Electric Vehicle Standards for the Pacific Region

Pacific Region Infrastructure Facility

This report was prepared by external consultant Andrew Campbell, with the support of the Pacific Region Infrastructure Facility (PRIF).

The PRIF is a multi-partner coordination and technical assistance facility for improved infrastructure in the Pacific region. The PRIF development partners are the Asian Development Bank, Australian Department of Foreign Affairs and Trade, European Union, European Investment Bank, Japan International Cooperation Agency, New Zealand Ministry of Foreign Affairs and Trade, United States Department of State and the World Bank Group.

Acknowledgments

The author would like to acknowledge the many people who have helped in the preparation of this report. In particular, thanks to Solomone Fifita (Secretariat of the Pacific Community) for endlessly providing contacts, Peter Morfee (Worksafe New Zealand) for your tireless debate, expert opinion and review on electric vehicle charging matters, Dave Potter (Top Logic Limited) for your wisdom and review of the marine standards section, Garry House (Environlight International Limited) for your wisdom on aviation standards, Dr Yu Tack Kim, for the detail and support on battery technology, Luke Smith (PRIF) for your valuable checks and direction, and John McCrystal, another sterling effort. Thank you all.

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Published February 2024

All tables, figures and photos are provided by the author, unless otherwise specified.

Table of Contents

Tables

Figures

Abbreviations

ABS	Anti-lock braking system
ABYC	American Boat and Yacht Council Standards
AC	Alternating Current
ADR	Australian Design Rules
AIS	Indian Automotive Industry Standard
AS	Australian Standard
BIG	New Zealand Battery Industry Group
BMS	Battery management system
CBS	Combined braking system
CCC	People's Republic of China Compulsory Certification
CCS	Combined Charging System is an AC and a DC fast-charging system for battery electric vehicles
CE	Conforms to European health, safety and environment protection standards
CFR	Code of Federal Regulations
CHAdeMO	CHAdeMO is a DC fast-charging system for battery electric vehicles
DC	Direct Current
e2W/e3W	Electric two-wheeler (motorbike or scooter) / Electric three-wheeler (trike)
e4W	Electric four-wheeler (motorbike or scooter)
EESS	Electric energy storage system
EN	European standard
EOL	End-of-life
ESC	Electronic Stability Control
EU	European Union
EV	Electric vehicle
GB	Guo Biao (People's Republic of China national standards)
IC-CPD	In Cord – Control and Protection Device
IEC	International Electrotechnical Commission
IP	Ingress Protection rating
ISO	International Organization of Standardization
NiMH	Nickel-metal hydride
NZS	New Zealand Standard
NZTA	New Zealand Transport Authority
PCREEE	Pacific Centre for Renewable Energy and Energy Efficiency
PIC	Pacific Island Country
PRIF	Pacific Region Infrastructure Facility
RCD	Residual Current Device
REESS	Rechargeable Electrical Energy Storage System
SAE	Society of Automotive Engineers
SDoC	Supplier Declaration of Conformity
SOH	State of Health
SOLAS	Safety of Life at Sea
UL	Underwriters Laboratory
UN	United Nations
UNECE	United Nations Economic Commission for Europe
US	United States
VAC	Voltage Alternating Current
VDC	Voltage Direct Current

Executive Summary

The uptake of electric vehicles has now become well established and Pacific Island Countries (PICs) are expected to follow this trend. This will involve significant change because the technologies involved are new to PICs and require new skill sets to support them. Accordingly, the Fourth Pacific Energy and Transport Ministers Meeting in 2019 directed the Secretariat of the Pacific Community to assist members in addressing barriers to adopting electric mobility (e-mobility).

The Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE) has been leading this work to develop a regional e-mobility policy and program with targets for 2030 and 2050, and to address existing barriers to uptake. The resulting PCREEE report *Regional Program to Promote Electric Vehicle Markets in the Pacific Island Countries and Territories (PICTs)* identified a need for standards and guidelines that pertained to electric vehicle imports, charging, and retirement.

The standards work provided in this report addresses this need and is aligned with the roadmap for regional e-mobility identified in the PCREEE report.

Approach

The methodology comprised:

- identifying the knowledge gaps in guidelines and standards across the various stages in the life of an electric vehicle (divided into design, build, supply, border entry, pre-on-road matters, marketing and sales, in-service operation (including general on-road operation, charging, servicing and maintenance, safety inspection, breakdown, towing and repair); accident first response, and retirement) and for equipment used to charge electric vehicles.
- reviewing global practices, guidelines and standards for each of the life stages of electric vehicles and charging equipment, and using these reviews to inform the identification and/or development of guidelines and standards recommended for introduction to pics;
- grouping of the recommended guidelines and standards into common themes (with the expectation that it would be more efficient to deploy the guidelines and standards in these groupings, rather than to deploy them individually); and
- developing a deployment roadmap around the groupings of recommended guidelines and standards.

Vehicle types considered

A wide range of electric vehicle types were considered.

For road vehicles, the electric vehicle options were divided into: low-powered electric vehicles; electric two-wheelers and electric three-wheelers; lightweight electric four-wheelers; light-duty electric vehicles; medium- and heavy-duty electric vehicles; and retrofit, low-volume, scratch-built, and exception electric vehicles.

Marine vessels and aircraft with battery-electric propulsion were also considered, although very briefly due to the strongly regulated environments in which they operate (which, incidentally, apart from small recreational watercraft, already largely contemplate electric propulsion systems).

Standards and guidance are aligned to vehicle life cycle

The standards knowledge gap analysis emphasized the following points in the life of a road vehicle:

- Design and build: it is important to manage the specifications to which vehicles and charging equipment are designed and built, as these concern important minimum safety and performance features that persist for the life of the equipment.

- Accident first response: there are significant knowledge gaps as to the kind of first response to provide at an accident involving an electric vehicle, which risks harm to people and damage to property.
- Retirement: there are significant concerns over the end-of-life (EOL) management of electric vehicles, particularly their batteries, with the unknown environmental outcome of EOL battery disposal voiced as a concern by many PIC stakeholders.

Guidelines and standards concerning other stages of life were also considered, with many captured at a higher level when it came to developing the deployment plan for the recommended guidelines and standards.

Relevance to Pacific Island Countries

A strong emphasis was also placed upon identifying guidelines and standards that were particularly applicable to PICs. For example, rather than specifying compliance of imported electric passenger cars to United Nations Economic Commission for Europe R100 (a recognized international standard for electric powertrains including their traction batteries), requiring the vehicle to be fitted with electronic stability control (a refinement of the braking system) is expected to have the same effect, with only a simple visual check necessary at the time of border crossing to determine if the vehicle complies – a lesson learned from New Zealand's border inspection process.

For cases where more explicit specification of standards is needed, these are detailed in Section3.3.

Roadmap and next steps for implementation

For road vehicles, standards knowledge gaps and their recommended solutions were found to fall into four themed groups. A deployment roadmap was developed to reflect these and resulted in the following proposed next-step tasks:

1. Introduce minimum specifications for electric two-wheelers, larger electric vehicles, and for charging equipment and installations;
2. Develop and promote tailored guides for PIC industry and the public to support electric vehicle and charging equipment purchase decisions, and to support best-practice charging set-up and use;
3. Develop and promote best-practice guides and information sheets, for new electric vehicle owners;
4. Develop and promote best-practice guidelines for those providing breakdown, first response, and end-of-life vehicle management services;
5. Assess the viability of developing and introducing a standard for connectors used for low-voltage charging (e.g., that used for charging the batteries of battery-assisted push bicycles ("e-bikes").

The marine sector is strongly regulated, and only small recreational craft with battery-electric propulsion systems are not well catered for within existing regulations. However, there appears to be an opportunity for capacity development to ensure that the existing regulations are robustly/correctly applied. There is also an opportunity to issue guidance on battery-electric propulsion systems for small recreational craft and a set of design principles has been developed for this task.

The aviation sector is strongly regulated and making standards recommendations to this sector is unnecessary.

1 Background and Introduction

E-Mobility in the Pacific

The uptake of electric vehicles has now become well established. Pacific Island Countries (PICs) are expected to follow this trend as, for them, the use of electric vehicles can also be an important part of a wider plan to make the transport sector more sustainable. Further, in the case of PICs, the uptake of electric vehicles in combination with their charging from electricity comprising a high renewable component could also reduce the importation of fossil fuels, which is currently a heavy financial burden for many PICs. As such, many PIC governments, regional organizations, and development partners in the region are increasingly considering developing programs and policies to support electric vehicle adoption.

The uptake of electric vehicles will require significant change: their technologies are new and require new skill sets to support them; charging electric vehicles and the infrastructure used for this is also different. Charging electric vehicles also has the potential to stress existing electricity infrastructure, if their introduction is not well planned and managed. These describe only some of the gaps in understandings and barriers that PICs face.

The need for standards

With this in mind, the Fourth Pacific Energy and Transport Ministers Meeting in 2019 directed the Secretariat of the Pacific Community to assist members in addressing barriers to electric mobility (e-mobility) uptake. The Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE) has been leading this work to develop a regional e-mobility policy and program with targets for 2030 and 2050, and to address existing barriers in the areas of (i) policy and regulation, (ii) knowledge management, (iii) qualification/certification, as well as (iv) the promotion of investment, entrepreneurship and innovation. The resulting "Regional Program to Promote Electric Vehicle Markets in the Pacific Island Countries and Territories (PICTs)"[1] identified a need for standards and guidelines that pertain to electric vehicle imports, charging, and retirement.

The need for PICs to adopt standards is evident. Compatibility between chargers and vehicles needs to be established, not to mention various consumer protection considerations. But above all, charging and operating electric vehicles must be safe. One of the primary concerns here is the safety of the battery: the use of lithium-ion batteries introduces a new technology that can be hazardous, and charging and using them must be carefully managed to avoid the kind of unfortunate incidents that have been seen in other countries.[2] The use of standards has an important part to play in efficiently managing these concerns and risks, and an advantage that PICs enjoy is that there is now a wealth of global information to draw upon in developing appropriate guideline- and standards-based interventions.

Implementing standards and guidelines

"Standards" come in many forms, ranging from the passing on of word-of-mouth and voluntary guidance — such as the type shared informally on social media — to the kind of stringent, detailed, mandatory safety specifications demanded by regulatory authorities. Standards have a role at each

[1] PCREEE. 2021. PCREEE Regional Program to Promote Electric Vehicle Markets in the Pacific Island Countries and Territories (PICTs). https://www.pcreee.org/document/pcreee-regional-program-promote-electric-vehicle-markets-pacific-island-countries-and.

[2] For example, see data released by the US Consumer Product Safety Commission on serious incidents in the US involving low-powered electric vehicles: CPSC. 2022. CPSC Calls on Manufacturers to Comply with Safety Standards for Battery-Powered Products to Reduce the Risk of Injury and Death. Press release. https://www.cpsc.gov/Newsroom/News-Releases/2023/CPSC-Calls-on-Manufacturers-to-Comply-with-Safety-Standards-for-Battery-Powered-Products-to-Reduce-the-Risk-of-Injury-and-Death.

of these levels: useful tips and guidance from interest groups can make the life of an electric vehicle user easier, including through providing sensible protocols and etiquette for managing charging at busy public charging stations; but more specific, mandatory standards are required where the stakes are higher — where there is a risk of high cost, personal injury or even death. It is in these areas, where the stakes are high, that the focus of this standards work lies.

Large economic regions or countries, particularly those with a significant manufacturing sector, tend to have their own suites of standards. For example, goods built for the European Union (EU) typically follow EU norms that make reference to EU-origin standards; those built for the United States (US) and Canadian markets follow US norms and tend to refer to Underwriters Laboratory (UL), and other standards of US origin; the People's Republic of China (PRC) has another set again, to mention only three of several internationally recognized standards regimes. Over and above the various regional sets of standards (and often referenced by them), there are "global" standards, such as those developed through the United Nations (UN) and complied with by most countries, and standards offered by specialist development organizations such as the International Organization of Standardization (ISO), International Electrotechnical Commission (IEC) and Society of Automotive Engineers (SAE). By contrast, smaller countries tend to be receivers of technology, and often from several different countries of supply. They cannot generally afford to develop and demand their own mandatory standards on multiple fronts.[3] This obliges them to navigate many different suites of standards if they wish to manage the build of goods received and yet still be open for supply from jurisdictions where different sets of standards apply.

This spaghetti of standards is the backdrop that PICs must negotiate. Any standards regime must be carefully designed to manage the various sector concerns (including safety, compatibility, interoperability, security and durability) and the different electricity supply specifications and arrangements. It must also avoid creating unnecessary barriers to the uptake of appropriate technology or otherwise needlessly restricting the options for goods supply. Importantly, implementation must also be practical in the various settings that different PICs present, including in the many cases where resources are constrained even before they are required to introduce, support and police an electric vehicle standards regime.

Purpose of this Study

A technical assistance project was developed to address these guideline and standards gaps, overseen by the Pacific Region Infrastructure Facility. The objectives were to identify appropriate electric vehicle-related international standards, policies and regulations relevant to electric vehicle adoption among the PICs, and identify suitable standards and draft a standards development roadmap.

Note that this report focuses on electric vehicles that use modern batteries for propulsion. Today, these batteries are mainly lithium-ion, but other chemistries are also used. The use of lead-acid batteries for propulsion is outdated and is not considered further in this report.

[3] Noting that not only is the development of standards time-consuming and expensive, but insisting upon compliance to own-developed specifications risks requiring very costly low-volume production runs that also may not maintain currency with global technology developments, unless local standards also move with the times.

Structure of this Report

The remainder of this Report is structured as follows:

2. Methodology
3. Design and Build Standards for Electric Road Vehicles
4. First Response
5. Charging Standards and Guidelines
6. Managing End-of-Life Electric Vehicles
7. Electric Propulsion Standards in the Marine Sector
8. Electric Propulsion Standards in the Aviation Sector
9. Standards Roadmap
10. Conclusions

Appendix A Minimum Build Specification Requirements for Electric Road Vehicles

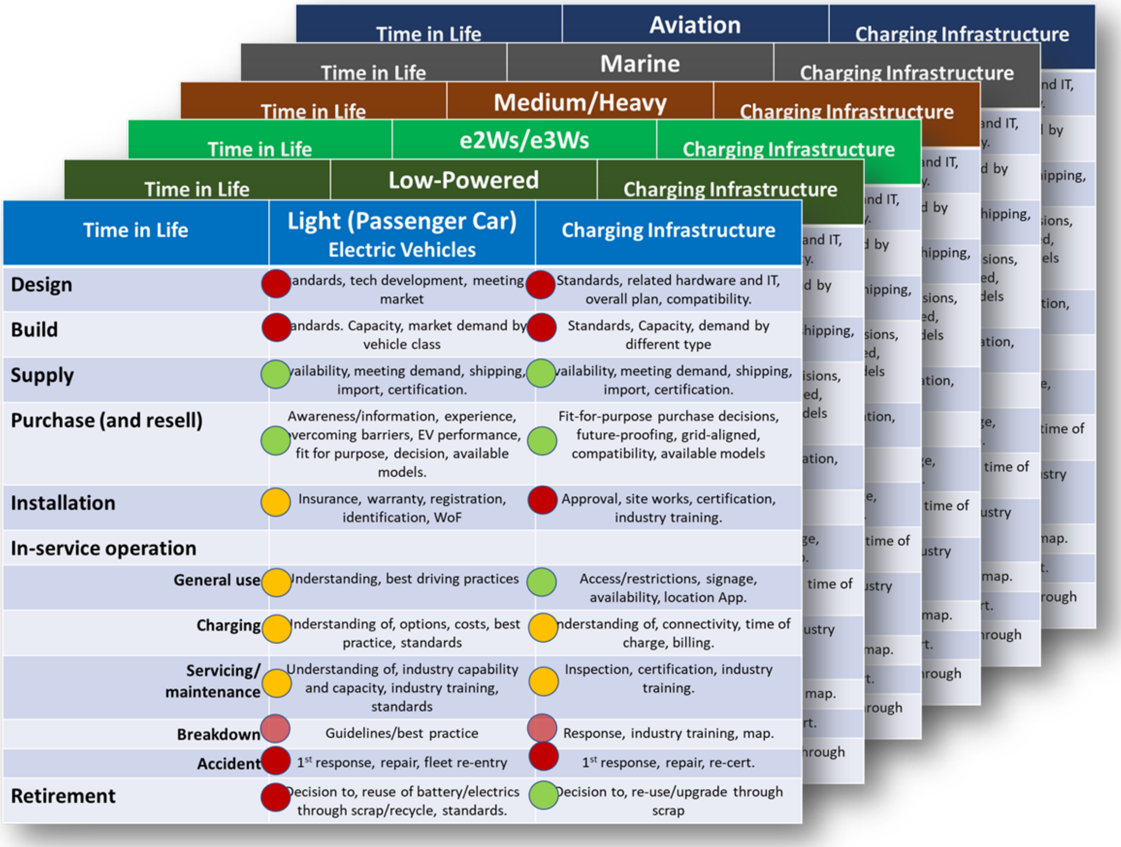
Appendix B Introduction and Background on Electric Vehicle Charging

Appendix C Base Principles of UNECE R100

2 Methodology

Figure 2-1 provides a series of tables illustrating the various stages in the life of an electric vehicle (divided into design, build, supply, border entry, pre-on-road matters, marketing and sales, in-service operation (including general on-road operation, charging, servicing and maintenance, safety inspection, breakdown, towing and repair), accident first response, and retirement) and for charging equipment used to charge electric vehicles (and a similar set of life stages exist for the electricity supply to the chargers). In the third dimension, this matrix can be applied to different vehicle types, including micro- to large-format road vehicles, marine vessels, and aircraft.

Figure 2-1: Gaps in Standards and Guidance by Life Cycle for Electric Vehicles and Charging Equipment



EV = electric vehicle, e2W = electric two-wheeler, e3W = electric three-wheeler.

Source: The authors.

There are guidelines and standards that apply to every cell of this three-dimensional table – from the minimum safety specifications that must be designed and built into an electric vehicle or charging equipment, to guidelines on their end-of-life (EOL) management. Where there are gaps in this matrix for a specific country and a specific vehicle type, there is the risk that the country does not have adequate knowledge to successfully introduce, operate and support that electric vehicle type, which creates barriers to the uptake of electric mobility. The intention, therefore, is to fill this matrix with sufficient knowledge so that no significant barriers remain and the deployment of electric vehicles stands to be successful: for PICs, the starting matrix of recognized guidelines and standards is currently relatively bare.

Ideally, there would be no knowledge gaps. Where such exist, however, it will be necessary not only to identify and/or develop suitable guidelines and standards, but also to disseminate the information developed. This will require a focus both on the important guidelines and standards and the development of a program that gradually develops the sector over time.

An assessment was carried out to consider which guidelines and standards deserve priority focus. One of the key determinants is managing risk where the safety of life and limb or significant property loss is at stake. The results of this assessment are illustrated by the "traffic lights" shown across Figure 2-1 for light road vehicles, with a red light indicating a knowledge gap of concern requiring urgent attention through to a green light indicating a cell where the absence of suitable standards is of relatively low concern. As an example, for those with a red light:

- Design and build: it is important to manage the specifications to which vehicles and charging equipment are designed and built, as these concern important minimum safety and performance features that persist for the life of the equipment.
- Accident first response: there appear to be significant knowledge gaps in the kind of first response that should be provided at an accident involving an electric vehicle, which risks harm to people and damage to property.
- Retirement: there are significant concerns over the EOL management of electric vehicles, particularly their batteries, with the unknown environmental outcome of EOL battery disposal voiced as a concern by many PIC stakeholders.

As mentioned, the "traffic light" system applied here is an exercise in prioritization. Those cells issued a green light are still important. The significance of a green light is that, right now, those cells so marked do not require the same attention as red or amber cells in a resource-constrained setting. Section 10 addresses this further, as it pulls together the recommended standards interventions into a proposed standards development roadmap, creating the opportunity to include a wider set of amber- and green-light cells, where this makes sense.

Note also that the degree of specificity targeted also requires careful thought within each guidelines and standards cell. For example, whether the motor fitted to an e-bike is limited to 250 W (EU standards), or 300 W (New Zealand and Australia regulations), or 750 W (US standards) is relatively unimportant. Yet the battery of that same e-bike might catch fire if there were a mismatch of charger and/or poor specifications of charger and battery, (outcomes that would be unlikely if the e-bike, battery and charger complied with the requirements of the EU standard EN 15194 *Electrically power assisted bicycles*) and therefore these specifications are important.

Based on the above priority assessment, the chosen focus of this guidelines and standards work is:

- Design and build standards for different electric road vehicle types: providing a review of standards used globally for different electric road vehicles (the different types are listed below) considered how they could be adopted in a PIC setting, and yielded recommendations for the introduction of minimum standards for electric vehicles for PICs. This work is detailed in Section3.
- Accident first response: providing a review of global best-practice methods and recommendations and putting these into the PIC context. This work is detailed in Section 4
- Charging: providing a review of global standards used and identifying those to be adopted by PICs. This work is detailed in Section 5.
- Managing EOL electric vehicles: providing a status update of global best practices and from these, drawing recommendations for practices to be adopted by PICs. This work is detailed in Section 6.
- Guidelines and standards for battery-electric propulsion in the marine sector: providing a status update of global practices and making recommendations for next steps for PICs. This work is detailed in Section 7.
- Guidelines and standards for battery-electric propulsion in the aviation sector: providing a status update of global practices. This work is detailed in Section 9.

The recommendations arising from the sections concerning road vehicles, Sections 3to 6, were then combined and a standards development roadmap designed around them. This work is detailed in Section 9.

The different electric road vehicle types considered are detailed in the following table.

Table 2-1: Electric Road Vehicle Types Considered

Vehicle	Description

Low-Powered Electric Vehicles	Also referred to as micromobility, including:
	• Power-assisted push scooters.
	• Power-assisted pedal cycles (hereafter referred to as "e-bikes" unless citing the title of a guideline or standard). These are Class AB vehicles in the Australian, New Zealand and Fijian vehicle classification systems.
	• Mopeds (Class LA for a low-powered e2W and LB for a low-powered e3W vehicle).
	• Within these are the sub-classifications:
	  ○ Those designed for providing assisted operation up to 25 km/h.
	  ○ Those designed for providing assisted operation up to 50 km/h.

Electric Motorcycle	Production model e2Ws and e3Ws with maximum speed exceeding 50 km/h (Class LC, LD and LE vehicles).
Lightweight e4W	Production models with the following two sub-classifications (as defined by the EU classification system): • Light e4Ws: those with an unladen body mass of less than 425 kg, a motor of less than 6 kW and that travel at no more than 50 km/h (and including golf cart-type, slow vehicles). • Heavy e4Ws: those with an unladen body mass of less than 450 kg (or 600 kg if intended for carrying goods), a motor of less than 15 kW), and capable of travelling faster than 50 km/h.
Light-duty EVs	Primarily for the carriage of people (Category MA vehicles) or goods (Class NA vehicles).
Medium and Heavy EVs	Primarily for the carriage of people (Class MB and MC vehicles) or goods (Class NB and NC vehicles), vehicles of these classifications grouped together here because of their similar technical requirements.
Retrofit, Scratch-Builds, Low-Volume Vehicles	Of all vehicle size formats, but normally referring to electric motorcycle and larger size-format vehicles – those vehicles often requiring fitness inspections and registration in more regulated countries.

EV = electric vehicle, e2W = electric two-wheeler, e3W = electric three-wheeler, e4W = electric four-wheeler

Source: The authors.

As a point of clarification for step-through and similar-sized motor scooters (a very popular form of 2-wheeler throughout the Pacific and Asia): those fitted with 50 cc gasoline engines — or, if electric and governed to a maximum speed of 50 km/h — are classified as mopeds in this system (and tend to be exempt from annual inspections and have less stringent build requirements in highly regulated regimes), whereas variants with larger engines/capable of higher speeds are normally classified as motorcycles.

Low-powered, motorcycle, and lightweight electric vehicles tend to be all-electric, i.e., where the battery electric systems provide all of the motorized propulsion. Larger vehicles may be all-electric or hybrid, with the latter being where the vehicle has both battery-electric and fossil-fueled (or other) propulsion systems. This report focuses on the standards related to the battery-electric component of electric vehicles (whether for an all-electric or hybrid electric vehicle).

Because of their significant differences, marine vessels and aircraft were considered separately and reported in their own sections. Table Table 2-2 summarizes the marine and aviation vehicle types considered.

Table 2-2: Marine and Aviation Electric Vehicle Types Considered

Vehicle	Description
Small vessel	Typically, small e-outboard or other battery powered propulsion motor
Medium vessel	Larger e-outboard or other battery powered motor, < 15 meters in length
Large vessel	Larger battery propulsion vessel > 15 meters in length, e.g., inter-island ferry or larger
Aircraft (all)	All manned aviation
Electric Drones	Unmanned aerial vehicles

Source: The authors.

Chargers, connectivity and electricity supply considerations are addressed for each vehicle type.

3 Design and Build Standards for Electric Road Vehicles

As the features that get designed and built into a vehicle stay with that vehicle for life, the first stage in the life of an electric vehicle — the design and build stage — is arguably the most important to get right in terms of realizing safety and function. PICs have limited influence on the design features for most of the road vehicle types that they receive. Instead, PICs normally select from vehicles that have been designed and built to meet the standards prevailing in other markets. But even from these sources, it is still possible for vehicles of unwanted or poor design to make their way into PICs, which could be avoided through the introduction of minimum specification requirements. For used electric vehicles, it would also seem sensible to implement controls that only allow the importation of vehicles with batteries with no or minimal degradation.

There are many factors to consider in designing such minimum specification requirements for electric vehicles. For example, the requirements cannot be any more stringent than the original standards to which the vehicle was built: it should be relatively easy to prove compliance (at border entry, say); the process should be relatively simple and robust (particularly in view of the limited administrative resources that might be available in smaller-sized PICs); the requirements should not exceed those of neighboring, source countries, such as New Zealand, unless there is a very good reason for this; and the overall regime should be a good fit within a PIC setting.

These factors were considered in reviews carried out for each of the vehicle categories. These reviews are provided in Appendix A and the main findings are now summarized.

Keeping in mind the resourcing challenges many PICs are likely to face in implementing standards for e-mobility, the following tiered approach for the introduction and use of standards is recommended, comprising a Tier 1 approach aimed at providing an entry-level electric vehicles standards regime supported by Tier 2 complementary measures, and a Tier 3 approach providing a best-practice approach (where resources allow). Table 3-1 describes this tiered approach.

Table 3-1: Tiered Approach to Design and Build Standards for Electric Road Vehicles

Approach	Tier 1 Minimum Intervention Requirements	Tier 2 Complementary Measures	Tier 3 Detailed Specification of Standards
Key features	• For lower-powered electric mobility: supply under consumer protection	• Supplementary labeling and import controls supported by consumer	• Specific standards aligned to international norms and best practice.

Approach	Tier 1 Minimum Intervention Requirements	Tier 2 Complementary Measures	Tier 3 Detailed Specification of Standards
	laws, supported by consumer information and guidelines. • For larger-sized electric mobility, import inspections that include identifying proxy for suitable specification vehicles and labeling checks.	information and guidelines.	
Example use case	• Deploy in low resource setting: e.g., practical guidance for customs / transport inspectors on visual safety inspection of electric system.	• Consumer education on buying, usage and disposal.	• Procurement of fleet and charging infrastructure by government, commercial and industrial customers, and development partner-supported projects.

Source: The authors.

Each of these tiers is discussed in more detail under the headings below, along with discussion of border and annual inspections, which offer opportunities to enforce the proposed standards intervention.

3.1 Tier 1 - Recommended Minimum Requirement Interventions

All lithium-ion batteries must meet UN 38.3

The batteries of most modern electric vehicles are lithium-ion and are classified as a Class 9 Dangerous Goods for transportation (via air, sea, rail, or road), requiring compliance with the specifications outlined in Standard UN 38.3. This standard is applicable to batteries being transported individually or when integrated within a device. This is a standard that is already in place globally, and shippers should not accept carriage unless suitable proof of compliance is provided.

While compliance with UN 38.3 establishes a baseline level of safety for batteries: it is not considered sufficient by itself for some electric vehicle types and additional interventions are recommended, as detailed below.

Mandated minimum build specification requirements for low-powered electric vehicles are not recommended

Apart from UN 38.3, it was found to be inadvisable to mandate minimum specification build requirements for low-powered electric vehicles, because only some models of these vehicle types currently comply to desired standards[4] and to impose a minimum standard or other specification requirements would significantly restrict supply options at a time when growth in the sector is desirable.

Instead, a Consumer Guarantees Act approach is recommended (noting that most, if not all, PICs have some form of consumer protection legislation in place), supported by a guideline-supported industry and awareness program.

Requiring anti-lock brakes or combined brakes for all motorcycles at import should prevent importation of low-quality electric two-wheelers (e2Ws) and electric three-wheelers (e3Ws).

Requiring all (fossil-fueled and electric-powered) motorcycles to be fitted with an anti-lock braking system (ABS) or a combined braking system (CBS) at the time of border crossing/first entry to the fleet is expected to effectively exclude low-quality e2Ws and e3Ws – the sort that may have higher risk batteries. And the proxy of checking for the physical presence of ABS/CBS is very simple compared with checking compliance to various electric powertrain standards (including the battery standards[5]). As it is a proxy, it is recommended that regulators maintain a watching brief and introduce a more stringent requirement if such proves necessary.

An all-motorcycle approach has been proposed, as this seems sensible in view of the drive toward the use of safer vehicles across PICs, and captures fossil-fueled motorcycles as well.

Requiring electronic stability control for all light-duty vehicles provides a simple check of likely compliance of the electric powertrain to recognized standards

In a similar manner, requiring electronic stability control (ESC) to be fitted on every light-duty vehicle at the time of border crossing/first entry to the fleet is a proxy for, and has the likely effect of, requiring the electric powertrain of light-duty electric vehicles to be built to the standards in place in the PRC, Europe, Japan, and/or the US – with a simple check of the tell-tale ESC symbol on dashboard lights and on a switch providing proof of compliance,[6] compared with what could otherwise be a much more time-intensive process to prove compliance of the electric powertrain with a suitable standard. As for motorcycles, an all-light-duty vehicle approach is proposed, as arguably every new light-vehicle entrant to the fleet should feature ESC for safety reasons.

The electric powertrain of medium- and heavy-duty electric vehicles must be compliant with the technical principles of UNECE R100

It is recommended that the electric powertrain of medium- and heavy-duty electrical vehicles must comply with the relevant technical principles of UNECE R100, meaning that the vehicles in question have the safety-related functionality described in standard UNECE R100 (a standard for the electric powertrain of electric vehicles that has been adopted globally, apart from by the US, although many of the US technical requirements are the same in principle). In saying this, it should be recognized that strict observance of the test procedures, and others detailed in the standard UNECE R100, would present an unnecessary and insurmountable barrier for some electric vehicles that would otherwise

[4] Noting that this includes low-powered vehicles that would likely meet the desired standards if they had been tested to them, but that have not been tested due to a combination of the absence of standards requirements in the target market and the expense of such compliance.
[5] Note that reference to the "electric powertrain" in this report follows IEC convention and includes the battery (unless otherwise stated).
[6] For example, as detailed by New Zealand Land Transport Authority's Vehicle Inspection Requirements Manuals for braking. New Zealand Land Transport Authority. Technical Bulletins. https://vehicleinspection.nzta.govt.nz/virms/entry-certification/technical-bulletins/esc-id.

have a place in PICs (including buses), due to the (non-technical) administrative requirements of UNECE R100, and hence the proposed (less administrative) requirement of "compliance with the technical principles".

Acceptable proof of compliance with the technical principles of UNECE R100 includes proof of compliance with People's Republic of China Compulsory Certification (CCC) and/or the US and North America's SAE and/or the Republic of Korea's Korea Motor Vehicle Safety Standards (KMVSS) and/or India's Central Motor Vehicles Rules (CMVR). Further, an acceptable proxy for compliance of these is proof of previous registration of the vehicle for on-road use in a country/region that has highly regulated vehicle specification requirements (e.g., Australia, the PRC, Republic of Korea, Japan, EU, New Zealand, and the US and North America).

The electric powertrain of retrofit, scratch-builds, and low-volume vehicles must also meet the technical principles of UNECE R100

It is recommended that the electric powertrain of retrofit, scratch-builds, and low-volume medium- and heavy-duty electrical vehicles must be compliant with the relevant technical principles of UNECE R100 (or UNECE R136 for e2Ws and e3Ws), allowing the same options for proof of compliance as for medium- and heavy-duty electric vehicles, as detailed above.

PICs would benefit from battery durability standards; however international standards are still being developed

There are several standards in the making, including a UN standard that details the durability expectations of batteries.[7] PICs would likely see the benefit of these new standards as they filter through to market, but it is not necessary to consider them at this time.

Recommended build standards for electric vehicles and complementary border/fleet entry requirements

The resulting list of recommended minimum specification requirements for the electrical components of an electric vehicle (i.e., the electric powertrain and onboard charging arrangement) for each of the six vehicle categories are provided below (Table 3-2).

These recommended minimum specification requirements would be in addition to any standards requirements that a PIC may already have in place (with the exception of an exhaust emissions standard, from which an all-electric vehicle should be exempt).

Also listed in Table 3-2 are recommended complementary border controls that could be used to check a vehicle's compliance, also across the six electric vehicle categories considered.

[7] UNECE. 2021. Major Auto Markets Join Forces for Draft UN Legislation on Electric Vehicle Battery Durability. Press release. 12 November. https://unece.org/circular-economy/press/major-auto-markets-join-forces-draft-un-legislation-electric-vehicle-battery#:~:text=The%20new%20provisions%2C%20developed%20as,8%20years%20or%20160%2C000%20kms

Table 3-2: Recommended Build Standards for Electric Vehicles and Complementary Border/Fleet Entry Requirements.

	Electric powertrain Build Standard Approach for New Fleet Entrants	Charging Arrangement	Complementary Border/1st Registration Recommendations
Low-Powered EVs	Target responsible imports with goods sold subject to consumer protection requirements, supported by industry (and public) guidelines and an awareness campaign.	Clear, permanent label of the vehicle's charging requirements. Prefer charging using DC supply of less than 50 VDC. Prefer special connector to avoid mismatched charging. Direct connect to mains AC supply discouraged (and must be a CE/UL-approved appliance if it is).	Consider reduced tax/duties to encourage uptake of goods that comply with internationally recognized standards (and higher tax/duties for non-compliant product).
Electric Motorcycle	ABS or CBS requirement for all motorcycles >50 cc and/or capable of >50 km/h.	Clear, permanent label of vehicle's charging requirements. Prefer charging using DC supply of less than 80 V. Prefer special connector to avoid mismatched charging. Discourage direct connection to mains AC supply (and must be a CE/UL-approved appliance if it is).	Border control: visual identification that ABS or CBS is fitted. Visual safety inspection of electric system (connectors secure, no exposed live parts, etc.).
Lightweight e4W	Vehicle has CCC and/or is EU-compliant and/or battery has CCC mark or meets the relevant technical require-ments of UNECE R100/R136 and/or UL 2271, or near equivalent.	Clear, permanent label of vehicle’s charging requirements. Prefer charging using DC supply of less than 80 V. Prefer special connector to avoid mismatched charging. Discourage direct connection to mains AC supply (and must be a CE/UL-approved appliance if it is).	Proof of standards compliance and/or proof of previous registration in countries that demand compliance with CCC, EU, Japan, ADR and/or US jurisdictions, and/or proof principles of UNECE R100 or R136 met. Visual safety inspection of electric system.
Light-duty EVs	ESC required for all light-duty vehicles (internal combustion engine and EVs). Minimum 80% residual battery capacity at time of import.	Encourage use of Type 2, CCS Type 2 and/or CHAdeMO charging port(s).	Proof of ESC fitted, including statement of compliance and/or dash tell-tale symbol (e.g., on dash lights and switch). Visual safety inspection of electrical system including for warning/ malfunction indication lights. Use diagnostics to check battery SOH.
Medium/Heavy EVs	Electric powertrain compliant with relevant technical principles of UNECE R100. Minimum 80% residual battery capacity at time of import.	Encourage use of Type 2, CCS Type 2 and/or CHAdeMO charging port(s).	Proof of necessary compliance — statement of compliance from manufacturer/supplier and/or proof of previous registration in countries that demand compliance with CCC, EU, Japan, ADR and/or US jurisdictions standards. Visual safety inspection. Use diagnostics to check battery SOH.

	Electric powertrain Build Standard Approach for New Fleet Entrants	Charging Arrangement	Complementary Border/1st Registration Recommendations
Retrofit, Scratch-Builds, Low-Volume Vehicles	Electric powertrain compliant with relevant technical principles of UNECE R100 or R136, as applicable.	Encourage use of CCS Type 2 or CHAdeMO charging port.	Proof that minimum safety requirements have been met. Visual safety inspection.

ABS = Anti-lock braking system, ADR = Australian Design Rules, CBS = Combined braking system, CCC = People's Republic of China Compulsory Certification, CCS = Combined Charging System, CE = Conforms to European health, safety and environment protection standards, ESC = Electronic Stability Control, EV = electric vehicle, e4W = electric four-wheeler, SOH = State of Health, UL = Underwriters Laboratory, UNECE = United Nations Economic Commission for Europe.

Source: The authors.

3.2 Tier 2 - Suggested Complementary Measures

The effectiveness of the recommended minimum requirement interventions would be expected to be greater if supported by other measures, such as the provision of information at the point of the electric vehicle's sale (this measure aimed at educating suppliers, so that they make correct import and market supply decisions, and buyers, so that they can make informed and better purchase decisions), and others. This could be further complemented by the provision of user guidelines that include quality information on charging (aimed at bringing about safer practices).

These suggested complementary measures are listed in Table 3-3.

Table 3-3: Suggested Complementary Measures

Vehicle	Complementary at-Point-of-Sale Recommendations	Complementary In-Use Recommendations
Low-Powered Electric Vehicles	Industry and public awareness program supported by guidelines that encourage uptake of preferred technologies. Encourage reporting/call-out of low-quality goods, with govt support system for this.	User guidelines, including information on best-practice operation and charging.
Electric Motorcycle	Industry and public awareness program supported with guidelines for buyers that encourage uptake of preferred technologies.	User guidelines, including information on best-practice operation and charging.
Lightweight e4W	Industry and public awareness program supported with guidelines for buyers that encourage uptake of preferred technologies.	User guidelines, including information on best-practice operation and charging.
Light-duty EVs	Industry and public awareness program supported with guidelines for buyers that encourage uptake of preferred technologies.	User guidelines, including information on best-practice operation and charging.
Medium/Heavy EVs	Industry awareness program supported with guidelines for buyers that encourage uptake of preferred technologies.	User guidelines, including information on best-practice operation and charging.
Retrofit, Scratch-Builds, Low-Volume Vehicles	Generally, not applicable.	Refer to user guidelines of other vehicle categories, as applicable.

EV = electric vehicle, e4W = electric four-wheeler.

Source: The authors.

3.3 Tier 3 - Detailed Specification of Standards

As explained in Appendix A, the Tier 1 - Recommended Minimum Requirements for the electric powertrain have been drawn in a way that is expected to make it easy to deploy the proposed standards interventions in a low-resource setting, typical in many PICs.

The standards specification for electric vehicles can, in some cases, be more specific — for example, in procurement of fleet and charging infrastructure by government, commercial and industrial customers and development partners. In these cases, there is an opportunity to be more specific, and deliberately emulate global best practice, by requiring the electric powertrain of electric vehicles to be compliant with the technical, specific, recognized international standards. PICs with better resourced standards and regulatory regimes may also wish to consider these more detailed standards.

These specific standards, by vehicle type, are listed in Table 3-4. The derivation of these standards is also explained in Appendix A.

Table 3-4: Tier 3 - Detailed Specification of Standards

Vehicle	Recommended Electric Powertrain Build Standard Requirements	Recommended Charging Arrangement
Low-Powered Electric Vehicles	Compliant with EN 15194, and/or EN 60335-1, and/or UL 2849 and/or UL 2271 and/or UL 2272, as relevant. Nominal 36 VDC (10-Series) for e-scooters and 48 VDC (13-Series) for e-bikes.	Clear, permanent label of vehicle's charging requirements. charging using nominal 36 VDC or 48 VDC power supply/cable chargers. Prefer special connector to avoid mismatched charging until charger cable plugs are standardized.
Electric Motorcycle	Meets the relevant technical requirements UNECE R136 and/or UL 2271 or near-equivalent recognized international standard. Prefer the use of 48VDC electric powertrain systems.	Charging using nominal 48 VDC power supply/cable chargers. Prefer special connector to avoid mismatched charging until charging cable plugs are standardized.
Lightweight e4W	Meets the relevant technical requirements of UNECE R100 or R136 and/or UL 2271, or near-equivalent recognized international standard. Prefer the use of 48 VDC electric powertrain systems.	Charging using nominal 48 VDC power supply/cable chargers. Prefer special connector to avoid mismatched charging until charging cable plugs are standardized or Type 2 AC charging (and Type 2 charging port).
Light-duty EVs	Electric powertrain meets the relevant technical requirements of UNECE R100 or near-equivalent recognized international standard.	Type 2 AC plus either CCS Type 2 and/or CHAdeMO DC charging port(s) (and charging in accordance with relevant IEC standards).
Medium/Heavy EVs	Electric powertrain meets the relevant technical requirements of UNECE R100 or near-equivalent recognized international standard.	Type 2 AC (medium-duty EVs) plus either CCS Type 2 and/or CHAdeMO DC charging port(s) (and charging in accordance with relevant IEC standards).
Retrofit, Scratch-Builds, Low-Volume Vehicles	Electric powertrain meets the relevant technical requirements of UNECE R100 (or R136, as applicable) or near-equivalent recognized international standard.	For high-voltage powertrains, Type 2 AC plus either CCS Type 2 and/or CHAdeMO DC charging port(s) (and charging in accordance with relevant IEC standards).

CCS = Combined Charging System, EN = European standard, IEC = International Electrotechnical Commission. UL = Underwriters Laboratory, UNECE = United Nations Economic Commission for Europe.

Source: The authors.

3.4 Border and annual inspections

As for any vehicle, an electric vehicle must be safe to operate and its parts must be within safe tolerance of their as-built (or as-approved, modified) condition.

A border inspection, for imported used vehicles, and an annual inspection, for in-service vehicles, provides the opportunity to visually check that the electrical system components of an electric vehicle still satisfy this requirement (with any required inspection of other, non-electrical system components to be added to this). This includes inspection to identify any modifications to the electrical system which must not be allowed.[8]

The New Zealand Transport Authority (NZTA) provides details of what such a visual inspection of the electrical system could comprise, which includes an inspection of the high-voltage wiring and batteries for inadequate security, damage or deterioration, risk of damage occurring, and the illumination of electrical system warning lamps, as detailed in the procedure available on NZTA's website.[9] This visual inspection procedure suits a PIC setting and is recommended to be followed.

[8] Noting that the Fiji Land Transport Authority reports a number of fires of hybrid electric vehicles that have occurred due to modifications of the hybrid electrical system.

[9] New Zealand Transport Agency. Miscellaneous Items. https://vehicleinspection.nzta.govt.nz/virms/in-service-wof-and-cof/general/miscellaneous-items/electric-hybrid-electrical-system#tab1.

4 First Response

4.1 Introduction

For most accidents, an electric vehicle is no different from a gasoline- or diesel-fueled vehicle. Where differences may come about is when the incident is so severe that the high-voltage cabling (in the case of passenger cars and larger-format electric vehicles – most motorcycles and smaller electric vehicles have low-voltage electrical systems) might be compromised and there may be a risk of electrocution, and/or where the battery might be compromised and there is an associated risk of fire. If a fire should occur, the characteristics of that fire are also different and require a different response to, say, a gasoline or diesel-fueled vehicle fire.

First response agencies often have established policies and tactical responses handed down from national bodies. The fundamentals provided in this section are aimed at those instances where policies and tactical responses are not available for the first response to an electric vehicle incident. These fundamentals have been drawn and collated from those published by various reputable first response agencies, including the US National Fire Protection Association,[10] the International Association of Fire Chiefs,[11] the Deutsche Gesetzliche Unfallversicherung,[12] and the New Zealand Fire Service.[13] It is emphasized that the recommendations are still high-level in nature, and they are focused on responses to a fire of the battery (as this is the most significant difference from an internal combustion engine vehicle fire that responders have experienced), and it is advised that first responders receive detailed, specific training on the first response to an electric vehicle fire.[14]

4.2 Background

The following background information is relevant when considering standards and guidelines for first responders.

Electric vehicles that have high-voltage systems and/or large batteries are built to standards that aim to minimize the risks involved.

The practices demanded by these build-related standards include color-coding and specification of high-voltage cables and fittings, protective cases around batteries, and providing various means to isolate the high-voltage systems.

[10] National Fire Protection Association. Emergency Response Guides. https://www.nfpa.org/Training-and-Events/By-topic/Alternative-Fuel-Vehicle-Safety-Training/Emergency-Response-Guides.

[11] In particular, see IAFC Bulletin. 2021. *Fire Department Response to Electric Vehicle Fires*. https://www.iafc.org/docs/default-source/1haz/respondingtoelectricalvehiclefires.pdf

[12] German Association of Accident Insurance Institutions. 2020. Instructions For Lithium-Ion Battery Firefighting In Vehicle Fires. https://publikationen.dguv.de/regelwerk/publikationen-nach-fachbereich/feuerwehren-hilfeleistungen-brandschutz/feuerwehren-und-hilfeleistungsorganisationen/3926/fbfhb-024-instructions-for-lithium-ion-battery-firefighting-in-vehicle-fires.

[13] Including BRANZ. 2020. Lithium Batteries - What's the Problem? *Fire and Emergency New Zealand Research Report* No. 174. Wellington, NZ: Fire and Emergency New Zealand. https://www.fireandemergency.nz/assets/Documents/Files/Report_174_Lithium_Batteries_Whats_the_problem.pdf.

[14] There are several on-line training courses available including member-access training through NFPA and open-access through the National Alternative Fuels Training Consortium and others: for example, courses available on the YouTube platform at the time of writing include: https://www.youtube.com/watch?v=JbDzUPybjI8 and https://www.youtube.com/watch?v=B89iU2fETBw,

Tests have shown that water is both suitable and recommended as an extinguishing agent for lithium-ion batteries

Quoting from the Deutsche Gesetzliche Unfallversicherung information publication FBFHB-024:[15]

> "Experience has also shown that a fire in a lithium-ion battery will be extinguished only once sufficient amounts of water can reach the inside of the lithium-ion battery. Tests have shown that water is both suitable and recommended as extinguishing agent. Extinguishing additives are not required.
>
> Not every (high-voltage) battery installed in a vehicle is a lithium-ion battery. Other technologies (e.g. nickel-metal hydride (NiMH)) are installed, for example, in many hybrid vehicles. They are less reactive and also less dynamic in terms of their fire behavior.
>
> Burning lithium-ion batteries just like other fires release considerable amounts of respiratory toxins as well as harmful combustion products and residues."

Several factors make firefighting more difficult in the case of a lithium-ion battery

These include that the protection normally surrounding the battery in an automotive application and the insulative nature of the batteries surrounding a fire zone make it difficult to get cooling to the fire zone, and that there is the potential for a fire to be rekindled, even days later, including due to the instability of cells not in the fire zone that still get heat damaged.

Fire-related risks for first responders to consider

The lists of fire-related risks for firefighters to consider and manage include released toxins, bursts of flame and heat from the combustion of off-gases, flying debris from explosions (for example, from the destruction of other vehicle parts including airbags and tires – the batteries themselves do not normally explode), the potential for the vehicle to start rolling, the overall intensity of the fire, and the high voltages that may be involved (requiring hose operators to maintain suitable distances when applying solid jets of water, even though the risks of electrocution through the water jet are low).

Wet and dry chemical extinguishers are not effective on a vehicle battery fire

Dry chemical extinguishers[16] and wet chemical extinguishers[17] are not effective on a vehicle battery fire – the important part of fighting a battery fire is providing cooling, which is best achieved by using (copious amounts of) water. Where a dry chemical extinguisher may be useful is for a fire associated with an e-bike battery, but more to manage the spread of the fire (but also noting that home-sized dry chemical extinguishers tend to deliver only for about 30 seconds). Here again, a hose directing water on the battery would likely be more effective.

[15] Deutsche Gesetzliche Unfallversicherung. Instructions for Lithium-Ion Battery Firefighting in Vehicle Fires. https://publikationen.dguv.de/widgets/pdf/download/article/3926.
[16] Sometimes referred to as an ABC dry chemical extinguisher or an ABE dry powder extinguisher depending upon country.
[17] The type recommended for use in kitchens.

The use of submersion is debated

There is debate whether an electric vehicle should be submersed in water as part of an after-fire response. However, priorities in PICs suggest that it would be unlikely for such tank facilities to be available and therefore this is unlikely to be an option for PICs. While the use of the nearby sea may be another submersion option, this is not recommended because of how long it may take to recover the remains and pollution concerns.

If safe to do so and the fire is already well established, allowing the fire to burn out is an option.

4.3 First Response Guidelines

Figure 4-1 shows the guidelines for first response to an electric vehicle fire, which collate those provided by the above-mentioned organizations:

Figure 4-1: First Response Guidelines

Assessment of Incident

- Identify the vehicle type and, if an electric vehicle, what type (a hybrid has a smaller battery and any fire would be less intense and of shorter duration than that expected for a long-range, all-electric vehicle).
- Assess the unfolding incident, including verifying whether there are people trapped within the vehicle who require extrication, the safety risk to people and property near the vehicle, and the available first response resources. Look for signs that the battery might have been damaged or if there is a potential that the vehicle might be electrically live. Based on these, devise a tactical response and communicate this across the first response team.
- If safe to do so, power down the vehicle and isolate the vehicle's high-voltage system (referring to the vehicle's rescue data sheet[18]). Only then should extrication procedures be undertaken.
- Maintain a watch for indications that the battery is failing, including the release of white smoke, the sound of hissing or other noises from the battery, and odd smells or eye irritation (a sign of venting of gases).
- If the battery is showing signs of failing, clear the surrounding area or, if safe to do so, move the vehicle to a safer position and chock the wheels. Get ready to apply water on the battery.
- Ventilate the inside of the vehicle by opening a window or a door.

Should a Fire Develop

- Wear full personal protective equipment.
- Approaching the vehicle diagonally from the corners ensures the greatest possible distance from the direct danger zone.
- Use copious amounts of water, training the hose on the battery area to suppress and cool the fire and the battery.

Post-Incident

- Brief the tow truck operator on the risks.
- Have a first response team follow the wreckage to the storage site.

[18] The following link provides an example of information that vehicle importers should make available to first responders. This example is from the US National Fire Protection Association, for the 2013-2017 model Nissan Leaf: https://www.nfpa.org/downloadable-resources/guides-and-manuals/nissan-leaf-2013-2017-guide

- Park the wreckage in a safe location, whether the incident involved a fire or not.
- Get an assessment of the condition of the battery by trained personnel. This might be a representative of the vehicle's manufacturer.
- If deemed required, remove and manage the battery by trained personnel.

In the case of a fire of an e-bike-sized battery in a home situation, it may be possible to pick the battery up with a spade or other implement and remove it from the house.

Source: The authors, adapted from International Association of Fire Chiefs 2021 Fire Department Response to Electrical Vehicle Fires[19] and other sources

[19] International Association of Fire Chiefs. 2021. Fire Department Response to Electrical Vehicle Fires *IAFC Bulletin.* https://www.iafc.org/docs/default-source/1haz/respondingtoelectricalvehiclefires.pdf

5 Charging Standards and Guidelines

5.1 Introduction and background

Appendix B provides an introduction and background on electric vehicle charging and it is recommended that those less familiar with the charging of electric vehicles read this appendix before reading this section.

As explained in Appendix B, there are several arrangements commonly used, or becoming common, to supply electricity for charging electric vehicles. These arrangements include low-voltage DC charging, portable AC charging, fixed AC charging, high-voltage DC charging, and battery swapping. Low-voltage DC charging is normally associated with the charging of micro- and small-format electric vehicles, AC and DC charging with passenger car-type electric vehicles through heavy-duty electric vehicles, and battery swapping tends to focus on small-format electric vehicles, although there has been a recent resurgence in the use of battery swapping in heavy duty vehicles.

AC charging from mains electricity utilizes the vehicle's onboard AC to DC charger and can be carried out in one of three modes:

- **Mode 1** using a simple, portable electricity supply cable
- **Mode 2** using a portable electrical supply cable with an In-Cord Control and Protection Device (IC-CPD), and
- **Mode 3** which also provides the safety features of Mode 2 and is hard-wired to the electricity supply

Normal high-voltage DC charging is referred to as Mode 4 charging:

- **Mode 4** high-voltage DC charging

These mode definitions concern high-voltage conductive charging and the low-voltage conductive charging of the likes of e-bikes; high-voltage inductive (contactless) charging is not included in these definitions.

5.2 Standards requirements

The charging connectors used for Modes 2, 3, and 4 charging are multi-pin, carrying both the charging electricity and the communications between the vehicle and the IC-CPD, Mode 3 charger, or DC charger. Developments in different markets around the world have seen several different charging connectors in use in the marketplace, but with an emerging preference for the use of Type 2 connectors for AC charging and CHAdeMO and Combined Charging System (CCS) Type 2 for DC charging for public charging (and customers providing their own charging cables when connecting with public Mode 3 chargers to ensure compatibility with their vehicle).[20]

Besides protocols concerning safety functions and the vehicle's control of the charging event, there are other charger-related communications that enable a range of useful services: for example, the ability to remotely control smart chargers, as has been mentioned. Communications also allow the status and health of charging stations to be monitored (providing data for mobile phone-based apps

[20] For, example, the charging cable may have a Type 2 connector at the Mode 3 charging point outlet and a Type 1 or Type 2 connector at the other end, depending upon the needs of the vehicle to be charged.

to show whether a specific public charger is in use or available, for example),[21] allow remote software upgrades, and automated billing.

These arrangements require physical and communications compatibility between the parts, sometimes also referred to as interoperability (the ability for chargers to provide charging to a broad range of different vehicle types — so long as they share the same connector types — and the ability for electric vehicles to be able to use most public charging stations and any private charging point with matching connector). All parts in these arrangements must also be fit-for-purpose, which includes the suitability of the electrical supply equipment for the setting (weather, marine, and other) in which it is installed. To achieve this, there are many internationally recognized standards that can be referred to, including the IEC 61851 series, concerning the general requirements of electric vehicle conductive charging systems, and the IEC 62196 series, concerning the specifications of various conductive charging plugs, socket outlets, vehicle connectors and vehicle inlets, to give but two examples.

Many of these standards have PRC near-equivalents; in fact, some PRC charging-related standards refer to corresponding IEC standards. Likewise, many global standards relating to charging refer to SAE J1772 for the specifications of the Type 1 charging connector (as SAE J1772 provides the original specifications for Type 1 connectors, which are used in many countries). Thus "charging standards" comprise a mixture of interrelated, globally recognized standards that define the specifications of electric vehicle charging equipment and how it must operate.

Further, installations must comply with the national electricity rules and regulations where they are in place, noting that, for several PICs, these require compliance with the wiring rules of another country or region: for example, Fiji's electricity regulations refer to compliance with the "Wiring Rules" of Australia and New Zealand (currently AS/NZS 3000:2018),[22] and French Polynesia refers to the requirements of the European electrical standards (as it is a territory of France and France is a member of the EU). Where a country does not mandate such requirements, installers should still abide by such standards in their duty to provide safe and fit-for-purpose charging facilities.

Over and above these are guidelines developed through experience – recommendations that are not mandatory, even in countries with strong regulatory systems, but which make good sense for one reason or another. Examples include:

- Identifying sites for DC charging that require minimal upgrade of the local supply circuits (in response to the very high cost of network upgrades, such as installing or up-sizing local transformers).
- Positioning wall chargers so that electric vehicles can be easily connected and the charging cables are least likely to present a trip hazard.
- The purchase and use of smart chargers (discussed in Appendix B).

[21] The database EVRoam has been set up by the New Zealand Government to provide real-time data, enabling App providers to display the real-time status of every public charger in New Zealand. For further information, see https://nzta.govt.nz/planning-and-investment/planning/transport-planning/planning-for-electric-vehicles/evroam/

[22] Government of Fiji. 2019. *Electricity Regulations.* Clause 13. https://fccc.gov.fj/wp-content/uploads/2019/10/LN-8890-Electricity-Regulations-2019-4.pdf

5.3 Guidelines and standards recommendations

Low-voltage DC power supply/chargers

Guidelines and standards recommendations for low-voltage DC power supply/chargers are summarized in Figure 5-1. It is recommended that these guidelines are developed into readily available public information.

Figure 5-1: Guidelines and Standards Recommendations for Low-Voltage DC Power Supply/Chargers

- The low-voltage DC charger must have a manufacturer's label that shows that the charger is rated for connection to the grid supply of electricity.
- The supply plug on the power supply/charger must only be changed from that fitted by the manufacturer by an approved electrician.
- Either the power supply/charger has a unique DC charging connector or the DC charger connector and the battery/vehicle charging port are clearly labeled with their respective nominal voltages (or other), and these labels must clearly show if the two are compatible.
- The power supply/charger should switch off at the end of charging.[23]
- It is recommended that batteries that are charged using low-voltage DC power supplies have a built-inBMS. If this is not the case (for example, in the case of drones), then the BMS must be contained within the power supply/charger, the charging should be carried out in a safe area and the battery preferably contained within a fireproof pouch or container, the charging process should be monitored, and the power supply/charger disconnected soon after the charge has been completed.
- It is preferred that low-voltage DC charging should take place away from areas where people sleep.
- A battery should be checked by a suitably skilled person should it show signs of damage or look different from its as-new condition (for example, showing signs of swelling). Under no circumstance should a battery showing signs of degradation be connected to a charger.

BMS= battery management system

Source: The authors.

Mode 1 Charging

Guidelines and standards recommendations for Mode 1 Charging are summarized in Figure 5-2.

Figure 5-2: Guidelines and Standards Recommendations for Mode 1 Charging

- Mode 1 charging is strongly discouraged and it is recommended that it not be permitted in a commercial setting.
- Mode 1 charging should only be carried out through a RCD-protected supply circuit and only through a three-pin mains socket outlet with a sound earth circuit, without adaptors, and using a single, three-core lead. Any socket outlet used for charging an electric vehicle should be checked as suitable for this purpose by an appropriately qualified person.

[23] Noting that many power supply/chargers with this function have a light that is red during charging and switches to green once the charge is complete.

- Mode 1 charging should not be carried out outdoors, and must not be carried out in conditions where the charging cable, socket outlet or vehicle may get wet during the charging operation.

RCD = residual current device

Source: The authors.

Mode 2 Charging

Guidelines and standards recommendations for Mode 2 Charging are summarized in Figure 5-3.

Figure 5-3: Guidelines and Standards Recommendations for Mode 2 Charging

- The IC-CPD charging cable must be compliant with IEC 62752[24] or an internationally recognized near-equivalent.
- The manufacturer's label must show that the cable is rated for use with the grid supply of electricity.[25]
- The plug of an IC-CPD charging cable must only be changed by an approved electrician (who will check that the IC-CPD charging cable, its plug, and the socket outlets expected to be used with it match and are appropriately rated).
- It is highly recommended that Mode 2 charging is carried out from an overload- and RCD-protected supply sub-circuit, through a three-pin mains socket outlet with a sound earth circuit, without adaptors, and without the use of an extension cord.
- Any socket outlet used for charging an electric vehicle should be checked as suitable for this purpose by an appropriately qualified person. The checks should include the rating of the sub-circuit and the protection on it, and the continuity of the (safety) earth circuit. It is suggested that the socket outlets that have been so checked are labeled as suitable for vehicle charging. It is also preferred that the socket outlet be on a dedicated sub-circuit, or at least on a sub-circuit with few other loads.
- The IC-CPD must not be used if it appears to be damaged and/or it does not seem to function correctly (poor or intermittent operation indicates that there may be a fault and the IC-CPD charging cable and the vehicle should be checked).

IC-CPD = In Cord – Control and Protection Device, IEC = International Electrotechnical Commission, RCD = residual current device

Source: The authors.

Mode 3 Charging

Guidelines and standards recommendations for Mode 3 Charging are summarized in Figure 5-4.

Figure 5-4: Guidelines and Standards Recommendations for Mode 3 Charging

- Mode 3 chargers are available in a number of different configurations: single- or multi-phase (multi-phase enabling higher charge rates); suitability for indoor or outdoor use, fitted with a socket outlet (allowing a range of charging cables to connect it with electric vehicles) or fitted with a tethered charging cable; fitted with different charging connectors; and simple or

[24] IEC 62752:2016: *In-cable control and protection device for mode 2 charging of electric road vehicles (IC-CPD). https://webstore.iec.ch/publication/24284*

[25] Which is a reasonable indication that the IC-CPD charging cable has been built in accordance with internationally recognized standards.

"smart" (i.e., able to be controlled remotely). Seek guidance so that an informed decision can be made on which is the most appropriate for a specific installation.

- For a Mode 3 charging point located in a private space, it is recommended that it is a smart charging point (see next bullet point), it has a female Type 2 charging port outlet, and the hard-wired components of the installation are rated for potential future up-rating of the charging point where the rating of the mains supply circuit may allow this. It should also be located where it allows convenient coupling of the electric vehicle and the loose charging cable does not create a trip hazard. It is recommended that the Mode 3 charging point is also mounted at least 800 mm above the ground.[26]
- To be considered a smart charging point, the charging point must be compatible with the Open Charge Point Protocol (OCPP) 1.6 or above (Version 2.0 preferred), and it preferably can be controlled remotely by a third party without the need for access through a proprietary service.
- There are many additional requirements for Mode 3 charging points used in public spaces: they must be robust enough for the setting (and be suitably protected by bollards, gutters, or other structures); have the means by which electric vehicle owners can easily access (and pay for, as applicable) the charging service (which means that the site must also have access to a suitable communications stream); the site should be safe to use and secure (for example, well-lit overnight and within view of or adjacent to occupied dwellings), and ideally the site would be close to useful facilities and amenities. A permit to on-sell electricity may also be required.
- Both private and public Mode 3 charging points must be compliant with the relevant parts of IEC 61851 and IEC 62196,[27] or their internationally recognized and accepted near equivalents (such as UL 2202 and UL 2251, for example[28]). A Mode 3 charging point must also comply with the relevant IEC 61558 standard(s) for medium/high risk articles as specified in the regulations of countries with more stringent regulatory systems. It is recommended that this is required even in countries that do not have stringent regulatory systems.
- Mode 3 charging points must only be installed by approved electricians (who will check that the Mode 3 charging equipment, the electricity supply circuits, the overload- and RCD-protection,[29] and the earth circuits are appropriately specified and in good condition, and will also ensure that the installation complies with the local wiring rules or electricity regulations, as applicable, or with the principles of internationally recognized standards in the absence of electricity safety regulations). The charging point must be installed according to the manufacturer's instructions.
- Mode 3 charging points must be installed on a dedicated sub-circuit. Ideally the wiring on the sub-circuit would have a current-carrying capacity of 32A single phase and a minimum current capacity of 20A multi-phase,[30] if the mains supply circuit was sufficiently rated for this.

[26] Electric Vehicle Charging Equipment Installation, 4th Edition. The Institution Of Engineering And Technology ISBN 978-1-83953-180-4: (making it convenient to access, and also reducing the chance that a vehicle could damage it by being driven into it).
[27] That is, IEC 61851-1 *Electric Vehicle Conductive Charging System – Part One: General Requirements*, and IEC 62196-1: *Plugs, Socket Outlets, Vehicle Connectors and Vehicle Inlets – Conductive Charging of Electric Vehicles – Part One General Requirements.*
[28] UL 2202: *Standard for Electric Vehicle EV Charging System Equipment*, and UL 2251: *Plugs, Receptacles, and Couplers for Electric Vehicles.*
[29] That is, for RCD protection, the use of an RCD or combination that result in trip or AC and DC earth-leakage. This might be provided using a 30 mA Type B RCD or a 30 mA Type A RCD in combination with an RDC-DD).
[30] Master Electricians New Zealand. 2019. *EV Charging: Domestic Installation Guide*. https://driveelectric.org.nz/wp-content/uploads/2020/01/EV-Charging-Domestic-Installation-Guide.pdf.

- The installation of load-sharing Mode 3 charging points must be used where multiple charging points are supplied from an electricity supply circuit that does not have the rating to simultaneously supply all charging points at their full rated charging capacity (and the control across the charging points must ensure that the maximum sum of demand stays within the lowest rated component of the electricity supply circuit. It is also recommended that multiple, single-phase charging points are connected to different phases to balance demand across the phases).

IEC = International Electrotechnical Commission, Open Charge Point Protocol (OCPP), RCD = Residual Current Device, UL = Underwriters Laboratory,

Source: The authors.

Mode 4 Charging

A Mode 4 charging station tends to be used for public charging of electric vehicles. Other applications may include public (e.g., buses and government cars), commercial and industrial fleet operators. In addition to standards, there are several other factors, such as siting and design, which should be considered. These are discussed under the headings below.

Siting considerations

There are many factors to consider when choosing a site for Mode 4 public charging, including: affordable access to a suitable site (public charging stations tend to be sited where there is no charge for occupying the site); the availability of a suitable supply of electricity with minimal upgrades of the local network and/or supply circuits required; the security and safety of the site; the convenience of the site, and the convenience to use the charging station (which includes consideration of connector compatibility and charging rate, and the nearby amenities that could be used while the vehicle is charging).

Design considerations

The design of the charging station also requires consideration of many factors, including the flow of vehicles through the site, proximity to hazards (for example, distance from fuel bowsers on a petrol station forecourt), the shade that might be offered to charging vehicles, and the ability to perform maintenance on the charger.

The subject matter involved is far too detailed to be meaningfully discussed here, and it is advisable that a potential charging service provider carry out careful due diligence before committing to a fast charger installation, including checking: if the local permit requirements can be met; if it is legal to on-sell electricity, and what the line charges might be.[31]

Guidelines and standards

Guidelines and standards recommendations for Mode 4 Charging are summarized in Figure 5-5.

Figure 5-5: Guidelines and Standards Recommendations for Mode 4 Charging

- The presence of a charger in the public domain demands a higher level of standards compliance than for a charger located in a private space. For countries with highly regulated systems, this includes that the installation is carried out by an approved electrician, a Code of Compliance is issued by the Regulator before the charging station is first connected to the

[31] And, in particular, what demand charges might exist – those charges that are calculated on the peak demand. These can make fast charging unaffordable if a fast charger is poorly utilized.

electricity supply requiring compliance of the charging station components and its installation with applicable standards (see next bullet point), issue of an Electrical Safety Certificate by the installer before the charging station is first used beyond that required for commissioning purposes, the site must have an emergency plan (instructions for what to do if there is an incident) and first response equipment on site, and the equipment must have annual safety inspections. The site owner and/or operator must also ensure that the equipment is maintained and operated in accordance with the manufacturer's instructions. It is recommended that PICs without such regulatory requirements adopt the same principles to ensure the safety of the charging station and the people and vehicles that use it.

- A Mode 4 charging station must comply with the applicable parts of IEC 61851-1, IEC 61851-23, and IEC 62196-1.[32] A Mode 4 charging station point must also comply with the relevant IEC 61558 standard(s) for medium/high risk articles, as specified in the regulations of countries with more stringent regulatory systems. It is recommended that this is required even in countries that do not have stringent regulatory systems.
- A Mode 4 charging station should be compatible with Open Charge Point Protocol 1.6 or above (Version 2.0 preferred).

IEC = International Electrotechnical Commission, PICs = Pacific Island Country

Source: The authors.

Battery Swapping

It is expected that battery swapping will be introduced by a service provider who will require their customers to meet the service provider's instructions for use of the swap batteries. It is outside the scope of this report to suggest such operational requirements because this depends upon the type of battery swapping system that is used.

[32] IEC 61851-1: Electric vehicle conductive charging system - Part 1: General requirements, IEC 61851-23: Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station, and IEC 62196-1: Plugs, socket-outlets, vehicle connectors, and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements.

6 Managing End-of-Life Electric Vehicles

Background

The battery is the main difference, from a recycling point of view, between a fossil-fueled vehicle and an electric vehicle. This section focuses on the management of end-of-life (EOL) vehicle batteries.

While it is important for a circular economy to be developed around lithium-ion batteries, the development of EOL processes is still at an early stage. There remain significant risks to consider when working with batteries, including electrocution, intoxication and corrosion from leaking electrolyte, the release of toxic and flammable gases from thermal runaway, and fire. It can be expected that some EOL batteries will be damaged. Another level of risk management will be required to deal with damaged lithium-ion batteries, given how unstable they can be.

Review of international practices

To consider what EOL battery management may work for PICs, let us first consider the global status of EOL battery management:

- Globally, battery packs in good functioning condition that have been removed from vehicles are a valuable commodity for electrical energy storage (e.g., for supporting renewable electricity generation), and there is an active market for them. There is no reason why the same would not be the case for PICs.
- Globally, quality systems for managing EOL lithium-ion batteries are still in development – environmental regulations may spell out the desired outcomes, but specific mechanisms to achieve these (and the detail of supporting standards) have largely yet to be developed.[33]
- Guidelines for the collection and recycling of automobile batteries were issued by the National Development and Reform Commission of China in January 2016, under the Electric Vehicle Power Battery Recycling Technology Policy. This policy requires vehicle manufacturers to take the responsibility for battery collection and recycling (although this may be devolved to a third party), encourages the sharing of battery information with certified re-use application companies (who are responsible for batteries they provide to the market, including EOL management of these batteries), and encourages anticipating recycling at the design stage (i.e., by enabling easy disassembly and recycling of battery components).
- A similar set of guidelines is under development for the EU, including mandating that vehicle manufacturers take responsibility for battery collection and recycling. Some states in the US are developing similar lines of EOL battery responsibility (for example, the proposals for EOL

[33] Noting that while the PRC does have some standards concerning the recovery, assessment, and use of used electric vehicle batteries, these appear to be more in the nature of high-level guidelines. Translations of these PRC standards, available at the time of writing, include:
o GB/T 34015.3-2021: Recovery of traction battery used in electric vehicle - next use - Part 3: next use requirements (https://www.chinesestandard.net/PDF.aspx/GBT34015.3-2021).
o GB/T 34015.4-2021: Recovery of traction battery used in electric vehicle – next use - Part 4: Labels for next use battery products (https://www.chinesestandard.net/Related.aspx/GBT34015.4-2021).
o GB/T 34015.2-2020: Recycling of traction battery used in electric vehicle - Next use - Part 2: Removing requirements (https://www.chinesestandard.net/PDF.aspx/GBT34015.2-2020).

procedures developed by the Californian "Lithium-Ion Car Battery Recycling Advisory Group").[34]

- Representatives of vehicle manufacturers in Australia and New Zealand state that they will take responsibility for EOL vehicle batteries surrendered to them.
- Nonetheless, the writer considers it highly unlikely that such manufacturer responsibilities would apply to a situation where private parties ship used electric vehicles to PICs (private shipments of used vehicles are the main source of vehicles to PICs), on the grounds that the third party is removing the vehicle from its intended market, and the vehicle manufacturer would therefore no longer be responsible for providing local parts supply, local servicing, or EOL management. In short, parties within PICs will become responsible for managing EOL batteries.
- Both the PRC and the EU are considering the introduction of a "digital passport" platform that would hold important information on the history and "health" of the battery, and which would be updated with each change in use. Another measure that is under consideration to facilitate battery life cycle management is a universal diagnostic system.
- The New Zealand Battery Industry Group (BIG, launched in November 2019) aims to introduce a circular product stewardship scheme for vehicle and other large batteries and has developed guidelines concerning the safe handling, collection, transportation, and storage of large batteries after their initial use. Many aspects of this appear to be relevant to PIC settings.
- The risk of fires from poorly refurbished micromobility batteries has resulted in New York City banning the refurbishment of these batteries outright.[35] This is contrary to the drive to maximize the life of a battery through reuse, repurposing, and refurbishing. But it does serve to alert the industry to the risks involved and the need for high quality workmanship, even for small, low-voltage batteries.

Recommendations

The following is a list of recommendations for PICs for the EOL management of vehicle batteries, as gleaned from the above review and the background reading supporting it, industry guidelines such as BIG's *Guidelines for the Safe Handling, Transportation, Collection, and Storage of Large Used Batteries*,[36] the aforementioned PRC standards, the EU regulations for dangerous goods transport,[37] and also from the author's personal experience of working with battery systems.

Note that this list is provided to give the reader some appreciation of the scope of the task, and to underscore the need for practitioners to be thoroughly trained and for supporting facilities to be fit for purpose. The recommendations are split into general recommendations in

Figure 6-1, and specific recommendations for activities involving EOL vehicle batteries in Table 6-1.

[34] CalEPA. 2022. *Lithium-ion Car Battery Recycling Advisory Group Final Report*. https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-Recycling-Advisory-Goup-Final-Report.pdf.

[35] Government of New York City. 2023. *Charge Safe, Ride Safe: NYC's Electric Micromobility Action Plan*. https://www.nyc.gov/assets/home/downloads/pdf/office-of-the-mayor/2023/micromobility-action-plan.pdf

[36] BIG. 2021. *Safety Guidelines for the Safe Handling, Transportation, Collection, and Storage of Large Used Batteries*. https://big.org.nz/wp-content/uploads/2021/06/B.I.G.-Safety-Guidelines-FINAL.pdf

[37] For example: https://adrbook.com/en/2017/ADR/2.2.9.1.7 and https://adrbook.com/en/2017/Sutun/8/P908

Figure 6-1: General Recommendations for EOL Management of Vehicle Batteries

General recommendations

- Only trained personnel should be involved in the handling, collecting, storage and/or transportation of large, used batteries. Only experts with specific specialist knowledge and training should open and unpack battery packs, undertake repair of batteries, and/or rebuild battery packs. Some of this work also requires the use of specialist personal protective equipment: for example, that used when working with high-voltage circuits, connectors, and cables.[38]
- Personnel working in EOL battery management are recommended to keep up with the literature – there are many groups working in the handling, transportation, and storage of lithium-ion batteries and new information seems to be released on a regular basis.
- Refer to the manufacturer's guidelines and safety data sheets – this includes the information released by the vehicle manufacturer concerning the assembled battery pack, and the information released by the battery component supplier, as applicable.
- Know the history of the battery pack and assess its state of safety before removing it from the vehicle and/or unpacking it, as this will inform the manner in which the work should be carried out. For example, extra care is required when working with batteries or battery cells that may have been damaged. Damaged battery packs and damaged battery cells must not be re-used or repurposed. Reassess the state of safety of battery packs and/or battery cells whenever there is a change in its operational status, with particular scrutiny given to used battery packs of cells: for example, as batteries are prepared for transport, before they are put into storage, and before battery cells are assembled into battery packs.
- Keep the record of the history of the battery pack up to date.
- Any site used for battery work and/or storage must be suitable, including possessing appropriate fire-fighting systems (including having access to fire-fighting water), a suitable clean room with non-conducting benches if unpacking batteries, lifting equipment that is appropriate for the battery packs in question, and separate containment areas for damaged batteries to be held, as appropriate. These sites should have readily available response plans in case of a battery failure event, and all staff should be familiar with those plans.

EOL = end of life.

Source: The authors.

[38] Which requires full PPE, from gloves through to footwear. Also, remove any potentially conducting jewelry and tie back any loose hair, other jewelry and clothing.

Table 6-1: Specific Recommendations for EOL Management of Vehicle Batteries

Activity	Recommendation
Battery Pack Removal	Ensure that the lifting gear is rated for the weight of the battery and that it can gently handle and shift the battery pack as required around the site. Cover and protect all exposed terminals as soon as it is practical to do so. Do not stack battery packs on top of one another. If the battery may be in damaged condition or the vehicle is badly damaged, carry out the battery removal in an area where a fire could be managed.[39] After removal, reassess the battery and take a precautionary approach as to how it is stored – the battery should be stored as though it might catch fire if there is any evidence that the battery may have recently sustained damage.[40]
Repair/refurbishment: (where the battery is returned to same intended application, sometimes referred to as "remanufactured" or "rebuilt")	While carrying out the work, keep the exposed area of unshielded terminals or other components to a minimum. Only replace cells on a like-for-like basis in terms of chemistry, format and performance. If using used cells, not only must they be like-for-like, but any used cells must not show any signs of damage and the performance of the cells used should be close to those remaining in the battery pack. Record work done in the battery's history. The repaired battery pack must be tested before acceptance and release by the repairer. This includes testing that the BMS is functioning correctly.
Repurposing	Follow the principles of UL 1974: *Creating a Safe Second Life for Electric Vehicle Batteries*.[41] This includes the repurposing manufacturer possessing the necessary quality (control) systems for battery evaluation, storing, handling, and transporting used batteries,[42] the use of cells that comply with a recognized cell safety standard, the resulting battery pack meeting a recognized battery standard such as UL 2580 and UL 22712 (see Appendix A for further information on battery build standards), and relabeling by the repurposing manufacturer. As for repair and refurbishment, any used cells, BMS and/or other used components must only be used if they do not exhibit any signs of damage, and are proven to be functioning correctly.
Transport – non-damaged batteries	Lithium-ion batteries are Class 9 Dangerous Goods and subject to UN regulations for their transport[43] with respect to their packaging, labeling, and documentation. The safety measures to be used include firmly securing the batteries within protective packaging, appropriate protection of live connectors,[44] electrical isolation of cells (when not protected by a BMS), the use of electrically non-conducting separators if the batteries/cells are not in an application pack, and

[39] A yard with 15 m (45 feet) clearance on all sides of the vehicle is consistently recommended by US fire-fighting authorities.
[40] BIG's Safety Guidelines suggest the use of a bespoke container with an in-built smoke detector and automatic fire extinguishing system as one of the options.
[41] UL 1974 concerns a manufacturing standard-type approach to sorting and grading batteries and cells in preparation for repurposed use, and is available for purchase through various standards sites. A useful background on UL 1974 was available at the time of writing at UL Solutions. UL 1974: Creating a Safe Second Life for Electric Vehicle Batteries. https://www.ul.com/resources/ul-1974-creating-safe-second-life-electric-vehicle-batteries.
[42] Including SAE J2950: Recommended Practices for Shipping Transport and Handling of Automotive-Type Battery System - Lithium Ion.
[43] Guidance is provided by United Nations. 2015. *Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria*, 6th revised edition. https://unece.org/fileadmin/DAM/trans/danger/ST_SG_AC.10_11_Rev6_E_WEB_-With_corrections_from_Corr.1.pdf.
[44] Noting that the application of ordinary insulation tape may not be sufficient in many situations unless it is of multiple layers and is applied so that it cannot be moved without the application of reasonable force. Special insulation tapes, or pressed plastic covers, would normally be a better option.

Activity	Recommendation
	transporting batteries with SOC in the mid-range. Note that where used cells are destined for use as components, the original application battery pack can provide better security and protection than repackaging the cells for transport. An undamaged, unopened battery pack also has the likely security of a functioning BMS that will protect the cells from several failure modes, even when the battery has been electrically isolated.
Transport – damaged batteries	Many failure modes of damaged batteries and cells can lead to a fire incident. The added risks involved mean that those receiving a damaged battery must be fully aware of the damaged condition of the battery as not all carriers, storage facilities and battery workshops have the means to work with and accept damaged batteries. Damaged batteries cannot be transported by air and very few carriers allow transport by sea – meaning that damaged batteries will need to be managed at a local island level until they are de-energized electrically and chemically to a point where they are acceptable for shipping by sea to a suitable handling facility.[45] Even transport by road will likely require added measures (over and above those used for the transport of undamaged batteries), including: packaging in a leakproof package with absorbent to prevent the loss of electrolyte; the use of a thermally non-conductive inner packaging layer to contain any heat build-up; venting to prevent dangerous build-up of gases; monitoring (such as heat detection and alarm); and added fire-fighting response options. The packaging must also be appropriately labeled. As all of this implies, the transport of damaged batteries is a specialist service and should only be undertaken by trained personnel who have the necessary equipment.
Storage	There are several guidelines for the storage of lithium-ion batteries, such as those offered by the BIG, but currently there are no widely recognized standards. The value of useable batteries should keep stocks and the need for storage of useable batteries reasonably low. However, there are currently no suitable disposal or recycling options for EOL lithium-ion batteries in the PICs (a problem shared with most countries, including Australia and New Zealand), making storage of EOL batteries and cells the only option until such a time as suitable recycling or disposal options become available (the stance also currently taken by vehicle manufacturers in Australia and New Zealand). Note that good practice repurposing of batteries and cells has the potential to significantly reduce, or at least delay, the accumulation of EOL batteries requiring storage, and provides another reason to promote the repurposing and refurbishing of batteries (so long as this can be done safely). Considering that best practice is to store batteries in cool, dry conditions and out of direct sunlight,[46] even this EOL battery management option could be compromised in a PIC setting. As for other EOL battery workstreams, the storage of batteries should only be managed by trained personnel who use suitable facilities. The necessary quality and control systems include assessing and separating out damaged batteries (and repurposing good batteries), separating batteries and storing them in groups of like chemistries, and managing the receipt of batteries so that the important history of surrendered batteries is captured (to enable best management of the battery). As discussed in earlier sections, damaged batteries need to be handled differently, including the option of storing them in

[45] Noting that the difficulty in transporting batteries in general, and damaged batteries in particular, suggests the need for island-based facilities to be set up where trained experts can safety disassemble EOL batteries for the recovery of cells, in combination with local expertise that can safely repurpose recovered components, for example for renewable electricity storage.
[46] Several parties recommend storage at 15°C.

Activity	Recommendation
	bespoke containers that would minimize heat transfer rates should a fire happen. The facility must also have suitable smoke and heat detection, and fire-fighting facilities. As batteries have been known to catch fire many days after sustaining damage, it is also recommended that EOL batteries are kept in a safe, isolated area for at least one week before they are then assessed and assigned a longer-term storage place.
Recycling and disposal	There are currently no commercial recycling and disposal options for lithium-ion batteries available in the Pacific region, and few globally. The technologies involved are still developing and it is too early to consider the development of specific recycling and disposal standards for this sector.

BMS = Battery management system, BIG = Battery Industry Group, EOL = end of life, SOC = state of charge, UL = Underwriters Laboratory

Source: The authors.

7 Electric Propulsion Standards in the Marine Sector

Sector overview

The use of electric propulsion systems on vessels is not new: there are examples of battery-electric vessels in the history books dating as far back as before 1900. And for over a century, vessels have been powered by diesel-electric systems,[47] an arrangement that has become commonplace. The use (and the technology) of all-electric and hybrid propulsion systems powered by lithium-ion batteries, however, is relatively new. Standards governing the technical specification requirements for such systems are also still relatively new, with some in development, the latter attempting to keep pace with advances in, and different methods of, shore connection and on-board generation, not to mention a demonstrated need for better safety management of on-board lithium-ion batteries.

Several different maritime regulation regimes are used across the PIC territory, arising from different local requirements and/or different affiliations with international regulatory jurisdictions. For example: French Polynesia appears to acknowledge the maritime rules of France; American Samoa is subject to the maritime rules of the US Coast Guard; Cook Islands, Kiribati, Niue, Samoa, Tokelau, Tonga, and Tuvalu observe the maritime rules of New Zealand, and Fiji has its own maritime rules.[48]

These maritime rules cover a wide set of criteria, including the design and build standards with which a vessel must comply, according to the vessel use type and area of operation. Only some of the above-mentioned maritime rules regimes provide any detail on the design requirements for an electric energy storage system (EESS) and/or electric propulsion systems. However, all but recreational craft require a recognized marine surveyor to assess and accept the safety of the vessel before it enters service, whether it be a surveyor accredited by the country's regulating authority or from a recognized classification society.[49] This should prevent the registration of commercial vessels (a step required before a commercial vessel can be legally used for in-service duties) with poorly specified electric propulsion systems and battery systems where appropriate regulatory frameworks are in place.

At one end of this scale of acceptance of the specifications for battery-electric propulsion systems are small recreational vessels with little specific guidance available and few demands provided by regulatory authorities. The risks involved for these types of vessel tend to be low, as the voltages themselves are low (for example, many e-outboards and propulsion systems for personal watercraft are based on 48 V systems) and thus less life-threatening, and the proprietary nature of these designs, with the use of non-standard couplings and controls, tends to result in integrated "plug and play" systems designed by the equipment manufacturer that are not so reliant on the capability of installers.

For these simple arrangements, it is recommended that they are installed in full accordance with the manufacturer's instructions and only modified under the guidance of an expert in the field. In addition, it is highly recommended that batteries are either fitted with watertight terminal couplings or they are secured in watertight battery compartments, particularly where the battery-electric propulsion systems are used in an open boat that at times operates in conditions that could result in water splashing across the terminals. Likewise, the motor controller and other electrical components should

[47] Dating back to the launch of the tanker Vandal in 1903. D. Hubbell. 2019. The Vandal Was the First Diesel-Electric Vessel. *The Waterways Journal Weekly*. 19 November. https://www.waterwaysjournal.net/2019/11/19/the-vandal-was-the-first-diesel-electric-vessel/.

[48] Maritime Safety Authority Fiji. Legislation. https://www.msaf.com.fj/legislation/.

[49] Classification societies are organizations that develop and apply technical standards for the design, construction, and survey of ships and which carry out surveys and inspections of ships. DNV is the largest marine classification society, and they have developed and regularly update their own technical rules and standards for lithium-ion-based electrical energy storage systems and electric propulsion systems.

be specifically designed to the challenges of a marine environment. Electronics exposed to marine conditions, despite protective potting, have been known to fail, demanding a cautious and careful approach to ensure their suitability for marine use. At the other end of this scale are vessels that are surveyed and classed by a classification society, which will require the design and installation to be compliant with the applicable Class Rules (and require the surveyors involved to carefully assess the safety of the EESS, the name commonly used for the battery system for larger vessels).

Between the poles of these e-vessel types are small, locally registered craft, the scrutineering of the designs of which are the responsibility of local boat builders and/or surveyors, and for which there currently appears to be little in the way of specifications for the battery-electric propulsion system (because, for example, the electrical safety design requirements do not go beyond furnishing electrical wiring diagrams and a general philosophy applied by an assessor that the vessel must be safe: i.e., "to determine the proper construction, machinery, equipment and safety of the ship", as it is described in Fiji's maritime regulations[50]). Section 7.2 is intended to fill this void until such a time as regulations directly addressing the specification requirements of battery-electric propulsion systems are introduced by applicable regulatory authorities.

7.1 Review of international standards

A review of the internationally recognized standards that could be applied to battery-electric propulsion systems for small craft found that:

It is normal for maritime regulatory regimes to have standards in place concerning the technical safety requirements of general, low-voltage AC and DC electrical systems aboard a vessel and dock

The dock,[51] and any dock-based electric system used to supply a vessel with electricity, including that used to charge a vessel's propulsion batteries, are typically included.

These standards do not provide specifics concerning battery-electric propulsions systems, but they must be complied with, as applicable, nonetheless. The standards used for vessels include:

- AS/NZS 3004-2 *Electrical installations - Marinas and boats - Part 2: Boat installations* (which specifies the requirements for the design, construction, and installation of electrical systems in boats up to 50 m in length), for those countries that comply with Australian or New Zealand maritime regulations.[52]
- ISO 13297:2020 *Small craft — Electrical systems — Alternating and direct current installations,*[53] for those countries that comply with the European Recreational Craft Directive.
- US Coast Guard Electrical Regulations Code of Federal Regulations (CFR) Title 33 Chapter 1, Subchapter S, Part 183[54] for recreational small craft and CFR Part 46 Chapter 1, Subchapter

[50] Quotation is from Fiji's Maritime (Ship Registration) Regulations 2014: https://www.msaf.com.fj/wp-content/uploads/2020/12/24.-Maritime_Ship_Registration_Regulations_2014_1-min-1.pdf
[51] Noting that a country's wiring rules and regulations cover land-side systems, and maritime regulations apply to docks and other sea-side structures and installations.
[52] Which details the general requirements set out in New Zealand Maritime Rules Part 40A *Design, Construction and Equipment – Passenger Ships which are not SOLAS Ships*, Subpart 38 *Design*, available at the time of writing at https://www.maritimenz.govt.nz/media/agqk50xi/part40a-maritime-rule-current.pdf.
[53] Noting that US regulations refer to 60 VDC as the threshold for low- or safety extra-low-voltage electrical systems – a point at which the supply is considered non-lethal in normal circumstances. ISO. 2000. *Small Craft — Electrical Systems — Alternating Current Installations*. https://www.iso.org/standard/27316.html.
[54] National Archives. 2023. Code of Federal Regulations – Title 33. https://www.ecfr.gov/current/title-33/chapter-I/subchapter-S/part-183.

T, sec 183[55] for commercial small craft, for those complying with the requirements in the US, but noting that the industry also uses the American Boat and Yacht Council (ABYC) Standards ABYC E-11 *AC and DC Electrical Systems on Boats*[56] (which concerns the design and installation of AC and DC electrical systems on boats for voltages less than 300 VAC and 60 VDC, which the US Coast Guard also recognizes.

There tend to be maritime standards already in place that provide general specifications that the propulsion system must meet

This is regardless of the method of propulsion involved. For example, the New Zealand Maritime Rules Part 40A *Design, Construction and Equipment – Passenger Ships which are not SOLAS Ships*, Subpart 32 *Machinery* concerns the general performance of the propulsion system.

Marine standards that specifically concern battery-electric propulsion systems, or parts thereof, can often be very narrow in scope

This happens because often marine standards refer to defined vessel sizes, uses and/or specific voltages. Even though a vessel may not fall within the scope of a particular standard, the principle underpinning that standard can provide valuable guidance for designers and assessors, particularly in the absence of other applicable standards. Examples include:

- ISO 16315:2016 - *Small craft — Electric propulsion system*, which concerns the design and installation of alternating current (AC, up to 1,000 V) and direct current (DC, up to 1,500) battery-electric propulsion systems installed in small craft up to 24 m length.[57] Note that the European Standard ISO 16315:2016 provides specific detail on the technical requirements in support of Directive 2013/53/EU, which provides high-level description of the compliance requirements for recreational craft and personal watercraft destined for the European market.
- IEC 60092-507 *Electrical Installations in Ships – Part 507: Small vessels*, which concerns the design and installation of electrical systems, including electric propulsion systems, in certain small vessels up to 50 m in length.
- ABYC Standard E-30 *Electric Propulsion Systems*, which concerns the design and installation of systems on boats for the purpose of propulsion for voltage more than 300 VAC but less than 1,000 VAC and more than 60 VDC but less than 1,000 VDC. In addition, ABYC standard report E-13 *Lithium-Ion Batteries* provides broad guidance on lithium-ion battery selection, installation and use in systems less than 60 VDC.

Marine surveyors should be aware of the important safety role of the lithium-ion battery management system

In the opinion of the author, a major omission in these specific battery-electric propulsion standards is guidance for surveyors on the important safety role of the lithium-ion battery management system (BMS), and it is recommended that the applicable battery-related safety specifications

[55] National Archives. 2023. Code of Federal Regulations – Title 46. https://www.ecfr.gov/current/title-46/chapter-I/subchapter-T/part-183.
[56] American Boat and Yacht Council, Inc. 2008. *AC and DC Electrical Systems on Boats*. https://www.paneltronics.com/images/technical/E11Excerpts.pdf.
[57] Available for short-term viewing at https://standards.iteh.ai/catalog/standards/cen/16ec6122-5eb4-4d6c-a70f-58dc59bc327e/en-iso-16315-2016.

outlined in UNECE R100 (a standard often referred to for the build specifications of road vehicles – see Appendix A) should be consulted, with due consideration for the marine application.[58]

Standards extend by reference into other standards.

For simplicity, the main, or "parent", standards only are mentioned in this section (as is also the case for the rest of the report).

7.2 Guidelines and standards recommendations for maritime battery-electric propulsion

Based on the above review, for vessels not classed by a classification society or where there are gaps in existing maritime regulations concerning battery-electric propulsion, the following guidelines and standards are recommended (Figure 7-1).

Figure 7-1: Guidelines and Standards Recommendations for Maritime Battery-Electric Propulsion

For vessels not classed by a classification society or where there are gaps in existing maritime regulations concerning battery-electric propulsion, it is recommended that the following must be met.

- The low-voltage parts of a battery-electric propulsion installation must comply with an internationally recognized maritime standard for low-voltage electrical systems. Acceptable standards include AS/NZS 3004-2 *Electrical installations - Marinas and boats - Part 2: Boat installations* and near-equivalent standards.
- The electric propulsion system must comply with the principles of an internationally recognized electric propulsion standard. Acceptable standards include ISO 16315:2016, IEC 60092-507, ABYC E-13 and E-30, CFR 33.183 and CFR Part 46.183, as applicable.
- The batteries, motors (including electric outboards), controllers and other essential components should be made by reputable manufacturers or other proof provided of their safety and reliability.
- The technical safety specifications of the resulting, installed EESS must also comply with the general principles for battery systems of UNECE R100.

ABYC = American Boat and Yacht Council Standards, AS = Australian Standard, CFR = Code of Federal Regulations, EESS = Electric energy storage system, IEC = International Electrotechnical Commission, ISO = International Organization of Standardization, NZS = New Zealand Standard, UNECE = United Nations Economic Commission for Europe.

Source: The authors.

[58] For example, the BMS on road vehicles is designed to isolate propulsion batteries if voltages fall below critical levels. However, disabling propulsion in marine applications is risky. Rather, a series of alarms should provide early warning/monitoring well before isolation is necessary. A means to override isolation might also be provided for life-threatening incidents (albeit at the risk of damaging or destroying the battery).

7.3 Guidelines and standards recommendations for maritime battery-electric propulsion design principles

Together, these result in the following set of design principles for battery-electric propulsion (listed in Figure 7-2 to illustrate the breadth of the subject), for vessels not classed by a classification society or where there are gaps in existing maritime regulations concerning battery-electric propulsion.

Figure 7-2: Guidelines and Standards Recommendations For Maritime Battery-Electric Propulsion Design Principles

- Where used, electrical sockets and connectors should be designed to prevent incorrect coupling of electrical circuits.
- Small marine swap batteries must be fit for the application, which may require them to be housed in at least an IP65-rated battery compartment. If not, they must otherwise be protected from falling objects and their connectors preferably IP47 rated. Permanently installed batteries must be housed in a battery compartment and that compartment must vent to open spaces and not into passenger spaces and/or egress routes. The build of these compartments should enable a fire to be contained for at least 30 minutes, and preferably 60 minutes.
- The battery system(s) must be provided with:
    - Overcharging, over current, under voltage, and over temperature protection. Audible and visual alarms must provide warning that cell temperatures or voltages are approaching unacceptable levels.
    - An off-gas detection system, fire/smoke detection and fire suppression system.
    - An isolation switch located outside the battery space.
- All cables and connectors, including battery terminals, must be protected against direct contact. Connectors that are at risk of immersion in water should be at least IP47 rated. Interlocked connectors should be used for systems operating above 50 VDC, to prevent accidental contact with electrically live parts.
- All circuits must be provided with manually reset, over-current protection that is appropriate for its location in the circuit.
- The propulsion motor(s) must be provided with over-current and over-temperature protection.
- A logical set of motor controls, instruments and alarms should be provided, including those for monitoring the battery SOC, current draw, available run time under the current draw, motor speed, and alarms for battery and motor over-temperature and unacceptable variations in cell voltages.
- Audible and visual alarms must be provided to warn that battery cell temperatures or voltages are approaching unacceptable levels.
- Automated power reduction with higher battery and/or motor temperatures must be provided, with full isolation of the battery on detection of very high battery temperatures and/or low voltages.
- The design, build and installation should only be provided by qualified personnel. Components used should be sourced from reputable manufacturers.
- The electric circuits of the propulsion system and the house and other on-board electrical systems should be separate.

- Where data networks form part of the EESS safety system, they must be used exclusively for that function.
- The potential for electromagnetic interference should be minimized through choice of components and cabling, and due care as to where they are installed relative to navigation, radio and other potentially sensitive equipment.

IP = Ingress Protection rating, EESS = Electric energy storage system, SOC = State of charge.

Source: The authors.

In addition, it is recommended that designers of vessel electric energy storage and electric propulsion systems are knowledgeable on current best practice.[59]

7.4 Electric vessel charging

Many small, personal watercraft use batteries that are removed from the vessel for land-based charging. The charging involved is typically performed by mains-supplied DC power supplies – with the power supplies themselves and their use subject to the (mains) electricity safety regulations that are in place (as such power supplies are classified as medium-risk articles). Similarly, but on a very different scale, the use of ISO containerized batteries for battery swapping on larger vessels is also emerging. The standards involved for the charging of these containerized batteries would also be captured by existing electricity safety regulations (Figure 7-3).

The other option is dockside charging of permanently installed propulsion batteries which, as for land vehicles, can utilize an off-board AC to DC converter and the vessel supplied a DC voltage suitable for charging the batteries, or the AC to DC converter can be aboard the vessel and the vessel provided a mains AC supply. Either arrangement would need to comply with the marine regulations in place for the dock-side part of the installation (for example, AS/NZS 3004-1 *Electrical installations—Marinas and pleasure craft at low-voltage*, for those countries that reference the New Zealand maritime regulations) and the national electricity regulations for the land-side part of the installation.

With the relatively recent emergence of vessels with larger batteries, fast charging by supplying vessels with DC current has begun to emerge, which relieves the vessel of the weight (and cost) of an on-board AC to DC converter (both of which can be significant when providing high charging rates). It appears that projects involving DC charging of vessels at rates within those typically used for road vehicles use the same connectors that have been developed for road vehicles, as well as the same communications protocols and (broadly) the same chargers, albeit marinized versions.[60]

There does not appear to be any existing official guidance in any regulatory jurisdiction on which charging connector to use, but it would make sense to adopt the CCS Type 2 connector for DC charging (the type recommended for the DC charging of road vehicles), where, of course, the charging

[59] Recommended reading includes the following: Maritime and Coastguard Agency. 2022. *The Workboat Code Edition 3: The Safety of Small Workboats and Pilot Boats – A Code of Practice*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1109431/WB3_Code_of_Practice.pdf; Maritime and Coastguard Agency. 2016. *Electrical Installations - Guidance for Safe Design, Installation and Operation of Lithium-ion Batteries*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/882850/MGN_550_Electrical_Installations_-_Guidance_for_Safe_Design__Installatio....pdf; Norwegian Maritime Authority. 2022. *Guideline for Electrical Energy Storage Systems (Maritime EES Systems) Onboard Norwegian Ships of Less than 24 Meters in Length (L)*. https://www.sdir.no/contentassets/5cea73b79d84449e8174ebcb8aae909c/guideline-for-electrical-energy-storage-systems-maritime-ees-systems-onboard-norwegian-ships-of-less-than-24-meters.pdf.

[60] For example, ABB advertise a marinized charger with an all-stainless steel, IP54-rated enclosure (ABB product list).

rates fall within those intended for CCS Type 2 charging. For further information, please refer to Section 6 for the standards supporting the DC charging of road vehicles.

Figure 7-3: Guidelines and Standards Recommendations for Electric Vessel Charging

- Land-based charging of small watercraft batteries and ISO containerized batteries for battery swapping on larger vessels should be captured by existing electricity safety regulations.
- Dockside charging of permanently installed propulsion batteries need to comply with the marine regulations in place for the dockside part of the installation (for example, AS/NZS 3004-1 Electrical installations—Marinas and pleasure craft at low-voltage, for those countries that reference the New Zealand maritime regulations) and the national electricity regulations for the land-side part of the installation.
- There does not appear to be any existing official guidance in any regulatory jurisdiction on which charging connector to use, but it would make sense to adopt the CCS Type 2 connector for DC charging (the type recommended for the DC charging of road vehicles), where, of course, the charging rates fall within those intended for CCS Type 2 charging. For further information, please refer to the standards supporting the DC charging of road vehicles (Section 5).

AS = Australian Standard, CCS = Combined Charging System is an AC and a DC fast-charging system for battery electric vehicles, ISO = International Organization of Standardization, NZS = New Zealand Standard.

Source: The authors.

8 Electric Propulsion Standards in the Aviation Sector

8.1 Aviation

Sector overview

The electrification of the aviation sector is playing catch-up to the road and marine sectors. It faces the same dilemma — the practicality of application is very much constrained by the weight of the apparatus required to store the necessary amount of energy. This has meant that early market entries have been limited to smaller aircraft, such as the two-seater Pipistrel Alpha Electro.[61] However, many airline companies are anticipating that 12- and 19-seater all-electric aircraft will become important assets within the next five years in their drive to reduce carbon emissions from the sector.

The use of hybrid-electric systems on larger aircraft is also expected to enter the marketplace. The sector is also keenly awaiting improvement in battery and supercapacitor technologies, as well as investing in the generation, storage, and use of hydrogen for on-demand electricity generation, keeping many options open in this regard. Regulatory agencies will need to monitor developments in technology and standards.

Standards System

The “air-side” components of an electric aircraft system comprise the electrical supply equipment and the electric aircraft. Both are subject to the rules put in place by the national aviation regulatory body The connection of the electrical supply equipment to the grid supply of electricity is subject to national electricity regulations; however, the potential for the electrical supply to damage the aircraft

[61] Pipistrel. Velis Electro. https://www.pipistrel-aircraft.com/products/velis-electro/.

means that the specification and use of the electrical supply to an aircraft is under the direction of the aviation regulatory body.

The international aviation sector recognizes technical standards from many origins, including: the International Air Transport Association, Joint Aviation Requirements, IEC, ISO, and UL. Despite this wealth of sources, because standards inevitably follow innovation and the sector is new and experiencing rapid technological development, there are no international or national standards specific to battery-electric aircraft propulsion. The nearest equivalents are (private) standards that have been developed by individual aircraft manufacturers (which are based on the manufacturer's experience).

For PICs, as is the case globally, national regulatory bodies provide approval for the use of each model of aircraft. They do not recognize private standards (such as those the manufacturer's build aircraft to); instead, a national regulator accepts a model of aircraft that has been certified by a recognized aviation authority (such as the Federal Aviation Authority, as just one example), with that authority only issuing certification upon acceptance that the design, production systems, etc., have met both the manufacturer's and industry's standards. In short, for battery-electric aircraft to be used in PICs, they must be certified by a recognized aviation authority.

Electricity is normally supplied to an aircraft at 28 VDC and 115/200 V or 230/400 V three-phase AC at 400 or 600 Hz,[62] the subject of the standard ISO 6858:2017 *Aircraft — Ground support electrical supplies — General requirements*. None of these are practical supplies for fast charging on-board batteries. Rather, a combination of both high-voltage and a DC supply is required to provide high charge rates and avoid the need for (and weight of) an on-board AC to DC converter. Hence this is another area that requires development before the use of electric aircraft can be commercialized. Even when developed to a stage where standards are available, the systems would still be required to be certified by a recognized aviation authority (Figure 8-1).

Figure 8-1: Guidelines and Standards Recommendations for Aviation

- Electric propulsion systems for the aviation sector are still in the early stages of development and commercialization. Hybrid-electric systems on larger aircraft may soon enter the marketplace, but the aviation industry is awaiting new and improved technologies, keeping many options open in this regard. Regulatory agencies will need to monitor developments in technology and standards.
- The connection of the electrical supply equipment to the grid supply of electricity is subject to national electricity regulations; however, the potential for the electrical supply to damage the aircraft means that the specification and use of the electrical supply to an aircraft is under the direction of the aviation regulatory body.
- There are currently no international or national standards specific to battery-electric aircraft propulsion. The nearest equivalents are (private) standards that have been developed by individual aircraft manufacturers (which are based on the manufacturer's experience).
- National regulatory bodies provide approval for the use of each model of aircraft. They do not recognize private standards (such as those the manufacturer's build aircraft to). for battery-electric aircraft to be used in PICs, they must be certified by a recognized aviation authority.
- Electricity supply typically used for aircraft is not practical for fast charging on-board batteries and requires further development before the use of electric aircraft can be commercialized. Even when developed to a stage where standards are available, the systems will require certification by a recognized aviation authority.

Source: The authors.

[62] Which is different to the grid supply of electricity, which is supplied at 50 Hz or 60 Hz, depending upon the PIC country.

8.2 Electric drones (aerial)

The use of drones is subject to the unmanned aircraft rules and regulations recognized by the country's aviation authority. These rules and regulations concern the use of drones irrespective of how they are propelled. None of the rules and regulations found by the author concern the build of the drone.

Drone standards

As PICs are largely receivers of drone technology, there is no reason to introduce build standards ahead of any other country, and it would likely be limiting to do so. It is therefore recommended that the status quo is retained and no move is made to introduce build standards for drones.

Charging

Electric drones normally operate at low voltages – typically 24 VDC and below. The batteries tend to be charged off-board the drone using mains-powered DC power supplies, with matching low voltage.

These power supplies are medium- or high-risk articles under the electricity regulations of some countries and are required to comply with specific standards for those countries. This is further discussed in Appendix B.

As for other low-voltage DC charging, it is recommended that the output voltage is clearly indicated at the charging connector, and/or special connector designs are used to avoid mismatch of power supplies and the batteries of drones. Ideally the battery cells will always be protected by a BMS, but this may not always be the case for drones, in which case, at the very least, a BMS (which may be built into the charger) must always be used for charging (Figure 8-2).

Figure 8-2: Guidelines and Standards Recommendations for Electric Drones (Aerial)

- Electric drones normally operate at low voltages – typically 24 VDC and below. The batteries tend to be charged off-board the drone using mains-powered DC power supplies, with matching low voltage. These power supplies are medium- or high-risk articles under the electricity regulations of some countries and are required to comply with specific standards for those countries.
- As for other low-voltage DC charging, it is recommended that the output voltage is clearly indicated at the charging connector, and/or special connector designs are used to avoid mismatch of power supplies and the batteries of drones. Ideally the battery cells will always be protected by a BMS, but this may not always be the case for drones, in which case, at the very least, a BMS (which may be built into the charger) must always be used for charging.

BMS = Battery management system

Source: The authors.

9 Standards Roadmap

Sections 3 to 8 of this report, and their supporting appendices, provide recommended guidelines and/or standards for electric vehicles and charging. The following section discusses implementation, and a roadmap to assist PRIF Member Countries and their regional partners in prioritizing standards development for the following sectors:

- Road
- Marine
- Aviation

These are each discussed under the following headings.

9.1 Road vehicle roadmap

Implementation is a national responsibility

Implementation of standards will primarily be the responsibility of national regulatory agencies with carriage of consumer protection, transport and electrical safety issues. Customs and trade agencies will also have significant responsibilities around the importation and inspection of vehicles and charging equipment.

However, this occurs within the wider e-mobility policy framework for electric road vehicles, which benefits from the support of regional stakeholders and developer partners. This policy framework is set out in two recent reports:

- PCREEE's *Regional Electric Mobility Policy for Pacific Island Countries and Territories (PICTs);*[63] and
- The World Bank's *Design Regional Emobility Policy Framework and Technical Guidelines in the Pacific Island Countries.*[64]

Both reports recommend the development of guidelines and standards for electric vehicles and their charging.

They also describe common elements, such as capacity development, forming regional and national e-mobility groups, developing regional and national electric vehicle roadmaps, and developing and providing information and awareness.

Marketing and awareness

Both the PCREEE and World Bank reports note the low resourcing of PICs to administer an electric vehicle-related standards regime. To address national level resourcing challenges, they highlight the importance of promoting standards and guidelines by working with regional e-mobility groups, and publishing them within a wider electric vehicle marketing and awareness program. Figure 9-1 takes the additional step of applying the e-mobility and electric vehicle marketing and awareness themes to the guidelines and standards that have been identified or otherwise generated in this report.

[63] A. Campbell. 2020. *Regional Electric Mobility Policy for Pacific Island Countries and Territories (PICTs).* https://www.pcreee.org/sites/default/files/documents/files/200729%20PCREEE%20E-Mobility%20Program%20-%20Policy%20Document%20-%20Final%20clean.pdf

[64] Design Regional Emobility Policy Framework and Technical Guidelines in the Pacific Island Countries, Final Report, 10 October 2022, Submitted to the World Bank, Economic Consulting Associates Limited and TramaTecnoAmbiental, S.L. https://www.wbgkggtf.org/sites/kggtf/files/2023-02/Pacific%20E-mobility%20Roadmap%20-%20Final%20Report%20%28With%20presentational%20edits%29.pdf

Figure 9-1: Vehicle Lifecycle-Recommended Information on Guidelines and Standards

	Time in Life		Low-Powered Electric Vehicles	e2Ws and Larger Electric Vehicles	Charging	Proposed Next Step Guidelines and Standards Tasks
	Design and Build		OEM	OEM	OEM	N/A
1	Order/Supply/Border		Minimum specification guidance	Minimum specification requirements	Minimum specification requirements	Introduce identified minimum specifications (through transport and electrical safety authorities).
2	Purchase (and resell)		Guidelines	Guidelines	Guidelines	Develop and promote PIC industry and public purchasing guidelines (part of a greater e-mobility marketing and awareness program).
2	Installation		N/A	N/A	Guidelines for installations plus mandatory standards	Develop and promote PIC industry and public guidance for charging and installations (as addendum to proposed purchasing guidelines).
3	In-service Use	On-road use	Simple guidelines for new users	Simple guidelines for new users	N/A	Develop and promote best practice guidelines infosheet for new owners.
3		Charging	Guidelines	Guidelines	Guidelines	Develop and promote best practice guidelines infosheet on EV charging targeting the new EV owner.
3		Servicing	OEM specifications	OEM specifications	OEM specifications	Include high level requirements in new owner guidelines.
3/4		Breakdown	OEM specifications	OEM specifications	OEM specifications	Include 'what to do' information block in proposed new owner infosheet. Develop and promote best practice guidance for tow service providers.
3/4		Accident	Guidelines	Guidelines	Guidelines	Include 'what to do' information block in proposed new owner infosheet. Develop and promote best practice 1st response guidance with 1st response providers.
4	Retirement		Guidelines	Guidelines	As for standard electrical equipment	Publish expectations of sector. Examine options to regulate, if required.

E2W = electric two-wheeler, OEM = original equipment manufacturer

Source: The authors.

Implementation roadmap – next steps

It is recognized that different countries in the Pacific region have different views as to the urgency of introducing standards for electric vehicles and their charging, and that some countries are better placed than others to provide the resources to enable early introduction of the proposed standards. Taking these into consideration, it is proposed to prioritize establishing the proposed standards in a "lead" electric vehicle Pacific country or countries, to break the near-absence of relevant standards and guidelines across PICs, followed by duplication of the then-proven methods in other Pacific countries (the rationale being that less effort would then be required by the follower countries).

Five immediate next steps are recommended for implementation by the lead electric vehicle countries in the next 1–2 years.

1. Introduce minimum specifications for e2Ws, larger electric vehicles, and for charging equipment and installations.
2. Develop and promote tailored guides for the industry and public to support electric vehicle and charging equipment purchase decisions, and to support best-practice charging set-up and use.
3. Develop and promote best-practice guides and information sheets, for new electric vehicle owners.
4. Develop and promote best-practice guidelines for service providers, breakdown, first response, and end-of-life vehicle management.
5. Assess the viability of developing and introducing a standard for connectors used for low-voltage charging.

The sixth step in a regional program is the packaging of this electric vehicle standards solution and its dissemination to other countries.

This mechanism for implementation, and owners for each of the steps, are set out in Table 9-1.

Table 9-1: Roadmap for Implementation of Guidelines and Standards – Next Steps

Steps	Recommended Owner	Implementation recommendations
1. Introduce minimum specifications for e2Ws, larger EVs, and for charging equipment and installations.	National transport and electrical safety regulators of lead country (countries).	The formation of a national working group and a regional working group is recommended. The national working group shall be responsible for developing national policy, possibly supported by a TA.
2. Develop and promote tailored guides for the industry and public to support electric vehicle and charging equipment purchase decisions, and to support best-practice charging set-up and use.	Regional e-mobility organization[1] (TBC), with support from national transport, energy and electrical safety regulators of lead country (countries).	Information outreach is recommended to be undertaken as part of a greater e-mobility marketing and awareness program, overseen by a regional e-mobility group.
3. Develop and promote best-practice guides and information sheets, for new electric vehicle owners.	Regional e-mobility organization[1] (TBC), with support from national leads.	Information outreach is recommended to be undertaken as part of a greater e-mobility marketing and awareness campaign. This step aims to fill knowledge gaps through the development and provision of "infosheets" (on best driving practices; charging; expectations for servicing, and "what to do" in the case of a breakdown or accident) provided through various media outlets including print, web, and social media formats.
4. Develop and promote best-practice guidelines for servicing providers,	National training institutes of the lead country	It is recommended that the national training institutes are supported by TAs, with training packages also developed for regional

Steps	Recommended Owner	Implementation recommendations
breakdown, first response, and end-of-life vehicle management	(countries) supported by the regional e-mobility organization[1] (TBC)	dissemination through a regional e-mobility organization using various media including webinars and virtual workshops, and including practical workshops where necessary (for example, for the training of firefighters on first response best practices).
5. Assess the viability of developing and introducing a standard for connectors used for low-voltage charging	Regional e-mobility organization[1] (TBC) and/or development partners	The intention of this study is to reduce the profusion of chargers that will otherwise be required to support the charging of low-powered electric vehicles, with the consequent market inefficiencies).

[1] to date regional e-mobility initiatives have largely been pursued through PCREEE; however, carriage of these recommend activities is to be confirmed.

EV = Electric Vehicle, E2W = electric two-wheeler, TA = technical assistance.

Source: The authors.

An indicative timetable for implementing these next steps is set out in Figure 9-2.

Figure 9-2: Proposed Timetable for Deploying the Next Steps in Guidelines and Standards Development for Road Vehicles (Indicative only).

	Next Step Tasks	Months																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	**Introduction of Minimum Standards (EV and Charging).**																		
	Project definition and approval.																		
	Regulator sub-group workshopping.																		
	Development of draft regulations.																		
	Presentation of introduction-ready regulations.																		
2	**Industry and Public Purchase and Set Up Guidelines.**																		
	Project definition and approval.																		
	Development of publication-ready information.																		
	Workshopping with national and regional e-mobility group.																		
	Publication.																		
3	**Best Practice Infosheets for New Owners**																		
	Project definition and approval.																		
	Development of publication-ready information.																		
	Workshopping with national and regional e-mobility group.																		
	Publication.																		
4	**Breakdown, 1st Response and EOL Service-provider Guidelines**																		
	Project definition and approval.																		
	National, then regional workshopping with subject experts.																		
	Development of resource materials.																		
	Practical demonstration.																		
	Dissemination of knowledge.																		
5	**Development of Low Voltage Charging Connector Standard**																		
	Project definition and approval.																		
	Assessment (TA)																		
	Review of assessment and next steps.																		
6	**Regional EV Information Packaging and Dissemination**																		
	Project definition and approval.																		
	Information packaging																		
	Regional dissemination																	-->	-->	-->

Source: The authors.

9.2 Marine sector roadmap

The marine sector is strongly regulated, and only small recreational craft with battery-electric propulsion systems are not well catered for within existing regulations. A set of design principles has been offered for vessels not classed by a classification society or where there are gaps in existing maritime regulations concerning battery-electric propulsion (Section 8.2) and it is recommended that these are published to act as a check sheet for such vessels (Table 9-2).

Table 9-2: Marine Sector Roadmap

Vehicle type / service	Short term (1–2 years)	Medium term (3–5 years)	Long term (5–10 years)
Small	Publish guidance for vessels not classed by a classification society or where there are gaps in existing maritime regulations concerning battery-electric propulsion.	Continue to monitor	Continue to monitor
Medium	Strongly regulated – monitor. Identify knowledge gaps.	Continue to monitor. Provide capacity-building for local marine surveyors.	Continue to monitor
Large	Strongly regulated – monitor	Continue to monitor	Continue to monitor
Chargers, connectivity and electricity supply	Consider publishing information sheets on landside and dockside charging, and DC connectors	Continue to monitor	Continue to monitor

Source: The authors.

9.3 Aviation sector roadmap

The aviation sector is strongly regulated and providing standards recommendations to the sector is unnecessary at the time of writing. Regulators should continue to monitor international developments in this sector, and identify standards requirements as the technology and commercial applications evolve over the next 5–10 years (Figure 9-3).

Figure 9-3: Aviation Sector Roadmap

Vehicle type / service	Short term (1–2 years)	Medium term (3–5 years)	Long term (5–10 years)
Aviation	Monitor.	Continue to monitor	Continue to monitor
Electric Drones	Consider publishing information sheets on labelling, connector design, and charging safety.	Continue to monitor	Continue to monitor
Chargers, connectivity and electricity supply	Monitor.	Continue to monitor	Continue to monitor

Source: The authors.

10 Conclusions

A range of recommended guidelines and standards concerning electric vehicles and electric vehicle charging have been provided to close identified, standards-related knowledge gaps. The development process took in a broad view of global standards and practices, learnings from neighboring countries, and consideration of the potentially low resourcing of PICs to administer an electric vehicle-related standards regime. The latter, in particular, demanded simple but effective processes to fit in a PIC setting.

Guidelines and standards were considered for electric road vehicles, marine vessels, aircraft, and for the charging of these vehicles.

For road vehicles, the resulting recommended standards knowledge gaps were found to fall into four themed groups. A deployment roadmap was developed around these that first focused on establishing electric vehicle and charger standards in a lead country, or countries, then disseminating the developed solution to follower countries.

The marine sector is strongly regulated, and only small recreational craft with battery-electric propulsion systems are not well catered for within existing regulations. As such, there is an opportunity to issue guidance on battery-electric propulsion systems for small recreational craft and a set of design principles has been developed for this task. There also appears to be a need for capacity development of local marine surveyors to ensure correct interpretation of the rules and regulations that are in place.

Aviation is strongly regulated and providing standards recommendations to this sector is not appropriate.

Appendix A: Minimum Build Specification Requirements for Electric Vehicles

Global review

Build standards aim to "get it right from the start", with designs seeking to address issues both perceived and real, including consideration of the use of electric vehicles by uninformed users. In the development of standards concerning the propulsion battery, for example, the general philosophy for managing safety and durability is to avoid modes of operation that excessively stress the battery (which may cause high levels of degradation or even catastrophic failure). Much of this management is provided by the battery management system (BMS), a set of electronics programmed to avoid high currents. This functions, among many other things, to restrict the current drawn when the temperature of the battery is too high or too low, to isolate the battery's cells when their voltage becomes too low (to avoid lower voltages still, which can result in catastrophic failure),[65] and to balance the charge of individual cells. Standards that have been developed for the People's Republic of China (PRC), the European Union (EU), and the United States (US) (the standards jurisdiction "majors") specify various tests that sample batteries must pass, which ensure that the BMS is functioning as it should, as well as testing for other factors.

Other standards consider battery charging, and still others the vehicle as a whole—how, for example, the battery is physically secured and protected from damage, or how the vehicle can be prevented from driving away whilst plugged into a stationary electricity supply. Other design features might provide an alert when an electric vehicle is switched on and when the vehicle's drive mode has been selected or changed (recognizing the lack of noise accompanying accidental, unnoticed selections), and to send warnings if abnormalities are detected. All seem very sensible, but will not necessarily be included unless mandated.

Global harmonization of vehicle standards is drawing the standards of the majors together, and many aspects are becoming similar or even identical—as you would expect in a world where an electric vehicle supplied from the US needs to be compatible with a charger supplied from the PRC. Countries outside these major standards jurisdictions normally align with one or more of majors. For example, vehicle regulations in Australia, Japan and Indonesia require vehicles/vehicle components to be compliant with specific EU regulations and standards; vehicle regulations in New Zealand refer to EU and US regulations and standards; and India's vehicle standards draw heavily from EU regulations and standards.[66]

Globally, the greater part of these build standards are reasonably well developed and established in the major vehicle regulatory jurisdictions for light-, medium-, and heavy-duty vehicles, are moderately developed for e2Ws and e3Ws, but have only been developed relatively recently for low-powered vehicles (and in this case, are still to become established in the wider global marketplace). That said, technology is developing rapidly and the roll-out of new technologies such as vehicle-to-grid

[65] 'Deep discharge of cells promotes growth of lithium dendrites during charging, which can then puncture the very thin separator membrane, causing a short circuit, which in turn could lead to thermal runaway.' BRANZ, *2020. LITHIUM BATTERIES – WHAT'S THE PROBLEM?*, Fire and Emergency New Zealand Research Report Number 174, p.8. https://www.fireandemergency.nz/assets/Documents/Files/Report_174_Lithium_Batteries_Whats_the_problem.pdf

[66] For example, the Indian standard AIS 038 draws heavily from the European Standard UNECE R100.

(sometimes referred to as "bidirectional charging") will see a need for new standards again to be developed.

Specific vehicle considerations

Low-powered electric vehicles:

A review of the potential considerations relating to low-powered electric vehicles and options for introducing build standards found:

- One of the issues with small-format electric vehicles is the variety of voltages used (nominal voltages of 24 V, 36 V, 48 V, 60 V and 72 V are used — 36 V and 48 V are the most common — with the exact DC charging voltages (and currents, for that matter) dependent upon how the battery is configured, its chemistry, and others[67]) and the varying ability of the cheaper charger and/or battery systems found on these vehicles to cope with a mismatch. The issue is further exacerbated by the lack of a global standard that calls for specific connectors to be used for specific voltages, the frequent use of generic, low-cost components, including low-cost charging connectors for cheaper e-scooters and e-bikes, and the many different, incompatible chargers already in the marketplace designed for such purposes as charging batteries for hand tools. The use of clear, permanent labelling of vehicle and charger should lessen the risk of mismatches.
- The more expensive e-scooter and e-bike makes avoid this kind of mismatch by using connectors of their own design with pins that prevent coupling with anything other than an exactly matching connector (in line with recently introduced requirements for e-bikes and/or low-powered electric vehicles in US and EU standards. A drawback of such an approach is the multiplicity of chargers that would be required to provide for a range of low-powered electric vehicles of different makes, the specialized nature of the chargers likely rendering them less available and more expensive in a small-island situation, not to mention the higher wastage compared to the use of more generic chargers.
- The use of low-quality batteries (including those incorporating counterfeit components) is a concern. Poor quality build of the non-battery parts of an electric drivetrain is more of a consumer protection issue than a safety issue, as electrical circuit failures outside of the battery tend to fail (fuse) safely.
- There are EU, US, and PRC standards available that could be used to manage the risk described above, including the recently introduced European Standard EN 15194 for e-bikes, the US-origin standard UL 2272 for personal e-mobility devices, and/or (for the PRC) GB 24155-2020 for electric motorcycles and electric mopeds. These and complementary standards are described in the footnotes below.[68]

[67] It is not normal to have a (mains) AC to DC converter power supply on a low-powered vehicle. Instead, the AC to DC converter is external to the vehicle and the vehicle supplied a DC supply of electricity at a voltage that matches the configuration and specification of the battery. For example, a typical 48 V nominal lithium-ion battery is configured with 13 battery cells in series and is normally charged with a charger that has a peak voltage of 54.6 V (i.e., 13 cells in series and 4.2 V per cell), but differences in chemistries may require 53.3 V to 55.9 V to achieve 100% state of charge (SOC). Although the variation seems small, it can make a significant difference to how much charge is held and also to the durability of the battery.

[68] The US-origin standards involved (and mandatory in many regions of the US) are:

• UL 2849: Electrical Systems for eBikes – provides technical specification requirements concerning the electrical and mechanical robustness of the electric drivetrain including the electric motor, battery and BMS.

- The Australian and New Zealand governments do not currently refer to any standard that could be used to manage the design and build of low-powered electric vehicles. Rather, these governments currently use a “must be safe” and “fit-for-intended-purpose” consumer protection approach[69] and, in the case of New Zealand, the government has warned the industry of possible regulation if it cannot perform as required.[70] It appears that most Pacific Island Countries (PICs) also have some form of consumer protection legislation.[71]
- Lithium-ion batteries are dangerous goods under the United Nations (UN) classification system and they, or the battery plus vehicle if installed in a vehicle, require compliance to UN 38.3[72] when transported (by land, sea or air). UN 38.3 specifies several tests for battery stability under stress, among others, and provides a de facto minimum technical safety specification requirement for the battery (or vehicle).
- Electronic devices emit electromagnetic fields. The emissions from low-powered electric vehicles are expected to be well below the threshold limits of globally recognized electromagnetic compatibility (EMC) standards. It is therefore proposed that no advice on this aspect of low-powered electric vehicles is offered at this time, so that more important features remain the focus.

• UL 2271: Standard for Batteries for Use in Light Electric Vehicle (LEV) Applications – provides a set of technical safety specification requirements concerning the electrical and mechanical robustness of batteries.
• UL 2272: Standard for Electrical Systems for Personal E-Mobility Devices – has a wider scope than UL 2271, as it also considers the specifications of the electrical drivetrain system and battery and charger combination.
The EU-origin standards involved, and mandatory in the 34 European countries making up CEN, are:
• EN 15194: Cycles - Electrically power assisted cycles - EPAC Bicycles - specifies requirements and test methods for engine power management systems and electrical circuits — including the charging system — for the design and assembly of electrically power-assisted bicycles and sub-assemblies for systems having a rated voltage up to and including 48 VDC or integrated battery charger with a nominal 230 VAC input. Specifically refers to the acceptance of batteries compliant with EN 62133 or EN 50604-1, avoiding the need to provide a separate reference.
• EN 60335-1: Household and similar electrical appliances - Safety - Part 1: General requirements- provides a more generic standard for low-powered electric vehicles than EN 15194, which focuses on e-bikes.
• GB 24155-2020 Safety specifications for electric motorcycles and electric mopeds (compliance amounts to CCC certification).

[69] Which is demanded by both the Consumer Guarantees Act and New Zealand’s Land Transport Rule: Vehicle Standards Compliance Rule 2002 (quoting the latter, the vehicle must be safe to be operated and the components and materials must be fit for their purpose and within safe tolerance of their state when manufactured or modified; New Zealand Transport Agency. Miscellaneous Items. https://vehicleinspection.nzta.govt.nz/virms/in-service-wof-and-cof/general/miscellaneous-items/electric-hybrid-electrical-system#tab3.)

[70] Personal communication, Worksafe New Zealand.

[71] Based on checking the government regulations of a random sample of PICs: all PICs checked had consumer protection legislation of some description.

[72] Because of their fire hazard potential, lithium-ion batteries are classified as a Class 9 dangerous goods during transport (whether by sea, land or air, and whether transported by themselves or installed in a device). Complying with UN 38.3 requires sample batteries to pass various tests including an altitude simulation, rapid changes in temperature, vibration, shock, short circuit, impact, overcharge and forced discharge – effectively providing a minimum technical safety specification for batteries if no other intervention were introduced. It is arguably necessary to do better than this once an assembly of battery cells reaches a certain energy capacity threshold (meaning there is a certain amount of energy at risk) that is not protected by the transport packaging also required as part of UN 38.3. And labelling in accordance with UN 3480 for Lithium-ion batteries by themselves and UN 3481 for Li-ion batteries contained/packed in goods.

Without due cause, it would be difficult for PICs to regulate their industries more stringently than New Zealand and Australia do in this instance,[73] and therefore it is recommended that:

- A consumer protection approach is used for PICs with respect to the design, safety, fitness for intended purpose, and quality of low-powered electric vehicles, and supporting this measure:
- Guidelines are developed and issued as part of an industry and public awareness program on low-powered electric vehicles.

It is proposed that these guidelines clearly describe both what will meet the safety and fitness-for-purpose expectations of the vehicles and chargers and also offer specific advice on safe charging. Appendix B provides a list of suggested topics to be covered by such a guideline.

"Without due cause" was highlighted, as regulators should monitor the sector and introduce interventions where required. An example of such monitoring and intervention was the standards that were quickly introduced in many countries to manage the specification of hoverboards after a spate of fires caused by poor quality and practices in the absence of effective specification.

Some low-powered electric vehicles use swap batteries,[74] or at least have this capability. This requires the vehicle to possess a battery cradle and connector that is compatible with the swap battery. There are many different cradle and connector configurations and specifications used for battery swapping across low-powered electric vehicles (and e2W/e3Ws, and light-, medium- and heavy-duty vehicles, for that matter), and a single specification for any of these vehicle categories has yet to emerge. It is therefore too early to make a call on what standard to encourage for an all-of-PIC approach.[75]

Electric Motorcycles (e2Ws/e3Ws, Category L vehicles with a maximum speed greater than 50 km/h):

A review of the standards used for electric motorcycles found:

- The principal internationally recognized standards pertaining to the technical safety requirements of the electric drivetrain of electric motorbikes are:
    - For Europe, the European Standard UNECE R136 *Uniform provisions concerning the approval of vehicles of category L with regard to specific requirements for the electric power train* and referenced standards. UNECE R136 is mandatory in the 34 CEN countries and has also been used as the basis for standards in many other countries (for example, the Indian Automotive Industry Standard AIS-156 *Specific Requirements for L Category Electric Power Train Vehicles*[76] draws heavily from UNECE R136).

[73] For example, a more stringent requirement in PICs would prevent supply from New Zealand stocks or bulk orders, as New Zealand importers do not currently import e-bikes or e-scooters that comply with EN or UL standards other than by accident (personal communication, Bicycle Junction, Wellington, eBike Studio, Queenstown, Electric Scooter Shop, Auckland).

[74] Battery swapping is where electric vehicle users exchange depleted batteries for fully charged ones at battery swap charging stations. There are many benefits with such an arrangement, including the very short time that it takes to effectively recharge the vehicle, the fact that the swap service provider will likely provide a far better management of the batteries during and after their first life as a vehicle battery, and the potential for the (typically significant) cost of the battery to be removed from purchase price of the vehicle, making electric vehicle more affordable.

[75] Noting that there are additional benefits to be gained from the use of a one-size-fits-all approach, or something approaching it, across all PICs. One drawback of a one-design approach is that the lack of competition leads to monopoly control of service provision.

[76] Automotive Research Association of India. 2021. *Automotive Industry Standards: Specific Requirements for L Category Electric Powertrain Vehicles*. https://emobility.araiindia.com/wp-content/uploads/2022/04/AIS-156.pdf.

    - For the PRC, the PRC standard GB 24155-2020 *Safety specifications for electric motorcycles and electric mopeds* and referenced standards[77] (compliance leading to People's Republic of China Compulsory Certification (CCC), an internationally recognized mark of quality and standards compliance, and often advertised by PRC manufacturers).
- There does not appear to be a relevant US-origin technical standard that specifically considers the drivetrain of electric motorcycles (rather, proof of Environmental Protection Agency and/or Federal Motor Vehicle Safety Standards certification, and/or US Vehicle Identification Number would suggest an appropriate build quality had been met).
- The requirements specific to the electric drivetrain of electric motorcycles for Australia and for New Zealand only consider the risk of electrocution, the security of the batteries, and the condition of the batteries and related systems (which are the same requirements as for the electric drivetrain-related in-service inspection[78]). Both Australia and New Zealand now require motorcycles entering the fleet to be fitted with an anti-lock braking system (ABS) or combined braking system (CBS) and this, in some ways, acts as a barrier to the importation of lower-quality motorcycles, where the makeup of the electric drivetrain might be questionable. New Zealand would introduce more specific requirements if this was deemed necessary (and the same is likely to be the case for Australia).[79]

As for low-powered electric vehicles, it would seem that if PICs were to introduce more stringent specification requirements for electric motorcycles than those in place in Australia and New Zealand, they would find themselves out of step, unless it were required to manage a specific risk found in the local market. Therefore, in lieu of a particular specification requirement for the electric drivetrain, it is recommended:

- All new motorcycle fleet entrants with engine size greater than 50 cc and/or capable of travelling faster than 50 km/h must be fitted with ABS or CBS
- guidelines are developed and issued as part of an industry and public awareness program on electric motorcycles (and these guidelines describe the safety expectations of the operation and charging of electric motorcycles), and
- regulators maintain a watching brief and introduce more stringent requirements if found necessary.

Lightweight electric four-wheelers (e4Ws)

A review and consideration of the guidelines and standards that could be applied to lightweight, road-worthy e4Ws found:

- Lightweight, road-worthy four-wheeled vehicles are uncommon in the PICs. The availability of electric versions (i.e., lightweight e4Ws) may result in an increase in their number, if these vehicle types are permitted to be used (noting that most do not meet the safety requirements set by Australia and New Zealand and therefore cannot be used in these countries, but there does not appear to be a similar barrier in place for many PICs (and the Renault Twizy, a model of lightweight e4W, is already in use in Tahiti, for example).
- Supply options include Europe, the PRC, and Japan (for the latter, including some of the lighter Japanese "Kei[80] cars"). Models produced for on-road use in the country of origin's domestic market normally comply with a set of EU and/or CCC standards that consider the

[77] A useful summary of which is available here: https://www.chinesestandard.net/PDF.aspx/GB24155-2020
[78] NZTA VIRM portal: https://vehicleinspection.nzta.govt.nz/virms/in-service-wof-and-cof/motorcycles/miscellaneous-items/electric-hybrid-electrical-system#tab1.
[79] NZTA officer, personal communication.
[80] From "Keijidōsha", meaning "light automobile"; New Zealand Transport Agency. Used Vehicles from Japan. https://www.nzta.govt.nz/vehicles/importing-a-vehicle/step-2-evidence/used-vehicles-from-japan/.

safety of the electric drivetrain – this aspect is further detailed in the next section, on standards for light-duty electric vehicles.

- It is possible to order a range of lightweight e4Ws on-line that do not appear to be built in compliance with any recognized standard. These “no-standard” models include some that use lead-acid propulsion batteries (the use of lead-acid batteries is not recommended due to their short life and generally uncertain disposal in a PIC setting) and/or have maximum speeds of only 20–30 km/h. How appropriate these are for busy roads is questionable. Some have lithium-ion batteries above 5 kWh capacity, and for this size the battery should arguably be built to a safety standard more stringent than UN 38.3 (the standard for the carriage of lithium-ion batteries). There are like-model e4Ws that do have CCC certification that could provide a similar but better vehicle.
- There does not appear to be a lightweight e4W category of road-legal vehicle in the US.
- There is no specific vehicle inlet charging connector used for lightweight e4Ws. Most charge from low-voltage (less than 60V) power supplies. Some, such as the Renault Twizy, plug directly into an AC mains supply. In such cases, the vehicle is considered to be an electrical appliance and must meet the relevant standards for electrical appliances, which includes showing regulatory compliance marks and conforming to other regulations (including that the vehicle’s onboard charging system is rated and marked for use with the standard electricity supply of the country). The use of an off-board AC to DC converter power supply, that provides a DC supply to the vehicle for charging, only requires the power supply unit to comply with the regulatory requirements for electrical appliances.

In view of the above, it is recommended that:

- The electric drivetrain (including batteries) of all new lightweight e4Ws road fleet entrants with battery capacity above 2 kWh must:
    - have CCC certification; and/or
    - satisfy the relevant technical requirements of UNECE R100 or UNECE R136; or
    - satisfy near-equivalent technical requirements, and
    - comply with the regulatory requirements for electrical appliances, if capable of direct connection with mains AC supplies.

The use of low-voltage (i.e., less than 60 VDC) electric drivetrains is preferred, as is charging from a matching DC power supply (and therefore also at low voltage).

Light-duty electric vehicles

A review and consideration of the guidelines and standards that could apply to light-duty electric vehicles found:

- There are three main standards systems that provide technical safety specification requirements for the electric drivetrain of light-duty vehicles: those defined under CCC, and referring to GB, IEC, and SAE standards, among others, for the PRC; under EU regulations and referring to UNECE, ISO, IEC, SAE, GB standards, among others, for Europe; and under Federal Motor Vehicle Standards, and referring to IEC, Institute of Electrical and Electronics Engineers (IEEE), ISO, National Electrical Manufacturers Association (NEMA), UL and SAE standards, among others, for the US and Canada. For these, the overarching regulations describe the desired outcome and a cascading set of (many) referenced standards detail how that outcome is to be achieved.[81]

- The large number and mix of standards arises from the profusion of electric drivetrain-related parts and systems that comprise an electric vehicle, requiring numerous standards to consider safety and security, the charging connector and functions, and communications with chargers and power supplies. A simpler approach than listing all of the relevant standards is required for PICs.
- Australian Design Rules (ADRs) for motor vehicles refer to the European standards. The Japanese standards for electric vehicles have also been harmonized with the European requirements. And the Indian Automotive Industry Standard AIS-038[82] draws significantly from UNECE R100, providing examples of how individual countries have adopted and adapted internationally recognized standards.
- New Zealand requires the electric systems of electric vehicles to be safe, but makes no reference to technical build standard requirements. However, New Zealand requires light-duty vehicles to meet certain frontal impact and electronic stability control (ESC) standards and it is highly unlikely that a vehicle meeting these standards would not meet the requirements of one of the suites of electric vehicle standards of one of the major vehicle jurisdictions. This makes the process of checking for compliance[83] far easier than it would be if it were necessary to check compliance against various electric drivetrain standards. It is also highly likely that additional interventions would be swiftly introduced if this was required.
- PICs source new and used light-duty vehicles from a range of countries, including Japan, Republic of Korea, Thailand, the PRC, Indonesia, France, Australia, New Zealand, United Kingdom, India, Germany and the US/Canada.[84] If they were electric, it is highly likely they would be compliant with one of the three major sets of internationally recognized standards for electric vehicles. One possible exception, for those PICs with few technical vehicle specification requirements, is the situation where a "no-standards" electric vehicle is ordered from the PRC. Note that American Samoa does not have this gap, because it requires vehicles to have US Environmental Protection Agency approval, and vehicles so approved invariably comply to the full suite of US standards.
- A high proportion of light-duty vehicles are imported used and the same trend will likely be the case for electric vehicles. The batteries of electric vehicles degrade over time and use for numerous reasons. "Dumping" of vehicles in PICs is to be avoided. There is also less opportunity to repair or refurbish the battery in the PICs if it is found to be in poor condition. But the daily distances traveled tend to be relatively small and do not require a large vehicle capacity, and in any case, the battery capacities of electric vehicles are getting larger with newer models. Considered overall, it is proposed that used, light-duty electric

[81] For example, Regulation (EU) 2019/2144 of the European Parliament and of the Council (https://unece.org/sites/default/files/2022-07/R100r3e.pdf) concerning type approval (i.e., acceptance of a vehicle model(s) for use on the road) requires the high-voltage electrical components and circuits to be safe and refers to UNECE R100.
(https://unece.org/transport/documents/2022/03/standards/regulation-no-100-rev3) details their many tests and acceptance criteria, among other requirements, some of these referring to other standards.
[82] Automotive Research Association of India. *Specific Requirements for Electric Power Train of Vehicles.*
[83] For example, the presence of a working tell-tale symbol on the dash instrument lights is acceptable proof that the vehicle is fitted with ESC.
[84] See https://oec.world/en/profile/bilateral-product/cars/reporter/ncl , https://oec.world/en/profile/country/pyf and https://trendeconomy.com/data/h2/Fiji/8703#:~:text=Top%20trading%20partners%20(import%20of,13.1%25%20(6.41%20million%20US%24 and the US Environmental Protection Agency.

vehicles must have a residual capacity — sometimes called "state of health" (SOH) — of more than 80% of their original capacity at the time of importation.[85]
- The various technical safety standards detail the required function of charging connectors but do not demand the use of any particular connector type. Rather, vehicle suppliers choose to fit (vehicle inlet) charging connectors that match the market for which the vehicle is intended, with separate standards detailing physical and other specifications of the chosen connector. Internationally, there is a preference to use the female IEC 62196 Type 2 vehicle inlet port connector for AC charging and the female IEC 62196 CHAdeMO or CCS Type 2 vehicle inlet port connector for DC charging. Compliance to IEC 61851 and other standards for charging-related communications and function are implied, as otherwise the electric vehicle would not be operable, and therefore not fit for use.

In view of the above, it is recommended for PICs that (in addition to other requirements for vehicles that might be in place):
- All new light-duty fleet entrants[86] must be fitted with ESC.
- All new light-duty electric vehicle entrants must have at least 80% residual battery capacity at the time of entry.

If a more stringent standards regime was eventually required, then the recommended requirements would likely be:
- The electric drivetrain (including batteries) of all new lightweight e4Ws road fleet entrants must:
  - have CCC certification; and/or
  - satisfy the relevant technical requirements of UNECE R100 or UNECE R136; and/or
  - satisfy near-equivalent technical requirements; and/or.
  - be compliant with the relevant Federal Motor Vehicle Safety Standards.

It is recommended that light-duty vehicles are fitted with a female IEC 62196 Type 2 vehicle inlet port connector, for AC charging, and/or a female IEC 62196 CHAdeMO or CCS Type 2 vehicle inlet port connector, for DC charging.

Medium- and heavy-duty electric vehicles

A review and consideration of the guidelines and standards that could be applied to medium- and heavy-duty electric vehicles found:
- The type of electric vehicles that might be supplied to PICs include small and large hybrid and fully electric buses and trucks.
- The main supply options include production models from Japan and the PRC, "production retrofit" models (where suppliers fit electric drivetrains to vehicles and chassis "gliders" on a commercial production basis)[87], and post-market retrofits (considered in the next electric vehicle section). There has been a significant, recent increase in the number of production medium- and heavy-duty electric vehicle models available in the global marketplace. These vehicles are destined for the "global" marketplace and, as such, tend to be built to EU, CCC, and US standard requirements for electric vehicles, but not always.

[85] Noting that this is a somewhat arbitrary threshold, but it is a measure of the condition of the battery that can be gauged at a border inspection, providing a method of implementation. Further reading is available at New Zealand Energy Efficiency and Conservation Authority. 2017. *Electric Vehicle Battery Life*. https://genless.govt.nz/assets/Everyone-Resources/ev-battery-report.pdf.
[86] Noting that a new fleet entrant refers to time when it first enters the fleet and the vehicle may be either an imported new or imported used vehicle at that time.
[87] A "glider" is the term used to describe a vehicle or chassis and running gear that does not have an engine.

- Many heavy-duty electric vehicles are built to order, allowing some degree of customer specification of the electric drivetrain arrangement (for example, motor size, battery capacity, and battery placement). This process may still select across options of the electric drivetrain that are compliant with internationally recognized standards, but not always.[88]
- Australia and New Zealand do not currently require the electric drivetrain of large-format electric vehicles to meet any specific standards. Engineers spoken to said that they only purchase from reputable suppliers to ensure an appropriate level of safety and robustness/vehicle availability.[89] The only electric drivetrain specifications related to this requirement are "Requirements for Urban Buses in New Zealand."[90]
- There is an opportunity for PICs to be supplied with used electric buses and trucks from New Zealand and other countries. Based on the discussion above, the electric drivetrain of these vehicles may or may not be built to internationally recognized standards.
- There are additional risk factors with these types of electric vehicle: the size of the battery (and the energy they can store) tends to be large and buses can carry many people, demanding a high degree of safety.
- Operations involving private fleets of large-format electric vehicles would allow the use of a wide range of charging connectors including pantograph-type charging. However, it is still recommended that the common charging connectors are used (i.e., Type 2 for AC charging and CCS Type 2 or CHAdeMO for DC charging) where these and their charging arrangement suit the purpose. A megawatt charging system for vehicles capable of megawatt-rates of charging has also been recently released in the global marketplace.

In view of the above, it is difficult to demand that the electric drivetrain of medium- and heavy-duty electric vehicles strictly conform with the likes of UNECE R100 (the EU standard most referenced when considering the technical safety specification requirements). However, the electric drivetrain should at the very least comply with the base principals of UNECE R100. It is therefore recommended for PICs that (in addition to other requirements for vehicles that might be in place):

- The electric drivetrain of all new medium- and heavy-duty entrants to the fleet is compliant with all base principles of the relevant technical requirements of UNECE R100.
- All new medium- and heavy-duty electric vehicle entrants must have at least 80% residual battery capacity at the time of entry (imposing the same battery quality check as for light-duty electric vehicles).

Retrofit, Low-Volume Vehicles, Scratch-built and Exceptions:

A review of the electric vehicle retrofit and scratch-built[91] sector found:

- The vehicle regulations of large economies normally require changes to a vehicle that may result in any variation from build quality in its safety to be notified, inspected and approved by a recognized inspection agency – which is the Low Volume Vehicle Technical Association in the case of New Zealand, and an approved Low Volume Vehicle certifier in Australia.
- In New Zealand, the electric drivetrain component (where a retrofit to electric propulsion has been performed) or a scratch-built electric vehicle each must comply with the Low Volume Vehicle Standard (75-00[02] [Electric and Hybrid Vehicles]).[92] Although this

[88] Author experience working with electric bus manufacturers in the PRC and the experience of engineers responsible for purchasing electric buses for use in New Zealand.
[89] Personal communication, Tranzit NZ engineer.
[90] Issued by the New Zealand Government to direct the specification of the public bus fleet.
[91] The term used for a vehicle built from scratch.
[92] Low Volume Vehicle Technical Association. 2018. *LVVTA Low Volume Vehicle Standard 75-00(02).* https://www.lvvta.org.nz/documents/standards/LVVTA_STD_Electric_and_Hybrid_Vehicles.pdf

standard provides a list of useful commonsense safety requirements,[93] the standard appears to be based on the use of lead-acid batteries and omits several of the fundamental safety requirements that would be expected where lithium-ion batteries are used.

- There do not appear to be any aftermarket retrofit standards requirements in the US,[94] although the highly litigious environment in the US would tend to demand a high level of safety.
- A careful balance of stringency is required for the PICs – overly stringent requirements risk repressing the industry, but the use of retrofitted vehicles for public transport (a proposal that has been voiced several times) would demand a high level of safety.
- Exceptions to safety requirements may also be required for special interest vehicles.[95]

Considered overall, it is recommended that:

- the electric drivetrain of retrofit, low-volume and scratch-built vehicles entering the fleet for the first time is compliant with all base principles of the relevant technical requirements of UNECE R100.

A list of the base principles of UNECE R100 is provided in Appendix C. A residual battery capacity requirement has not been suggested, because retrofits, low-volume, scratch-builds and specialist vehicles tend to be one-off vehicles owned by the more informed enthusiasts.

[93] For example, including the use of a master isolation switch, use of appropriate circuit breakers, various measures to prevent electrocution, hazards labeling, and use of an internationally accepted charging port.
[94] Personal communication, James Hardisty, retrofit specialist EVlution, New Zealand.
[95] i.e., manufactured in low volumes and generally considered a collector's item.

Appendix B: Introduction and Background on Electric Vehicle Charging

Introduction

Apart from those countries that are territories of other nations and are subject to their administrative parent regulatory systems, there are relatively few charging-related standards requirements in place for Pacific Island Countries (PICs). Generally speaking, chargers must be installed to comply with the country's electrical safety rules and regulations where these exist (including that they must be safe), and consumer protection legislation ensures that they must be fit for purpose (i.e., function correctly, and do not cause damage to the electric vehicles they charge or other property). While at first glance the absence of regulatory control of vehicle charging may appear alarming, in practice it is difficult to acquire charging equipment that has not been built to some relevant standard and most equipment will feature in-built safety functions that will avoid incidents from happening. However, there is still a need for quality guidance to avoid some of the pitfalls that have been found in the past.[96] and to pre-empt potential new issues. Guidance is also required to direct the industry, so that they make good decisions about choice of chargers, the choice of charging connectors they make available for public charging, where to situate chargers and when to use them. These latter matters are more in the realm of best practice direction rather than direction provided by standards.

This section describes the different charging arrangements in common use, then makes recommendations as to which are the best fit for PICs and the standards that apply to them.

Charging Background

There are several arrangements commonly used, or becoming common, to supply electricity for charging electric vehicles.

Low-voltage DC power supply

A supply where an AC-to-DC converter connected to a mains socket outlet provides a relatively low-current, low-voltage DC power supply for the direct charging of the battery. This arrangement is typical of that used for charging e-bikes and electric motor-scooters (which typically use 36 V or 48 V electric propulsion systems). Even though the output voltage is low, the low-voltage charger/power supply is an "appliance" that is plugged into a mains supply of electricity and accordingly poses a risk of electrocution from mains electricity. In countries with strong regulatory systems, such as New Zealand, this makes them "declared medium-risk articles", and they are required to meet certain standards (IEC 61558-1 and IEC 61558-2-12[97] in the case of constant-voltage power supplies made

[96] Referring here to the issue of hoverboards catching fire.

[97] For New Zealand, as detailed in Schedule 4 of the New Zealand Electricity (Safety) Amendment Regulations 2011. The standards referred to are: IEC 61558-1:2017: *Safety of transformers, reactors, power supply units and combinations thereof - Part 1: General requirements and tests* and IEC 61558-2-12: *Safety of transformers, reactors, power supply units and combination thereof - Part 2-12: Particular requirements and tests for constant voltage transformers and power supply units for constant voltage.* A Supplier Declaration of Conformity (SDoC) is also required for declared medium-risk articles to be sold in New Zealand. These contain a description of the article and a statement that it complies with the required standard or other safety assurance. For further information on the SDoC s,ee Worksafe. Medium Risk Product List: Supplier Declaration of Conformity. https://www.worksafe.govt.nz/topic-and-industry/electricity/appliances-and-fittings/high-and-medium-risk-products/medium-risk-product-list/supplier-declaration-of-conformity/#:~:text=A%20Supplier%20Declaration%20of%20Conformity,standard%20or%20other%20safety%20assurance.

available for sale in Australia, New Zealand and Europe[98]). Apart from those countries that are territories of other nations, there do not appear to be any standards requirements for the same power supplies in PICs, beyond the general beforementioned “must be safe” and “fit for purpose” stipulations. It could be claimed that both are met if the power supplied to the power supply/charger is within the range provided by the manufacturer’s labeling – as such labeling is required by such standards (and indicates a high likelihood that the charger has been built to an applicable standard). Better proof is labeling that shows a CE, Underwriters Laboratory, or other recognizable quality mark. And better proof again is equipment supported by a supplier’s “Supplier Declaration of Conformity (SDoC).”

Even so, the power supply/charger must only be used with mains power supplies that are within the range provided by the manufacturer’s label, as has been mentioned. There is less risk that this is not the case today due to the wider voltage ranges that this type of equipment is now designed for, but there are still the odd exceptions. Some equipment might also allow selection between 110–120 VAC and 220–240 VAC mains electricity supplies, which ideally would be set by the supplier and require special tools to change.

There is no standard for the charging connectors used at low voltage, and as a result, there is a risk of mismatching the lower-voltage DC power supply and the battery to be charged. For example, Figure B.1 exhibits two common low-voltage DC charging connectors that can be found on 18 VDC, 24 VDC, 36 VDC and 48 VDC chargers. The greatest risk occurs when the power supply/charger provides a higher voltage than the battery is designed for and the neither the battery’s BMS nor the power supply/charger have features that shut down the charging event (which can be the case for low quality components). In such an instance, the battery will likely be damaged and overcharging may even lead to a fire event. There can also be small, but sufficiently significant differences in the charging DC voltage requirements for batteries of different chemistry. Unfortunately, this makes it more difficult to introduce a universal 36 V charger and a universal 48 V charger, say, which would otherwise avoid a lot of duplication of chargers, reduce costs and enhance convenience (an area that requires further consideration and work because of the significant benefits that could be realized in a PIC setting[99]). Higher quality products avoid mismatching through the use of unique charging connectors (but with added cost, inconvenience, etc.). Other options include preferring only vehicles with 48 V systems[100], and clear marking of the DC power connector and the battery charging connector (although this is less safe, as it requires the operator to pay due care and attention).

An example of a generic, low-voltage power supply/charger and the labeling that might be found is provided in Figure B.2. Note that manufacturer’s label is permanent and clearly states that the charger is for charging 48 V lithium-ion batteries.[101] Reference to specific supply voltages and not voltage supply ranges indicates that this charger may not be compliant to EU or like design and build standards, despite the CE label – a product of its uncertain pedigree. However, the manufacturer was able to provide evidence of People’s Republic of China Compulsory Certification (CCC) which is a near equivalent and acceptable for countries without strong regulated systems.

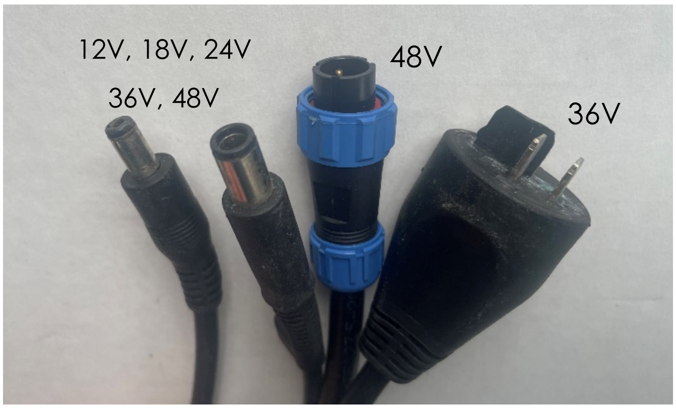
[98] Worksafe New Zealand.

[99] Noting that providing a range of different chargers for every different model of small electric vehicle, plus spares for the same, would be particularly expensive in a PIC setting. It is therefore recommended that a program of standardization, similar to that recommended to direct suppliers for the use of certain charging connectors for passenger car electric vehicles, is developed and introduced.

[100] Or more precisely, systems that use 18650 cells in a series of 13.

[101] But also noting reference to 54 V: the voltage of a nominal 48 V lithium-ion battery ranges from around 44 VDC to 54 VDC, depending upon its state of charge (SOC). The 54 V refers to the maximum voltage that the power supply charger will provide, and is within the safe maximum charging voltage for common lithium-ion batteries and is the more critical specification used when specifying low-voltage cable chargers. Also note the non-standard plug, avoiding mismatch of charger and battery.

Figure B. 1 Example of Connectors Used for a Range of Different Output Voltages on Low-Voltage DC Power Supply/Chargers.



Source: supplied by the Authors.

Figure B. 2: Example of a Generic Power Supply/Charger

Source: supplied by the Authors.

AC Charging (portable)

A charging cable connects a (normally single-phase[102]) electrical socket outlet to the vehicle's on-board AC-to-DC charger with the on-board charger then delivering a DC supply to charge the battery. The connecting electricity cable may be simple (i.e., no more than an extension cord, referred to as Mode 1 charging) or it may be a cable with an in-cord control and (safety) protection device (IC-CPD) — an arrangement referred to as Mode 2 charging — using the portable "brick"-type charging cable often supplied with a passenger car-type electric vehicle (see Figure B. 3). Mode 1 charging is banned in some countries and its use is discouraged in others because of the lower level of safety it provides. Because an IC-CPD is connected to a mains electricity supply, it is a medium-risk article, and in countries with strong regulatory systems, must meet the associated required standards.

Note that there is a risk that IC-CPDs supplied with imported used vehicles are not specified for use with the electricity supply in some PICs, and ideally these non-compatible IC-CPD charging cables would not be allowed to enter the country.[103] Similarly, a check is required to ensure that the IC-CPD does not draw a greater current than can be safely delivered by the socket outlets that they might use.[104] Furthermore, the earth return on a three-wire electricity supply provides an important safety function and an IC-CPD charging cable should only be used with a three-pin supply plug on circuits that have a sound earth circuit.

Figure B. 3: Example of a Typical IC-CPD Charging Cable

Source: supplied by the Authors.

[102] The standard electrical system used in households, comprising a two-wire phase and neutral connection, preferably also with an earth safety circuit as a third wire.
[103] For example, some IC-CPD charging cables that come with used electric vehicles from Japan are rated for use with electricity supplies at 90 V to 130 V and could be unsafe when connected with mains electricity supplies at 220–240 V. Likewise, some IC-CPD charging cables are rated for use with electricity supplies at 200–250 V and could be unsafe to use in the Marshall Islands or the Republic of Palau (120 V).
[104] Some IC-CPD charging cables that feature temperature sensing in the original plug, and some higher charge rate cables (15 A) designed for use in the UK and some countries in Asia, risk operating at currents that are higher than the socket outlets can provide when their plugs are changed (noting that the most common plug used across the PICs is the Type I (i, and not 1) plug used in Fiji, which has a rating of 8 A continuous and 10 A standard use (with 10 A often stamped on the socket-outlet), which risks causing parts of the circuit to burn out and starting a fire.

AC Charging (fixed)

Where the electrical supply's safety protection system is hard-wired to the dwelling's local electricity supply circuit and connects via a charging cable to the vehicle's on-board AC-to-DC charger (with the onboard charger then delivering a DC supply to charge the battery, see Figure B. 4). This is referred to as Mode 3 charging. The safety features of the Mode 2 "brick" are present but are hard-wired, and the arrangement and specification of safety components provides added safety – which is why Mode 3 charging is encouraged for the slower charging of EVs over the use of (Mode 2) portable devices. As for other hard-wired domestic appliances (such as an electric oven), a wall charger must be installed by an accredited electrician, who is required to ensure all safety requirements are met, including that the supply circuit is appropriate for the expected current draw (whereas while the supply circuits to the socket outlets used for Mode 1 and Mode 2 charging should be checked, it is less certain that these checks will happen in practice). Ideally, Mode 3 chargers would also be "smart" – where the charging rate and time of charging can be managed remotely. This is discussed further below. Mode 3 charging can be either single- or multi-phase, with multi-phase enabling higher charge rates if the supply circuits (and Mode 3 charging point) are suitably rated.

Figure B. 4: Example of a Typical Mode 3 Charging Point

Source: supplied by the Authors.

DC Charging

The conversion of AC to the required DC electricity supply for charging batteries occurs off-board the vehicle and a DC supply of electricity is provided to the vehicle's charging connector inlet via a tethered charging cable (referred to as Mode 4 charging, see Figure B. 5). Removing the need for an onboard charger means that the weight and size of the charger are no longer limited, enabling the use of much larger chargers and faster charging rates. DC chargers are also very expensive, which tends to restrict their use to public and commercial charging. DC charging is normally associated with fast "now" charging.

Figure B. 5: Example of a Typical Mode 4 Charger with Choices of Different Connectors

Source: supplied by the Authors.

Battery Swapping

Where the charge-depleted battery is removed from the vehicle for charging and replaced with a battery that has already being charged (avoiding the downtime of charging an in-situ battery, see Figure B. 6). Battery swapping is becoming popular in many countries that have large motorcycle populations. For example, Gogoro (now a global battery-swap service provider) claims to have 1.1 million smart batteries in circulation and 12,000 battery swapping stations globally.[105] While these are normally used only for two-wheeler electric scooters and motorcycles in Taipei,China, they are also used for three-wheelers in many countries, including India and Africa.[106] Battery swapping for heavy vehicles has also seen a recent resurgence.[107]

There are other types of charging also in the marketplace including **inductive charging** (which does not require a physical (conductive) connection between vehicle and electricity supply), and **overhead pantograph** and rail systems for heavy vehicles. These are not considered in this report because they are uncommon, the specifications require consideration on a project-by-project basis, and they are far less likely to feature in the PICs, except perhaps on a specific demonstration project basis (in which case experts involved in the project can provide appropriate specifications).

[105] J. Borrás. 2023. Gogoro Batteries Power 90% of [Taipei,China]'s Electric Scooters. *Cleantechnica*. 11 January.
[106] Global Green Growth Institute. 2022. *GGGI Technical Report: Pre-feasibility Study on a Battery Swapping System for Electric 2-wheelers in Vientiane Capital, Lao PDR*. https://gggi.org/wp-content/uploads/2022/10/Prer-feasibility-Battery-Swapping-of-Lao-PDR.pdf.
[107] For example, as illustrated by project examples shown on eTrucks' (a supplier of truck battery swap solutions in New Zealand) monthly newsletter.

Figure B. 6: Example of a Battery Swap Station at a Convenience Store

Source: supplied by the Authors.

Smart Charging

As mentioned, “smart” charging is where the charging process can be managed remotely, requiring the charger to have additional communications capability. Road vehicles tend to be parked for a reasonable proportion of each day and there is often flexibility in when during the day they could be charged. Smart charging takes advantage of this situation by enabling the electricity provider (or a third party) to manage the charging events of many electric vehicles in concert with the availability of electricity from the grid or local power supply. For electricity supplies with a high component of solar renewable energy, this may be in the middle of the day. Or, where electricity is supplied from hydro, charging may occur at the dead of night when demand from other sources falls away. In either case, the advantages are obvious. A similar arrangement with a smart charger can also make use of available excess solar generation on a home-scale solar generation and electric vehicle charging system.

At some time in the future, electricity supply companies are expected to incentivize customers with electric vehicles to hand over control of their chargers, enabling suppliers to better balance network demand with supply. As an example, charging could be turned off (or at least the rate reduced) during the early evening peak (when many people arrive home and turn on their electrical appliances, etc., which tends to produce a spike in demand), thus avoiding the need to bring on more expensive “peaking” generation plant. Instead, the electricity supplier could move charging to times when it is more convenient and cost-effective to meet the additional demand from charging, with the connected electric vehicle customers rewarded for this through lower electricity prices. Besides avoiding the use of more expensive generation, this arrangement can also delay or even render network upgrades unnecessary.

These advantages are the reason for why the use of smart charging featured prominently in the 2030 and 2050 targets proposed by the Regional e-Mobility Program.[108] These targets were:

- By 2030, 50% of all four-wheeled electric vehicles are charged through devices that are managed-charging enabled.
- By 2050, 90% of grid-supplied charging of mainstream electric vehicles is provided through managed-charging systems.

An added level of sophistication, and service, is **bidirectional charging** – where electricity can also be drawn from the electric vehicle traction battery when it is plugged in and delivered back into the local (or grid) electricity supply circuits. While many might assume that this involves a significant draw from the battery, this needn't be the case: several seconds of export from the vehicle's battery can be sufficient to offset short periods of voltage drop in the local network (where the first response — switching off smart chargers on the same network — was insufficient).

[108] Regional Sustainable Energy Centres. 2019. *Regional Electric Mobility Policy for Pacific Island Countries and Territories (PICTs).* https://www.gn-sec.net/content/regional-electric-mobility-policy-pacific-island-countries-and-territories-picts

Appendix C: Base Principles of UNECE R100

The following outlines the principles of the technical requirements of UNECE R100 – the specific requirements referred to in approving the electric powertrain. Note that this report focuses on electric vehicle powertrains that use lithium-ion batteries. The principles of UNECE R100 that pertain to the use of open-cell batteries (that may emit hydrogen in normal use) have not been included.

The base technical principles of UNECE R100 are outlined under the following headings.

Protection against electrical shock

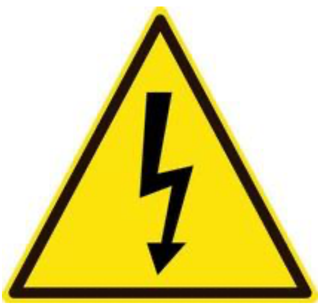
Electrical barriers, enclosures, solid insulators, and connectors on the Electrical Energy Storage System (EESS) or other assemblies containing high voltages must protect against direct contact with live parts, equivalent to passing a Test Wire test[109] for barriers in areas inside the passenger or luggage compartment, and equivalent to passing a Jointed Finger Test in other areas. These electrical barriers must not be capable of being opened, separated, disassembled, or removed without the use of tools, except in cases where such actions would not expose live parts.

The vehicle shall be provided with switches that enable the high voltage bus[110] to be isolated quickly. At least one such switch shall be accessible from outside the vehicle (providing first responders with an externally accessed means to isolate the high voltage bus).

The high voltage bus shall also be fitted with a Manual Service Disconnect that isolates the high voltage bus.

Figure C.1 provides a symbol that must be used to indicate the nearby presence of a high voltage source. This symbol should be visibly displayed on or near the EESS or on enclosures that are reasonably accessible to those operating the vehicle or providing service support to it, and where the enclosure protection barrier can be removed without the use of tools, potentially exposing live components of the high voltage system.

Figure C. 1: High Voltage Symbol



Source: supplied by the Authors.

Cables carrying high-voltage currents that are not enclosed as specified above shall be colored orange.

[109] The test probe used for this test defines the size of the gaps permitted, etc.
[110] A "bus" refers to the group of conductors that carry the electrical currents. In this case, reference is made to the high-voltage bus. This comprises the electrical cables that connect the EESS, motor controller, and motor.

Protection against indirect contact

All conductive protection barriers and enclosures shall be securely galvanically[111] connected to the vehicle chassis (providing a ground safety circuit).

The isolation resistance between the high-voltage electrical circuits (the high-voltage bus) and the electrical chassis shall have a minimum value of 100 Ω/volt of the working voltage for a DC bus, and a minimum value of 500 Ω/volt of the working voltage for an AC bus. This is to remain the case during charging of the EESS, and after vehicle exposure to water, e.g., washing and driving through standing water.[112]

Electrical Energy Storage System (EESS) Requirements

The EESS shall be installed in accordance with the instructions provided by the manufacturer of the EESS.

The model of EESS used must have passed internationally recognized tests for the following:

- Vibration
- Thermal shock and cycling
- Mechanical impact/shock
- Fire resistance
- External short circuit protection
- Over-charge protection
- Over-discharge protection
- Over-temperature protection
- Over-current protection
- Low-temperature protection[113]

The vehicle is required to issue suitable warnings to the driver where events of concern arise, which include:

- When the EESS experiences a critical failure, including when the monitoring and/or controls that manage the safety of the EESS experience a critical failure.
- When a thermal event is detected within the EESS.
- When the various EESS protection systems are invoked.
- In the event of low energy content of the EESS.

The design of the EESS shall avoid exposing the vehicle occupants to any hazardous environment caused by thermal propagation triggered by the thermal runaway of a cell or cells. Any off-gases shall also be directed away from those areas that can be occupied. A warning device or devices shall provide early warning of such events.

[111] i.e., in contact with, such that there is free flow of electrons (and current) between them.
[112] At a more detailed level, in order to comply with this requirement, it is specified that the vehicle should be driven at 20 km/hour through a pool of water of 100 mm depth, which also indicates the expected minimum capability of the electric vehicle.
[113] Note that the over-charge protection, over-discharge protection, over-temperature protection, over-current protection and low-temperature protection functions are normally performed by the local EESS battery management system. In addition, there may be an overall battery management system that manages the combined battery system.

Preventing accidental or unintended vehicle movement

Indications shall be given to the driver:

- Each time when the vehicle is placed in a possible active drive mode after manual activation of the propulsion system.
- Each time the driver leaves their seat and/or vehicle if the vehicle is still in an active drive mode.
- To clearly indicate the vehicle's active drive mode, direction, or neutral position.

It shall not be possible to move the vehicle when it is ready to be charged or it is charging.

Conformity of Production

Where individual vehicles and/or EESS are not directly checked for conformance, then the vehicle or EESS must be manufactured in accordance with recognized type approval norms.

Information/Manual

In addition to the above requirements, it is highly desirable that each vehicle is supplied with a manual that details the essential vehicle characteristics (intended for the reference of the driver and/or first responders). This documentation should include details such as the make and model of the vehicle, the specifications of the powertrain (including the EESS), the locations of fuses, circuit breakers, and high-voltage isolation switches, the routes of high-voltage cables, and operational instructions covering best-practice vehicle usage and charging procedures, along with actions that should be avoided.

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