers a technical guide for battery electric buses (BEBs), their supporting systems, and depot conversions in a Victorian context. It provides general information on typical situations and technology, acknowledging that unique circumstances exist.

Contents of this document should not be perceived as recommendations, or as prescribing one way of any practice: this is general guidance that should not replace specific site advice for operators. This document was prepared considering the Victorian Government's 2025 ZEB transition policy.

Areas of focus within the document are outlined below.

Category	Core focus of document	Within broader transition context, but not a focus of this document
Buses	— Rigid — Public transport	— Double-decker — Coaches — Articulated
Charging systems	— Ground-mounted Plug-in — Overhead Plug-in — Pantograph Down	— Induction — Pantograph Up
Fuel systems	— Electric — Diesel	— Compressed natural gas (CNG) — Hybrid Electric — Hydrogen
Operating areas	— Metro — Urban — Regional	
Power	— Grid — Solar — Battery energy storage systems	— Wind

1 Battery electric bus 101

Understanding the basics best places operators to make informed decisions for procurement, infrastructure investments, and long-term planning. This chapter covers basic information on battery electric buses (BEBs) for bus operators' reference as they consider transitioning their fleets. This includes:

- What BEBs are, and how they're different from internal combustion engine (ICE) buses (Section 1.1).
- Why the current focus is on BEBs, rather than hydrogen fuel cell buses (HFCBs) (Section 1.2).
- All the factors to consider when planning a transition to BEBs (Section 1.3).
- Key electrical considerations (Section 1.4).
- The different technologies used to charge the buses (Section 1.5).
- The basics about the batteries powering the buses (Section 1.6).
- Approaches to interoperability to ensure BEBs can seamlessly operate just like the buses they replace (Section 1.7).
- Value-for-money considerations that may make constructing a new depot a more pragmatic approach than converting an existing site (Section 1.8).

1.1 The basics of zero-emission and battery-electric buses

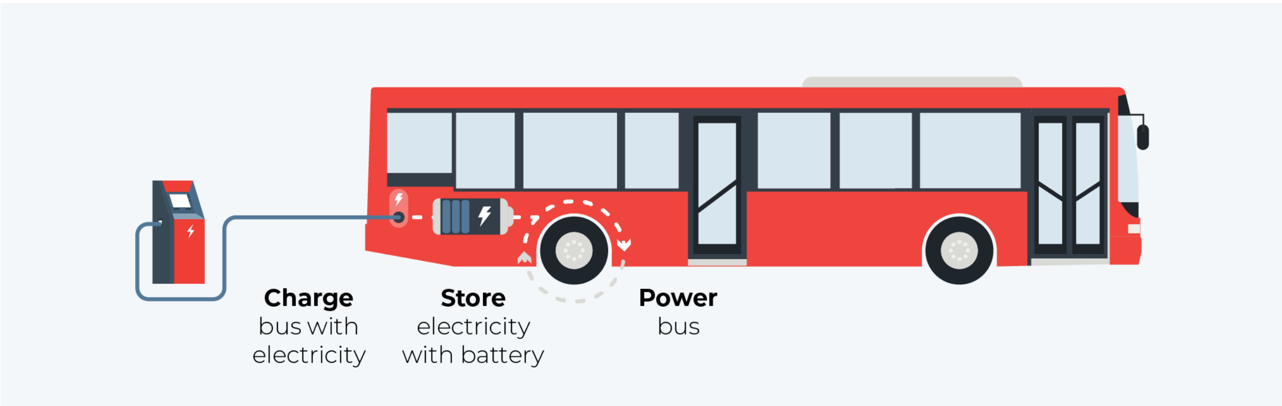

Figure 1.1 An overview of how a battery electric bus is charged and consumes its charge

Battery electric buses (BEBs) are a type of zero emissions bus (ZEB) with zero tailpipe emissions, achieved by storing energy in an on-board battery that powers one or more electric motors (see Figure 1.1). Compared to internal combustion engine (ICE) buses, such as diesel or compressed natural gas (CNG), BEBs help reduce greenhouse gas emissions from public transport, while simultaneously reducing bus noise and vibrations.

Figure 1.2 illustrates the key components of a successful BEB system, further explained in Table 1.1.

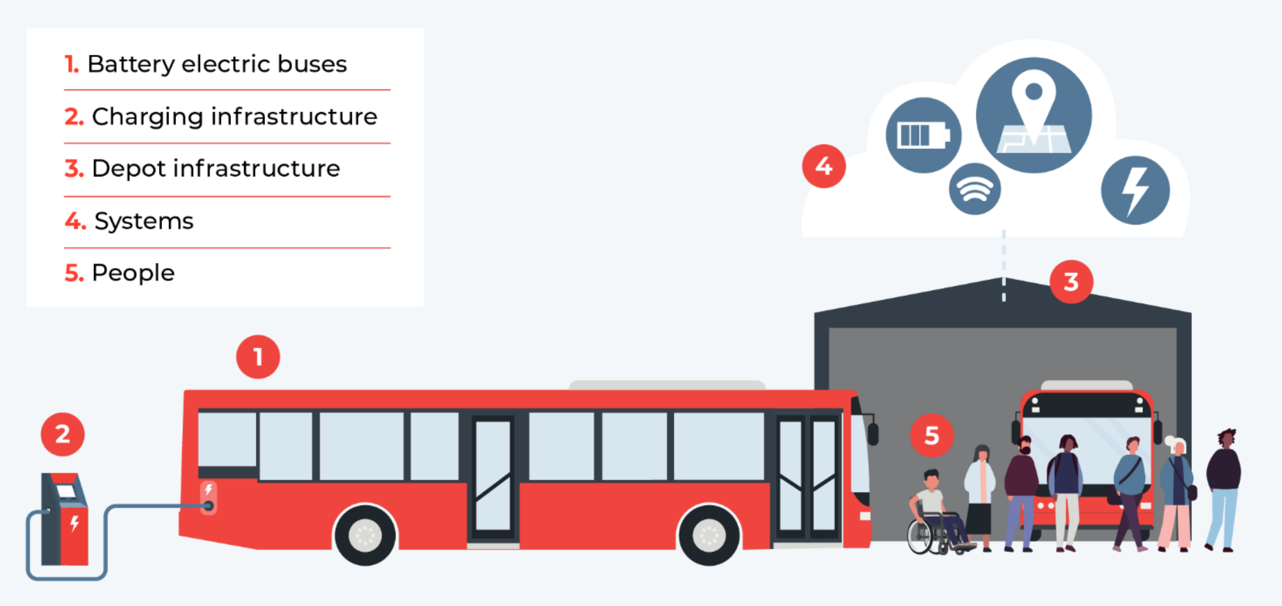

Figure 1.2 BEB system components

Table 1.1 BEB system components explained

Component	Explanation
1 Vehicles (Fleet)	This guidance document focuses on a ZEB fleet comprising BEBs. Alternative ZEB options such as hydrogen fuel cell electric buses (HFCBs) may become viable in future but are not yet readily available for mass roll-out. Over time, Victoria's bus service network may see a mix of these and other yet-to-emerge ZEB technologies, recognising the continuously evolving technological landscape (Department of Transport and Planning, 2023).
2 Charging infrastructure	All infrastructure at the depot, including cabinets housing the chargers, dispensers, and on-site power distribution. One critical enabler is electricity distribution grid upgrades, which this guidance document details.
3 Depots	The facilities where the fleets are maintained, stabled, and charged. These will typically be existing depots transitioned to BEBs, but can also include new depot sites.
4 Systems	All the systems needed to successfully operate and manage buses, including: — An operations management system (OMS): an umbrella term for other system functions, such as charge management, depot management, on-board diagnostics, battery management and other operator or DTP systems — Charge management system (CMS); software that can connect to, communicate with, and monitor each BEB and charging unit while integrating with a depot management system (DMS) that schedules dispatching — Any other system required to maintain bus operations
5 People	Including (but not limited to) drivers, maintainers, schedulers and all the people needed to successfully deliver bus services for public transport.

1.2 Why not hydrogen fuel cell electric buses?

Hydrogen fuel cell buses (HFCBs) are an alternative to BEBs. Based on BEBs and HFCBs' current technical and commercial maturity, along with charging/refuelling supply chains, BEBs are the best option to support the transition to zero emission buses for the 2025 horizon. BEB vehicles and supporting technology are proven, well established, including locally in Australia, and are suitable for most urban and many regional applications in Victoria.

HFCBs do have advantages over BEBs – they are lighter, faster to refuel, and not as subject to battery degradation. As HFCB technology matures, they could provide additional advantages in regional depot settings where the power grid upgrades are more difficult. However, hydrogen's current cost and general unavailability currently makes HFCBs a less viable option until green hydrogen[1] production is at sufficient scale.

In line with DTP's *Zero Emission Bus Transition Consultation Paper*, the following reasons further summarise why HFCBs may be an option in the future (Department of Transport and Planning, 2023):

- **Cost**: HFCBs are generally more expensive to manufacture than BEBs, with potentially higher fuel (hydrogen), lifecycle, and refuelling infrastructure costs.
- **Technology maturity**: HFCB buses are proven, but the hydrogen fuel's production in Australia is in its early stages of technical development with ongoing investment needed to reach commercial viability at scale. Studies suggest that hydrogen could become available in sufficient quantities to power public transport from ~2030. Once this occurs, HFCBs may have a greater role in the ZEB transition, especially in rural and regional areas and for longer interstate commutes.
- **Fleet variation**: There are currently limited options in the market, although some established original equipment manufacturers (OEMs) have started developing HCFBs.
- **Current and future fuel-source constraints**: Victoria and Australia have limited hydrogen production, which would need to upscale to support local needs. However, the infrastructure to produce, distribute and store hydrogen is emerging.
- **Range**: HFCBs can offer more range than BEBs, although this is a function of many factors (e.g., hydrogen tank compared to battery size). HFCBs can also be quickly refuelled, while BEBs can take significant time to recharge.

[1] 'Green' hydrogen is hydrogen gas produced using renewable energy sources. It is regarded as the cleanest and most sustainable form of hydrogen.

1.3 Transition to zero emissions

The transition from ICE buses to BEBs involves the interplay of multiple factors and an increased complexity that must be considered for success. The key factors are shown in Figure 1.3 and further explained in Table 1.2.

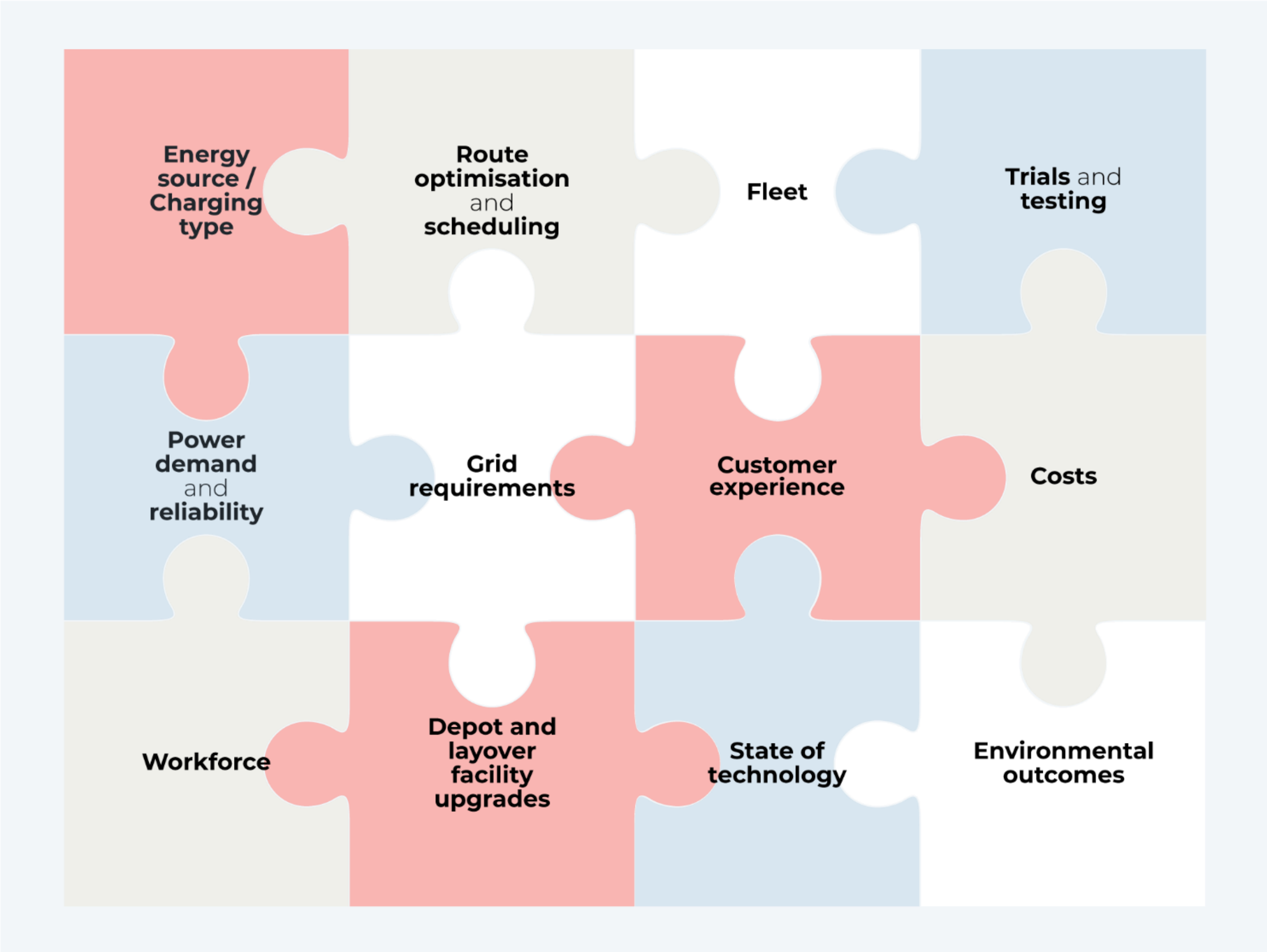

Figure 1.3 Key factors for a ZEB transition

Table 1.2 Key ZEB transition factors explained

Factor	Consideration
Energy source/charging type	Where will power be sourced from, and which charging technology will be selected? This will drive all other fleet and infrastructure decision making.
Grid requirements	Upgrading the electricity grid supply to existing depots is typically one of the transition's most challenging aspects, and requires collaboration with local Distribution Network Service Providers (DNSPs) to ensure sufficient power will be available. On-site energy sources (solar) or storage (batteries) can also be considered to mitigate grid upgrade requirements.
Fleet	Understanding current and future fleet will inform the depot's infrastructure and power requirements. Fleet should be as interoperable as possible to maximise flexibility and operational resilience. Having a long-term plan for fleet will ensure that infrastructure can be delivered without rework.
Route optimisation and scheduling	Existing routes and schedules may need to be optimised to accommodate the transition.
State of technology	Operators can take advantage of upgrades to new technology if/when available.
Trials and Testing	Trialling and testing BEBs, chargers, and systems before a broader roll out can provide confidence that solutions will work for regular operations – (e.g., test bus-charger combinations).
Power demand and reliability	While BEBs potentially offer greater reliability than ICE buses, they rely on an external power supply, and supply interruptions could impact service delivery. Operators may need to implement power management measures to ensure reliable power supply for charging and to minimise the potential impacts of power supply interruptions. Measures could include backup power sources, or planning for interoperability so the fleet can be charged at an alternative location.
Customer experience	BEBs run quieter and smoother, giving passengers a better ride experience.
Depot and layover facility upgrades	Charging infrastructure will be required at depots, and may also be needed at layovers. This will likely reduce the space available for bus parking, and require bus parking to be formalised, which could reduce the depot's overall capacity. BEBs introduce a new fire risk at depots to be safely managed as part of the upgrade. Upgrades should be master planned, allowing future growth to be catered for without requiring rework.
Workforce	BEB drivers, depot operators, and other associated personnel will need training. Examples include training drivers to maximise the effectiveness of regenerative braking, and upskilling maintenance staff to work with high voltages.
Environmental Outcomes	BEBs have zero tailpipe emissions, and are much quieter than the buses they replace, improving noise and environmental outcomes around depots and along bus routes. Emissions benefits are further enhanced when powered by renewable energy.
Costs	BEB operations generally have a lower OPEX – electricity is cheaper than fuel, and maintenance is reduced. However, operators will need manage new costs such as charger maintenance and more manufacturer involvement in bus maintenance. Typically, other OPEX savings more-than offset any new costs.

1.4 Thinking about electricity

When it comes to electricity, bus operators have three main considerations:

1. **On-site electrical distribution/reticulation (electrical works within the depot)**
   - from the meter/main switchboard to charging cabinets around the depot
   - between charging cabinets and the buses (see Section 1.5).
2. **Power (electricity) grid connection (electricity assets outside the depot boundary)**
   - Owned and operated by the local distribution network services provider (DNSP[2]), up to the point of supply
   - In most situations, at least some electricity grid or supply infrastructure upgrades are required, ranging from relatively minor metering upgrades to significant capital works
   - Costs of electricity.
3. **Electricity supply**
   - Electricity is supplied and paid for via a retailer, of which there are dozens in Australia.
   - To realise the full benefits of a zero emission fleet, the electricity should be supplied by renewable sources.

Operators will also need a basic understanding of power terminology, including:

Kilowatts and kilowatt-hours: Power is mostly measured in kilowatts (kW), while power use and storage are mostly measured and paid for in kilowatt-hours (kWh) (see Figure 1.4):

- kW can be thought of as power's flow 'speed', directly related to the time taken to recharge an electric vehicle/BEB (Figure 1.5).
- kWh is the volume of power transferred – also how battery size is measured, much like a fuel tank's size.
- Like ICE buses, the daily energy requirements for a BEB will vary based on their operations, with distance travelled core to overall energy consumption. Typical electricity use in an Australian context ranges between 0.9 kWh/km and 1.4 kWh/km[3] (see Section 3.1 for further discussion).

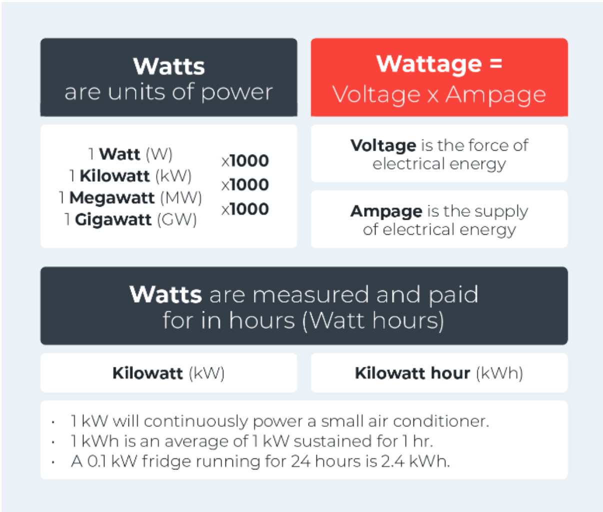

Figure 1.4 Understanding power and watts

Figure 1.5 Refuelling a tank compared with recharging a battery

2 Victoria has five DNSPs: AusNet Services, CitiPower, Jemena, Powercor and United Energy
3 Consumption rate of buses only. Does not consider any energy losses within the depot – e.g., at the charger.

Megavolt amperes: An additional measurement of electricity to be aware of is Megavolt amperes (MVA) representing 1,000,000 volt-amperes. This is how a consumer's maximum electricity demand on the distribution grid is measured. For larger bus depots, (e.g., more than 25 buses), this becomes important as there may be a maximum demand charge measured in MVA, along with the per-kWh charge. Section 2.3.2 discusses tariff structures and ways to mitigate them.

AC and DC Power: The power that is supplied to the Australian businesses and homes operate on an alternating current (AC) power supply. While the power stored in a bus's battery is DC (see Figure 1.6). As batteries store power in DC, the AC power from the grid will need to be converted.

This conversion can happen on the bus (an 'AC bus') or outside the bus (a 'DC bus'). When conversion happens outside the bus, much faster charging rates are possible (see Table 1.3). Some DC BEBs are 'backwards compatible' and can be charged, albeit slowly, by AC charging infrastructure. While initially common, AC-only buses are being phased out by most bus manufacturers (Figure 1.7).

While DC charging infrastructure has a higher upfront cost than AC charging infrastructure, BEBs capable of DC charging present a more resilient technology option that supports rapid charging and future automation for larger operations. Furthermore, DC chargers dominate the bus charging infrastructure market. For these reasons, DC BEBs are recommended in most situations.

AC-only-charged BEBs may have current and future applications in regional and remote areas, in situations where charging speeds are less important and minimising infrastructure costs are prioritised (See Section 2.4 for further discussion).

AC

Alternating current (AC) is an electric charge which constantly changes flow direction. Electricity is transferred from the grid to homes in AC. Almost all homes have AC outlets.

DC

Direct current (DC) is a linear flow of electric charge. Batteries can only store DC. DC charging does not need to be converted, and therefore results in rapid charging.

Figure 1.6 Difference between AC and DC

AC vs DC Charging

Batteries store direct current (DC) while power from the grid is alternating current (AC). To charge batteries, AC power needs to be converted to DC.

For the following reasons, AC charging is being phased out:

- Batteries use DC power. AC charging requires a 'rectifier' on the bus, making the bus heavier. A DC bus can carry a bigger battery, or more passengers.
- DC charging is faster than AC charging
- There is a greater variety of DC charging solutions – these allow for greater flexibility when designing an electric depot.
- Manufacturers are moving away from AC charging

Figure 1.7 AC vs DC charging

Table 1.3 Charging point types and power rates

Charge point type	Maximum power outputs (kW)	Current/supply type
Domestic socket – slow	2.4–3.6 kW	AC – single phase
Standard	7 kW	AC – single phase
Fast	11–22 kW	AC – three phase
Rapid	22–49 kW	DC
	50–150 kW	DC
Ultra-rapid	>150 kW	DC

Note: These are generally accepted definitions, but 'fast', 'ultrafast', 'rapid' are often used as marketing terms and can vary between manufacturers

1.5 Charging technology

In most cases, BEBs will charge for an extended period (typically several hours) with charging infrastructure for each bus, unlike ICE buses that refuel and then park in a matter of minutes. Hence, it is essential to select the appropriate charging technology that aligns with current (and any future) operations.

There are four main methods of connecting the bus to a charger (shown in Figure 1.8): plug-in ground mounted, plug-in overhead, pantograph down, pantograph up[4]. All four are fed by charging cabinets powered from the mains supply. These cabinets vary in power capacity, AC/DC conversion capability, and safety and operational features.

Plug-in chargers consist of manually connected plugs and sockets. Plug-in chargers can be ground mounted or hung from overhead gantries to save space.

Pantographs can be mounted on a gantry and drop down to the bus ('pantograph down') or reach up from the bus ('pantograph up'). These systems require no manual handling and future automation could further reduce the need for human involvement.

Smaller depots without major space constraints are generally well served by ground-mounted plug-in solutions as these are typically the simplest to implement. However, each charging technology has different strengths and weaknesses (discussed further in Section 2.4.3), and operators should consider what best meets their needs.

Whatever the charging method, assuming the BEB has sufficient range to complete its operations, bus charging will most likely occur at the depot. Charging outside the depot ('opportunity charging') could be considered where needed.

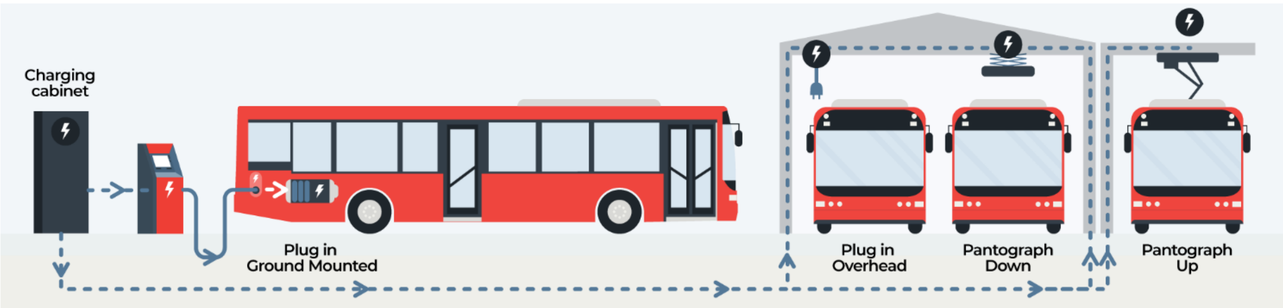

Figure 1.8 Charging technology overview: plug-in vs pantograph

Regardless of technology, charging cabinets and dispensers require regular maintenance and replacement. Operators should consult with manufacturers to understand their selected charging infrastructure's long-term costs and requirements.

1.6 Batteries

A bus battery is integrated into the bus chassis. While batteries are removeable and replaceable, in most cases, this is a major exercise typically only carried out mid-life. Battery technology is changing rapidly to improve BEBs' range, safety and reliability. Improvements focus on energy capacity, stability, weight, longevity, cost, safety, and improvements to charge and discharge rates. Integrating batteries into chassis elements can also offer weight reduction and chassis rigidity benefits.

Based on the BEBs currently available and operable in Victoria, on-board battery sizes range from 300 kWh to just under 400 kWh. A 300 kWh battery is around five times the battery size of a typical electric car (60kWh).

4 Pantograph up charging is not common in a depot environment. Pantograph up is primarily seen on BEBs that regularly opportunity charge en route. These buses are often charged with a plug when at the depot.

Lithium-ion (Li-ion) batteries are the current premier battery technology due to their high energy density, light weight, and ability to deliver enough power to drive vehicle engines. Li-ion is a generic term that covers several different battery types. Common electric-vehicle types include nickel-manganese-cobalt (NMC) and lithium-ferrous-phosphate (LFP).

Current battery lifespans are estimated at about 8-10 years, compared to a typical ICE bus/BEB bus's 20-year lifespan (Department of Transport and Planning, 2023). Generally, total rechargeability decreases over battery lifespans, which impacts ZEBs' achievable vehicle ranges, meaning the bus's travel-range degrades over time.

However, technology is continually improving. In the future, completely replacing a bus's battery may not be necessary: instead, we may be able to replace individual battery cells (a bus battery comprises thousands of individual battery cells). While Li-ion currently dominates battery technologies, alternatives will likely emerge – future batteries may not need lithium.

Battery reuse and recycling is an emerging industry that operators should consider as part of their fleet procurement. At the end of their useful lives powering buses, they still have 'second life' uses (e.g., static use such as electricity storage at an electric substation or for a building), and their raw materials still have value.

1.7 Interoperability: Fleet and flexibility

12.5m diesel buses are highly interoperable – typical bus parking is designed for them, typical maintenance facilities are set up for them, and they can refuel at any diesel bowser. Ensuring BEBs can seamlessly operate just like the buses they are replacing is a key outcome of the Victorian transition, so buses can be easily moved and shared between depots, optimising resource allocation, maintenance, and schedules.

Key considerations to ensure interoperability include:

BEB and charger interoperability – plugs and sockets

Combined Charging System Type 2 (CCS2) has been widely adopted in Australia for light and heavy vehicles (Figure 1.9). Procuring a bus using this standard maximises interoperability as chargers using this standard are common across the country. CCS2 (Figure 1.9) supports both DC (Figure 1.10) and AC (Figure 1.11) charging.

BEBs that can only be charged by an AC charger will use an AC Type 2 plug (Figure 1.11).

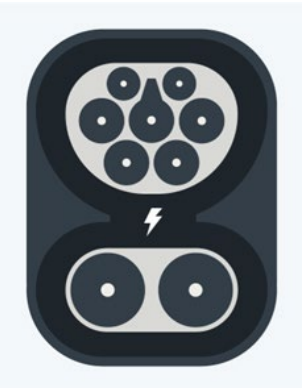

Figure 1.9 CCS2 socket

Figure 1.10 DC plug (CCS2)

Figure 1.11 AC plug (Type 2)

While the plug and socket may fit, this does not guarantee that the bus will charge:

- The underlying software and systems in BEBs and chargers may have compatibility issues.
- A Type 2 plug (e.g., from an AC-only charger, Figure 1.10) into a BEB's CCS2 socket will not charge if the bus is DC-only.

As such, operators should test charger and bus combinations before procurement, or procure known compatible combinations as recommended by the bus or charger manufacturer.

Operators also need to consider the number and location of charging sockets on their buses, and how they connect to the chargers placed in their depot, and ensure buses can be easily plugged in, without cables wrapping around buses or dragging along the ground (Figure 1.12).

Figure 1.12 Cable wraps around bus as socket and charger are not aligned. Potential for damage to cable due to tension, and tripping hazard in depot

BEB and charger interoperability – Open Charge Point Protocol (OCPP)

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. OCPP plays a crucial role in developing an open charging ecosystem across the depots, allowing operators to move and charge buses between depots.

While the technology matures, OCPP does not guarantee that all BEBs and chargers will be compatible – operators should test bus/charger combinations before procurement, or procure known compatible combinations.

Depot layout interoperability

Layout interoperability is particularly important when it comes to parking bay sizes and depot layouts to allow adequate vehicle manoeuvring and charging equipment. Like ICE buses, bus bays of all kinds (e.g., for parking, maintenance, etc) and storage areas, must accommodate the different bus types that would use the depots. This includes enough clearance for features such as parking space layout, adaptability of charging dispenser reach, height of gantries (if used), and pantograph charging reach between gantries and vehicles (if used). Section 2.7 outlines suggested dimensions to be used at the depot.

1.8 Value for money: Upgrade or a new depot?

If the costs of upgrading an existing depot for BEB operation outweigh the costs of establishing a new depot, opting for a new greenfield depot site may present a more pragmatic, value-for-money solution. Establishing a greenfield depot from scratch allows for design to be optimised and environmentally sustainable features, tailored to the specific requirements of BEBs to be integrated. It also avoids the potential operational challenges of upgrading a 'live' depot.

Operators should investigate the following to decide whether they convert their existing site, or consider establishing a new depot in another location:

- **Ground conditions/contamination:** Sites can have contaminated land or other geotechnical issues that are costly to resolve, or can disrupt bus operations. If contamination or problematic ground conditions are identified after conversion has begun, there can be expensive variations to the civil/construction contracts, exposing the operator to additional costs and delays.
- **Underground services:** A site may have complex underground services that require relocation, which can be prohibitively expensive, or add substantial lead times.
- **Electricity grid upgrade costs:** Electricity grid upgrades can be a large cost item when converting a depot to BEB operation. It is usually also the item with the longest lead time – up to two years. Find out and factor the distance to the nearest electricity zone substation (ZSS) and its available capacity, or that of the grid/poles and wires. This can determine whether a greenfield site represents lower connection costs than a brownfield site. Consulting with your relevant DNSP is the only way to confirm – see Section 2.3 for more information.
- **High costs of installing charging infrastructure at a brownfield site:** Site-specific issues can make installing charging infrastructure cost prohibitive or disruptive; for example, existing buildings/structures or space constraints.
- **Insufficient room to accommodate necessary bus fleet at existing site:** BEBs usually take up more space in a depot compared to ICE buses, therefore requiring more room. If there is insufficient 'spare' land then buses may have to be accommodated at another depot.

2 Depot conversion

By having a complete picture of the works that will be needed, operators place themselves in the best position to manage their depots' transitions. This chapter provides information on the key aspects of converting ICE bus depots to accommodate BEBs. This includes:

- A broad overview of the components of a BEB depot (Section 2.1).
- Key considerations when laying out a BEB depot (Section 2.2).
- Guidance on depot power supply (Section 2.3).
- Charging infrastructure basics (Section 2.4), and discussion on charging times (Section 2.5) and charging strategies (Section 2.6).
- Typical dimensions to inform depot layouts using a typical standard low-floor city bus as a design vehicle (Section 2.7).

Conversion timing and staging considerations are covered in Chapter 5.

2.1 Overview

Converting an ICE bus depot for BEBs involves assessing electrical capacity, installing appropriate charging infrastructure, and ensuring safety compliance. A realistic budget and timeline are crucial for a successful transition, requiring coordination among various stakeholders to seamlessly integrate electric buses into depot operations.

Realistic budgets and timelines are made more achievable by a masterplanning process that identifies the depot end state, the stages for achieving this, and the infrastructure required. The process could also identify whether converting an existing depot, or constructing a new greenfield site represents the best value for money (see Section 1.8). By having a complete picture of the works needed, operators place themselves in the best position to manage the third parties (designers, civil contractors, suppliers, DNSPs, etc.) who will be involved in the process.

Typical components of an electric depot are shown in Figure 2.1, and explained in Table 2.1, focusing on charging infrastructure.

Most depots are expected to adopt plug-in charging solutions (ground mounted (5) or cable reel (6), but pantographs may also be suitable (7), Figure 2.1). Pantograph up charging is not common in a depot environment and is not recommended for use in Victoria.

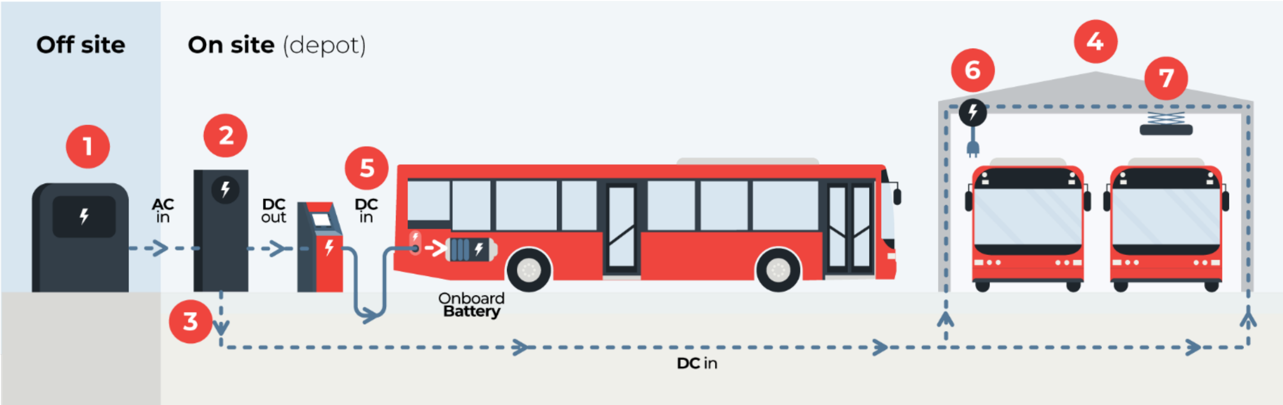

Figure 2.1 Typical components of a depot conversion (charging only)

Table 2.1 Typical components of a depot conversion

Component	Explanation
1 Off-site power infrastructure (grid upgrades)	Upgrades to assets owned by the electricity Distributed Network Service Provider (DNSP), such as at the zone substation, high voltage (HV) feeder lines (underground or overhead), and other infrastructure delivering power to depots.
2 On-site electrical infrastructure	On-site HV and low-voltage (LV) distribution transformers, cabling, circuit breakers, switchgears, and switchboards (not power-supply units or cabinets for charging).
3 Civil & earthworks	Excavation works will be required, such as for installing cable routes, pavements, foundations for gantries or other structural works, and kerbing. Substantial excavation, construction and disruption may occur, and must be planned for and managed.
4 Gantry or other overhead structure	A structure is required for mounting overhead charging dispenser units.
5 Ground mounted plug-in charger	Chargers are either integrated units, or separate power cabinets and dispensers.
6 Cable reel plug-in charger	Cable reel plug-in dispenser and power supply units.
7 Pantograph down charger	Pantograph down dispenser, automatic connections device, and power supply units.

Aside from the charging infrastructure, other aspects of the depot remain broadly similar. Figure 2.2 and Figure 2.3 show indicative BEB layouts.

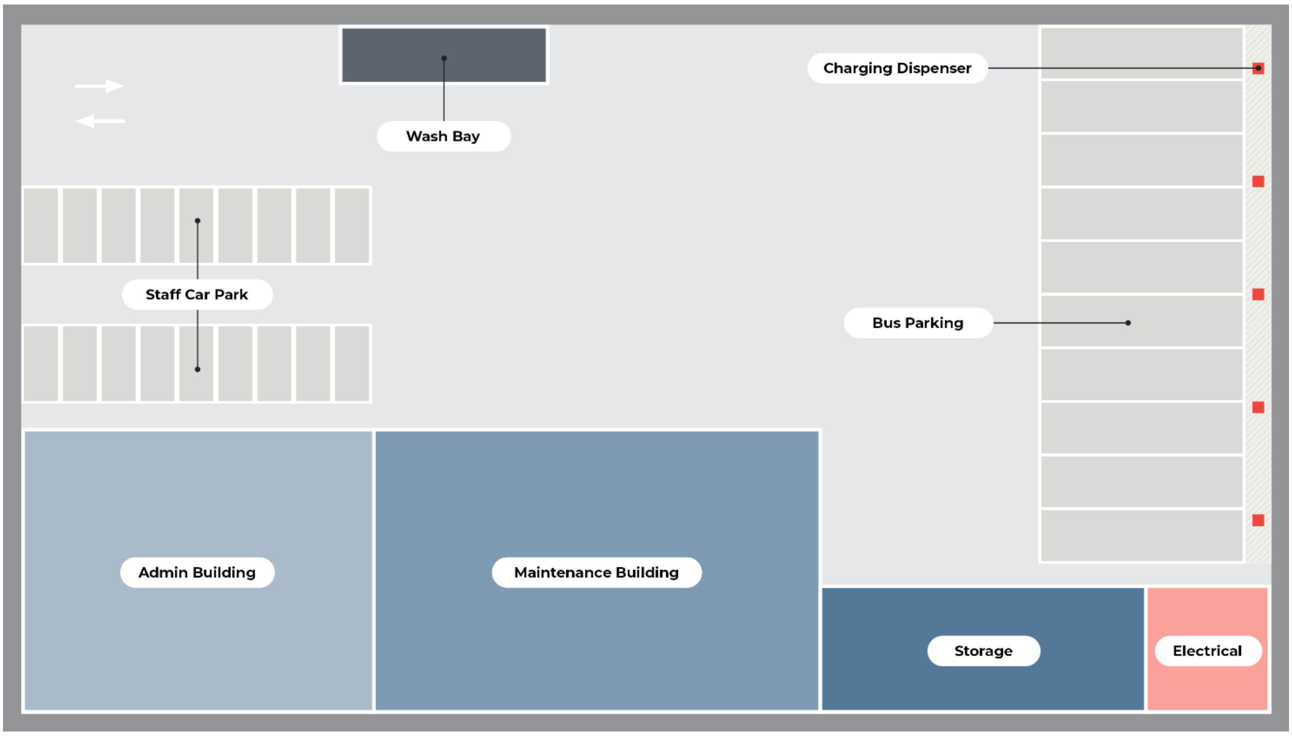

Figure 2.2 Indicative BEB depot layout

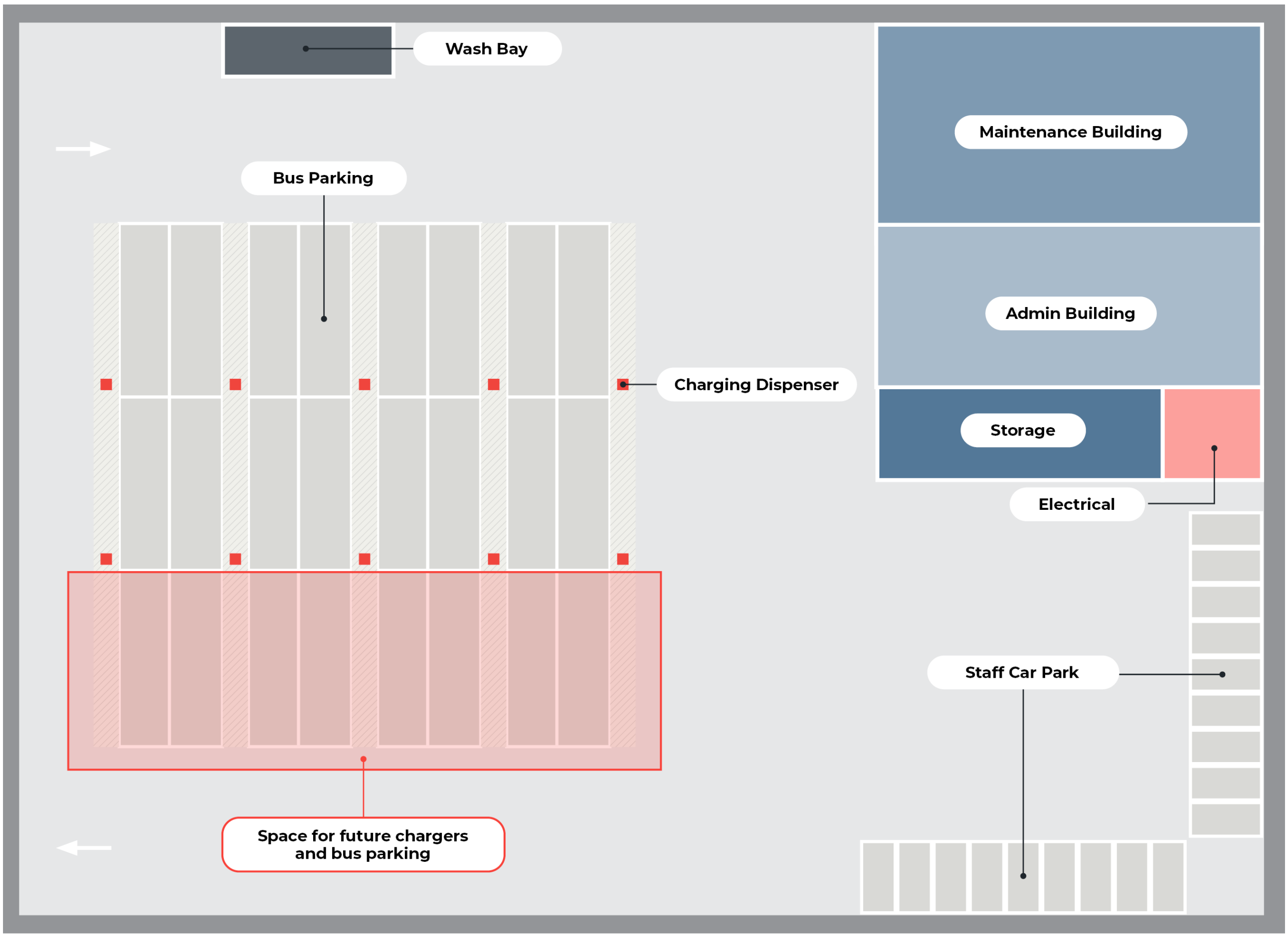

Figure 2.3 Indicative BEB depot layout

2.2 Design approach and key considerations

Key considerations when planning for a BEB depot are outlined in Table 2.2.

Table 2.2 Considerations for depot design

Depot conversion factor	Strategic objective	Considerations
Capacity	Maintain contract bus capacity	— Maximise space efficiency through charging layout, depot circulation, and technology selection — Use redundant space (e.g., fuelling facilities) — Manage loss of space (e.g., for charging infrastructure, additional storage for charger spare parts, etc.) — Formalise bus parking to allow for charging
Operational consistency	Minimise impacts and changes to existing operations	— Retain the variety of contract buses operating within the depot — Minimise changes to bus movement within depot/maximise bus movement efficiency within depot
Operational flexibility	Maximise operational flexibility	— Minimise 'overflow' parking (i.e., bus parking that inhibits the movement of other buses; primarily intended for overnight use) — Ensure buses can enter and leave fast charging bays without having to interact with (queue behind) another bus.
Value for money	Provide value for money cost conversion to ZEB operations	— Maximise space efficiency/depot capacity — Retain existing facilities and infrastructure (e.g., maintenance sheds, pavements, etc) — Minimise demolition of existing structures — Avoid redundant investment by constructing for end-state
Safety	Maintain or improve existing safety levels	— Safe pathways with sufficient widths for walking — Sufficient widths for vehicle turning movements — Planning for battery fire avoidance and mitigation

2.3 Power supply – typical upgrade requirements

While existing bus depots will have an existing power supply and other on-site electrical infrastructure, some power upgrade works will typically be required to provide the additional energy to charge BEBs. The extent of grid upgrade works needed depends on available 'spare' capacity in the local distribution network. **This will differ from site to site, and can only be confirmed by liaising directly with the area's relevant electricity DNSP**. As it typically takes up to two years from the first enquiry's date for upgrade works to be completed, it is critical to start consulting with the DNSP as soon as practicable (see Section 2.3.4).

2.3.1 Upgrades to electrical infrastructure

Upgrade works will most likely include grid connection upgrades, along with electrical infrastructure around the depot supplying power to the charging infrastructure, and from there to the buses. Three common BEB depot grid connection scenarios are illustrated in Figure 2.4.

Scenario 1: LV customer – Depot is an LV customer without any grid upgrades required. **Likely for smaller depots (up to 5 BEBs).**

Scenario 2: LV customer with grid upgrades – Bus depot is an LV customer, but a new HV feeder to a new distribution substation has been built as there is insufficient capacity on the existing network. These substations are often installed on the customer's property. **Likely for depots with up to 25 BEBs.**

Scenario 3: HV customer directly connected to HV feeder – Bus depot is an 'HV' customer (HVC), on an HV feeder, typically 22 kV. Upgrades to zone substation or HV feeders may be required. **Most likely scenario for larger depots (more than 25 BEBs).**

Further detail on the assets within the electrical grid, and their likely upgrade requirements are noted in Table 2.3.

On-site electrical infrastructure including the point of connection (POC), transformers, switchboards, charging cabinets, and dispensers are also indicated in Figure 2.4, these are discussed in further detail in Section 2.4.

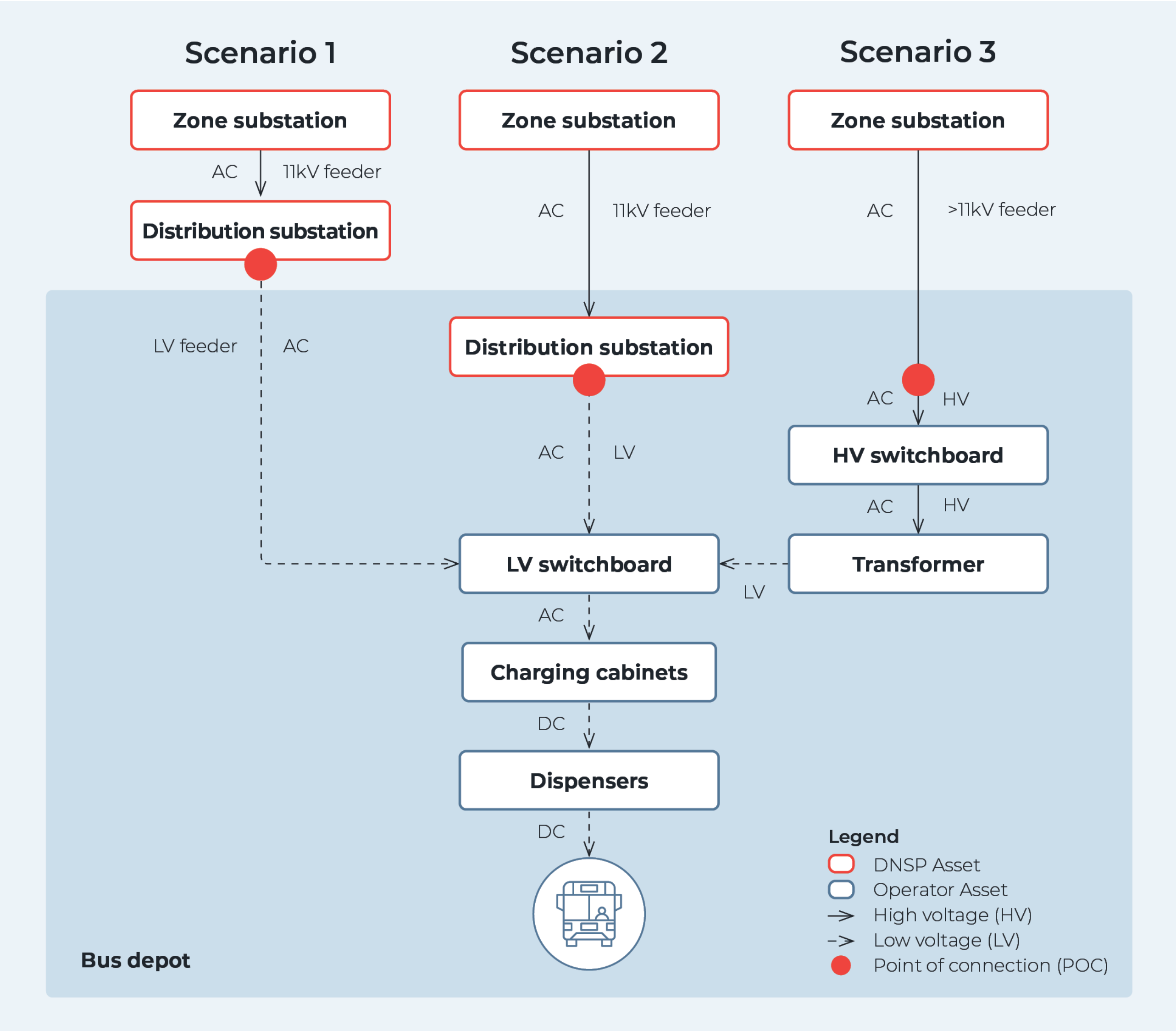

Figure 2.4 Typical power supply scenarios for a battery electric bus depot

Table 2.3 Power infrastructure requirements (typical)

Asset	Description	Likely upgrade requirements
Point of connection (POC)/meter	The meter marks where the distribution grid delivers electricity to the final customer, at the POC. As for other utilities such as water, the meter measures the import and export of energy to/from the depot. The electricity retailer will use the measurement data to bill the depot for its electricity supply.	A new POC / meter may be required.
LV distribution feeder lines	Low voltage (LV) distribution feeders carry power at low voltage (230V) from distribution substations to most businesses and residences. Feeders may be overhead (e.g., bare conductors or insulated cables mounted on poles, generally along the side of streets and roads) or underground (e.g., insulated cables buried under roads and footpaths).	Existing LV distribution feeders will likely only have enough capacity to support small BEB depots (up to 5 BEBs). For most depots, the BEB conversion will significantly increase demand, and LV feeder upgrades or conversion to a high voltage (HV) feeder connection may be required.
Distribution substation	Distribution substations provide the connections between the high voltage (HV) distribution network (typically 22 kV) and the LV distribution feeders that connect to individual customers. Most often, distribution substations are provided by small transformers mounted on roadside poles or (for areas with underground electricity lines) in small ground-mounted enclosures.	Existing distribution substations may have sufficient capacity to support small BEB depots. Larger depots may result in a significant demand increase, requiring a distribution substation upgrade; or conversion to a high voltage (HV) feeder connection (see previous item).
HV distribution feeder lines	HV distribution feeder lines carry power at high voltage (22kV) from the distribution network operator's zone substations to one or more distribution substations and/or high voltage customers. While most HV distribution feeders supply power to distribution substations for onward supply to LV customers, others directly supply large commercial and industrial customers – depots with more than 25 BEBs are likely to have a direct connection.	Depots currently supplied at low voltage, which plan to stable many buses (e.g., more than 25 BEBs, depending on the location), will almost certainly require an upgrade to a high voltage distribution feeder to accommodate the increased energy and power demands of charging multiple buses concurrently. This would mean the BEB depot is considered an 'HV customer (HVC)' (Scenario 3, Figure 2.4). The power and energy demands of smaller HVCs may be within the capability of existing HV feeders; however, larger HVC depots would probably require new HV feeders direct from the zone substation. The exact arrangement of the supply must be determined in consultation with the distribution network operator.

Asset	Description	Likely upgrade requirements
Zone substation	Zone substations provide the connection between the sub-transmission network (typically operating at/ or above 66 kV), and the high-voltage distribution network (22 kV). Zone substations are designed with redundant capacity to absorb future growth in numbers of customers supplied with connections, and those customers' aggregate power and energy needs.	Over time, available spare capacity will become increasingly limited. A significant step increase in demand – such as that required by a large BEB depot – will likely result in upgrades to the zone substation(s) supplying the power.

2.3.2 Electricity tariff structure considerations

For residential and smaller commercial electricity consumers, tariffs are structured around a daily fixed charge, and a variable volumetric charge (per kWh consumed). Note that the cost of electricity per kWh for a bus depot will usually vary according to the time of day.

For larger consumers of electricity (e.g., more than 25 BEBs, depending on the location), the variable volumetric tariffs would usually be less than for a small consumer, but there are additional network charges based on the maximum demand (MD), sometimes described as the user's peak load in a given period – measured in MVA.

There are several common opportunities available to optimise these electricity costs, including reducing the MD/peak load. The most common method that BEB operators use is 'load shifting' or 'smart charging' – charging buses during off-peak periods such as overnight; and by avoiding charging too many BEBs simultaneously. Other ways of reducing ongoing electricity costs are by installing solar photovoltaic (PV) panels, combined with an on-site battery energy storage system (BESS).

2.3.3 Solar PV panels and on-site batteries

Solar photovoltaic (PV) panels can reduce costs, but the power they generate will typically fall well short of the amount required to charge more than 1 or 2 buses. A battery energy storage system (BESS) will also be required unless BEBs will be on-site during peak sunlight hours. Costs, feasibility, and benefits of these systems will vary on a site by site basis, and will not be suited to all locations or operations.

Solar PV with a BESS in conjunction with a 'smart' charging system would enable some load shifting, potentially reducing the overall MD charges, and possibly reducing up front capital works needed for grid upgrades.

A BESS at a BEB depot would be located 'behind the meter'. The BESS stores excess electricity during periods of low demand or high renewable energy generation – from energy generated by the on-site solar PV or drawing from the grid. When the bus-charging demand is highest, particularly in peak hours, the stored energy can be used to supplement power supply, reducing strain on the grid, and avoiding peak electricity rates. The BESS also acts as a backup power source during grid outages, ensuring uninterrupted bus operations and maintaining a reliable charging infrastructure. This versatile system offers opportunities for load balancing, cost savings, and grid resilience, making it a valuable asset for a battery electric bus depot.

Beyond cost savings, adopting solar PV is a visible and cost-effective way to demonstrate sustainability, providing added renewable electricity generation for the local community.

2.3.4 Engaging with DNSPs

It is critical that the relevant DNSPs are contacted **early** in the depot transition process as **it can take up to two years** from the day of the first formal enquiry until electricity network upgrade works are carried out. The National Electricity Rules set out the regulatory requirements with which the DNSPs must comply when dealing with customers wishing to establish or modify their connections to the network[5].

With reference to the scenarios described in Section 2.3.1, engagement with DNSPs to confirm works required for an electrified depot is likely to be as follows:

- **Scenario 1 (up to 5 BEBs):** Grid upgrades, and a complex connection to the electrical grid are unlikely to be required. Operator's energy retailer can act as an agent, unless operator has relevant experience.
- **Scenario 2 and Scenario 3:** New grid infrastructure, a complex connection, or both is likely required. A Registered Electrical Contractor could be engaged to assist with the process, unless operator has relevant expertise.

Figure 2.5 provides a map of DNSP service areas. Contact information and an interactive and detailed service area map for DNSPs is available here: https://www.energy.vic.gov.au/for-households/find-your-energy-distributor.

Figure 2.5 DNSP service area overview map

Typical information requested by DNSPs is outlined in Table 2.4, and some planning, analysis, and design may be required before engaging with the DNSP.

5 The NER provisions are further detailed with specific requirements for the Victorian jurisdiction in the Service & Installation Rules, 2014, incorporating Amendment 3 in October 2022, published by the Victorian Electricity Distributors and available from the VSIR website at https://www.victoriansir.org.au/. Section 4 of the SIR specifically deal with the supply application, connection and disconnection processes.

Table 2.4 is general in nature, and each DNSP is different. Each has its own processes designed to comply with their obligations under the National Electricity Rules. These processes will vary according to the type, capacity and complexity of the connection. Details of the DNSPs' connection policies and procedures, including criteria that will determine the type of connection required, application forms and information requirements can be found on the businesses' websites.

Table 2.4 Typical information requested by DNSPs

Information	Notes
Operator, address, ABN Land ownership / title	If there is a third party acting on the operator's behalf, then written permission for the third party to act on their behalf should be provided. In the Victorian regulatory regime, third parties are most often Registered Electrical Contractors acting as Customer Agents.
Energisation date	For the most complex connections to the distribution networks, it can take up to two years from the day of the first formal enquiry until electricity network upgrade works are completed. Early engagement with the relevant DNSP is therefore strongly recommended.
Site plan, Single Line Diagram, Point of Supply	DNSP will need to understand the type of connection being proposed by the operator, and its location.
Power requirements (AS3000 Loadings) and Charging regime	An estimate of the depot's power demand and its profile throughout the day, is required, so that the DNSP can assess whether there is sufficient capacity in the power grid, and any upgrades that may be required. The DNSP will make a conservative estimate of peak power demand (e.g., 60-100kW per bus). Operator can demonstrate how a lower level of demand may be achieved by outlining its plans for operation, this could include power modelling at larger depots. If a lower level is agreed with the DNSP, they will hold the operator to it, and charge if it is exceeded.
High Voltage Connection	Larger depots (typically more than 25 BEBs), will likely have a high voltage connection. While this may provide access to a cheaper tariff regime, HV customers are required to have authorised 'high voltage operators' nominated for the site to make safe and operate the HV connection when required by the DNSP. The high voltage operator will not need to be permanently on site, but will be required to be available 24/7. The role is often filled by a contractor engaged under a term agreement to fulfil this role by the facility owner.
Proposed generation	If on site generation is planned (e.g. solar panels), DNSP will want to know if operator intends to sell back to the grid. Selling energy to the grid requires a two-way connection which is typically more costly.

2.4 Charging infrastructure

2.4.1 On-site electrical infrastructure

Along with the charging infrastructure/the chargers (this section's primary focus), on-site electrical infrastructure will be required between the point of connection/main meter, through various HV and LV switchboards and cabinets located in the depot.

To optimise depot space and improve circulation, common design practices include:

- Localised charging dispensers at each bus charge point.
- Large dispenser combinations at a single location, or a few locations in the depot, with more compact dispensers at each bus charge point.

Many operators are opting to use large, consolidated charging units (400 kW to 1 MW) paired with multiple smaller dispenser units as a more space-efficient approach. To avoid blocking access to cable connections, consider nominating cabinet-to-dispenser connection locations for such arrangements.

2.4.2 DC power is recommended over AC power for most operations

DC charging equipment has a higher upfront cost compared to its AC counterparts, because of its increased power capacity and internal complexity. Despite this, DC power represents the most suitable technology option that supports rapid charging for larger operations, in turn improving operational efficiency and reducing downtime, saving on costs.

AC power may have current and future applications in regional and remote areas, where low bus numbers need charging and where lower charge rates can be accepted (see Section 2.4.4.1 for discussion).

2.4.3 Charging dispenser type

Plug-in and pantograph charging are the most common ways BEBs are charged.

Smaller depots, without major space constraints, are generally well-served by ground-mounted plug-in solutions, as they are typically the simplest to implement. However, each charging technology has different strengths and weaknesses (summarised in Table 2.5), and operators will need to consider what makes the most sense at their site:

- **How much space is available?** Ground-mounted plug-in solutions do not require a gantry structure. But, having charging infrastructure on the ground takes up space that could be used for buses. A structure's additional cost and complexity may be justified for overhead plug-in or pantograph solutions when depot space is at a premium.
- **Is there substantial on-site contamination?** A solution with a structure may be less challenging to implement than the required boring and trenching for a ground-mounted solution.
- **Are there lots of buses on site?** At very large depots, the benefits of overhead plug-in or pantographs may justify the additional investment as they:
  - maximise the number of buses that can fit on site
  - reduce/remove the manual handling of heavy plugs – pantographs drop down automatically; overhead plug-ins can have automatic retractable systems
  - reduce/remove wear and tear of charger plugs and cables, and cable-related trip and entanglement hazards
  - remove the risk of bus or charger damage from collisions with infrastructure at ground level
  - create roof space that can be covered in solar panels
  - if suitably constructed, the structure used for overhead plug-in could support a pantograph system in the future.
- **Is there substantial growth planned for this depot?** Consider the spatial requirements for the current and future fleet, and how chargers would be laid out to accommodate them. Masterplanning the depot's transition, rather than planning incremental conversions, will minimise the risk of redundant works.

While these charging systems are most used now, new technology could be introduced in the future. It is therefore good practice to monitor and employ innovative solutions where feasible.

Regardless of dispenser type, operators should test their charger/bus combination before procurement, or procure known compatible combinations.

Table 2.5 Plug-in and pantograph charging technologies compared

Plug-in		Pantograph	
Ground Mounted	**Overhead**	**Down**	**Up***
+ Easy to implement as a first stage - Manual handling - Tripping and collision hazard - Wear and tear on plug - Occupies space at ground level - Rework required to convert to pantograph charging	+ Less depot space impact + Operational flexibility + Minimal trenching + Easier transition to pantograph in future - Reliant on overhead structure/frame - Manual handling - Risk of equipment damage	+ Automatable + No cord management + Operational flexibility + Less depot space impact + Typically faster charging rates than plug-in + Minimal trenching - More expensive technology - Reliant on overhead structure/frame - Greater precision for parking required	+ Automatable + No cord management + Less depot space + Minimal trenching + Typically faster charging rates than plug-in - More expensive technology - More weight on bus - Reliant on overhead structure/frame - Impact on operations if pantograph on bus is faulty and cannot charge.

* Pantograph up charging is not common in a depot environment. Pantograph up is primarily seen on BEBs that are regularly opportunity charging en-route. These buses are often charged with a plug when at the depot.

2.4.4 Charging infrastructure FAQs

2.4.4.1 Smaller depots (1 to 5 buses)

What would be the current best BEB technical solution for depot charging for a micro depot, or other location with 1 to 5 school buses? At these small regional town sites, how many typical ground plug-in chargers (with standard charging capacity) can be installed before you would need a material upgrade to the electricity supply?

In this context, simple solutions that require minimal infrastructure are ideal. These could include:

- Selecting a bus that supports AC plug-in charging – has chargers that can be powered by standard 3-phase power.
- Selecting a bus that supports DC plug-in charging, and buying a compatible portable DC charger that can be powered by standard 3-phase power.

Questions around electricity supply highly depend on site context. However, many depots can charge 1 to 5 buses without needing grid-related upgrades.

2.4.4.2 Alternative technology in future

How modular are the current BEB batteries in the chassis from suppliers? Could we move to other battery makers and/or battery technology (e.g., solid state) when replacing the batteries in 8–10 years' time?

Typically, the bus manufacturer will be responsible for the battery's replacement at the end of its life (8–10 years). In most cases the manufacturer will need to remove the battery off-site.

Battery technology is continually improving, and there is also a general trend towards standardisation and interchangeability in terms of battery footprints and connections.

Given this, it is reasonable to expect that at the end of their lives, batteries could be replaced with higher performing, or cheaper batteries.

2.4.4.3 Number of plugs and chargers per vehicle

What are the main drivers of the '1 charger to multiple vehicles' solution?

In Australia, jurisdictions are typically providing one charging unit for every two buses, with one dispenser per bus. One dispenser is provided per bus space because most depots do not have the ability to charge and relocate buses, given the length of time needed to charge. The key driver of the 1 charger to multiple vehicles solution, is the charging units' footprint requirement. There is a trend towards much larger integrated charging units placed in depot corners, linked to separate dispensers (this also works for overhead charging). Note that implementing this system as overhead charging, saves floor footprint while it keeps open the option of a later conversion to pantograph charging.

2.4.4.4 Plug types

What plugs are used to connect buses and chargers?

Combined Charging System Type 2 (CCS2) has been widely adopted in Australia for light and heavy vehicles (shown in This supports both DC and AC charging. See Section 1.6 for further discussion.

2.5 Charging time

Charging times depend on:

- **The charging strategy in place**: choosing an efficient strategy can minimise charging times. A CMS can assist with this. See Section 2.6 for more detail.
- **The size of the bus batteries or the amount of charge required**: the more charge a BEB requires, the longer it will take to charge.
- **The power outputs of the charging dispensers**: low-voltage charging systems are slower than high-voltage charging systems.
- **The operator's charging objective:** depot charging is often used to bring the battery level to that required for the next day's shift, with some extra charge as a buffer.

Table 2.6 shows sample charging times for two common charging-system types, and a set amount of charge required based on typical charge capacities that fleets try to reach. Note that typical BEB batteries are between 300 kWh and 400 kWh in capacity, so it is possible to charge the batteries for varying periods, depending on the charging strategy and the BEB's intended use. Also note that calculating the charging time is not as simple as dividing the required amount of charge by the charging rate; the last 5 to 10% of charge will take longer.

The guidance in Table 2.6 is only relevant for recharging a bus battery from 0% to approximately 90–95% full.

Table 2.6 Sample charging times

Charging system type/charging rate	Amount of charge required	Charging times
75 kW	300 kWh	4 hours
150 kW	300 kWh	2 hours

2.6 Charging strategies

An operator's charging strategy is their approach to ensuring their buses are sufficiently charged at the start of each day, to perform that day's operations.

For very small operations, this strategy could be as simple as plugging buses in and charging overnight. However, further consideration may be required as:

- Operators pay for power with reference to peak consumption, and time of day. Rather than charging all buses as quickly as possible, it may be advantageous to spread the load between the times buses are at the depot (see Sections 2.3.2 and 2.3.3).
- There may be limited capacity in the grid, and the operator may need to ensure power demand does not exceed a certain threshold.
- At larger depots, buses' charging order may need to ensure charged buses are available when they need to depart.

For very small operations, the strategy might be implemented at the charger itself (i.e., chargers are set to only operate after 9pm when an off-peak power rate applies); at larger depots, Charge Management System (CMS) might be used to coordinate the process. CMS is often employed as it can carry out charging strategies automatically. This could include turning the charging equipment on and off according to electricity price to minimise costs, prioritising buses with certain charge levels first, and alternating the order for plugged-in buses to receive charge.

2.7 Typical dimensions

While BEBs and ICE buses typically share similar exterior dimensions, the transition to BEBs can reduce the number of buses that can fit at the depot:

- As BEBs need to charge – usually in their parking bays (as opposed to a common refuelling station) – BEBs require more clearance to accommodate the charging units, and for personnel to operate the charging.
- BEB charging occurs in formalised spaces. Buses cannot be packed in, as is often the case at ICE depots.
- Clearance is required from chargers and associated infrastructure (e.g., gantries) for safety.
- BEBs' fire safety and management requirements (Section 4.4) will influence depot layout and parking bay spacing.

The following section outlines typical dimensions to inform a depot layout's development using a typical standard low-floor city bus as a design vehicle.

2.7.1 Vehicles

BEBs and ICE buses have reasonably similar dimensions, although as with any bus purchase, it is the operator's responsibility to ensure the vehicle is suited to its depot (including maintenance sheds, bus wash, etc.) and the roads it will run on (bridges, underpasses, etc.). Figure 2.6 outlines a typical design vehicle, noting:

- While there can be some variations, a standard 2-door bus is rarely longer than 12.5m.
- BEBs are typically 3.4–3.5m high, while some ICE buses can be slightly lower (3.1m–3.2m).

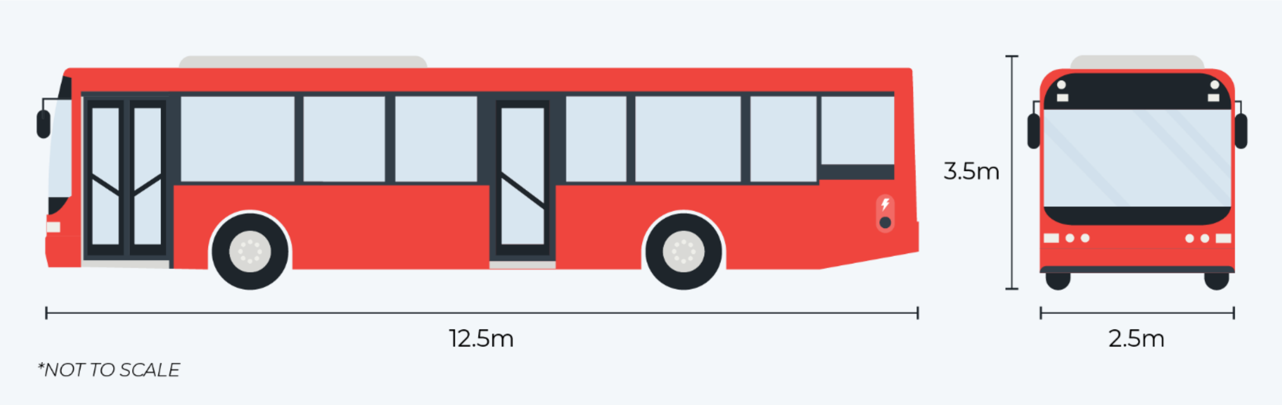

Figure 2.6 Design vehicle

2.7.2 Charging equipment and clearance

Unlike ICE depots, BEB depots need to include space for charging equipment and sufficient clearance for buses to move safely past. Enough space is also required for all charging equipment to be safely used and maintained, and to allow staff to walk through the depot unimpeded. Furthermore, infrastructure at ground level will require protection from buses, either via kerbed platforms, bollards, or other barriers (Figure 2.7). The space needed will vary depending on the charging technology used, the broader electrical system, and protection provided:

- Systems entirely at ground level (Figure 2.7) will typically take up the most space.
- Aisle width can be reduced by only having dispensers at ground level. These are powered by a large cabinet (also called a charging container) which can be located to the side of the depot (Figure 2.8).
- The space used for charging infrastructure can be further reduced by using a gantry structure (Figure 2.8).

In most cases, a **1.5m to 2.0m** wide allowance is sufficient for an aisle of infrastructure and its protection. This may be reduced depending on the design of the gantry structure.

Figure 2.7 Protection of chargers and electrical infrastructure using bollards, kerbs and guardrail. Chargers can be integrated units (left), or consist of a cabinet and dispenser (right)

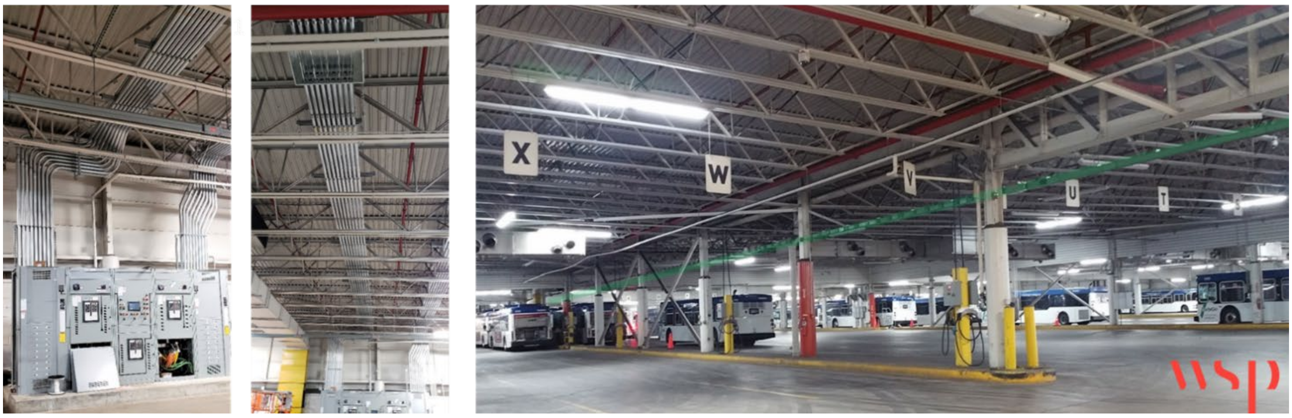

Figure 2.8 Large power cabinet (charging container) is located on the edge of the depot (left), power is distributed across depot (centre), buses are charged from dispensers (right)

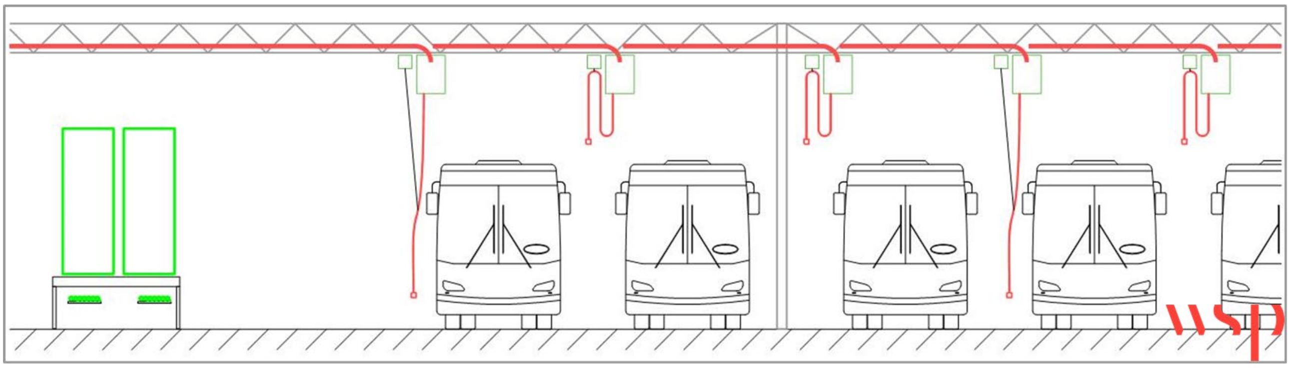

Figure 2.9 An example of overhead plug-in charging, powered by large power cabinet to side of depot. Pantograph charging could be supported in a similar fashion

2.7.3 Bus parking

As BEBs will typically charge in their parking bays, parking at depots must be formalised. Table 2.7 outlines suggested dimensions for BEB parking bays, with indicative parking layouts based on these dimensions and charging equipment clearances (Section 2.7.2) shown in Figure 2.10 and Figure 2.11.

In these examples, the gantry system saves space, as one less aisle is needed to charge the same number of buses. Each depot will have different needs and site-specific constraints that will drive design decisions.

Table 2.7 Parking bay dimensions

Dimension	Suggested BEB parking bay dimension	Rationale
Length	14.0 m (12.5m bus length +1.5 m buffer)	Creates space for diagnostic maintenance within parking area, rather than in a dedicated maintenance bay (see Section 3.4)
Width	3.8 m (2.5m bus width + 1.3m buffer)	Allows for dispenser plug to protrude from bus, while still allowing safe walking through bus parking. Provides drivers with some margin for error while parking.

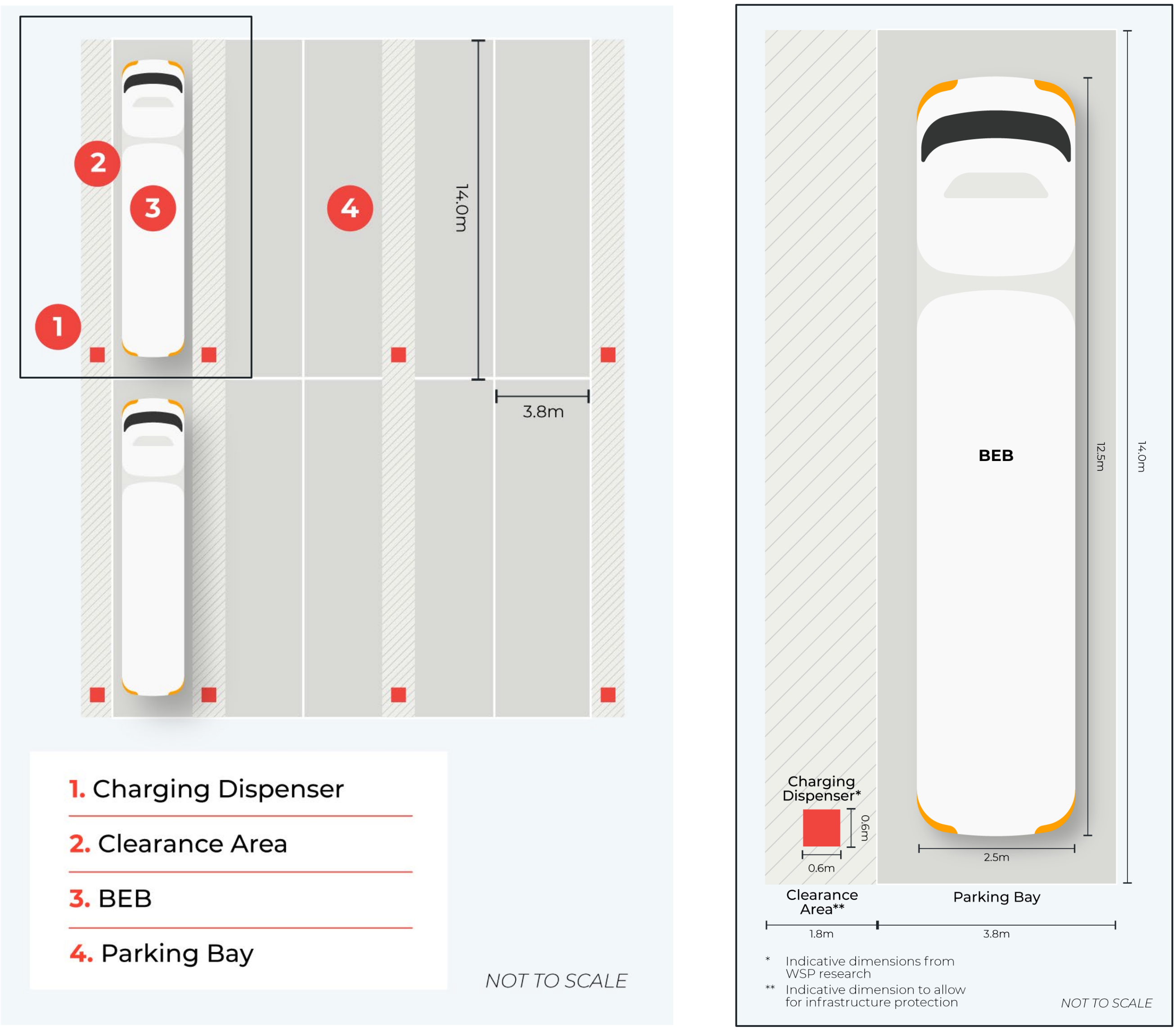

Figure 2.10 Parking bay dimensions and clearance for a ground mounted charging dispenser

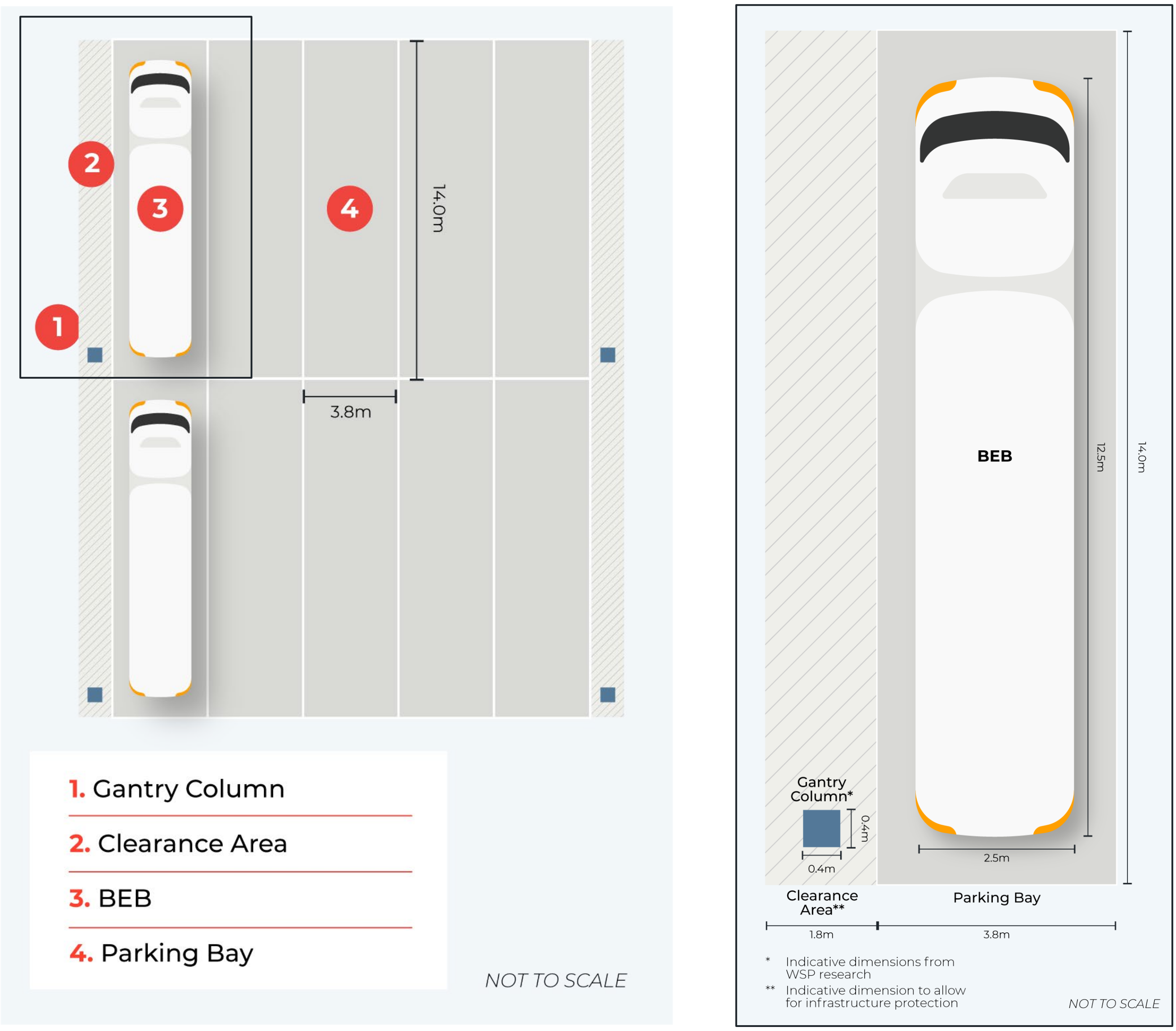

Figure 2.11 Parking bay dimensions and clearance for gantry mounted charging

3 Operational considerations

The primary difference between ICE buses and BEBs is the fuel source, which leads to the following operational considerations:

- Energy consumption becomes a relevant consideration – operators need to understand the factors that impact consumption, and plan their operations accordingly (Section 3.1).
- Batteries are now a key bus component, and their operation and management should be considered (Section 3.2).
- While operators currently assign drivers to shifts, the transition to BEBs requires operators to consider scheduling buses to runs (Section 3.3).
- BEBs have lower maintenance needs, and may also change how operators approach maintenance (Section 3.4).
- Software and systems could help with managing operations (Section 3.5).

3.1 Fleet and range

From a fleet perspective, the primary difference between ICE buses and BEBs is the fuel source – the BEB's battery and the range it can achieve. Batteries are discussed in detail in Section 3.2, but from a fleet perspective:

- The amount of energy stored in the battery (kWh) alongside the rate of consumption (kWh/km) determines the bus range. Batteries used in the fleet should optimise total energy provided against their additional weight.
- Ongoing OEM support is crucial. Current battery lifespans being considerably less than the lifespan of a bus, OEM support will be needed to refurbish and/or renew batteries during the buses' service lifetimes.

From a range perspective, while previously an operator would have monitored fuel consumption to understand cost, BEB energy consumption (kWh/km) becomes more relevant for operators as:

- The range of BEBs is lower relative to ICE buses.
- Unlike ICE buses, BEBs cannot be quickly refuelled.
- Over time, energy stored in a BEB battery decreases as its battery degrades (See Section 3.2).

As such, operators should understand and monitor their BEBs' power consumption to inform service planning, and consider scheduling buses to runs, as well as drivers to shifts, to ensure all services can be delivered.

Factors relating to energy consumption (kWh/km) (and therefore range), are shown in Figure 3.1, and discussed below:

- **Bus weight**: The greater the total weight of the bus and its passengers, the more energy it requires to accelerate, and the lower the range it can achieve. Other characteristics of a BEB, such as tyre pressure and vehicle frontal area, will also affect range. However, these considerations are the same for ICE buses.
- **Driver behaviour**: Through smooth acceleration and braking, drivers will conserve energy use, and maximise energy recovered through regenerative braking. Frequent, abrupt stopping reduces the efficiency of regenerative braking systems.
- **HVAC load**: At extreme temperatures (both cold and hot), the HVAC increases and consumes more power from the battery which decreases the bus's overall range.
- **Stops:** Energy is expended every time a bus accelerates from a stop. Hence, buses on routes with many stops requiring vehicles to regularly accelerate and decelerate, will have lower range. Some energy can be recovered through regenerative braking when stopping.
- **Terrain**: Additional energy is expended to climb hills; routes with steep climbs or hills reduce range. Some energy can be recovered through regenerative braking as buses go down hills.

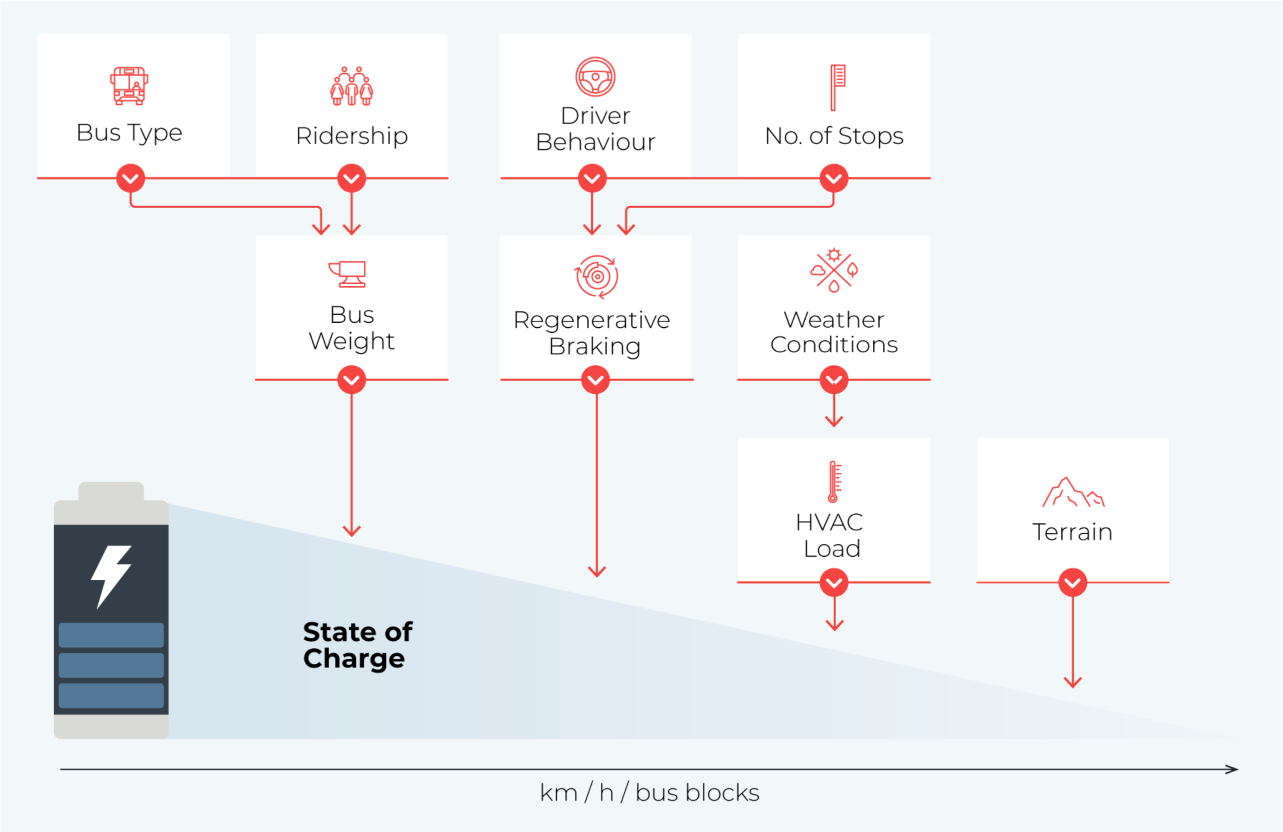

Figure 3.1 Summary of factors that influence energy consumption and vehicle range

The combination of these factors, and the varied conditions buses operate in, result in a broad range of potential consumption rates. Table 3.1 outlines the range observed on Australian and overseas operations. These rates are indicative, and should only be used to inform early transition planning. Operators can trial buses under typical conditions to be better understand how they will perform.

Table 3.1 Typical consumption rates and indicative range

Battery Size*	Average Consumption Rate	Indicative Range***
450 kWh – assume 80% (360 kWh) is available for operation.	0.8 kWh/km	450 km
	0.9 kWh/km**	**400 km**
	1.0 kWh/km**	**360 km**
	1.2 kWh/km**	**300 km**
	1.4 kWh/km**	**255 km**
	1.6 kWh/km	225 km
	1.8 kWh/km	200 km
	2.0 kWh/km	180 km

* As discussed in Section 3.2, a proportion of the battery's energy is not available to protect the battery's life. It is also prudent to keep a reserve of energy to manage any unexpected changes to operations.

** Average daily consumption rates between 0.9 kWh/km and 1.4 kWh/km were most commonly reported in the data reviewed for metropolitan operations in Australia. These rates were for new buses, typically operating under mild weather conditions.

*** Energy available for operation/average consumption rate

3.2 Batteries

The amount of energy left in a battery pack is referred to as the state of charge (SOC). Consider it like the gauge on a traditional vehicle telling the driver how much fuel remains. However unlike an ICE bus, a BEB battery can't be run to empty. Figure 3.2 provides an indicative breakdown of the energy within a battery:

- **Unusable energy:** To minimise battery degradation, most batteries have a minimum and maximum allowable SOC, these values are typically different to the battery size quoted by the manufacturer.
- **Reserved energy:** Once battery reaches this level it enters a power saving, 'emergency mode' - e.g. HVAC may stop functioning, bus maximum speed is reduced.
- **Useable energy:** Energy available for regular operations

Also shown in Figure 3.2 is the reduction in battery capacity over time as internal physical and chemical structures degrade (Trippe, Arunachala, Massier, Jossen, & Hamacher, 2009).There are a range of variables that affect batteries' degradation and their long-term useful life, including:

- Storage and operation at high temperatures significantly reduces battery lifespan. At high temperatures batteries tend to experience accelerated cycle ageing. Parking buses in shaded areas can help reduce these impacts.
- Cycle aging occurs when batteries that are charged and discharged more regularly, lose capacity faster. This is in opposition to calendar aging where all batteries lose capacity over time. As such, to maintain consistent asset use, vehicles should be rotated through routes and charging operations.
- Storage at low charge and with small deviations extends battery life. As such, charging regimens using 'just in time' models should be preferred. Batteries kept at lower states of charge will have longer lifespans.

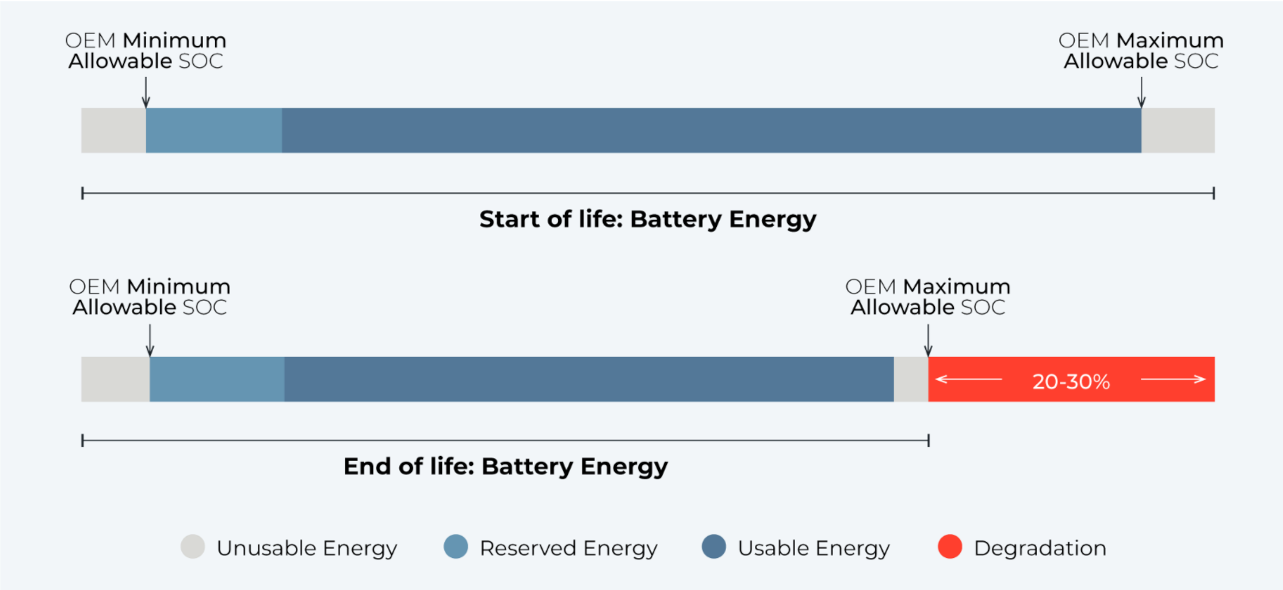

Figure 3.2 Breakdown of energy within a battery

As a new and rapidly evolving technology, batteries for electric buses are subject to some lifetime uncertainty, though some major manufacturers offer 10-year warranties on their batteries. The end of battery life typically occurs when a battery has less than 80% of its initial capacity, although this threshold can be pushed as low as 60% (Bloomberg, 2018).

3.3 Service planning and charging

While operators currently assign drivers to shifts, the transition to BEBs requires operators to consider scheduling buses to runs. This is to ensure buses are sufficiently charged before they commence their operation for the day, and are assigned to runs they can fulfil.

While experience to date in Victoria and New South Wales has demonstrated that start-of-life BEBs have not had range issues, assigning buses to runs and reconfiguring current schedules could be considered because:

- Some runs as currently scheduled may be highly demanding with many kilometres to travel, and may combine one or more of the factors that influence range (see Section 3.1), such as high patronage or speed all day, which increases their weight.
- Batteries (and therefore range) degrade over time – some runs may be achievable with newer buses, but not with older buses.
- Depending on the charging strategy implemented, not all buses may be fully charged when the first bus leaves in the morning.
- Operators may seek to ensure buses only charge when energy prices are off-peak – this could also be considered alongside on-site energy storage (see Section 2.3.3).

3.4 Maintenance

BEBs have significantly less maintenance requirements compared to ICE buses. Research suggests that fixed annual maintenance costs of BEVs are almost half (50.7%) those of ICE vehicles (AEMO, 2022).

Some of the key reasons for this are broken down in the following:

- **Simplified drivetrain**: BEBs have fewer moving parts in their drivetrain compared to ICE buses, which have complex engines, transmissions, and exhaust systems. This reduced mechanical complexity leads to fewer potential points of failure and less maintenance.
- **Fewer fluids**: BEBs eliminate the need for fluids like engine oil, transmission fluid, and coolant, reducing the need for fluid changes and related maintenance tasks.
- **Brake wear reduction**: Regenerative braking in BEBs reduces wear on traditional friction brakes, leading to less frequent brake pad replacement and maintenance.
- **Lower vibration and heat**: Electric drivetrains produce less vibration and heat than ICE counterparts, leading to less wear and tear on components over time.

Alongside vehicle maintenance savings, introducing BEBs may lead to changes in the depot's maintenance approach:

- Maintenance may become more diagnostic and focussed on parts, with the operator identifying issues with the bus, and the manufacturer undertaking the maintenance, or switching out the specific part with an issue.
- Simplifying maintenance presents an opportunity to move to more diagnostic and preventative maintenance over scheduled and reactive maintenance.
- Advanced sensors and data analysis in BEBs can assist with this predictive maintenance, addressing issues before they become major problems.
- There may be an increased need to work at heights as BEBs have their battery packs on the roof.
- A regular maintenance regimen will be required for chargers, dispensers, and associated equipment.

3.5 Software and systems

Bus and charger manufacturers, technology companies, and Zero Emission Bus ‘integrators’ offer various software and systems to help operators manage BEBs.

- Charge management systems (CMS) to monitor charging, ensuring all buses are sufficiently charged for their days’ operations, while optimising for loading on the grid and the cost of electricity (see Section 2.6).
- Depot management systems (DMS) to manage movements around the depot. As each BEB requires a dedicated parking space to charge, a DMS can maximise the efficient use of charging infrastructure and ensure the right buses are available when needed.
- Battery management systems (BMS) to monitor batteries’ charges, performance, and any degradation. These systems ensure batteries perform as expected and allow for any issues to be identified early.
- Analysis of trip data (including patronage, temperature, distance travelled, etc.) to understand energy requirements for operations.
- Real time information – most BEBs come with real-time tracking as standard; operators can know where their buses are and share the status of services with their customers.

Capturing and analysing the data generated by these systems presents a broader opportunity to optimise all aspects of operations at the depot and on the road.

4 Safety

By being well-informed, operators can protect passengers and staff, respond effectively to emergencies, and comply with safety standards and requirements. This chapter covers the safety considerations that are markedly different for BEBs compared to ICE buses. This includes:

- The training that will be required for BEBs' safe and efficient operation (Section 4.1).
- Risk assessments that should be considered to capture the operational changes associated with BEBs and the BEB transition (Section 4.2).
- Considering how the workforce will use BEBs and associated infrastructure (Section 4.3).
- Fire safety for BEBs (Section 4.4).
- Managing charging cables (Section 4.5).

4.1 Training

Training will be required to ensure all people working with BEBs have the necessary skills and expertise for safe and efficient operation. Table 4.1 outlines relevant training for introducing BEBs.

Appropriate training ensures:

- Technology will be operated safely and securely.
- Experiences and insights can be shared, enhancing safety and refining implementation.
- Personnel can adapt to the new technology and embrace any necessary adjustments to roles and responsibilities.
- Issues and disruptions are minimised during the implementation process.
- The value of new technology is used to its greatest potential.

As there is extensive experience in operating ICE buses in Victoria, training can be focussed on the key points of difference relating to BEBs without requiring operators to change their broader staff-training approach.

Table 4.1 BEB training

Change in operational activity	Relevant training
BEBs are electrically powered, and charged rather than refuelled (see Sections 1 and 2.4)	Drivers will need to be trained in the safe operation of BEBs, including dashboard warnings relating to electrical systems. Drivers (or dedicated depot staff) will need to be trained in the safe use of chargers, and parking requirements so chargers can be safely operated.
BEBs have reduced range, and can't be quickly refuelled like ICE buses (see Sections 3.1 and 3.3)	Drivers will need to be trained to use regenerative braking, and in the importance of smooth, controlled driving that maximises the braking system's effectiveness and reduces energy consumption. Service planners and depot operations staff may require training to assign buses to runs with reference to factors that can impact BEB operation (e.g., demanding nature of service, charging strategy, battery age).
Increased use of software and systems to manage buses and charging (Section 3.5)	Training by OEMs and technology companies in the use of new systems at the depot. Depending on operator approach, these systems could be managed entirely by operations staff at the depot, or may require involvement of drivers and maintenance staff.

Change in operational activity	Relevant training
BEBs require different types of maintenance (See Section 3.4)	Maintenance staff will need training on all new BEB components and their servicing requirements. The level of training will depend on operators' approach to maintenance: — Operator could take a diagnostic approach, identifying issues and having the OEM undertake all complex maintenance relating to electrical systems. — Operator could retain control of complex maintenance, requiring highly trained staff who can undertake complex electrical works on site.
BEBs present different fire risks (See Section 4.4)	Drivers will need to be trained to safely evacuate buses in case of an on-road incident, and in how to engage with emergency services. Drivers and depot staff will need to be trained to identify battery anomalies and how to safely isolate at-risk buses.

The types of training provided will vary by staff roles, the operator's needs, and the operator's familiarity with BEBs. Approaches could include a blend of the following:

- Operator adds BEB-specific content to existing training (e.g., include regenerative braking in driver training).
- Operator develops new training packages responding to aspects of their BEB operations (e.g., BEB fire safety at a depot).
- 'Training the trainers', whereby OEMs train certain key personnel, who then train the broader workforce.
- Bus/charger OEMs provide training directly to drivers and maintenance staff.
- Training provided by education providers (including formal qualifications).

There are a limited range of ZEB-specific training courses and qualifications available in Victoria and across Australia. In Victoria, The Kangan Institute in partnership with TAFE Victoria offers an Electric Vehicle Skill Set course[6]. It offers 'a skill set in depowering and reinitialising battery electric vehicles and inspecting and maintaining battery electric vehicles (BEVs)' (Kangan Institute, 2023). There are plans to offer this course in other Victorian TAFEs. A course focussing specifically on battery electric buses does not currently exist in Victoria, but is available through learning institutions in other states.

Similar transitions are taking place nationally and globally, with lessons learned from other jurisdictions emerging and being made available to DTP. DTP will continue to work with its stakeholders, including in other states, as training programs develop and requirements are better understood (Department of Transport and Planning, 2023).

Training is not a substitute for providing a safe and intuitive operating environment:

- Section 4.2 outlines risks that should be considered, and approaches to mitigation (it is preferable to remove risks rather than change the ways people work).
- Section 4.3 outlines the importance of considering how the workforce will use BEBs and associated infrastructure in achieving safer outcomes.

4.2 Risk assessment

It is leading practice to conduct a comprehensive risk assessment that assesses the impact of changes made to depots and operations to accommodate BEBs. ISO 31000 should be followed. Risk assessments should cover and consider:

- **Bus operation:** the potential operational disruptions due to new technology.

[6] Information on the Electric Vehicle Skill Set Course (SCAEVTS2) can be found here: https://www.kangan.edu.au/courses/department/automotive/electric-vehicle-skill-set-9842

- **Charging operation:** the potential operational disruptions due to new technology.
- **Emergency response:** how drivers and emergency responders will manage incidents, including development and training in new safety procedures.
- **Fire safety:** lithium-ion batteries can pose fire hazards during accidents or charging.
- **Electrical safety:** high-voltage systems in BEBs and charging infrastructure pose electrical hazards.
- **Bus movements:** reconfiguration of bus depots for charging infrastructure can impact how buses manoeuvre around depots.
- **Bus maintenance:** preventative maintenance procedures to avoid vehicle breakdowns and safety hazards.
- **Staging:** how to manage existing bus operations if BEBs are introduced in a 'live' depot.
- **Supply chain disruptions:** consider delays or supply-chain shortages for BEB components.
- **Data security and connectivity:** vulnerabilities in data transmission, vehicle-to-infrastructure connectivity, and cyber security.
- **Human factors:** how humans interact with the BEB interfaces, and how to minimise opportunities for human error.

Risk assessments should include suitably qualified and experienced personnel from all business areas, together with external experts in business areas where the relevant knowledge does not currently exist. This may include contracting professionals such as human factors specialists, occupational hygienists, fire engineers, electrical engineers, BEB technicians, transport planners, and data management consultants.

Each depot site will have different risks. Their pre-existing layouts will need unique management. Risk mitigation strategies should be implemented in alignment with the risk mitigation hierarchy (see Figure 4.1).

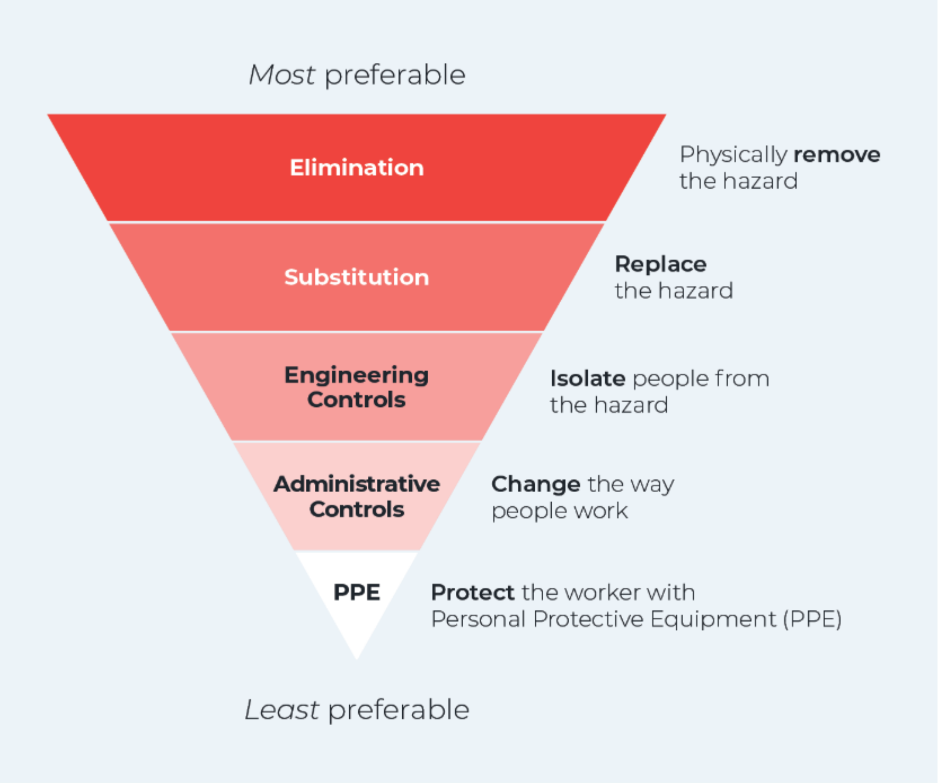

Figure 4.1 Risk mitigation hierarchy

Generally, all identified controls will be the operator's responsibility to enact. This may include modifying depot premises, changing training provided to bus drivers and maintenance staff, changing qualifications and skills for (or to become) maintenance staff, and changing normal and abnormal operations.

Create a capture-all risk register as the output of the risk assessment exercise, and provide it to DTP as assurance of proper risk management. The risk register may be used to inform transition strategies.

4.3 Human factors integration

A human factors approach means considering human capabilities and limitations as part of the design process. This approach achieves safer outcomes for BEB operation by considering how an operator's workforce will use BEBs and associated infrastructure.

Effective human factors integration in BEB transition planning will ensure safety and workforce wellbeing, optimisation and efficiency, and legal and regulatory compliance.

In WSP's experience, common human factors issues relating to BEB depots include:

- Manual handling of plugs and cables when charging buses. Location of chargers and bus parking should ensure this process can be safely carried out with minimal force or reaching, so staff are not at risk of injury.
- Aligning charging dispensers and cables with bus parking and bus charging ports to minimise the risks of staff tripping over or colliding with charging infrastructure.
- Ensuring there is sufficient space to walk through bus parking. There can be pressure to reduce these widths to fit charging infrastructure in, while maximising the number of bus parking spaces. Where relevant, widths should consider the charging plug protruding from the bus.
- Providing sufficient lighting at the depot (particularly where larger numbers of buses are parked together) so staff can walk safely between buses, can safely operate charging equipment, and can ensure charging cables are correctly plugged in.
- Intuitive design, and appropriate signs and line marking to ensure drivers park in correct locations (e.g., can safely plug in without blocking an independent bay).
- Position and size of parking, and placement of charging infrastructure to minimise risks of buses striking chargers.
- Layout of maintenance facility ensure all heavy lifting required for maintenance activities can be easily and safely performed.

4.4 Fire safety

The transition to BEBs changes the nature of bus operations' fire risk. Fire risks for ICE buses are primarily on-road, relating to fuels/lubricants/hot exhaust and friction brakes. As BEBs are electrically powered and use regenerative braking, these risks do not apply. Instead, BEB fire risk primarily relates to batteries and charging. These new fire risks must be managed from design and operations perspectives:

- Monitor to prevent fires by detecting battery anomalies early.
- Isolate at-risk buses, and potentially use fire breaks when laying out bus parking.
- Extinguish fires using suppression systems, and have enough hydrants for use by trained professionals.

While there is a large amount of historical data, and lessons from fires with traditional hydrocarbon fuelled vehicles, similar experience is still being gathered for BEB fleets. The current overarching guidance is that BEB fires are fought by isolating affected vehicles and using large volumes of water. However, when applying water or other extinguishing liquid to a charger fire, or the charger/vehicle connection, it adds an electrocution risk.

As with an ICE bus fire, the priority in a fire event is to ensure the safety of passengers and staff, and to contact the emergency services – leaving the firefighting to trained professionals.

4.4.1 Monitoring

The battery management system (BMS) monitors all the cells in the battery pack and regulates each cell within a safe operating range, considering both voltage and temperature. The state of the battery pack must be accurately estimated to guarantee safe operation. Fault diagnosis is an important safety function for the BMS. Early warning from a BMS is a key indicator for fire risk, and should be communicated immediately to the driver's dashboard and to depot operators.

Important detection system performance requirements are rapid annunciation, reliable performance (low-false alarms) and a low-as-practicable maintenance burden. Additional detection options should be investigated and tailored to a depot-specific solution. A review of each depot site and the expected fire scenario (which can include infrastructure fires, not just bus fires) is necessary to select the most appropriate option. Options include:

- **Smoke detection**: In covered areas, optical smoke detectors located above parked/charging vehicles are recommended where awning or roof is present.
- **Heat detection**: In covered areas, consider a point heat-detector system located above parked/charging vehicles.
- **Fire detection** (flame detector camera): In open air and covered areas, flame-detector cameras could be positioned around the perimeter of the parking/charging bays at a distance that accords with the minimum fire size to be detected. Visual, IR and UV flame detectors are available and a review of the site and expected fire scenario is necessary to select the best option.
- **CCTV monitoring**: In open-air and covered areas, CCTV monitor cameras can be positioned around the perimeter of the parking and charging bays, providing real-time footage to be monitored by security or other appropriate staff. CCTV monitoring could be centralised for monitoring a series of depots in one location. The CCTV system would also serve to thwart vandalism and theft.

4.4.2 Fire engineering

Bus batteries, and the charging process generally introduce a plausible, additional ignition risk compared to ICE vehicles' fire risks. Where possible, area and layout plans should include:

- An isolation bay where at risk buses (e.g., battery anomaly, involved in a collision) can be kept away from other buses until deemed safe.
- Circulation lanes to allow neighbouring vehicles to be safely evacuated, in the case of fire involving another vehicle.

A risk assessment undertaken at the time of layout design, will help fully and appropriately assess the range of design considerations noted in the following:

- **Access to fire hydrants:** An accessible, adequate fire hydrant system is critical to helping the fire brigade control a depot fire.
- **Separation distance:** Increasing the separation distance between buses reduces the quantity of radiant heat flux received by the neighbouring bus, and avoids direct flame impingement. To be effective as a mitigation measure, the separation distance would likely be sizable and rely on bus dimensions and material fire properties for a given site.
- **Physical separation barriers:** An alternative approach to limiting fire spread, is to install fire walls – with a level of fire resistance that accords with AS1530.4 – at regular intervals throughout the bus parking and charging areas. Buses could be nominally grouped (e.g., 5 buses, 10, etc.) to limit an uncontrolled fire spreading to only buses bound by the fire walls.
- **Automatic fire suppression:** Automatic suppression systems, such as sprinklers or deluge, may present a benefit in slowing the fire's growth and its spread to adjacent vehicles, by cooling neighbouring vehicles and structure surfaces.

4.5 Charging-cable management

Charging-cable management is a common safety concern at BEB depots. Without proper management, charging cables can be accidentally or negligently left on the ground, creating trip hazards. It also increases the likelihood of cables being damaged by tangling, being exposed to rough surfaces, being trodden on, or being run over by vehicles. Even when properly stored, cables can still be an entanglement hazard. Damaged cables have the potential to damage vehicles, charging stations, and cause serious harm to people if exposed to electricity.

A range of potential practices and procedures can be implemented to avoid damage to charging cables. In line with the hierarchy of controls (see Section 4.2), eliminating the hazard is the best approach, but would mean exclusively using pantograph chargers. Other controls include replacing manual cable reels with automatic drop-down charging cord dispensers, retracting cable dispensers, or using coloured sacrificial cables around the main cable. The least preferred approach would be implementing administrative controls, which require staff to act to avoid the risk of charging cable damage. These methods of managing cables for various charging systems are described in Table 4.2.

Table 4.2 Cable management methods

Charging system	Cable management method(s)
Pantograph	**Controlled by the system:** the cables are built into the system and not exposed to operators.
Plug-in Overhead	**Controlled by the system:** the system typically retracts the cables when not in use.
Plug-in Mounted	**Administrative controls:** drivers/personnel are trained to stow cables appropriately. **Controlled by the system:** it is possible to add a mechanism to automatically retract the cables, similar to Plug-in Overhead systems.

5 Timing and staging

A smooth transition to BEBs requires planning, and then methodical implementation. This chapter covers:

- Using a risk-based approach for transition planning (Section 5.1).
- The lead times to consider when planning for BEB transition (Section 5.2).
- Taking a staged approach to transition (Section 5.3).

5.1 Planning

Planning should be a top priority to facilitate a successful transition to BEBs to support net zero ambitions.

Risk-based planning should start as soon as possible to encourage momentum on the task of retrofitting brownfield depots and building greenfield depots. It is best to plan and design towards a full depot conversion and configure a realistic staging plan accordingly. This will minimise overall cost, avoid redundant work risks, and provide assurance to stakeholders.

Some key risks to be aware of, and manage, include making sure:

- Power grid connection electrical infrastructure (e.g., substation and feeder) is appropriately sized to support a full depot conversion.
- Depot operations are designed to minimise service interruptions.
- There is space for buses to park during construction.
- Charging infrastructure and its configuration can support a fully converted depot's operations.
- Depot will have all relevant infrastructure, systems and support in place when BEBs arrive on site.
- All services can be delivered by BEBs by undertaking a high level analysis of bus operations.

5.2 Lead times

When planning, consider lead times for vehicles, infrastructure, training, and the like, as they can vary and be longer than equivalent ICE components. If not managed properly, they can create preventable delays that affect other transition aspects.

Some of the major areas where lead times matter the most, include:

- **Fleet procurement**: Lead times for ordering BEBs can vary. Factor manufacturing, customisation, and delivery times.
- **Charging infrastructure**: It takes time to design, permit, and install charging infrastructure. Lead times depend on factors such as the charging setup's complexity, availability of equipment, and regulatory approvals.
- **Power grid upgrades (DNSP engagement)**: If the electrical grid at the depot needs upgrading to handle the increased power demand, lead times for permits, design and physical upgrades can be substantial – in the order of 12 to 24 months from the time of initial enquiry to the DNSP. As noted in Section, early engagement with the DNSP is critical.
- **Infrastructure modifications**: Any modifications or renovations to the existing depot to accommodate BEBs and charging stations require lead times for planning, design, and construction.
- **Training**: Training drivers and maintenance staff on the specifics of BEBs can take time, especially if the technology and maintenance procedures are new.

- **Regulatory approvals**: Depending on local regulations, permits and approvals for the transition may have lead times that need to be factored.
- **Testing and validation**: To identify and address any issues, incorporate pilot phases, and testing of charging infrastructure, vehicles, and operational processes into the timeline. Ensure testing takes into consideration operation in extreme weather conditions,
- **Supplier availability**: Factor lead times for procuring components, parts and equipment to avoid delays from supply-chain disruptions.
- **Communication and stakeholder engagement**: Communicating the transition to various stakeholders, including employees, passengers, and the wider community, requires time to plan and implement.
- **Government approvals**: Lead times for local Government approvals and works, such as upgrading sub stations, can take between 12 and 24 months, depending on the agency managing the approval.

5.3 Staging

Staging means implementing the transition, gradually and strategically. Instead of overhauling the entire fleet and infrastructure all at once, the transition could be divided into stages, allowing for a more manageable and structured progression. This approach enables depots to progressively address challenges, incorporate lessons learnt and mitigate risks, adapting operations, infrastructure and training as each stage unfolds.

Staged conversions often begin with a pilot phase involving a subset of BEBs to test infrastructure compatibility and operational adjustments. Subsequent stages can involve scaling up the BEB fleet, expanding charging infrastructure, and upgrading power systems while continually evaluating performance and addressing any issues as they arise. This incremental approach offers the advantage of minimising disruption to daily operations, optimising resource allocation, and refining strategies based on real-world experience, leading to a smoother and more successful transition to BEBs.

Victoria has already started piloting ZEB technology, with six Victorian bus operators trialling 52 ZEBs (50 BEBs and two HFCBs) on existing routes across the state's metropolitan and regional bus networks (Department of Transport and Planning, 2023).

While staging may be an appropriate approach for a particular depot, operators should ensure this does not come at a greater cost or trigger operational issues. For example, while it may make sense to only install enough chargers and dispensers for an initial conversion stage, it may also make sense to have the full grid upgrade carried out along with providing all underground conduits and similar infrastructure, to avoid costly and disruptive works when the depot undergoes full conversion. A site-by-site assessment is required to determine the appropriate staging.

6 Limitations

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