Battery Electric Bus Charging

Public Transport Design Guidance

Waka Kotahi NZ Transport Agency

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WAKA KOTAHI NZ TRANSPORT AGENCY

Te Kāwanatanga o Aotearoa New Zealand Government

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Contents

1. Introduction

Charging design principles, the important role of battery electric buses, and relevant standards and references.

1.1. Charging design principles

Key overarching design principles that should guide the development of an electric bus network include:

- **Interoperability**: Interoperability is defined by multiple systems being able to work together without restriction. Bus charging should be compatible throughout different regions in New Zealand and between different bus operators, which requires interoperable charging infrastructure and software to allow seamless operation.
- **Safe**: Electric Vehicle Supply Equipment (EVSE) must be consistent with Worksafe installation guidelines. Bus charging infrastructure should support Vision Zero, a New Zealand objective where no one is killed or seriously injured on our roads.
- **Operationally efficient**: Electric bus charging systems should support the operational efficiency of public transport networks by minimising out of service running and supporting a range of bus types.
- **Dynamic, smart, and data driven**: Data monitoring of real-time charging provided in a standardised format will allow for optimisation of the battery electric bus charging network.
- **Futureproofed**: Battery electric buses are relatively new in public transport so designs should allow for easy adoption of evolving technology.

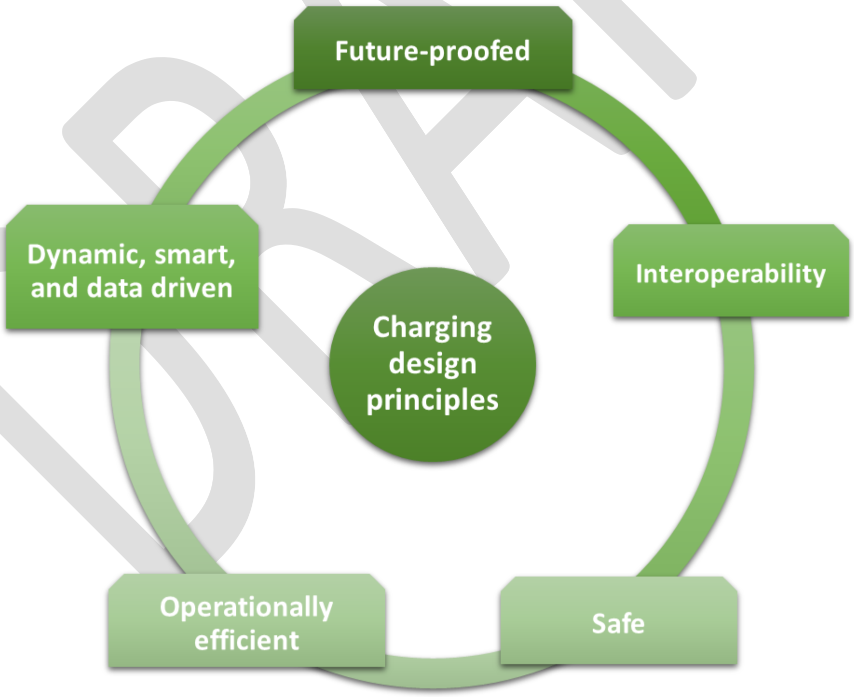

Figure 1: Charging design principles

1.1.1. Road to Zero

Road to Zero 2020–2030, New Zealand's road safety strategy, tells us all what we need to do to improve road safety. This strategy sets the country on a path to achieve Vision Zero – a New Zealand where no one is killed or seriously injured on the roads. The Road to Zero strategy sets an initial target to reduce deaths and serious injuries on New Zealand's roads, streets, cycleways and footpaths by 40 percent over the 10 years to 2030 (from 2018 levels). Reaching that target would mean reducing annual road deaths to 227 and serious injuries to 1,680 by 2030. Improving safety on New Zealand roads is a Waka Kotahi priority, and this guidance is a part of our contribution to a safer transport network.

[Road to Zero 2020–2030]

The Battery electric bus charging topic is relevant to four focus areas under Road to Zero:

- infrastructure improvements and speed management
- work-related road safety (for bus drivers)
- road user choices (for example, making public transport more appealing to customers, developing better multi-modal integration with other road users such as pedestrians, cyclists and general traffic)
- system management (support best practice road safety activity through leadership, coordination, and engagement, to bring the public along on the journey towards Vision Zero)

1.2. The role of battery electric buses

The deployment of low or zero emission buses in place of diesel buses reduces carbon emissions as well as air and noise pollution in urban areas. Public transport provides social and economic benefits such as enabling people to access jobs, schools, shops and other services, and has lower greenhouse gas emissions than driving.

Battery electric buses offer an excellent alternative to diesel buses, particularly because public transport vehicles typically return to a depot at the end of the day, which allows for overnight charging. Public transport buses also tend to run many hours a day compared to other vehicles, so electrifying buses can make an important contribution in decarbonising our transport system. In addition, Auckland trials indicated operating costs that were 70-85% lower than equivalent diesel bus services on the same route.

Public transport contracting authorities have begun encouraging the use of lower emission buses as part of their bus contracts. Battery electric buses have already been implemented on numerous routes in Auckland, Tauranga, Wellington, and Christchurch, with many public transport contracting authorities looking to accelerate their roll out. The government has announced a target of decarbonising the public transport fleet by 2035. Furthermore, the government has mandated that all new buses procured after 01 July 2025 must have zero emissions at the exhaust pipe[1].

Key benefits of battery electric buses for residents, public transport users, and bus operators compared to diesel buses are listed in Table 1.

Table 1: Key benefits of battery electric buses compared to diesel buses

Greenhouse gas emissions	Battery electric buses have zero tailpipe emissions and will help New Zealand in the journey to be carbon neutral
Air pollution	Diesel buses emit pollutants including nitrogen and particulate matter which has been linked to respiratory and cardiovascular conditions. Buses tend to operate in concentrated areas (such as town and city centres) which exacerbates the air pollution issue.
Reduced noise*	Battery electric buses generate less noise and vibrations than diesel buses, making for a more pleasant journey for passengers and reduces noise pollution for residents and pedestrians along public transport routes.
Lower maintenance costs	Battery electric buses have less regular serviceable parts than those with internal combustion engines. Therefore, battery electric buses have lower maintenance costs than diesel buses.
Lower fuel costs	Battery electric buses have lower driving costs because, per kilometre, electricity is cheaper than diesel. Furthermore, battery electric buses are more energy efficient then internal combustion engines.

[1] https://www.transport.govt.nz/area-of-interest/environment-and-climate-change/public-transport-decarbonisation/

*Note the quietness of e-buses may pose a safety issue for those in the street environment who have visual impairments so Acoustic Vehicle Alerting Systems should be considered. Note that parts of Australia are already planning to mandate this type of system.

Figure 2: Image of an electric bus with the display celebrating zero emissions (Credit: Mark Edwards)

2. Service design and operational consideration

Provides advice on battery electric bus characteristics and the trade-off between vehicle capacity, weight and range issues to inform procurement of high capacity or long-range battery electric buses. Section also covers vehicle range, public transport network considerations to consider along with electricity supply characteristics.

2.1. Battery electric bus characteristics

Most of the diesel bus fleet in New Zealand is comprised of 10.0m to 13.5m single deck buses and includes two to three axle vehicles as described in Bus Dimensions for Design.

Three axle diesel double deck buses are used in Auckland, Hamilton, and Wellington on high demand routes. The diesel buses used in New Zealand have capacity for 30 to 110 passengers and have a range of approximately 800km[2], though the RUB only requires a range of greater than 350km or 15 hours of operation. There are also select routes in Auckland that use articulated buses and they are being considered for other routes in both Auckland and Wellington.[3]

Currently, the most common type of battery electric bus is a 12m single deck bus with two axles, which typically have a 50 to 60 passenger capacity (including standing). The Requirement for Urban Buses in New Zealand (RUB) specifies that a battery electric bus range must be able to meet operational requirements without the need for an additional bus. This is a transitional measure while technology is advancing at a considerable pace and may be revisited. Expected battery degradation should be considered in calculating the service life of an electric bus, as typically a battery loses 30% capacity after 8 years of operation. However, improvements in battery chemistry and battery management systems are extending the service life of batteries.

Since 2021, larger battery electric buses with three axles have been operating in Auckland and Wellington. The battery electric bus market is evolving with electric double deck and articulated buses becoming available from manufacturers. Exemptions may be granted to the Vehicle Dimensions and Mass Rule (VDAM) requirements to support heavier buses depending on the strength of the road surface and the weight limit of any bridges along the route. It is recommended that an assessment of pavement and bridge condition is completed in advance of purchasing any buses which required a VDAM weight limit exemption.

[2] Note this is an approximate figure. Many vehicles have lesser range depending on fuel tank size and expected loading weight.

[3] Note the Public Transport Design Guidance will provide additional guidance related to articulated buses at some stage in the future.

Figure 3: Three axle battery electric bus used in Auckland (Source: Auckland Transport)

2.1.1. Charging port location

The RUB requires future battery electric buses purchased in New Zealand to have at least one CCS2 charging port. The location of charging ports on buses needs careful consideration with public transport contracting authorities to ensure consistency in depot layout and interoperability of buses around New Zealand. As shown in Figure 4, consistent placement of the charging port on the left-hand side of the bus rearward of the rear axle is very strongly recommended (note that this recommendation applies to pantograph-charged buses too). A second plug on the right-hand side of the bus is optional but also recommended to support charging flexibility. Some operators might wish to have multiple plugs in these locations to accommodate different types of charging (e.g. slow and fast charging).

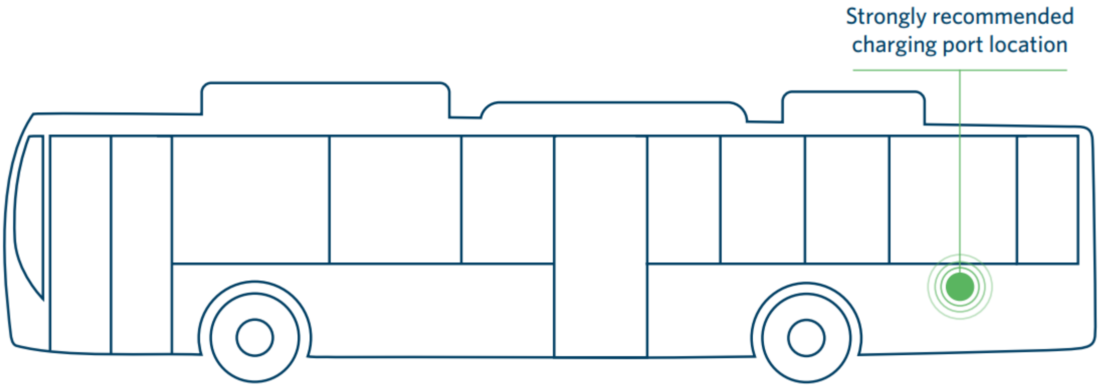

Figure 4: Recommended location of charging port is on the left side of the bus behind the back axle

Figure 5: A bus with multiple charging ports (Credit: Kirsten Boardman)

To support a safe system, locating charging points on the rear (back) or front of the bus is discouraged. This is due to risks of bus roll-away or necessitating the driver to step into the road corridor to plug in if at a road-side charger.

Consider the placement of any charging pedestals in relation to the bus charging port location as this can affect:

- the number of buses that can be charged at a time, and
- the length of the charging cables needed

While you need to ensure charging cables are long enough to be safe and convenient (Figure 6), we also recommend keeping charging cables as short as practicable to keep the cable weights low enough to support a healthy and safe working environment for staff.

Figure 6: Wellington Airport have established capacity to charge two buses at a time by positioning a pedestal charger between two bus parking spaces and providing two relatively long cords (credit: Edward Wright)

It is acknowledged that in some instances longer cables many be required, in which case they can be accommodated by support structures (see Figure 7).

Figure 7: A support structure for the charging cable (Credit Meaghan Scanlon/Linkedin)

2.2. Vehicle capacity and weight

A key consideration for implementing battery electric buses is the vehicle weight because the weight of the batteries generally makes battery electric buses heavier than an equivalent diesel bus. However, as battery technology continues to improve it is anticipated that the difference in weight between electric and diesel buses will reduce in the future. In New Zealand all vehicles which use public roads must comply with the Vehicle Dimensions and Mass Rule (VDAM).

VDAM sets maximum weight limits for all vehicles for the purpose of managing road surface degradation and ensuring safety of road users. For urban buses the maximum axle mass is shown in Table 2, noting that the specialist vehicle limits are only allowed for buses which have a permit from the relevant road controlling authority.

Table 2: VDAM 2016 schedule 3 as of 1 May 2021

Type of axle set	Mass without a permit (kg)	Mass with a specialist vehicle permit (kg)
Single large-tyred axle[4]	5,500	8,100
Twin-tyred axle in any axle set	9,000	12,000
Two axles in a tandem axle set comprising:		
• A twin-tyred axle with a single large-tyred axle and a 60/40 load share	14,500	16,000
• A twin-tyred axle with a single large-tyred axle and a 55/45 load share	14,500	18,000
Two twin-tyred axles:		
• Spaced less than 1.3 metres from the first axle to the last axle	14,500	17,000
• Spaced 1.3 metres or more from the first axle to the last axle	15,000	18,000

The following diagrams (Figure 8 and Figure 9) shows the different common axle configurations for urban buses, with buses with two rear axles having higher weight limits because the extra rear axle spreads the vehicle weight across a larger area.

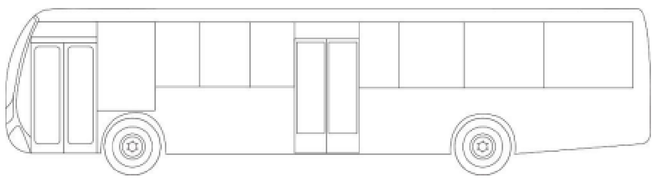

Figure 8: Single rear axle

[4] For a specialist vehicle permit the single large-tyred axle must be in a tandem axle set with a twin-tyred axle with a 55/45 load share

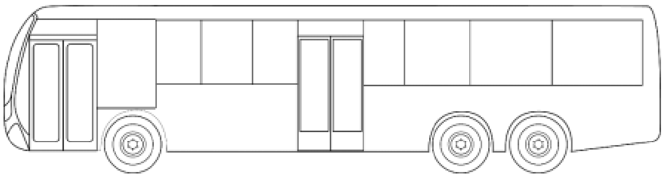

Figure 9: Two rear axles

The maximum number of passengers which a bus is permitted to carry is determined by the lesser of two calculations which is:

- The number of standing passengers is calculated by dividing the standing area available by 0.17m^2 per passenger (as contained in Land Transport Rule: Passenger Service Vehicles 1999). The standing area plus seating capacity gives a passenger limit; and
- Whether the gross vehicle weight exceeds the weight limit for the type of bus as specified in VDAM. The gross vehicle weight is calculated by multiplying the number of passengers by 80kg per passenger and adding this to the unladen vehicle weight (as contained in Land Transport Rule: Passenger Service Vehicles 1999)

Table 3 compares the typical gross vehicle weight to the weight limit for a selection of comparable diesel and electric buses of different sizes.

Table 3: Typical gross vehicle weight compared to the weight limit for a comparable diesel and electric buses

Bus type	Single deck with one rear axle		Single deck with two rear axles		Double deck with one rear axle		Double deck with two rear axles	
Fuel	Diesel	Battery electric	Diesel	Battery electric	Diesel	Battery electric	Diesel	Battery electric
Length	11.5m	11.4 - 11.6m	12.6 – 13.5m	12.6 – 13.5m	10.9m	10.8m	12.4 - 13.5m	12.5 - 13.5m
Number of rear axles	1	1	2	2	1	1	2	2
Seats	35	35	41 - 43	41 -43	70	70	80 - 85	80 -85
Standing passengers	20	20	31 - 34	31 - 34	10	10	15 - 20	15 - 20
Total maximum passengers	55	55	72 - 75	72 - 75	80	80	95 - 100	95 - 100
Unladen weight	9,000 kg	11,100 - 12,500 kg	11,400 – 12,820 kg	12,800 – 15,210 kg	10,800 kg	12,300 - 13,300 kg	14,140 - 16,500 kg	16,800 - 19,000 kg
Gross vehicle weight	13,400 kg	15,580 - 16,900 kg	17,480 – 18,820 kg	18,800 – 21,280 kg	17,200 kg	18,700 - 19,700 kg	22,220 - 24,500 kg	24,480 - 27,000 kg
NZ weight limit without permit	14,500 kg	14,500 kg	20,000 kg	20,000 kg	14,500 kg	14,500 kg	20,000 kg	20,000 kg
NZ weight limit with permit	20,100 kg	20,100 kg	26,100 kg	26,100 kg	20,100 kg	20,100 kg	26,100 kg	26,100 kg

Notes:

Values are based on manufacturers specifications
Standing passenger capacity is approximate only
Assumes the bus has a 55/45 load share
Not all bus models shown are used in New Zealand

Please note that technical specifications vary between manufacturers and between bus models and therefore some buses may have specifications outside the range shown. The results show that all types of battery electric buses can fit within the New Zealand weight limits with a specialist vehicle permit being required in some instances. Battery Electric Buses which have a single rear axle or are double decker are more likely to require a specialist vehicle permit because there is a higher load placed on the axles. Some manufacturers produce single deck Battery Electric Buses which are within the standard weight limit and can therefore operate without a specialist vehicle permit. Whether a battery electric bus is above or below the weight limits depends on a number of factors including the size of bus, the number of passengers carried, the number of axles, the load share between axles, the number of batteries and the materials used for the batteries, chassis and body.

We recommend careful consideration of bus weights from a full bus network lifecycle perspective. There may be advantages to selecting lower weight buses that do not require specialist permits because they would have less restrictions in terms of where they can be used. They also may not require costly pavement upgrades or as much maintenance costs. This is because heavy weight buses, especially when fully laden, can cause rutting and potholes on surfaces that are not designed for high stress use. Further information related to road surface maintenance on bus routes is available in the PTDG topic Corridor inspections and maintenance requirements.

2.3. Vehicle range

Another important consideration when transitioning to battery electric buses is vehicle range. The range is influenced by a number of factors which include:

- Vehicle weight
- Vehicle frontal area
- Tyre pressure
- Vehicle speed
- Heat ventilation and cooling (HVAC) load
- Gradient of the route
- Climate conditions
- Passenger weight
- Battery size
- Battery age
- Regenerative braking

Manufacturers advise on ranges using the unit ‘KWh per KM’ that is supposed to indicate shows how well the bus uses the energy. Quoted ranges for battery electric buses vary greatly depending on manufacturer specifications. A range of approximately 300km is relatively common. Long range battery electric buses tend to have more batteries with the trade-off being higher capital cost and increased vehicle weight, which may mean a lower legal passenger carrying capacity.

Be aware and cautious of the different ways in which battery electric bus range is measured when procuring fleet. Some bus manufacturers quote a guaranteed range (worst case scenarios) at the end of the battery life whilst others quote best case or average range at the start of the battery life. Some quoted ranges assume the buses are fully laden and using heating, ventilation, or air conditioning (HVAC) while other manufacturers do not take as conservative an approach. A more direct comparison is to compare the capacity of the battery, which is measured in kilowatt hours, qualified with the expected life cycle of the battery.

Instead of relying on manufacturer specifications public transport contracting authorities and bus operators should request range analysis that uses information about the actual services which the battery electric buses will be used to deliver. This analysis can be used to test a number of different scenarios such as high HVAC use during times of temperature extremes and near end-of-life operation when the range of the battery electric buses is expected to be reduced.

2.3.1. Scheduled travel distance

Irrespective of whether operated by battery electric or diesel buses, the distance that a bus may need to travel on any given day is determined by several factors which can include the following:

- Length of bus routes
- Number of trips in a shift
- Amount of dead running (repositioning) between trips
- Location of the depot in relation to the termini of the bus routes
- Whether the driver takes the bus back to the depot for a lunch break

A bus used for a split shift (with a break during the middle of the day) could travel approximately 30km to 60km before returning to the depot, at which point it could be charged briefly before the afternoon proportion of the shift. A bus used for an all-day shift could be on the road for approximately 150km to 350km before returning to the depot for charging overnight.

Based on the typical range quoted by manufacturers, start of life battery electric buses should comfortably be able to complete split shifts and be charged at the depot either between shifts or at end of day. However, as the battery degrades over time adjustments to driver schedules or bus assignment may be necessary to manage the range of mid-life battery electric buses.

Long range battery electric buses could complete all-day shifts on a single charge, however in some situations, opportunity charging may be required to extend the time on road before returning to the depot. Alternatively, bus operators could shorten drivers' shifts where these exceed the range of battery electric buses (however this could increase operating costs due to increased dead running back to depot).

In situations where bus operators have battery electric bus fleets which include buses with degraded batteries there could be the need to assign individual buses to schedules. This is because a start of life bus could complete a long shift but a mid-life bus with a shorter range might not be able to complete the same shift. Therefore, bus operators should regularly monitor the battery state of charge and manage the fleet and driver schedules according to the expected range. For diesel bus operations it is uncommon for buses to be assigned to specific driver shifts and therefore the management of battery electric bus fleets would represent a change in practice for bus operators.

2.3.2. State of charge

The amount of energy left in a battery pack is referred to as the state of charge (SOC). It is equivalent to the fuel gauge on a traditional vehicle, telling the driver how much energy remains. While SOC can theoretically be between 0% and 100% full, in practice the SOC has minimum and maximum limits in place to protect the long-term useful life of the battery. The minimum allowable SOC is set above 0% to minimise battery performance degradation[5]. An additional lower level of the SOC, "reserved energy", is set aside as a contingency during emergencies and unforeseen delays. This reserve varies from 10% to 35% between battery manufacturers. When fast charging near the upper SOC limit (typically the upper 10%–

[5] Optimization of Fast Charging Infrastructure for Electric Bus Transportation – Electrification of a City Bus Network. (Accessed on 12 Oct. 2021)

25%), you may find the allowable charge rate tapers quickly as well. After all limits are applied, the usable energy is roughly 70% of theoretical battery capacity at its beginning of life[6] (Figure 10).

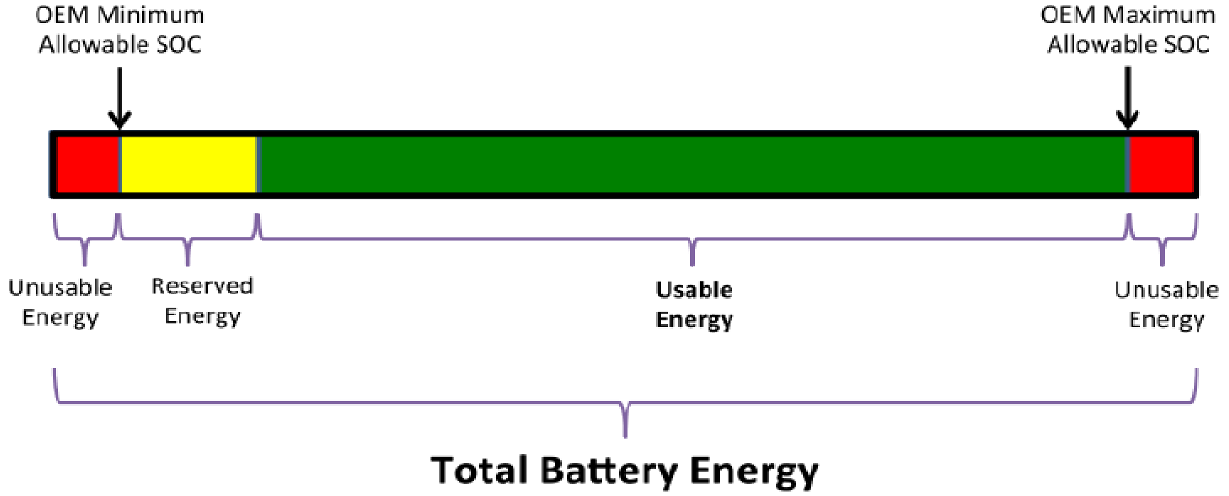

Figure 10: Beginning of life battery. Image source: Bigelow 2017

Battery capacity diminishes over time and usage. As batteries charge and discharge, their internal physical and chemical structures degrade[7]. As a new and rapidly evolving technology, batteries for electric buses are subject to lifetime uncertainty, though some major manufacturers offer 12-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%[8]. Figure 11 shows the SOC limits for a battery near the end of its life[9]. While the minimum allowable SOC is highly similar to a new battery, the upper charge limit is significantly lower than a new battery.

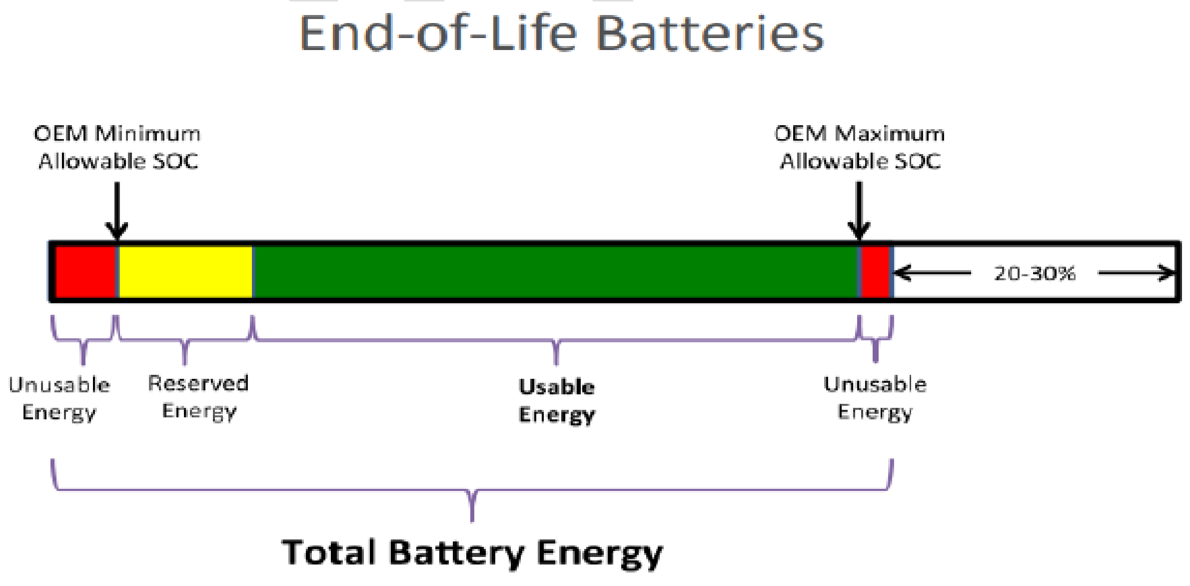

Figure 11: End-of-life battery. Image source: Erik Bigelow 2017

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[6] Fast Charging Battery Buses for the Electrification of Urban Public Transport—A Feasibility Study Focusing on Charging Infrastructure and Energy Storage Requirements Available online: https://doi.org/10.3390/en8054587. (Accessed on 12 Oct. 2021)

[7] Charging Optimization of Battery Electric Vehicles Including Cycle Battery Aging. Available online: https://doi.org/10.1109/ISGTEurope.2014.7028735. (Accessed on 12 Oct. 2021)

[8] Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2. Available online: https://about.bnef.com/blog/electric-buses-cities-driving-towards-cleaner-air-lower-co2/. (Accessed on 12 Oct. 2021)

[9] https://www.nrel.gov/docs/fy21osti/76932.pdf

2.3.3. Battery service life

The rate at which bus batteries degrade depends on several factors including:

- the battery chemistry,
- the rate at which batteries are charged (fast vs slow charging)
- the temperature of the battery
- charging management systems
- the extent to which batteries are charged and discharged,

The chemistry and structure of batteries determines the characteristics of the battery including specific energy, specific power, self-heating rate and lifespan.

Specific energy is the amount of energy that a battery can store per kilogram whereas specific power is the rate at which a battery can deliver power. Battery technology is constantly changing but the typical characteristics of different types of batteries are shown in the diagrams below. Generally speaking, nickel manganese cobalt batteries have good overall performance with excellent specific energy, lithium iron phosphate batteries have enhanced safety and lithium titanate oxide batteries enable fast charging but low specific energy.

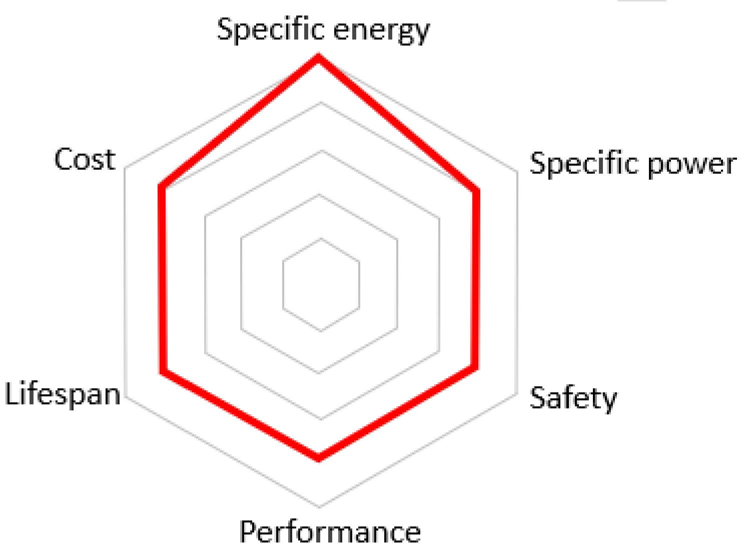

Figure 12: Nickel manganese cobalt (MCA)

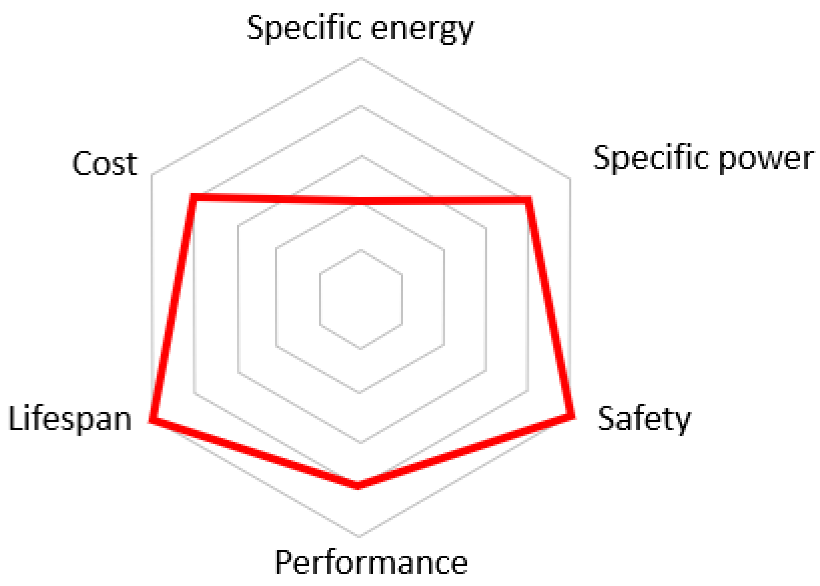

Figure 13: Lithium iron phosphate (LFP)

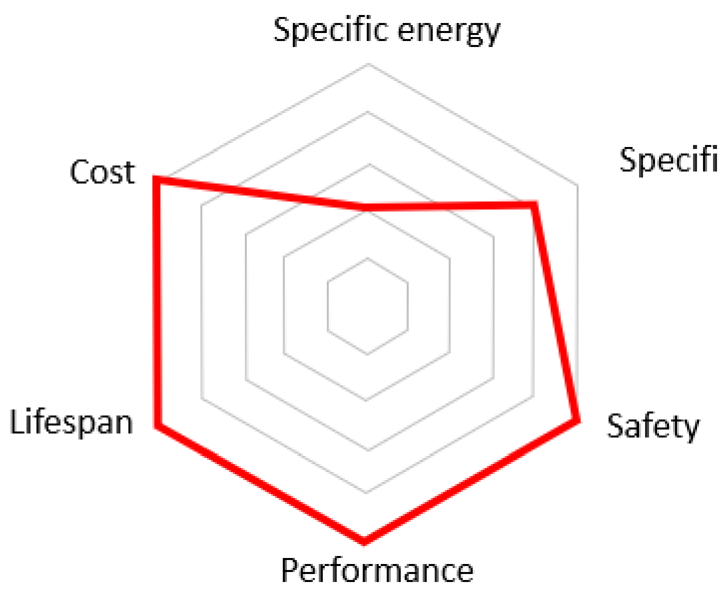

Figure 14: Lithium titanate oxide (LTO)

Another factor which influences the rate at which batteries degrade is the charging method used. Fast chargers can degrade batteries quicker than slow charging due to the higher heat which results from the rapid transfer of electricity. Mitigation strategies which can reduce this impact include:

- procuring the right type of battery to match the type of charging expected,
- charging management systems which measure the battery temperature and resistance then adjust the rate of charging accordingly.
- the use of vehicles HVAC system to cool the battery as it is charged.

Maintaining an optimal SoC range can also help to extend battery service life with the optimal range generally being between 20% to 80% SoC[10]. This is because a partial charge and discharge cycle places less stress on the battery than a full cycle. In practice this could mean charging the bus as much as is needed for the following shift allowing for some contingency instead of charging all buses to 100%.

2.3.4. Case study: Christchurch route 29

In 2019, three two axle battery electric buses were introduced on Christchurch's Route 29 between the central bus interchange and Christchurch Airport (Figure 15). They were a direct replacement for three diesel buses which operate on a route of just over 11km along flat terrain. The battery electric buses were contractually required to be able to travel 300km over a 16.5 hour operating period on a single overnight charge. They also had to have suitable luggage provision for an airport service while maximising seated capacity. The buses procured for this service are quoted to easily achieve the range required of them and have capacity for 55 passengers (36 seated). They are recharged simultaneously overnight at the depot with no need for opportunity charging.

The combined weight of the batteries, customers and their luggage on a two-axle vehicle required an over-weight permit to be issued by Waka Kotahi. This limits the use of the electric buses to the permitted route, but given it is an airport specific service, this has not constrained the operator. The operator has subsequently sought approval for the use of these three buses on another contracted services, which creates vehicle allocation flexibility should the need arise.

Vehicle weights and the possibility of requiring approvals should occur in any planning or procurement discussions.

Figure 15: Christchurch battery electric bus (source: Environment Canterbury)

[10] Optimal electric bus fleet scheduling considering battery degradation and non-linear charging profile - ScienceDirect

2.4. Public transport network considerations

There are a number of operational aspects of public transport networks that need to be considered in planning and designing for battery electric bus charging because they can impact scheduling of recharging buses and also the electricity demand requirements. These considerations include:

- Split day versus all-day use
- School bus routes
- Vehicle size
- Layover and driver breaks
- Driver changes over versus vehicle charging
- Specialist fleet considerations

2.4.1. Split day versus all-day use

Urban buses in New Zealand are used in various ways, with weekday usage driven by peak demand, particularly in cities. This is because more buses and drivers are needed during peak periods when commuters and students are travelling compared to the middle of the day and in the evening. An example of this is shown in (Figure 16) which has the number of bus trips by time of day for Wellington City.

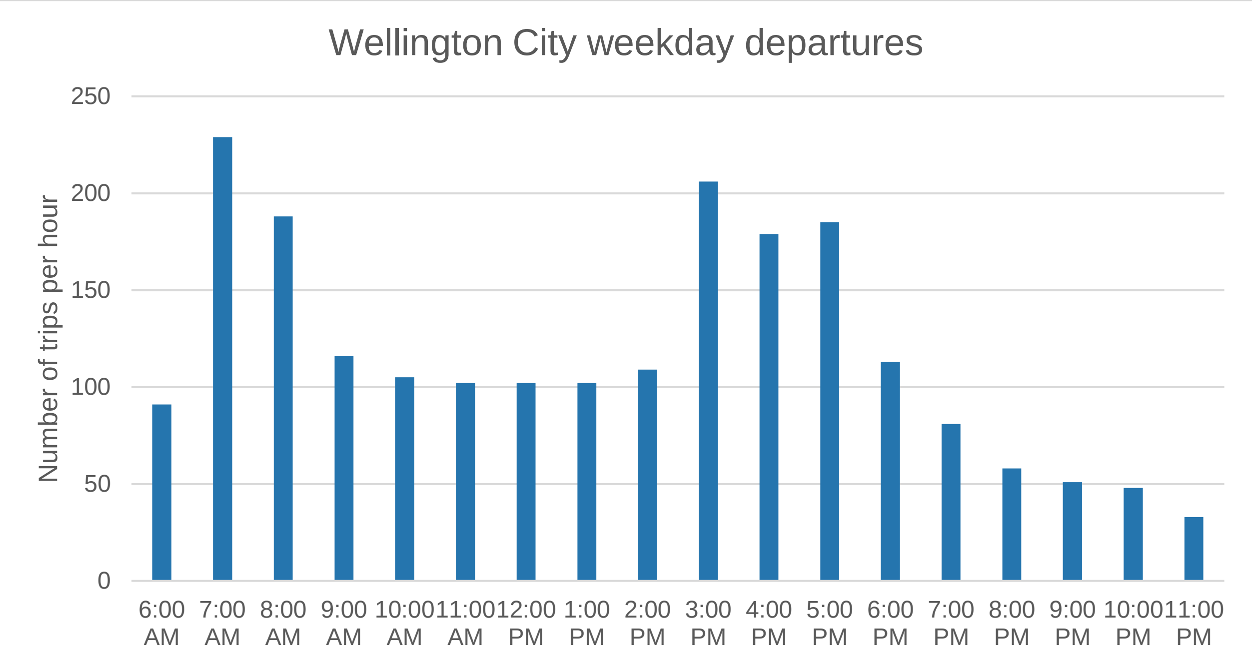

Figure 16: Number of bus trips by time of day for Wellington City

The best time to charge a battery electric bus depends on its schedule, with two common scenarios discussed below:

- Some vehicles may only be on the road for the peak morning period and then will return to depot for approximately four to six hours before being used again for the afternoon peak period. This period provides an opportunity for vehicles to be charged in the middle of the day as well as overnight, meaning they can potentially have a lower battery range.
- Other vehicles may be on the road from 6am until midnight, with driver changeovers happening mid-route. Vehicles utilised in this way need to have sufficient range and they may need opportunity charging during the day.
- Bus operators may also use battery electric buses for charters (school trips, sports events, etc.) or rail replacement services. Trips that occur outside of public timetables can present challenges, particularly

if the additional trips occur when a bus would otherwise be charging. Operators should be aware that non-scheduled trips can have an impact on battery electric bus availability for scheduled public trips.

The costs, benefits, operational considerations, and other guidance related to depot and opportunity charging are provided in the section on Infrastructure considerations.

Guidance related to ranges of battery electric buses is provided in the section on Vehicle range.

2.4.2. School bus routes

A school bus service is a bus route that is operated solely to get students to and from school with members of the general public generally being excluded. The demand for school bus services is highly concentrated between 7:30am and 9:00am and from 3:00pm to 4:30pm because classes tend to start and end at these times. As a result, the number of school bus services will strongly influence the number of buses required to operate a public transport service. School bus routes can be easier to operate with lower range battery electric buses than public bus services because the distance travelled by school buses per day tends to be short. That said, it is acknowledged that many school routes are combined in or around urban bus service operations.

2.4.3. Vehicle size

Another important characteristic of the public transport network is the frequency and capacity required for different types of bus routes as follows:

- For high demand routes, it is more efficient to use larger buses which can accommodate more passengers per bus and therefore reduce the number of buses and drivers required.
- For low demand routes, capacity is not an issue. Frequency is determined by balancing the level of accessibility desired and the cost of providing the service.

In general, larger buses require more energy than small buses to travel the same distance due to the vehicle weight. As such, large buses may need opportunity charging or additional battery capacity to achieve the operational range required (refer to section on Vehicle range).

2.4.4. Layover and driver breaks

A layover is the term for the time between scheduled services which is added into a driver's shift to improve the reliability of the public transport service. This works by providing a buffer between trips so that if the first trip runs late then the second trip can start on time. The amount of time provided for a layover is typically between 2 to 15 minutes. Under the Employment Relations Amendment Act 2018 a bus driver is entitled to 10-minute rest breaks during the workday in addition to a 30-minute meal break. Rest and meal breaks provide drivers with an opportunity to rest, refresh and take care of personal matters.

Full guidance on planning and design for bus layover and driver facilities is available in the PTDG topic Bus layover and driver facilities.

From a battery electric bus perspective, layover and driver breaks provide an opportunity to charge a battery electric bus while out of depot. Layovers provide relatively frequent opportunities to charge the bus, however, they are typically short in duration and may be skipped if the incoming bus is behind schedule.

Rest and meal breaks occur less often but have the advantage of being longer in duration and are a legal requirement so cannot be skipped, even if the bus is running late. If opportunity charging during layover is used to top up electric bus batteries, it is important to factor in shorter and skipped layovers where appropriate due to late running. If top up charging is expected during bus layover / driver breaks, this should be factored into choice of battery types as some batteries are more prone to degradation from multiple short burst charges than others, as discussed in the Vehicle range section.

Vehicle range

2.4.5. Driver changeover versus vehicle changeover

Operational needs for driver or vehicle changeover can affect battery electric bus charging requirements. When a bus driver needs to take a meal break or is ending their shift the bus operator can either:

- Change out the driver and keep the vehicle on the road (driver changeover), or
- Bring the driver and vehicle back to the depot (vehicle changeover)

Driver changeover (also called hot seating) may be preferred by bus operators because it reduces dead running (out of service bus movements). However, a vehicle changeover may be preferred from a battery electric bus charging point of view because it enables the bus to be charged at the depot and may avoid the need for opportunity charging on the route itself.

The travel associated with dead running (which often occurs with vehicle changeover) needs to be accounted for in calculating battery capacity and charging requirements. The degree to which bus operators utilise driver or vehicle changeover depends on the network structure, the location of the depot and any contractual requirements.

2.4.6. Specialist fleet considerations

Having an interoperable fleet generally results in a more reliable public transport service because it provides more flexibility to the bus operator if a vehicle is out of service for repairs or maintenance.

Meanwhile, a specialist fleet has the advantage of being able to tailor the vehicle to the characteristics of the route such as road constraints, branded livery, and required capacity. Existing diesel bus fleets are typically partly specialised, with most operators having multiple bus sizes and branded buses for special services such as Christchurch’s Orbiter or Auckland’s Northern Express.

Battery electric buses can add another layer of complexity to fleet allocation if various buses of different ranges or charging requirements are used. Therefore, when converting the bus fleet from diesel to electric, public transport contracting authorities should seek to maximise interoperability where possible. This can include charging port locations, compatibility with charging dispensers and chargers, as well as communications and data protocols.

2.5. Electric supply

Electric buses have substantial energy requirements. Energy supply is imperative to consider in the planning and design of electric bus networks. This section provides a broad overview of characteristics of the electricity supply in New Zealand.

In New Zealand, approximately 84% of energy generation comes from renewable sources (hydro, geothermal, and wind) with the remaining 16% from fossil fuels including gas and coal (Figure 17).

The share of renewable power generation is high by international standards, which provides a comparatively clean source of energy for battery electric buses with more renewable energy projects being planned and consented. The availability of electricity generated from renewable sources provides the opportunity to reduce greenhouse gas emissions from the provision of public transport services.

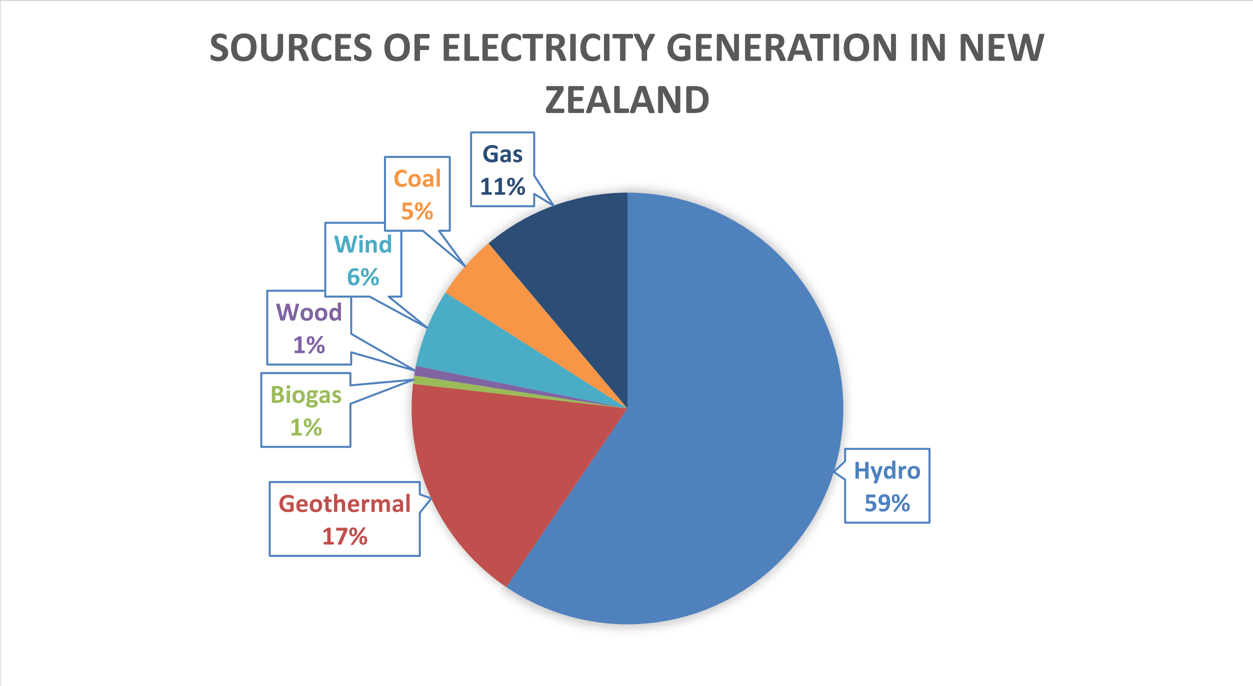

Figure 17: Sources of electricity generation in New Zealand for December 2020 (Source: MBIE)

Another feature of the electricity market is that demand peaks are bimodal. Demand is highest during the morning (7:30am to 8:30am) and evening (6:00pm to 7:30pm) (Figure 18). These are times when households tend to use heating and appliances and higher demand increases electricity prices. Overnight and during the middle of the day is when there is less demand for electricity, which in turn means that it is cheaper at these times. For bus operators the uneven power demand presents the opportunity to charge some battery electric buses overnight or in the middle of the day to reduce operating costs. This may also be more practicable as the peaks in electricity demand also overlap with peak travel times when most buses will be in service, particularly during the morning peak. However, the interface between the electricity market and bus operational requirements may impact the cost of opportunity (on-route) charging.

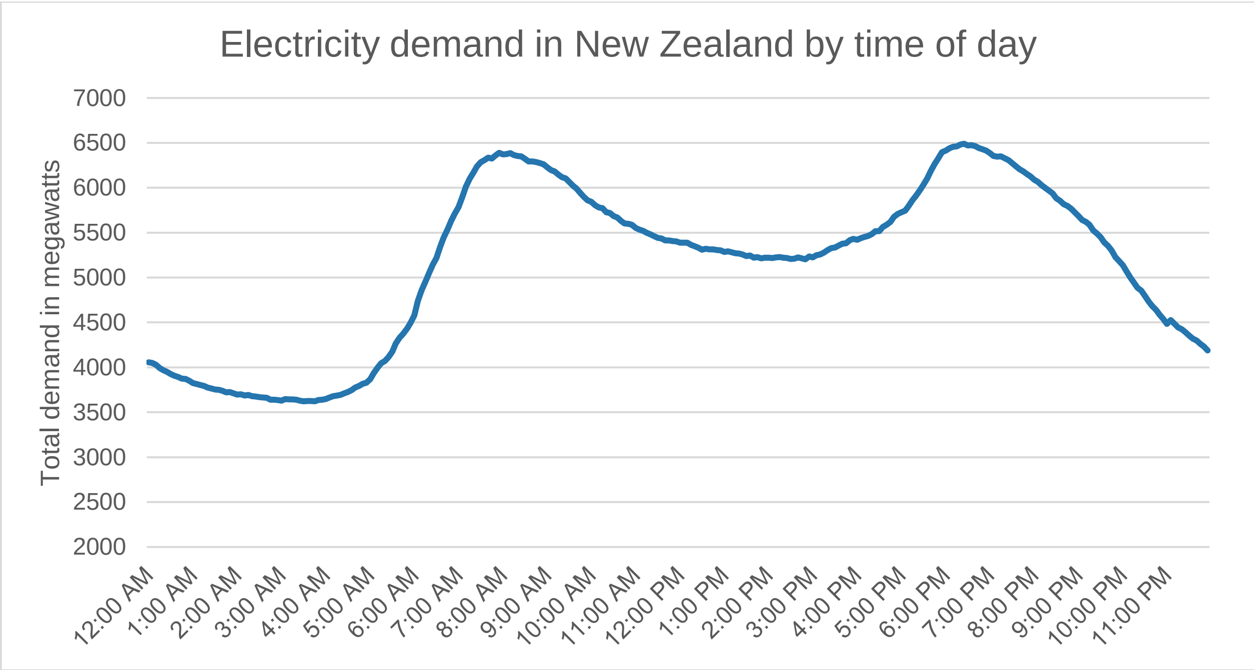

Figure 18: Typical electricity demand by time of day (source: Transpower)

For further guidance to support discussions between electricity sector participants on the provision of electricity infrastructure and power supply for heavy commercial vehicles refer to the Local Electricity Market Guidance. This resource provides further advice on:

- what is involved in obtaining the electricity infrastructure (including connection to the electricity distribution network) and power supply required for an electrified bus depot,
- the choices around managing the infrastructure, minimising future upgrades and ensuring resilience,
- how to ensure that engagement between depot owners/operators and the electricity distribution business is productive,
- background information on the New Zealand electricity sector, and
- the regulatory environment governing electricity distribution and supply.

[Local Electricity Market Guidance]

3. Infrastructure considerations

Guidance on battery electric bus charging infrastructure for both depot charging and opportunity charging. Covers a range of considerations to inform infrastructure development such as charging time, charging strategies, charger location, depot layout AC versus DC chargers and converters, connector type, grid capacity, DERMS, electricity supply resilience, types of charger connections, top-down vs bottom-up pantographs and a case study in Wellington.

Take care in procuring buses and charging infrastructure to ensure compatibility between batteries and charging equipment as there are different types of batteries suited to different charging strategies. For instance, not all batteries are designed for fast charging so 'fast-charging compatibility' may need to be explicitly specified in vehicle procurement if you plan to use fast charging infrastructure.

Note that Standards New Zealand PAS 6010:2021 provides a best practice guide for public and commercial electric vehicle charging with many of the same principles also applying to battery electric buses. We recommend that you read this in conjunction with this guidance.

Note that the Low Emission Bus Working Group CCS2 Plug Type Standard Recommendation report also identifies the following safety requirements:

1. Where a supply lead is intended to be used outdoors or in a damp location, it should be selected with a degree of protection of at least IPX4 in accordance with IEC 60529.
2. Vehicle supply adaptors (electrical vehicle adaptors) should only be used if specifically intended and supplied by the vehicle manufacturer or by the EVSE manufacturer for that purpose.
3. Electric vehicle adaptors should comply with the requirements of IEC 61851:2017. The adaptors shall be marked to indicate any specific conditions of use allowed by the manufacturer.

The report also notes specifications and standards which are captured in the Relevant specifications and standards section.

Pavement strength

Consider pavement strength when designing charging points for both depot and opportunity charging locations. This is because buses will need to park in these locations for periods of time to access the charger which, due to the weight of the vehicles, can cause high stress on the ground surface. If this stress is not adequately designed for, surface damage such as potholes and wheel ruts may form over time. The maintaining corridor clearance section of the Corridor clearance topic provides further guidance on pavement design at high stress locations.

3.1. Depot charging

3.1.1. Charging time

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 safety buffer. Advantages of this approach include: electric buses are charged overnight when electricity costs are lower and utilising the long duration of time when the bus is out of operation.

The amount of time required to fully charge battery electric buses varies by:

- the size of the batteries
- the rate of charging
- whether alternating current or direct current is used.

Based on a selection of bus manufacturer specifications, the size of electric bus batteries is between 180 kWh and 675 kWh, with typical capacity levels being in the 200-300 kWh range. Assuming a low voltage charger of 60kW, batteries would normally take between 4 and 5 hours to fully charge. An alternative strategy is to deploy high voltage chargers at the depot (typically more than 100 kW) which shortens the charge time and enables the charger to be used for multiple buses simultaneously. Another application for high voltage chargers is as an emergency backup in situations where a bus has not received a full overnight charge.

The amount of time buses spend at depots varies by driver shifts; however, most buses will spend approximately 10 hours overnight. This typically provides ample time to fully charge a bus.

With the growing proportion of battery electric buses in the fleet, increasingly bus operators use software which automatically turns the charger on and off depending on electricity price to minimise the fleet recharging cost. We recommend introducing this technology early to manage load on the grid and certainly prior to there being 10 or more battery electric buses being used at a depot. The larger the fleet, the more potential savings can be accrued from the use of smart charging.

Figure 19: A bus charging using a plug connection (Credit: Kirsten Boardman)

3.1.2. Charging strategies

Many manufacturers offer depot management applications which facilitate smart charging to optimise energy use, as well as manage charging rates and duration of charge for electric bus fleets. Smart charging systems can provide operational efficiency benefits to bus operators by linking operational needs (scheduled range and operating duration needs by day) with the fleet charging strategy (not every bus in the depot may need to be fully charged to deliver schedules, and in the future the bus fleet may contain buses with different range limits due to battery degradation). Smart charging systems can also cap the power drawn from the grid to a level agreed with the electricity distributor in order to manage demands on the electrical grid.

Multiple charging dispensers can be operated from one charger and the distribution of power can be sequenced to support operator needs under different scenarios, with output shared between dispensers, or full power provided in turn.

Figure 20 illustrates three approaches for buses parked in a depot where sequencing can be used to support different bus dispatch or assignment strategies:

- On the left, Charging by Parking Block is shown – here the smart charging application can prioritise charging to the orange highlighted buses, allowing these to be dispatched initially, with charging then sequenced to the block of bus shown in blue, to the rear.
- In the second column, Charge by Row, the smart charging system could alternately charge rows of buses.
- On the far right, a Charge by Track strategy would prioritise columns of parked buses (highlighted in orange) which could then be dispatched initially to potentially clear a movement track. As the figure shows, with smart charging systems and multiple dispensers operating from charging units, a range of charging strategies can be used to support different bus dispatch strategies.

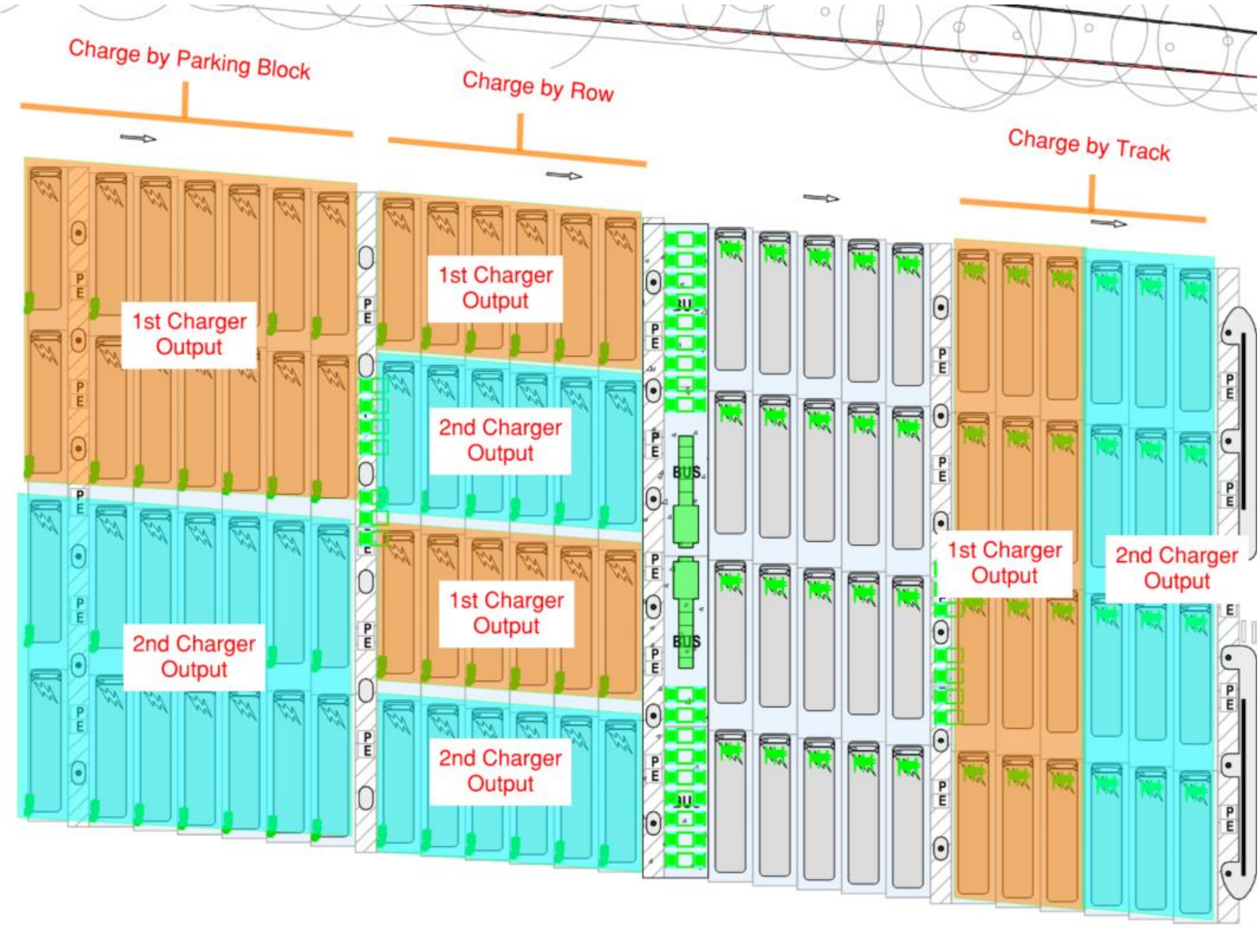

Figure 20: Conceptual bus depot layout showing different charging strategies (Source: Transport Canberra)

3.1.3. Charger location

The optimal location of depot chargers is influenced by the type of charger and the layout of the bus depot. Chargers have specifications depending on the manufacturer with some chargers having a single dispenser (plug) with other chargers having multiple dispensers (typically 2 to 4). Chargers with multiple dispensers provide the opportunity to reduce the number of chargers required because multiple buses could be charged from the same unit.

In order to use multiple dispenser chargers, buses need to be positioned so that they can connect to the charger with the location of the charging port varying between battery electric bus manufacturers and models. Therefore, flexibility to change charger location and charger type is an important concept for the design of battery electric bus depots. For guidance on recommended location of charging ports on buses (the left side of the bus, behind the rear axle), see: Charging port location.

The weight of the charging cables should be considered to ensure that they are safely usable for a range of people. Cable management should also be used to minimise the risk of buses colliding with dispensers or becoming entangled in charging cables. Wing mirror clearance and space for general maintenance like cleaning is important to consider when buses are parked in rows. For example, Transport for New South Wales currently requires a 0.8m minimum gap between buses in depot layouts though this is under review.

The advantages and disadvantages of different charger configurations are discussed in Table 4.

Table 4 Advantages and disadvantages of different charger configurations

Charger location	Advantages and disadvantages	Example
Wall mounted	• Advantage: Reduces the amount of space required for the charger • Disadvantage: Can only be used for parking spaces adjacent to walls or buildings • Disadvantage: Requires manual connection and disconnection • Disadvantage: Can require reversing which is less preferred in bus depots • Disadvantage: Potential for operator error from manual handling (dispenser and port damage, incomplete charge, cables being driven over, wear to cables and dispensers)	 *Figure 21: Wall mounted charging. (Image source: Kirsten Boardman)*
Pedestal	• Advantage: Flexibility as can locate the charger adjacent to the parking space, Advantage: often lower cost than other charging configurations • Disadvantage: Risk of charger being hit by bus whilst manoeuvring • Disadvantage: Requires manual connection and disconnection • Disadvantage: Chargers and dispensers usually located on a platform or island that can reduce space in the depot yard • Disadvantage: Potential for operator error from manual handling (dispenser and port damage, incomplete charge, cables being driven over, wear to cables and dispensers)	 *Figure 22: Pedestal charging. (Image source: Sam Wilkes)*

Charger location	Advantages and disadvantages	Example
Overhead	• Advantage: Space efficient because the charger unit is located out of the way, reducing depot capacity impact • Advantage: Charging process can be automated, reducing operating costs and reducing human error • Advantage: Can be compatible with future automated depot yard operations • Disadvantage: requires an overhead structure which may require additional planning controls – some may construe a high gantry in an open depot as an eyesore • Disadvantage: Higher capital cost •	 *Figure 23: Overhead charging. (Source: Omexom)*
Pantograph	• Advantage: Less depot space required • Advantage: Allows for future opportunity charging if needed • Advantage: Automated process with less room for error • Disadvantage: More expensive charging units (compared to plug in) • Disadvantage: Higher fleet costs due to additional equipment • Disadvantage: Requires overhead structures to support the pantograph or the connection point, this may require additional planning controls – some may construe this in an open depot as an eyesore • Disadvantage: May lead to higher battery degradation if the wrong battery type is used	 *Figure 24: Pantograph charging. (Source: ABB)*

Charger location	Advantages and disadvantages	Example
Induction	• Advantages: Space efficient because the charger plates are located underneath the road surface • Advantages: No physical connection such as overhead structures or cables required for connection. • Advantages: Quick and easy to make connection which is an automated process • Disadvantages: decreased charging efficiency (higher energy loss during transmission) • Disadvantages: Higher costs because the induction plates need to be built into the road	 *Figure 25: Induction charging in London (Source: IPT Technology)*

3.1.4. Depot layout

Planning for depots

Anticipate planning considerations for depots, some of which might include issues like:

- Trenching works that need to take place in the depot for cables which may have an earthworks or contamination trigger
- Construction works associated with gantries or implementing power may also trigger planning controls
- Location in relation route start and end points
- The size and shape of the site which determines the layout of the depot
- The type of electrical connection to the site
- The capacity of the local electric grid
- Access to the site and impact on the transport network

Design of depot

At a standard bus depot diesel buses are refuelled at an onsite fuel pump or at a petrol station before being parked in closely spaced rows overnight. However, for battery electric bus depots buses are typically parked and then connected to the charger. Depending on the charging strategy the bus may be left connected to the charger overnight or multiple buses may be cycled through a charger.

More space may be required for a battery electric bus depot than an equivalent diesel bus depot. Space required may depend on factors such as the:

- location of the charging units
- charging port locations
- configuration of the bus depot
- charging strategy used.

With ground level plug-in charging for instance, chargers and dispensers arranged in columns adjacent to bus parking columns (allowing one charger to service buses to the left and right) can reduce bus parking capacity in the depot by approximately 25 percent. While overhead charging methods (pantograph or drop-down plug-in charging) can minimise the space impacts at ground level, structures to support overhead charging (roofs or gantries) may have an impact on bus depot yard capacity and circulation. Therefore, when planning for the implementation of battery electric buses it is important that bus companies consider different charger and parking configurations to understand any space implications.

Under diesel bus operation, with homogeneous range capabilities and rapid refuelling times, buses require little independence of movement once parked in the bus depot. With battery electric buses, particularly several years after deployment, different buses may have different range capabilities. Therefore, it can be advantageous to design battery electric bus depots to allow greater independent bus movement and flexibility which enables buses to be charged and ranked in accordance with their scheduled work and the bus range capability.

3.1.5. AC versus DC chargers

The electrical grid supplies alternating current (AC) because this type of electricity is easier to transmit over long distances. However, batteries, including those used in electric buses store electricity as DC. The conversion from AC to DC can take place on board the bus via an inbuilt converter or at the charger with the converter being integrated into the charger. Chargers which supply the bus with AC are called AC chargers and chargers which convert the power supply to DC are called DC chargers.

AC chargers

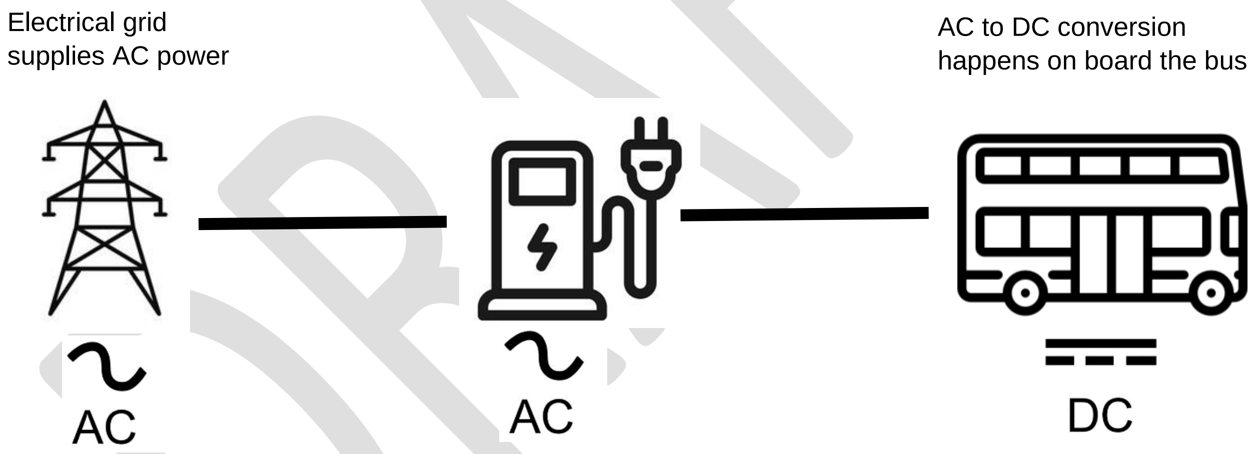

Figure 26: AC chargers convert AC power from the electrical grid to DC on board the bus.

DC Chargers

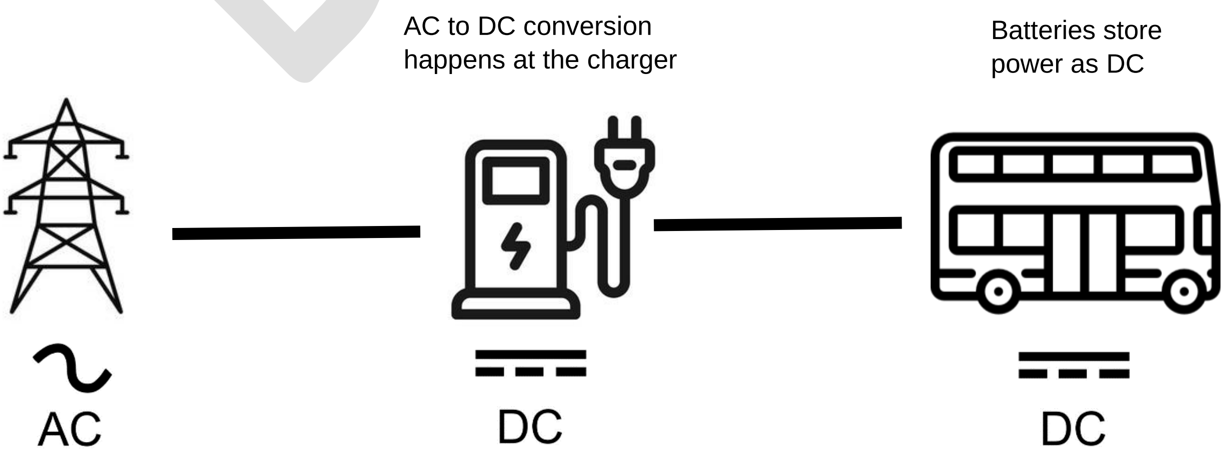

Figure 27: DC chargers convert AC power from the electrical grid to DC at the charger and then store it as DC power in the batteries on the bus.

The capacity of AC chargers is typically up to 60kW (using a dual plug configuration) whereas DC chargers can provide up to 600kW which means that buses can be charged quicker. However, a disadvantage of DC charging is that it can place higher demands on the electricity grid unless separate power storage (i.e., battery) is used instead of connecting directly to the grid. Therefore, AC chargers have tended to be used at bus depots where there is a long period of time to recharge.

DC chargers tend to be for opportunity charging where a large amount of energy needs to be transferred in a short period of time. Nevertheless, there is a general trend towards DC chargers being used at depots where buses need to be charged quicker such as when buses are used for services which have a long span of operating hours.

We generally recommend DC charging for higher capacity buses such as double deck and articulated buses, due to the compatibility with fast charging and weight savings. In some areas, such as regional New Zealand, public transport demand is more likely to be accommodated through standard sized buses and AC charging may still be relevant. In these contexts, consider an AC to DC converter.

3.1.6. AC to DC converter

Whether to specify an on-board AC to DC converter is an important consideration when procuring battery electric vehicles. There are some reasons public transport contracting authorities and bus operators may want to procure battery electric buses which have AC to DC converters:

- The flexibility to charge using both AC and DC chargers results in greater interoperability than relying solely on DC chargers.
- It is common for buses to be moved between depots, between regions, or sold to other operators, and therefore AC to DC converters further enable the transference of battery electric buses around New Zealand.

On the other hand, an AC to DC converter is not relevant for a bus configured for opportunity charging.

3.1.7. Connector type

There are several different standards used around the world for charger plugs and ports with battery electric bus manufacturers offering different connection types. The most common types of connectors are CCS2, CHAdeMO and GB/T.

It is desirable from an interoperability perspective for all battery electric buses in New Zealand to use the same connector type which enables electric buses to be moved between operators and around the country more freely. For this reason it has been agreed with the sector to adopt CCS2 as a standard plug type, as specified in the Requirement for Urban Buses (the 'RUB'). Therefore, **public transport contracting authorities and bus operators must select battery electric buses which have the CCS2 type plug.** This may be in addition to other types of charging infrastructure like pantograph or induction equipment (discussed further in the Opportunity charging section).

The RUB also requires that Open Charge Point Protocol (OCPP) is used. This is an is an open-source communication standard for EV charging stations and network software companies. This is relevant to vehicle to grid (V2G) communication interfaces.

Figure 28: CCS2 plug. Image source: https://evse.com.au/product/ccs-2-w-6m-cable-80-amp/

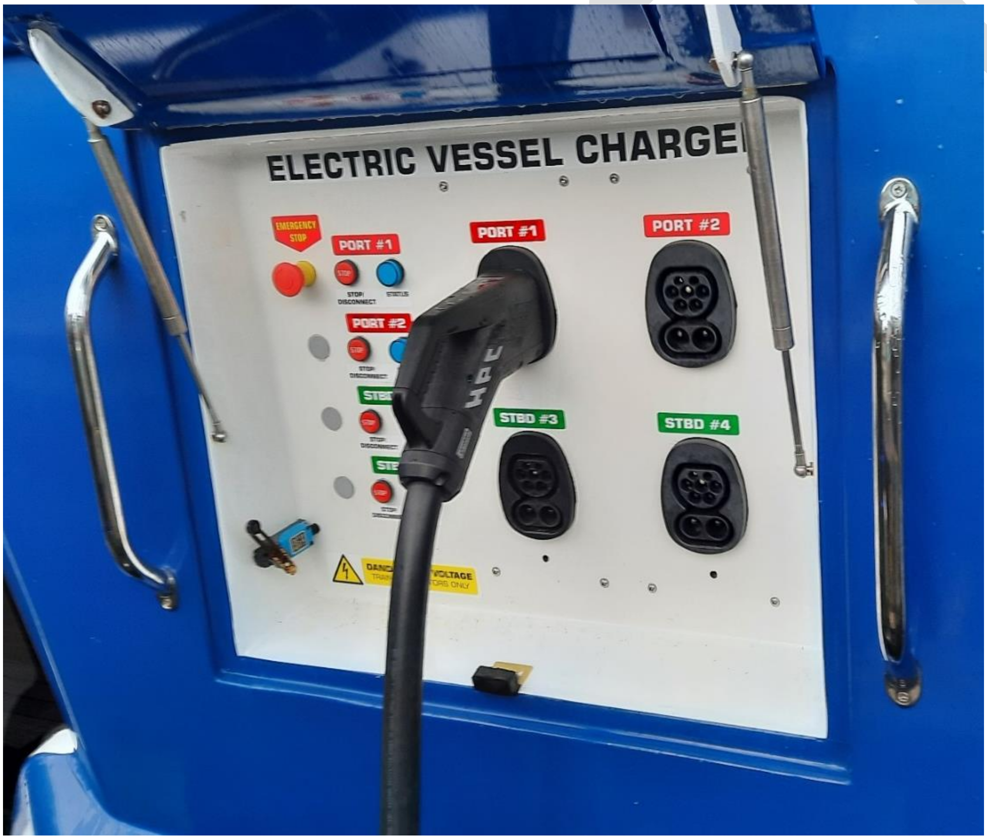

Figure 29: CCS2 port on an electric ferry in Wellington. (Source: Lorelei Schmitt)

3.1.8. Grid capacity

Battery electric bus charging requires substantial energy, so consider the capacity of the electricity in planning and designing your battery electric bus charging network.

Distribution refers to the network of powerlines and substations that take electricity from the national grid and transmit it to the place where it is consumed.

Electricity distributors use substations to reduce the voltage from the national grid with industrial consumers receiving high voltage supply and household consumers receiving low voltage supply. Bus depots can often be connected to low voltage supply because with a diesel bus fleet the electricity demand of a bus depot is comparable to residential properties.

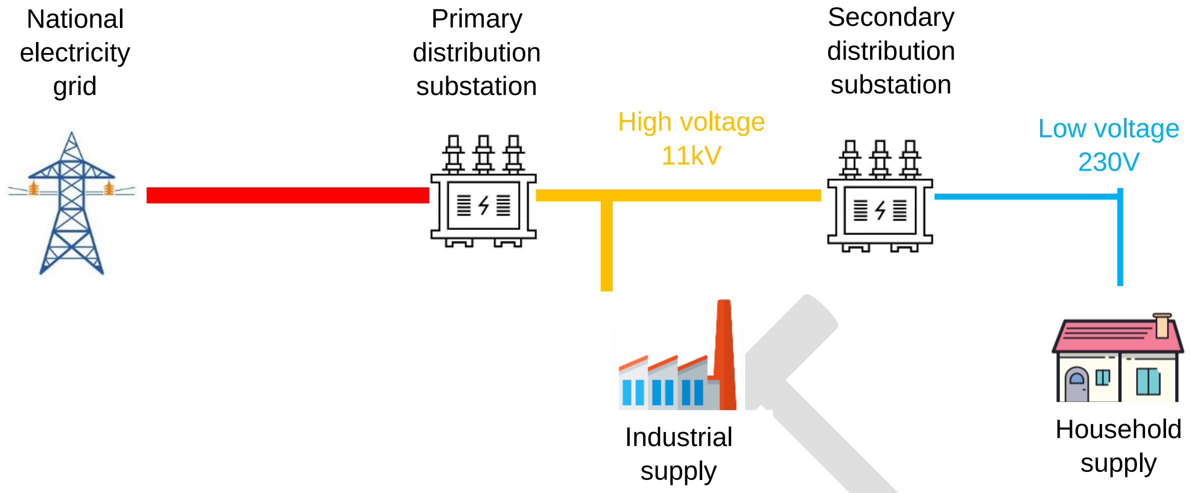

Figure 30: Electricity distribution schematic

However, when transitioning to a battery electric bus fleet, consider the peak electricity demand that would result from charging the battery electric buses at the depot. For example, an 80kW AC charger draws up to 100kVA of power and therefore charging 50 battery electric buses simultaneously would require 5,000kVA and 100 battery electric buses would require 10,000kVA.

The size of bus depots varies greatly across New Zealand with bus depots in Auckland being from 25 up to 150 buses per site. The capacity of the low voltage electricity supply depends on the transformer that is used which varies from 5kVA to 1,000kVA. Therefore, it is common for the peak electricity demand from charging battery electric buses at a depot to exceed the capacity of the low voltage network. If the capacity of the distribution network is exceeded, then this can cause substation overloading at which point safety systems will shut or slow down the substation to avoid damage to infrastructure.

Discuss the energy required to operate the battery electric bus network with the local electricity distribution companies to identify preferable locations from a grid perspective and what, if any, upgrades to the electrical network are required. The distribution companies can also provide advice on the timeframes required to support any necessary upgrades.

It is likely that most depots in New Zealand will eventually require some upgrades to the electricity network as the fleet is decarbonised. Plan for the full fleet being decarbonised so that any incremental fleet changes and charging installations do not cause major disruptions.

The electricity supply to bus depots can be upgraded by providing a dedicated secondary substation on site which is connected to a primary substation via a new high voltage cable.

The cost of connecting to the high voltage network is influenced by the length of high voltage cable required and the size of the secondary substation. Typically, the cost of connecting to the high voltage network is borne by the customer with the onsite secondary substation being owned by the customer.

Depending on the spare capacity of the primary substation a large battery electric bus fleet can also trigger the need to upgrade the primary substation. The cost of upgrading the primary substation is generally shared between the network provider and the customer with the share depending on the proportion of their use. A study completed for Auckland Transport estimated the cost of upgrading Auckland bus depots to accommodate battery electric buses is $650,000 to $4.4 million per depot without any mitigation measures[11].

[11] Element Energy, A study of the impact of electrification of Auckland's bus depots on the local electricity grid (2018).

Grid upgrade and running costs can potentially be reduced through mitigation strategies to reduce the peak power demand from bus depots, though larger depots will almost certainly require some upgrades as more battery electric buses come online. Some examples are outlined in Table 5.

Table 5 Mitigation strategies to reduce peak power demand from bus depots

Mitigation strategy	Description
Shifting charging time	Smart charging management can significantly reduce peak power demand by charging buses outside of peak times. For example, operators may find their peak power demand can be reduced by charging midday as well as overnight
Shifting charging location	Opportunity charging can top up electric bus batteries whilst on the road which reduces the amount of charging that needs to occur at the depot. However, the installation of opportunity chargers can be a significant cost and therefore may only be cost effective where it avoids the need for primary substation upgrades.
On-site energy storage	On-site energy storage could be charged from the grid at a constant low power level and then used to recharge buses when demand for power is high. On site energy storage could use second life batteries which is the term for batteries recycled from electric vehicles which have lower capacity than new batteries but are sufficient for on-site energy storage. Glen Innes is the first place in New Zealand to install a grid-scale battery storage system which stores enough electricity to power 450 homes for 2.3 hours[12]

3.1.9. Distributed Energy Resource Management Systems (DERMS)

Distributed Energy Resource Management Systems (DERMS) support the dynamic management of energy loads on electrical systems. It is highly recommended that public transport authorities include a specification for buses that their electrical systems be DERMS compatible to support electricity demand management. This can provide economic benefits as grid ancillary services can serve as an additional revenue stream improving the return on investment in battery electric buses.

Case Study: Auckland Transport and local utility company collaborate on network planning and specify DERMS compatibility

Auckland Transport worked with the local electricity network entity, Vector, to support the rollout of battery electric buses in Auckland. Vector used a purpose-developed report and tool to investigate and analyse the electricity infrastructure reinforcement requirements needed to provide adequate capacity and security of energy supply to support each bus depot. An overview of this methodology is provided in Figure 31.

[12] Vector: New Zealand leads in global power revolution, Available online: https://www.nzherald.co.nz/brand-insight/vector-nz-leads-in-global-power-revolution/FZNFTYKJFQRQT7Q6QAQHALJ3XQ/ A (Accessed on 14 Oct. 2021)

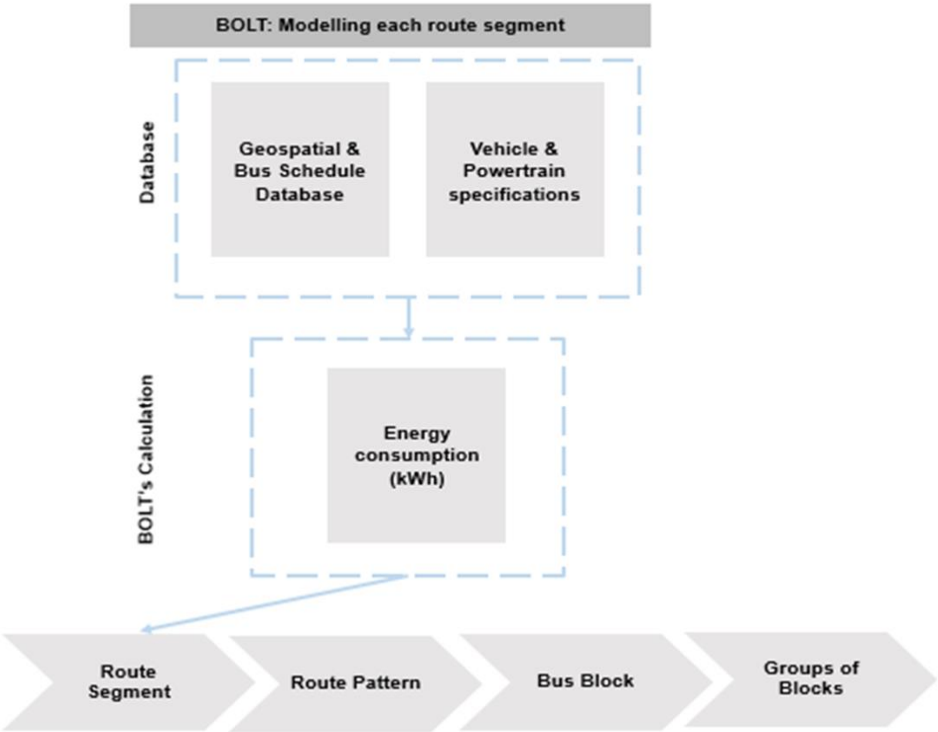

Figure 31: Auckland Transport power demand study - methodology to model each 'block' and calculate energy consumption. (Source: Auckland Transport)

The analysis provided information on:

- average energy consumption (kWh/km) on AT's system for different powertrain and battery degradation scenarios
- fleet requirement
- associated power demand (MW) based on number of buses and time of day
- impact of changing output power
- charging power demand at each depot

This analysis enabled Vector to work with AT to provide high level cost estimates and recommendations for potential commercial arrangements to negotiate between AT, bus operators and Vector to minimise costs.

Vector recommended that all contracts include a specification for compatibility with DERMS to support demand management of electricity to help negate the need for costly infrastructure upgrades to the local grid. This involved ramping the load down in the mornings (after 6am) as competing demands on the network increased and ramping up in the evening (after 11pm) when extra energy was available. It also involved 'smoothing' the demand to a more consistent, manageable rate. AT and bus operators then came to an agreement for charging equipment that it:

- must comply with the Vector's (the network provider) connection code
- all charging must be fleet manged to achieve as smooth a load profile as possible
- charging should only occur during the suggested time

This is a good example of a collaborative approach to supporting the transition to battery electric bus charging in a cost-effective way. That said, the approach discussed in this case study does involve some charging restrictions. It is recommended that when bus operators, public transport authorities and the electrical distribution company are developing a charging strategy they model for scenarios like unforeseen events such as rail replacement services or major events and include contingency for this on top of the typical day-to-day operations.

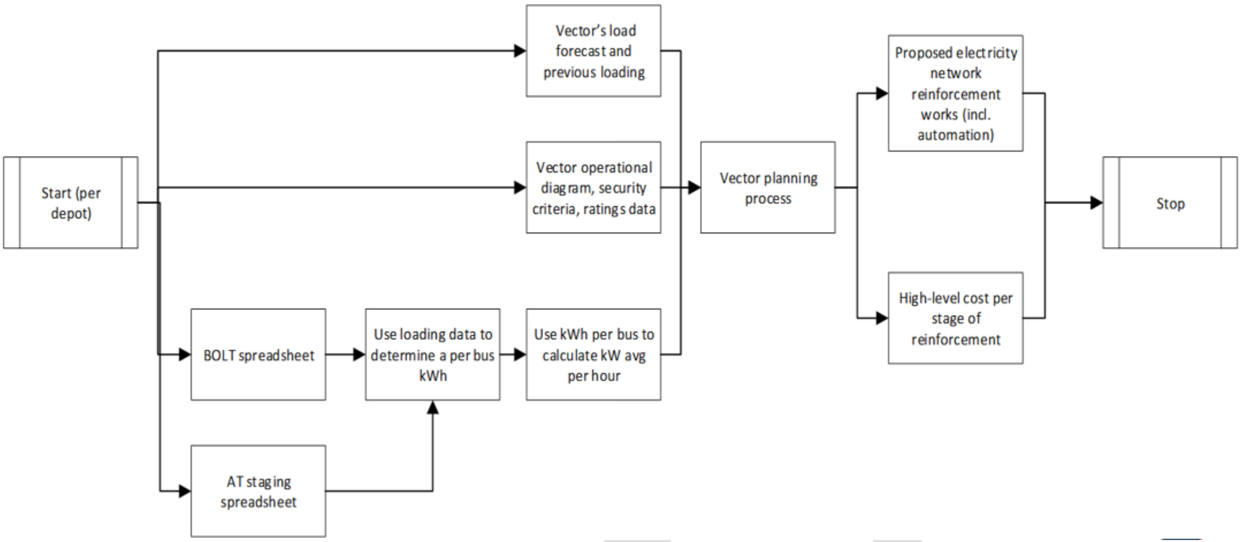

Figure 32: Electricity network planning process to manage grid impact. Source: Auckland Transport

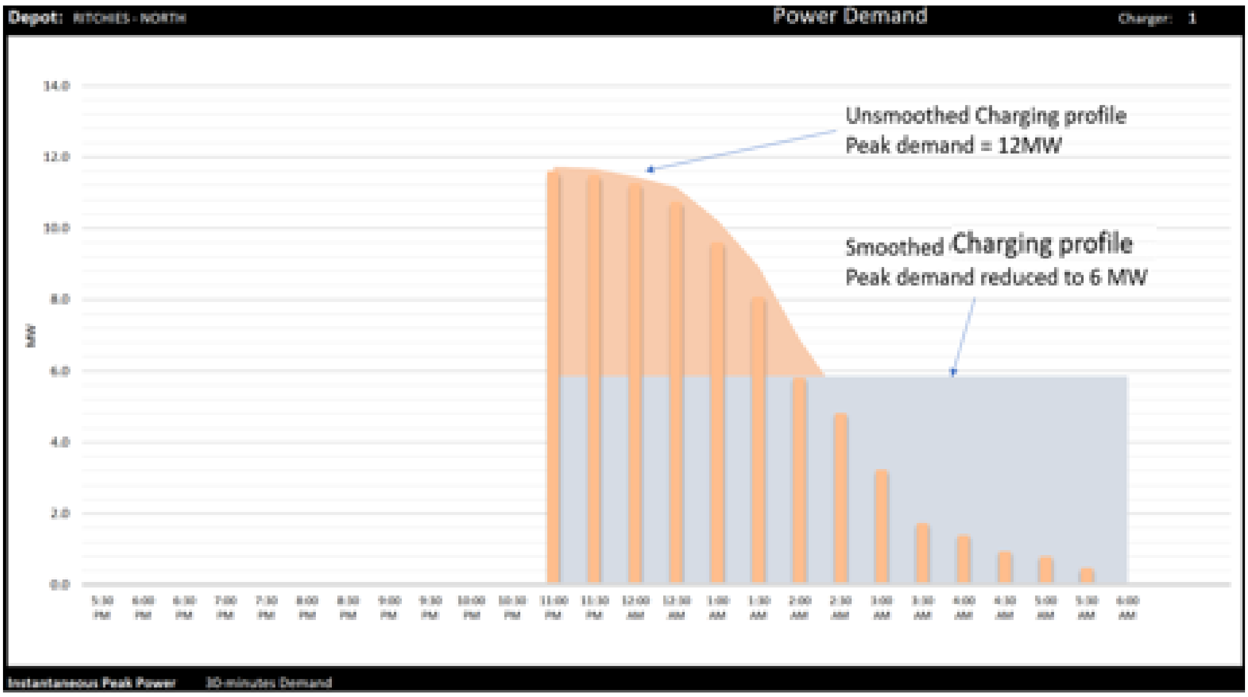

Figure 33: Load profile with and without bus depot managed charging (Source: Auckland Transport)

3.1.10. Electricity supply resilience

Another important consideration is designing the public transport system to be resilient to power outages. This is because when there is a disruption to the electricity supply to battery electric bus depots this can impact on public transport service delivery.

Techniques to improve resilience include having multiple connections to the electrical grid, being able to charge fleet from a different location, providing additional on-site energy storage and having backup power generation. Public transport authorities should consider contractual requirements for electric bus depots to have backup power generation so that bus operations can continue in the event of a black out or brown out. Some of these mitigation strategies may be associated with costs that should be accounted for in project planning.

In addition, bus operators and public transport contracting authorities should discuss bus depots being placed on the priority list for reconnection with electricity network providers. Being on the priority list can reduce the duration of the power outage for bus depots which means that normal operation could resume sooner.

Bus operators should have plans in place for electricity supply disruptions so that they know in advance which reduced timetables to operate in different scenarios. Such scenarios could include no overnight charging, partial overnight charging or an opportunity charger being out of service. The goal of disruption planning is being able to operate essential public transport trips throughout the day whilst having enough range for the battery electric buses to complete the shift and return to depot.

3.2. Opportunity charging

Opportunity charging is when battery electric buses are charged while out of the depot with the charger generally being located at bus stops or layovers. Opportunity charging is often time constrained because the charging window is the length of a dwell at a bus stop or a layover (typically between 30 seconds up to 30 minutes in duration). Therefore, opportunity charging normally uses DC chargers which are able to transmit a large amount of power over a short time period.

Typically, opportunity charging tops up the batteries in order to extend the range of battery electric buses but does not fully charge the electric bus batteries. The additional range provided by opportunity charging depends on its duration and the power rating of the charger. Table 6 shows the additional range provided by different types of opportunity chargers assuming that a battery electric bus consumes 1.5 kWh per km[13].

Table 6: Additional range provided by different types of opportunity chargers assuming bus consumes 1.5 kWh/km

Charger power rating	1 min charge (dwell at bus stop)	10 min charge (duration of layover)
150 kW	1.7 km	16.7 km
300 kW	3.3 km	33.3 km
600 kW	6.7 km	66.7 km

The cost of purchasing and installing an opportunity charger generally increases with the power rating therefore opportunity chargers are sized to provide the additional range required before the next charge. To reduce the demand on the electricity grid some opportunity chargers have built-in energy storage such as capacitors or batteries. This built-in energy storage allows the opportunity charger to be charged gradually from the electricity grid and then rapidly release the energy to charge the bus.

Not all battery electric buses are compatible with opportunity charging and bus manufacturers may specify a limit for the maximum charging rate that can be used. Therefore, bus operators and public transport contracting authorities should determine whether opportunity charging is required and their requirements for the charging rate before procuring battery electric bus fleet.

The overall advantages and disadvantages of using opportunity charging instead of relying solely on depot charging are discussed in Table 7.

Table 7: Advantages and disadvantages of opportunity charging

Advantages	Disadvantages
• Extended vehicle range which can avoid the need for additional buses and drivers	• Capital cost from purchasing and installing the opportunity chargers, especially high powered fast chargers

[13] Based on a selection of electric bus manufacturer specifications which gave a range of efficiencies between 1.2 kWh/km and 1.9 kWh/km, with heavier buses generally having higher energy usage.

Advantages	Disadvantages
• Spreads the electricity demand across multiple locations which may avoid the need for a primary substation upgrade • May lower the weight of the vehicle because less battery capacity is required which could enable more passengers to be carried	• Potentially reduced battery life compared to depot charging only • Risk of operational issues if charger is out of order or occupied • Reduced interoperability of buses in situations where only some routes have opportunity chargers installed

Current practice is for the capital cost of opportunity charges to be negotiated between the public transport contracting authority and the bus operator on a contract-by-contract basis. However, this is an evolving area of practice which may change as opportunity chargers become more common in New Zealand.

Types of charger connections

There are three main types of connections between the bus and the charger: plug-in, pantograph, and induction:

- **Plug-in** uses a cable to connect the bus to the charger.
- **Pantographs** use an extendable connector which is either located on the bus or on the charger.
- **Induction chargers** use a primary coil built into the road surface and a secondary coil located on the underside of the bus. During charging, an electrical current is passed through the primary coil to create a magnetic field, inducing an electrical current in the secondary coil which charges the bus battery.

The advantages and disadvantages of the charger connection types are shown in Table 8.

Table 8: Advantages and disadvantages of charger connection types

	Advantages	Disadvantages	
Plug-in	• Lower cost to purchase and install the charger • Lower energy loss because a physical connection is made	• Manual process to connect the bus to the charger • Can be affected by human error, requires manual operation, and prone to wear, damage and trip and fall • Cables can be awkward to move around depending on their weight	 *Figure 34: Plug-in charging. Source: Lorelei Schmitt*
Pantograph	• Quick to make a connection which is an automated process • Lower energy loss because a physical connection is made	• Requires an overhead structure • Higher infrastructure costs • Depending on location can be difficult to gain permission to install	 *Figure 35: Pantograph charging. Source: Lorelei Schmitt*

	Advantages	Disadvantages
Induction	• Improved aesthetics because no overhead structures or cables are required • Quick to make a connection which is an automated process	• Higher energy loss during transmission • Requires the charging plates to be built into the road • High cost

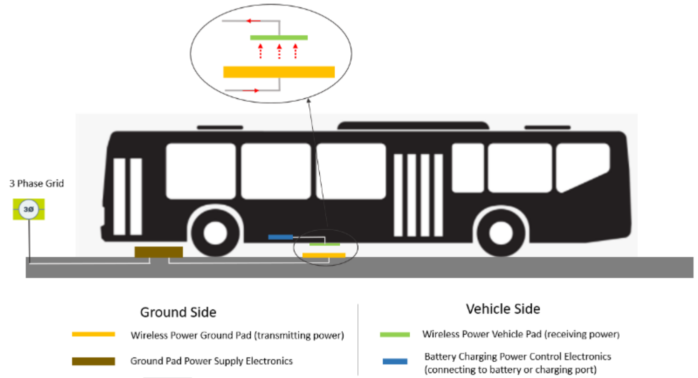

Figure 36: Induction charging (Source: Auckland Transport)

For opportunity charging the speed of the connection is important, therefore, pantograph or induction are used whereas for depot charging efficiency is important therefore plug in or pantograph are used. Increasingly, technology is evolving to support chargers that are faster to connect and more efficient at charging. Depending on the manufacturer some battery electric buses can use multiple connection types (e.g. plug in and pantograph) while others have only one connection type.

Top down vs bottom up pantographs

The two types of pantograph charging systems (shown in Figure 37 and Figure 38) are:

- **bottom up** (also referred to as roof mounted pantograph)
- **top-down** (also known as inverted pantograph)

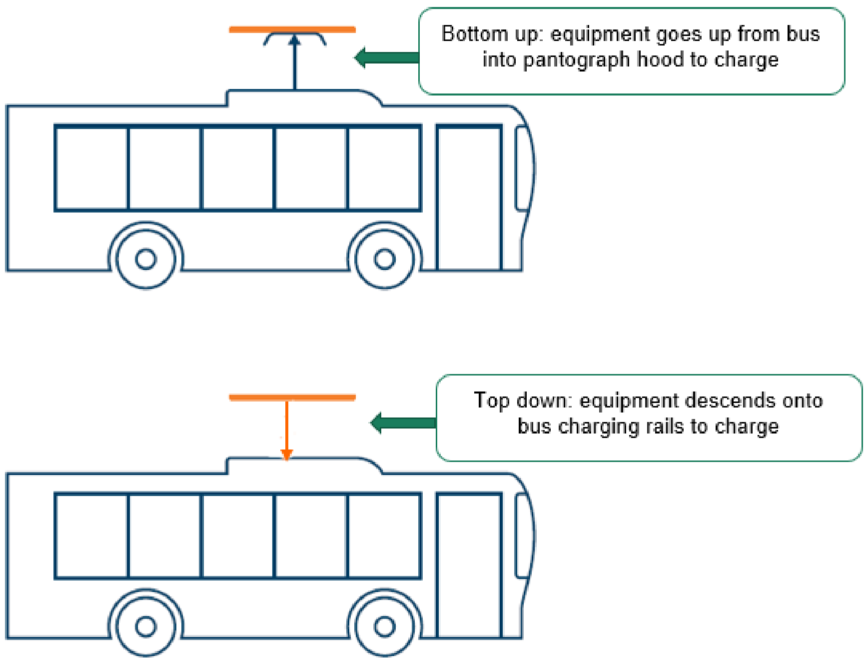

Figure 37: Pantograph (a) bottom-up and (b) top-down

There are advantages and disadvantages to each type of pantograph and varied industry preferences for one or the other in New Zealand. Australia uses top down. Which is preferable is largely dependent on operational needs. Ensure whichever you choose, if you will be using pantographs at all, is compatible with your operational requirements such as the CCS2 plug type and the number of buses you would like to be charging at any given time.

Note that top-down pantographs have less equipment on the bus and more equipment on the overhead structure, this means less weight for the bus to carry but also means that the overhead structure must be stronger and bulkier. For bottom-up pantographs, the pantograph arm and electrical equipment is generally made lighter because this is carried by the bus and with less equipment on the overhead structure this can also be made lighter.

With bottom up, configuration failure of the charger mechanism requires the bus to be taken out of operation, whereas for top-down configuration the failure of the charger mechanism can impact on wider service delivery. Australia's preference for top-down pantograph charging relates to a perception that it is more reliable than bottom-up and has lower maintenance costs, though these are still typically higher than plug-in charging maintenance costs.

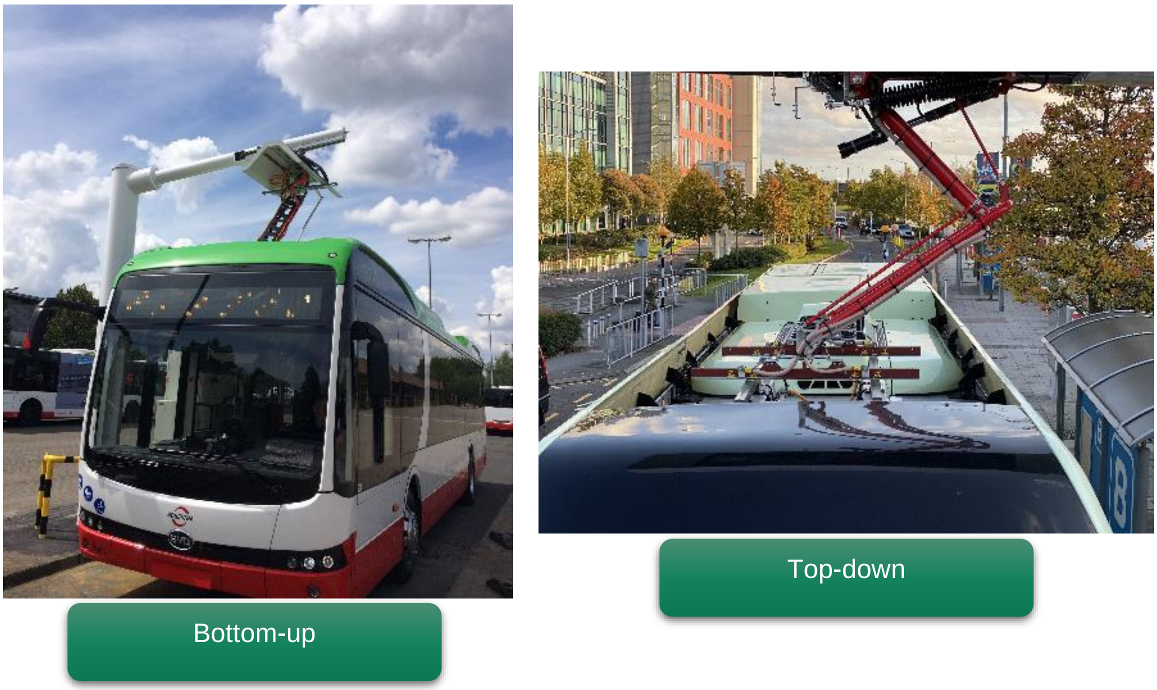

Figure 38: Pantograph (a) bottom-up and (b) top-down (source: ABB)

The typical characteristics of each type of pantograph are listed in **Error! Not a valid bookmark self-reference.**.

Table 9: Typical characteristics of each type of pantograph (Source: Pirooz, A., Heidari Gandoman, F., Firouz, Y., & Van Mierlo, J. (2020). Feasibility study of reconfigurability between different power transmission concepts for electric bus charging. In Transport Research Arena)

Parameters	Top-down	Bottom-up	Unit
Maximum rated voltage	1500	1000	*VDC*
Nominal voltage	750	750	*VDC*
Charging current	500	500	*A*
Maximum current (<10min)	600	800	*A*
Electric lowering unit voltage	24 ± 30%	24 ± 30%	*VDC*
Contact force	500	250 +10%	*N*
Total weight	175~180	85	*Kg*
Operational temperature	-30 to +65	-30 to +65	*°C*

3.2.1. Case study: Wellington Route 1

In 2019 bus operator Tranzurban implemented 10 battery electric double deck buses in Wellington. These buses are used on route 1 (Island Bay to Churton Park/ Johnsonville West/ Grenada North) which is a 21km long route that has frequent services and gradients of up to 8%.

Each bus can carry up to 90 passengers and has a range of 150km on a single full charge. To extend the range the buses use a 450kW bottom-up pantograph charger at the Island Bay terminus to charge for 10 minutes during the layover and driver breaks.

Figure 39: Battery electric double deck bus with pantograph opportunity charger (Source: Lorelei Schmitt)

Lessons learnt:

- This type of opportunity charging is a viable way to augment battery charging, making efficient use of layover time and enabling smaller battery packs on the buses which can reduce bus costs and weight
- The on-route high speed charging enabled several buses to be charged using just one charger and a small transformer compared to a depot-based strategy. More specifically, a single 450kW charge running off a 500KVA transformer was used rather than a depot-only based charging strategy which might use a 1.5-6MVA to charge a depot of buses with large batteries in a 7-hour overnight charge window (10pm-5am).
- The smaller battery packs enabled by this type of opportunity charging may still require a charge at the depot overnight but the demand on the electrical infrastructure supply would be less
- Being on public land made the consenting process a bit complex; it required a wrap of the charging infrastructure, harmonics testing and numerous visual designs to be submitted.

- The time available to undertake top up charging was somewhat limited in this location by the timetable. In this type of charging strategy, timetables must be structured to be sympathetic to the need to charge.
- This type of charging strategy is more appropriate for locations that serve as the terminus to high frequency services and/or have additional routes terminating nearby.
- Ongoing maintenance is an important consideration: this pantograph is located near the ocean in a windy part of Wellington and thus the mast connection plate has been subject to salty sea spray which has required cleaning of the hood to take place approximately every three months or after a significant storm. This takes approximately half a day.
- Some drivers have struggled to line the bus up for connecting the pantograph. That said, visual aides to support accurate bus alignment have been in place for more than 3 years, which has enabled near 100% strike rate.
- Another option for opportunity charging in this location would now be a street side pedestal with a charging lead, though this technology may have been less viable at the time this project was established.

4. Safety and maintenance

Practices and processes that can be applied to maximise the safety of battery electric bus operation.

For a technical guide on the installing of electric vehicle charging equipment please refer to WorkSafe Guidelines.

Figure 40: Wall mounted connection with an emergency stop button (Credit: Kirsten Boardman)

4.1. Battery fires

Battery fires, while less probable than combustion engine fires, can be catastrophic and require large volumes of specialised fire suppressants to extinguish[14]. Although improbable, the highest risk time of battery fires is during charging, notably fast charging.

To help manage this risk the Requirement for Urban Buses (RUB) therefore requires a fire suppression system for high-voltage battery compartments compliant with Australian Design Standard 5062-2006 or an equivalent internationally recognised standard. Storage of spare batteries on site also poses a fire risk. Public transport authorities should require operators to develop and submit a fire mitigation plan to manage the risk of vehicle or battery fires. This plan should consider the specific characteristics of the depot.

Some potential fire risk mitigation strategies include:

- Fast charging should take place in an area in which other buses could easily moved away in the event of a fire
- Identify a location where a damaged or at-risk bus can be moved to so that if a fire erupts then the damage to other buses and depot structures is minimised. However, towing a bus that's actively burning is likely to be unsafe so it will likely be more practicable to move the surrounding buses away from the bus.
- Ideally a bus damaged whilst out on the road should be parked in a place clear of other buses or structures until it has been checked over to ensure there is not additional fire risk.
- Consider fire risks at both depots and opportunity charging locations

[14] https://rip.trb.org/view/1893354

Fire safety measures and procedures for battery electric buses and depots is an evolving area of practice and may need to be retrofitted into depot design. At current, the industry has largely addressed the fire risk by incorporating rigorous early detection and protection protocols in battery management systems to prevent thermal runaway of damaged battery cells. High voltage battery electric buses also create additional considerations for incident responders, including emergency services and operator recovery crews. New training and accreditation for high voltage working is required for maintenance staff, as well as personal protective equipment and static-free tools.

4.2. Maintenance

Battery electric buses require less maintenance which enables a move from scheduled maintenance to a diagnostic maintenance schedule. In addition, battery electric buses are more reliable, which may translate to fewer maintenance bays needed and smaller spare fleet requirements.

Battery buses are generally heavier than diesel counterparts, new towing and recovery vehicles and processes may be needed. Another difference is that battery electric buses often have equipment located in the roof which requires more working at heights for maintenance staff.

With more electrical equipment, maintenance of battery electric buses is somewhat simplified. Many issues can be dealt with using laptops rather than in conventional maintenance bays.

Additional maintenance regimes, diagnostics and spares storage space may also be required for the fleet of chargers and dispensers at electric bus depots, in addition to buses.

Figure 41: Tranzit's electric bus mechanic Thomas Nikolaison works on one of the company's growing fleet of e-buses (Source: Tranzit)

5. Relevant specifications and standards

AS 2067 Substations and high voltage installations exceeding 1 kV a.c

AS 2550.1 Cranes, Hoists and Winches – Safe Use – General Requirements

AS 2676 Guide to the installation, maintenance, testing and replacement of secondary batteries in buildings Sealed cells

AS 5062-2006 Fire protection for mobile and transportable equipment

AS/ACIF S009:2020 Installation requirements for customer cabling (wiring rules)

AS/NZS 1020 The control of undesirable static electricity

AS/NZS 1319 Safety signs for the occupational environment

AS/NZS 1418.10 Cranes, Hoists and Winches – Part 10: Mobile Elevating Work Platforms: Amendment 1:2017

AS/NZS 1657 Fixed platforms, walkways, stairways and ladders. Design, construction and installation

AS/NZS 1768 Lightning protection

AS/NZS 1891 Personal equipment for Work at Height, Part 1: Manufacturing requirements for full body combination and lower body harnesses

AS/NZS 2053 Conduits and fittings for electrical installations – General requirements

AS/NZS 2293.1 Emergency escape lighting and exit signs for buildings – Part 1: System design, installation, and operation

AS/NZS 2312 Guide to the protection of iron and steel against exterior atmospheric corrosion by the use of protective coatings – Part 1: Paint coatings

AS/NZS 3000 – AS/NZS 3000:2007 *Electrical Installations (known as the wiring rules)*

AS/NZS 3008.1.1 Electrical installations – Selection of cables – Part 1:1 cables for alternating voltages up to and including 0.6/1kV – Typical Australian installation conditions

AS/NZS 3012 Electrical Installations - Construction and demolition Sites

AS/NZS 3017 Electrical installations – Verification guidelines

AS/NZS 3013 Electrical installations – Classification of the fire and mechanical performance of wiring systems

AS/NZS 3100 Approval and test specification – General requirements for electrical equipment

AS/NZS 3112 – AS/NZS 3112:2011 *Approval and test specification – Plugs and socket-outlets*

AS/NZS 3123 – AS/NZS 3123:2005 (R2016) *Approval and test specification – Plugs, socket-outlets and couplers for general industrial application* AS/NZS 3760 – AS/NZS 3760 *In-service safety inspection and testing of electrical equipment, incorporating Amendments No. 1 and No. 2*

AS/NZS 3820:2009 – AS/NZS 3820:2009 *Essential safety requirements for electrical equipment*

AS/NZS 4024 Safeguarding of machinery – Electrical equipment of machines – Part 1204: General requirements

AS/NZS 61439.1 Low-voltage switchgear and control gear assemblies – Part 1: General rules

CCM Communications Cabling Manual 2007 Vol.1 Handbooks, codes and regulations, Vol.2 Standards

IEC60309-1 – IEC60309-1 *Plugs and socket-outlets and couplers for industrial purposes – Part 1: General requirements* Edition 4.2

IEC60529 Degrees of protection provided by enclosures (IP Code) https://webstore.iec.ch/publication/2452

IEC61439-7 – IEC61439-7:2018 *Low-voltage switchgear and control gear assemblies – Part 7: Assemblies for specific applications such as marinas, camping sites, market squares, electric vehicle charging stations* Edition 1.0 (or IEC TS 61439-7-2014)

IEC61851-1 – IEC61851-1:2017 *Electric vehicle conductive charging system – Part 1: General requirements* Edition 3.0 or, until 1 December 2020

IEC61851-22 – Until December 2020, IEC 651851-22:2001 *Electric vehicle conductive charging system – Part 22: AC electric vehicle charging station* Edition 1.0

IEC61851-23 – IEC61851-23:2014 *Electric vehicle conductive charging system – Part 23: DC electric vehicle charging station* Edition 1.0

IEC62196-1 – *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles – Part 1: General requirements* Edition 3.0

IEC62262 – *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code) Edition 1.0*

ISO17409 – ISO17409:2015 Electrically propelled road vehicles – connection to an external electric power supply – Safety requirements

ISO15118 - Road vehicles – Vehicle to grid communication interface

M30 Specific Specification and Guidelines for Road Lighting Design

SAEJ1772 – Standard for Electrical Connectors for Electric Vehicles maintained by SAE International

Standards New Zealand PAS 6010:2021 provides a best practice guide for public and commercial electric vehicle charging with many of the same principles also applying to battery electric buses. We recommend that you read this in conjunction with this guidance.

UL2202 – Standard for Electric Vehicle (EV) Charging System Equipment Edition 2

UL2251 – Standard for Plugs, Receptacles, and Couplers for Electric Vehicles Edition 4

6. Glossary of terms

Acoustic vehicle alerting systems: A device which is designed to emit sound to alert pedestrians and cyclists of the presence of electric vehicles

Alternating current (AC): The type of electricity supply provided by the national grid

Battery electric bus: A bus which powered solely by batteries and charged by an external electricity source

BOL: Beginning-of-life (of battery)

Dead running: When a bus repositions to the start of the next trip or back to depot whilst being out of service

Depot charging: When the battery electric bus is charged at the depot when not in use

Distributed Energy Resource Management Systems (DERMS) systems to support the dynamic management of energy loads on electrical systems

Direct current (DC): The type of electricity supply provided by batteries

DOD: Depth-of-discharge (of battery), %

Driver changeover: When drivers switch at breaks or during the end of a shift but the bus stays on the road

Drivers shift: The series of trips, breaks and dead runs which a driver makes during a day

EOL: End-of-life (of battery)

Electric vehicle supply equipment (EVSE): a collective term for the plug, cable and charger

Gross vehicle weight: The weight of the bus including the driver and maximum allowable passengers

Induction: The use of electromagnetic fields to transfer electricity to the bus without physical contact with the charger

Interoperability: The extent to which battery electric buses and chargers from different manufacturers can be mixed and matched

Kilovolt amperes (KVA): a unit of power measurement equal to 1000 volt-amperes

Layover: The time in between trips which can act as a buffer so that late running on the first trip does not impact on the second trip

Maximum axle mass: the total weight transmitted by the several wheels attached to that axle to the surface on which the vehicle rests

Megavolt-amperes (MVA): a unit of power equal to one million volt-amperes

Operationally efficiency: The proportion of in-service time compared to out of service time, the higher the proportion of in-service time the more efficient the public transport system is

Opportunity charging: When the battery electric bus is charged on the road during a layover, meal break or dwell at bus stops

Pantograph: A mechanism which provides a connection between a battery electric bus and an overhead charger

Range: The distance which a battery electric vehicle can travel before needing to be recharged

RUB: Requirement for Urban Buses:

SOC: State-of-charge (of battery), %

SOH: State-of-health (of battery), %

Split shift: When a driver has trips in the morning and afternoon but is off duty in the middle of the day

State of charge: A measure of the amount of energy available in a battery pack at a specific point in time expressed as a percentage

Unladen vehicle weight: The weight of the bus without the driver or any passengers

Vehicle changeover: When a bus is returned to the depot and a different bus is used for the remainder of the shift

Vehicle Dimensions and Mass Rule (VDAM): VDAM sets the maximum weights for all vehicles with the purpose being to manage wear on the road surface and to ensure the safety of road users.

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