Contents

1 – Scope

This paper is a summary and compilation of industry accepted knowledge on battery electric powered industrial truck use and in no way seeks to impose additional requirements beyond 'state-of-knowledge'.

The use and management of electric industrial trucks continues to grow and evolve, alongside advancements of battery technologies for industrial trucks in general. AFITA recognises that this paper will periodically require alteration and additions.

The information presented in this paper is for educational and informational purposes only. While every effort has been made to ensure the accuracy and completeness of the content, AFITA assumes no responsibility for errors, omissions, or for any outcomes related to the use of this information. Readers are advised to consult with appropriate professionals before making any decisions based on the information provided in this paper

2 – Compliance Requirements in Australia

2.1 Australian Standards Requirements

AS 2359 / 5144 series – Powered industrial trucks

AS 2402.1.1 – Traction batteries – Lead-acid, Part 1.1: Vented cells – Requirements

AS 2402.1.2 – Traction batteries – Lead-acid, Part 1.2: Vented cells – Installation and usage

AS 2402.2.1 – Traction batteries – Lead-acid, Part 2.1: Valve-regulated cells – Requirements

AS 2402.2.2 – Traction batteries – Lead-acid, Part 2.2: Valve-regulated cells – Installation and usage

AS 2548.1 – Battery chargers for lead-acid traction batteries, Part 1: Battery chargers for vented cells

AS / IEC 62619 – Secondary cells and batteries containing alkaline or non-acid electrolytes – Safety requirements for secondary lithium cells, for use in industrial applications

2.2 UN & IEC Requirements

Australia recognises both UN and IEC international standards surrounding lithium-ion batteries

UN38.3, UN3480, UN3481, IEC 62620

Local Regulations will need to be checked for specific applications.

3 – Identification of Equipment

3.1 Labelling on Machines and Packaging

Industrial trucks equipped with electric drives, especially newer models, may display a decal on the machine informing which power source is installed, for example lead-acid (Pb) or lithium-ion (lithium).

Additionally, each battery system may be labelled with key specifications such as manufacturer, serial number, chemistry, nominal voltage, battery capacity, energy content and weight.

However, if the battery is permanently integrated into the truck and inaccessible by the user, this information might not be externally visible.

Manufacturers also provide operating manuals which include details on operation, charging procedures, intended usage and safety instructions. Safety data sheets are also available upon request.

3.2 Labelling & Documentation – Road Use

If an industrial forklift truck is to be used on public roads, it may require full registration, conditional registration or restricted-use registration - regardless of the energy type. Number plates, issued by the road regulator, must also be fitted.

Additional roadworthiness requirements may apply - such as a road lighting kit, labelling / signage, reflectors and mirrors. Always check the requirement with your local vehicle registration authority. Road worthiness must adhere to the laws of the state in which the truck is operating and registered for. These laws may be different state to state and are subject to change.

By the Australian Design Regulations, road registered automotive electric vehicles require a blue triangle on the registration plate to indicate that it is an electric vehicle and thus contains a battery. There are no regulations or Standards requiring this for non-road (e.g. forklifts, earthmoving) equipment.

4 – General

4.1 Industrial Truck Power Source

When selecting any powered industrial truck, the choice of energy source is a critical consideration and should not be overlooked.

While this guideline primarily focuses on electrically powered industrial trucks, it's important to understand all available energy options. This section provides a comparison of the different energy sources used in industrial trucks to support informed decision-making.

It is essential to seek guidance from equipment suppliers. Due to the wide range of operational scenarios and application types, it is not possible to cover every situation in detail within this document.

4.1.1 Internal Combustion Industrial Trucks

Internal combustion (IC) industrial trucks are powered by engines fuelled by diesel or gas (LPG/CNG). Their benefits are well established: high power output, quick refuelling, cost-effective operation, and suitability for demanding, high-intensity applications.

However, a drawback is that fuel dependence is on non-renewable resources and the combustion process produces tailpipe emissions. These impact on both a company's carbon footprint and local air quality, releasing substances such as hydrocarbons, nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter.

Choosing fuel-efficient drives and engines equipped with exhaust aftertreatment systems can help to reduce these emissions. Also, in addition to conventional fuels, alternatives such as Hydrotreated Vegetable Oil (HVO) are emerging as being both more available and more sustainable.

Another consideration is noise emissions. Internal combustion trucks typically generate higher noise levels, which can impact operators and others working nearby.

4.1.2 Electric Industrial Trucks

Unlike in the automotive sector, electric power units have long been established in the intralogistics supply chain sector. Their key advantages—zero local emissions and low noise made them historically well-suited to indoor environments.

Lead-acid batteries are a proven technology, having powered industrial trucks for decades. They remain widely available, cost-effective, and continue to be developed. However, they can have technical limitations, especially when compared to some newer technologies like lithium-ion batteries, in areas such as performance, energy efficiency, durability, and handling.

Lithium-ion batteries are now an integral part of modern industrial truck offerings. The increasing popularity is driven by the benefits stated by manufacturers. Benefits like:

- They require less maintenance and the durable technology maintains more consistent performance, even as the state of charge decreases.
- Batteries can be 'opportunity' charged with high power quickly at any time.

- Due to different electrochemical processes at cell level, they can be up to 20 - 30% more efficient than lead-acid batteries, which translates directly into energy and cost savings.

Industrial trucks with electric battery systems and paired with modern electrically powered-drive systems are a high-performance alternative to internal combustion engines and their uptake is a key drive of the electrification and decarbonisation of the supply chain.

It must be noted that fuel cell-powered industrial trucks are also available, though not yet common in Australia. Their limited uptake is largely driven by high investment costs associated with hydrogen refuelling infrastructure and the low system efficiency compared to other battery powered trucks.

Many factors influence the choice of industrial truck, and the energy source used to power it. These include application profile (such as intensity, shift patterns and environmental conditions), sustainability goals, return on investment (including initial outlay, ongoing operational, maintenance and energy costs), infrastructure requirements, availability of external funding or incentives.

Given the complexity of these considerations alongside much conflicting publicity and variations in technology, we strongly recommend seeking expert advice from suppliers to identify the best fit for your specific operation and circumstances.

Going forward, this document focuses specifically on electric drives powered by lithium and lead-acid batteries, as these are currently the most prevalent technologies alongside internal combustion (IC) engines.

The energy landscape is evolving rapidly with new technologies in the research & development stage. As such, this document will require updates over time to reflect emerging innovations and industry developments.

4.2 Types of Battery

In industrial trucks, the two most common battery types are lead-acid and lithium-ion.

4.2.1 Lead-Acid

Lead-acid batteries consist of positive plates made of lead dioxide (PbO_2) and negative plates made of sponge lead (Pb). These plates are immersed in an electrolyte solution of dilute (watery) sulfuric acid (H_2SO_4).

The plates are arranged in layers and separated by plastic separators to prevent internal short circuits during operation. Multiple plates are connected via bridges to form cells, with each cell featuring externally marked positive and negative terminals. These terminals are used to connect cells together using specialist bolts or soldered links, which are covered with external insulation to prevent short circuits.

The size of the cells and number connected determine the battery's voltage, capacity, and overall energy content.

There are generally two types of cells available to choose from

- Vented cells with liquid electrolyte (e.g. PzS / PzB types): These require regular maintenance, including electrolyte top-ups and adequate ventilation to safely release oxyhydrogen gases produced during charging.

- Valve-regulated cells with immobilised electrolyte (e.g. PzV, types): These use gel, absorbent glass mat (AGM), or other forms of immobilised electrolyte. They are designed to be filled once and never topped up again over their service life. Instead of a conventional vent plug, they feature a pressure relief valve that opens if internal pressure exceeds design limits.

Valve-regulated cells are considered virtually maintenance-free, as no topping-up is required. However, this convenience comes with trade-offs, such as a lower usable depth of discharge relative to nominal capacity and/or reduced durability in terms of total charge/discharge cycles.

Because the electrolyte cannot be replenished, valve-regulated batteries rely on optimal recombination during the electrochemical charging process. To prevent the cell from drying out, gassing and water loss must be kept to an absolute minimum.

4.2.2 Lithium-ion

Lithium-ion cells and batteries in the context of industrial trucks are undergoing rapid development. However, the primary chemical compositions currently in use include:

- LFP (Lithium-Ferric-Phosphate / Lithium-Iron-Phosphate)
- NMC (Lithium Nickel-Manganese-Cobalt Oxide)
- LTO (Lithium Titanate)
- NCA (Lithium Nickel-Cobalt-Aluminium Oxide)

Cells—available in pouch, prismatic, or cylindrical formats—are grouped into modules, connected internally and assembled into a complete battery pack.

All of these options come with a variability in cost, stability and performance.

The electrolyte consists of a liquid organic solvent with dissolved lithium salts which has constant properties with extremely low resistance. There is no outgassing in normal use and therefore the batteries are completely sealed

Key performance characteristics such as lifetime, runtime, charging time, operating temperature range, and energy content are influenced by several factors, including cell chemistry, cell type, number of cells, cell size and specific energy density.

Due to the high energy density, a lithium battery used for industrial trucks requires the use of a battery management system (BMS). The BMS monitors and controls the key aspects of the lithium battery construct, including temperature, voltage and current of each cell (or module) during charging and operation.

The battery and charger communicate via a CANbus system and these contribute to increased efficiency, service life and safe operation.

If any of the monitored parameters fall outside of the correct range, the BMS is intended to safely cut off the battery or charger. Lead-acid batteries generally don't have such systems. Furthermore, the BMS may calculate, store and report secondary data such as energy throughput, charging profiles, cycle life, error messages and historic temperature levels for analysis.

Conventional lead-acid batteries generally do not require a lithium-style BMS, although battery monitoring systems, electrolyte monitors, temperature sensors and charger communication may be used to record operating data and support correct charging and maintenance.

4.2.3 Interchanging

Unless the manufacturer has specifically designed the forklift truck to be used for dual battery technologies, lithium batteries are not generally intended to be interchangeable with lead-acid batteries or in-fact other battery designs, including alternative lithium-ion batteries. Key factors such as operating voltage, battery weight and centre of gravity, regenerative braking, and fail-safe shutdown mechanisms must be carefully considered.

If the truck is not designed for dual battery use, an expert assessment is required, and the original equipment manufacturer (OEM) must always be consulted. This applies to any battery type.

Even within the same industrial truck model, a range of battery types, chemistries and sizes may be available to suit different operational & application requirements. These variations can result in significantly different performance levels in terms of charging speed, runtime, overall longevity and maintenance effort.

Given the diversity of options and the importance of matching truck, battery & charger specifications to the application needs, it is essential to consult the industrial truck manufacturer or provider for detailed specifications and information on performance parameters for truck, battery and charger before purchase.

4.3 Maintenance

Manufacturers recommendation should be followed for all maintenance requirements.

4.3.1 Lead Acid - Vented Cells with Liquid Electrolyte

4.3.1.1 Maintenance

Maintenance for vented lead-acid batteries involves several routine tasks, including:

- Daily visual checks of charging status and electrolyte levels
- Daily inspection of electrolyte levels after charging and topping-up of electrolyte (water) if required
- Monitoring float valves for automatic water refill systems or light indicators for level sensors
- Weekly inspection of battery and charger plugs, and cleaning to prevent conductive residue from forming across external cell connections
- Periodic tasks, such as performing an equalising charge, recording total battery voltage, individual cell voltages, and measuring the specific gravity of the electrolyte. These tasks are typically performed at the end of charging, after termination, and once voltage stability has been achieved. Depending on usage, equalising charges may be weekly.
- Checks of electrical connections (sockets, screws, cables, and contacts) should be performed.

4.3.1.2 Topping-Up Methods

There are several topping-up methods available:

- Manual vent lids
- Float-based systems, often used with water carts
- Fully automatic refill systems, controlled via valves integrated with the charger

The level of maintenance effort required and degree of contact with the battery from a user perspective depends on the service level agreement with the OEM and/or the battery supplier. A risk assessment should be carried out to determine what level of precautions are taken when maintaining in-house.

4.3.1.3 Safety Considerations

Any maintenance work must be carried out by trained and competent personnel.

Before disconnecting any component, it must be ensured that gassing and degassing has stopped. A small spark can trigger a fire.

Additionally, contact with sulphuric acid can cause severe burns or blindness. Appropriate personal protective equipment (PPE) and procedures are therefore essential. A dedicated maintenance area with eye-wash station should be available and the following PPE should be provided and worn

- eye protection
- long sleeves
- rubber apron
- rubber gloves
- appropriate safety footwear.

Facilities should be provided for neutralising and removing spilled electrolyte – under no circumstances should sulphuric acid be allowed to enter drains.

The information outlined is generalised. For specific maintenance tasks & scheduling, alongside water purity requirements, always consult the user manual and obtain advice from the supplier.

It is imperative that maintenance schedules are adhered to and performed correctly by trained staff. Mistreatment or neglect of lead-acid batteries can lead to severe reduction in performance and early failure.

4.3.2 Lead Acid Batteries – Valve Regulated

Valve-regulated lead-acid (VRLA) batteries are designed to be filled once and never topped up again during their service life, which is why they are often marketed as virtually maintenance-free. The electrolyte is immobilised, meaning it cannot be replenished, and specific gravity cannot be measured. In fact, the safety valves on top of the battery should never be removed.

However, aside from these differences, valve-regulated lead-acid (VRLA) batteries are operated and maintained in a similar way to vented batteries. The other general maintenance practice already listed still apply, as do the same safety requirements, including protection against; electric current hazards, explosion risks from electrolytic gas and – with some limitations – from the corrosive electrolyte, although risk here is significantly reduced if the battery is handled correctly.

Although the risk of contact with the electrolyte is lower compared to vented cells, PPE requirements listed in operation manuals for maintenance often remain the same for both types of cells and lead-acid batteries in general.

Always seek specific guidance from the user manual and the OEM or battery / charger supplier to ensure safe and proper handling.

4.3.3 Lithium-ion

4.3.3.1 General

Lithium-ion batteries are completely sealed and do not require 'watering' (topping-up). They can be considered as low maintenance from a user perspective.

When the lithium-ion battery is in regular use, a daily inspection should be undertaken. Daily lithium-ion battery checks should be limited to user-level visual and operational checks specified by the manufacturer, such as state of charge, visible damage, connector condition, warning lights, error messages, unusual heat, swelling, leakage or impact damage.

However, during the scheduled service intervals or periodic inspection of the industrial truck, visual checks of the battery casing, cable connectors and charging equipment should be carried out by a qualified person and the battery cleaned. For unusually dusty environments, the cleaning frequency may need to be increased. Servicing of lithium batteries must only be performed by trained and authorised persons.

Additionally, some manufacturers/suppliers may recommend visual inspections of the charger and battery itself for damage (if accessible) and checking the state of charge as part of the pre-shift checklist.

For exact pre-checklist requirements, including those related to the remainder of the truck and charger, refer to the user manual provided by the manufacturer.

4.3.3.2 State of Charge

A battery display indicator (BDI) is normally positioned in sight of the operator driving position for all electrically powered vehicles displaying amongst other things the state of charge (SOC). Additional charge indicators may also be located on the battery, charger, or elsewhere on the truck to allow easy viewing by personnel outside the vehicle.

Lithium-ion batteries generally maintain more consistent performance through the discharge cycle than lead-acid batteries due to better voltage stability. However, like all batteries, should not be over-discharged. If a lithium-ion battery is discharged below its safe voltage range, the BMS may shut the battery down and specialist recovery may be required. Attempting to recharge or bypass a deeply discharged lithium-ion battery outside manufacturer instructions can create safety risks.

In all cases, to prevent over discharge occurring, warning signals (audible and/or visual) are provided to the operators, who should ensure that the equipment has sufficient remaining charge to complete the next task or return to a charging / changing station. Batteries discharged to the manufacturers specified 'depth of discharge' should be immediately recharged and not be left to discharge further.

4.4 Discharging

4.4.1 Discharging Lead Acid - Vented Cells with Liquid Electrolyte

Vented lead-acid traction batteries are normally designed to be discharged to a maximum depth of discharge of around 80% of their nominal capacity. On many battery discharge indicators, this is shown as approximately 20% remaining.

During normal discharge, the active materials in the battery plates react with sulphuric acid in the electrolyte. Lead sulphate forms on the plates and the electrolyte becomes more diluted as sulphuric acid is used in the reaction. This process is part of normal battery operation and is reversed when the battery is properly charged.

Problems occur when a battery is repeatedly over-discharged, left in a discharged state, or not fully charged. In these conditions, the lead sulphate can become harder and more difficult to convert back into active material during charging. Over time, this can reduce the battery's available capacity, increase charging difficulty, and shorten service life.

A single accidental over-discharge does not necessarily ruin a battery, provided it is charged correctly and promptly. However, chronic over-discharge or prolonged storage in a discharged condition can cause permanent damage.

Severely sulphated batteries may sometimes be recovered using a controlled or specialised charging process, but results are not guaranteed. Even where recovery is possible, the battery may already have suffered some permanent capacity loss.

4.4.2 Discharging Lead Acid – Valve Regulated

Valve-regulated lead-acid (VRLA) batteries generally allow a depth of discharge (DoD) of up to 60% relative to their nominal capacity. Similar to above, this will normally show as 40% (remaining). To preserve battery health, the state of charge (SoC) swing must be carefully controlled—both over-discharging and overcharging are strictly prohibited.

Discharging any lead-acid battery produces increasing amounts of lead sulphate on the active plates. While regular recharging converts most of this back to active material, fully dissolving stubborn, crystallised lead sulphate requires charging beyond the normal full charge level. For vented (flooded) lead-acid batteries, this is achieved through a controlled equalization charge. However, for VRLA batteries, attempting to apply such a charge, or any form of overcharging, causes outgassing and water loss. Since VRLA batteries are sealed units, the electrolyte cannot be refilled, and applying any level of overcharge leads to electrolyte pressure release through the safety valve, drying out the battery and permanently reducing its performance.

It is crucial that the truck's Battery Discharge Indicator (BDI) is properly calibrated to the exact fitted battery specification. This will help prevent both deep discharge and overcharging. VRLA batteries are not easily recoverable once deeply discharged or overcharged, with multiple failure risks including dry-out, thermal runaway, corrosion, sulphation, and sudden failure.

In some cases, a discharge depth greater than 60% may be permitted, but this always comes at the cost of reduced overall service life. The trade-off is a choice between higher usable energy and runtime between charges, or a longer overall battery lifespan.

Certain types of sealed lead-acid batteries, mandate additional low-voltage alarms, in conjunction with the truck's BDI, as well as battery monitoring, temperature control and reporting systems to help manage SoC swing and to prevent damage.

4.4.3 Discharging Lithium-ion

Depending on the cell chemistry, lithium-ion batteries used in industrial trucks allow a theoretical discharge depth of 80-90% (subject to settings and variation between manufacturers), relative to the nominal capacity with little affect in performance or aging (except for the usual cyclic and calendrical ageing that affects all batteries).

If the battery continues to be used beyond the warning stage, the BMS is designed to shut it down before reaching the critical undervoltage level. The effort of recovery from such a shutdown then depends on how quickly action is taken. Immediate reporting to the industrial truck manufacturer's service department is necessary. If the response speed is prompt, the BMS should allow charging without special intervention, however if the voltage is allowed to collapse further, specialist recovery measures may be required - and in extreme over-discharge states, cell modules or even the complete battery pack may become unrecoverable.

Do not attempt to dismantle the battery and attempt repairs unless trained and authorised to do so by the OEM or battery supplier.

4.5 Charging

4.5.1 General

- Always use a charger which is compatible with the battery technology
- Always charge via the manufacturers charge point
- Do not charge if any of the connectors have been damaged or modified. Use only the correct mating connectors.
- Do not charge if the connectors are loose or hot to touch.

During discharge, stored chemical energy is converted into electrical energy. Charging reverses this process, transforming alternating current (AC) from the grid into direct current (DC) that the battery can accept. This restores the active materials on the electrodes to their high-energy states and returns the battery to its maximum potential difference (voltage) when fully charged.

For all electric drives, the industrial truck must be properly positioned in a designated charging area, with the parking brake applied before battery charging or changing begins.

Battery charging and changing should only be carried out by trained and authorised personnel, following the manufacturer's instructions. The following section provides general guidance on charging different battery types.

Charge cycles are mentioned in the following paragraphs. It is important to clarify with manufacturers what the interpretation of a "full discharge cycle" is, as some manufacturers and battery types define a 'cycle' as 60% of the battery's capacity used, some as 80%, some more. Some manufacturers class connecting the battery to charger as one "cycle", regardless of how much or how little the depth of discharge is. The cycle specification is typically provided in the technical specification or warranty statement of the battery

4.5.2 Charging – Lead-Acid Batteries (Vented Cells with Liquid Electrolyte)

In lead-acid batteries, charging reverses the discharge process: lead sulphate on the active plates is dissolved, restoring the plates to lead and lead dioxide, and the electrolyte to dilute sulphuric acid. Depending on the battery and charger selection, charge time is typically around 6-8 hours for a standard charge and 12 hours for an equalizing charge – which is recommended once a week to help battery life.

When charging lead-acid batteries inside an industrial truck, the battery compartment must be open to the atmosphere. However, some manufacturers provide onboard chargers and forced ventilation systems which operate throughout the charging process, eliminating the need to open covers.

Regardless of the charging method, gases generated during charging - primarily hydrogen and oxygen - must be allowed to dissipate effectively. Hydrogen is lighter than air and will typically rise and disperse naturally in a well-ventilated area. However, if it is allowed to accumulate in enclosed or poorly ventilated spaces, such as pockets within a truck, it can become hazardous. Hydrogen becomes flammable at around 4% concentration in air, but it still requires an ignition source to ignite. Charging areas should therefore be designed and maintained to prevent gas build-up and to keep hydrogen levels well below this threshold.

Refer to 5.4.3 – Charge Area Setup – For more information

In ideal conditions and with correct maintenance, many vented lead-acid traction batteries are designed for around 1,500 full cycles, while some premium or application-specific products may claim higher cycle life. Actual life depends on the manufacturer's specification, depth of discharge, temperature, charging regime and maintenance.

4.5.3 Charging – Lead-Acid Batteries (Valve Regulated)

Valve-Regulated Lead-Acid (VRLA) batteries generate less gas during charging compared to vented lead-acid batteries. However, some gas is still produced, and adequate ventilation remains necessary.

Battery manufacturers also provide specific values and guidelines for calculating ventilation requirements for VRLA batteries. If you're unsure about the correct approach, always consult the manufacturer or seek expert advice.

Under ideal laboratory conditions, VRLA batteries can deliver up to 900 full charging cycles, provided that charging regimes are strictly followed. This usually means avoiding deep discharge (limiting the depth of discharge to no more than 60%), avoiding overcharging and controlling temperature, which all helps to maintain battery life.

4.5.4 Charging – Lead-Acid Batteries (Vented and Valve-Regulated)

In most cases involving both vented and valve-regulated lead-acid batteries, the level of operator contact with the battery increases during the charging process. As a result, additional personal protective equipment (PPE) may be required when initiating charging.

At the end of charge, the charger should be switched off or allowed to stop charging before the connector is unplugged. Disconnecting under load can cause arcing at the connector. While hydrogen produced during lead-acid charging normally disperses in a well-ventilated area, any avoidable spark or arc should be prevented, particularly in enclosed or poorly ventilated areas where gas could accumulate.

4.5.5 Opportunity Charging and Partial State Charging – Lead-Acid Batteries

Opportunity charging and partial state-of-charge (PSoC) charging using higher charging currents may be approved for certain lead-acid battery products. These types of batteries typically come at a higher cost due to enhancements on both the battery and charger sides.

On the battery side, increased active surface area at the cell level is used to reduce internal resistance, enabling faster charging. On the charger side, proprietary charging systems and battery monitoring technologies, with temperature control, are required to manage the process.

This monitoring system (as distinct from a management system) can be used to communicate with the charging system, allowing the charger to change its behaviour to suit the current battery condition. This may allow for faster charging if the battery is unstressed (not overheated from intense discharge, not at too high or too low a state of charge, etc.) or slow charging down to extend battery life if battery is stressed. The effectiveness depends on the exact VRLA type and construction specifics (AGM, GEL, TPPL, etc.). It is important to understand the differences when choosing a battery and charger combination for your application. If in doubt, always refer to your industrial truck manufacturer or provider.

These conveniences may come with trade-offs. Due to the electrochemical nature of lead-acid batteries, frequent partial charging can reduce cycle life and overall capacity. Over time, the batteries suffer from acid stratification and/or sulphation, leading to a condition often mistaken for the "memory effect," where the battery loses its ability to hold a full charge, has progressive capacity loss and delivers shorter run times. Additionally, frequent opportunity charging can raise battery temperature, which can further shorten service life.

These battery types vary greatly, but are generally held to have a lower cycle life than regular flooded cell lead-acid batteries.

Cycle life varies significantly by battery type, charger profile, duty cycle, temperature, depth of discharge and manufacturer specification. Users should rely on the battery manufacturer's published data and warranty terms rather than assuming a fixed cycle life.

4.5.6 Charging – Lithium-ion

Never try to 'jump-start' a lithium battery or bypass the BMS

Lithium-ion batteries can be opportunity charged, meaning that it can be charged for short intervals, rather than waiting until the battery is low, before performing a full charge.

Opportunity charging (rapid and partial) is not detrimental to lithium-ion battery life or performance. Often batteries with a smaller energy content may be used due to the ability to apply high levels of charge over short periods, whenever there is an operational break. The ability to opportunity charge can also mean that changeover equipment, along with associated space and handling equipment is no longer required.

Due to the differing electro-chemical processes, lithium-ion batteries do not release oxyhydrogen (or any other) gases during charging. Under normal operating conditions, the risk of potentially explosive gas mixtures is removed, and no specialist ventilation is required.

As a result, charging stations can often be located closer to working areas or break rooms. The need to access the battery or open the bonnet, doors or covers is commonly removed with charging ports positioned for easy use.

Depending on the cell chemistry, lithium batteries used in industrial trucks can deliver up to 4,000 (or even 6,000) full charging cycles under optimal conditions. Partial cycling and opportunity charging are not harmful to lithium-ion batteries, and their wide acceptable state of charge range allows for comparatively predictable ageing behaviour over time.

Given the wide range of available options, it's important to research thoroughly and consult suppliers to understand the specific warranty terms and operating conditions before making a purchase.

5 - Charger and Charging

5.1 Charger Type

5.1.1 Lead-Acid Batteries (Vented Cells with Liquid Electrolyte)

In general, vented lead-acid batteries can be charged using any 50 Hz or high-frequency (HF) chargers, provided the voltage and current are matched to the battery size. However, it's common practice to purchase the truck, battery, and charger as a complete package from the original equipment manufacturer (OEM), and you should check before using anything else.

Although the charger represents a relatively small portion of the overall investment in a truck-battery-charger system, its impact on system efficiency can be significant. The choice and quality of the charger can influence ongoing energy costs and contribute to reducing CO_2 emissions.

50 Hz chargers use traditional transformer and rectifier technology to convert alternating current (AC) from the grid into pulsating direct current (DC) for battery charging. These chargers are typically inexpensive to purchase but produce a less stable output, and their charging curves tend to be less precise. The rippled DC output can lead to increased battery temperatures and may contribute to issues such as sulphation and acid stratification, particularly when paired with basic charging algorithms.

Compared to high-frequency chargers, 50 Hz units are less energy-efficient. A significant portion of energy is lost as heat—both through the large transformer and within the battery itself.

5.1.2 High-Frequency (HF) Chargers for Lead-Acid Batteries (Vented Cells with Liquid Electrolyte)

High-frequency chargers are microprocessor-controlled devices that use advanced switching technology. They first rectify incoming AC power into DC, then switch this DC at high frequencies using electronic components. This allows the use of much smaller transformers to step down the voltage, followed by a final rectification stage to produce smooth DC output.

Operating at frequencies far above the grid standard, HF chargers deliver precise and stable charging curves, enabling accurate control of voltage and current through multi-stage charging algorithms. Their compact and lightweight design is made possible by the reduced size of internal components. With charger efficiencies typically around 90%, HF chargers minimise energy loss and heat generation during the AC-to-DC conversion process.

However, due to the variable internal resistance of lead-acid batteries, additional energy losses occur within the battery itself. These losses depend heavily on battery condition and maintenance. For a well-maintained new lead-acid battery, you can expect higher overall efficiency than a 50Hz charger.

While HF chargers generally come at a higher initial cost, their long-term benefits in performance, energy efficiency, and battery health—especially when the battery is properly maintained—make them a worthwhile investment

Additionally, some battery manufacturers may claim to offer specialised charging profiles tailored to their specific battery designs, and using non-approved chargers could have warranty implications. For this reason, it often makes sense to purchase the truck, battery, and charger as a package from the manufacturer, provided the decision is made with full awareness of the technologies and options available.

5.1.3 High-Frequency (HF) Chargers for Lead-Acid Batteries (Valve Regulated)

As previously described, valve-regulated lead-acid (VRLA) batteries must never be overcharged, as this can lead to electrolyte loss and irreversible drying out. In addition, temperature must be strictly controlled throughout the charging process. To ensure proper battery function and maximise service life, it is essential to use the charger recommended by the battery manufacturer.

5.1.4 Lithium-ion Battery Chargers

Much like VRLA, lithium-ion batteries must never be overcharged.

Overcharging can lead to the formation of “dendrites” within the cells that can internally short circuit the cell. Overdischarging can also cause this.

Adding more energy (charge) to a lithium battery that has formed internal dendrites make it even more unstable, which is why lithium batteries are fitted with full battery management systems (BMS).

The BMS not only monitors the internal condition of the battery, but it can also disconnect the battery from its external input / output leads in circumstances of overcharge /discharge, over temp, short circuit or any other hazardous event, ensuring charge is not given to (or taken from) a battery cell in an unsafe condition.

The BMS will communicate with the correct charger to ensure the appropriate charge profile is used and charging will not initiate if there is a fault or compatibility issue. For that reason, it is critical to ONLY use the charger supplied with the lithium-ion battery.

5.2 Charger Options

5.2.1 Lead-Acid

Most battery manufacturers offer additional charger features such as temperature-controlled charging and air agitation. These options, along with proprietary chargers that use specialised charging profiles, are often used during opportunity charging of lead-acid batteries. Air-agitation gently mixes the electrolyte to aid against acid stratification and when paired with temperature control, to help maintain battery life

5.2.2 Lithium-ion

Due to the efficiency of modern chargers and the electrochemical properties of lithium-ion batteries—such as low, stable internal resistance and the absence of plate sulphation or the need for ongoing user maintenance—charging efficiency is often high. Less energy is wasted during charging, which translates into both cost savings and reduced CO_2 emissions.

Lithium-ion powered industrial trucks are usually purchased as a complete system; truck, battery, and charger. Many OEM systems communicate constantly via a CANbus protocol. While this usually means that an incompatible charger cannot be connected , always use a charger specifically matched to the lithium-ion battery being charged. This ensures the Battery Management System (BMS) can safely and efficiently manage the charging process, preventing overcharging, overheating and halting charging if any faults are detected.

Users must not bypass or disable the BMS, or connect chargers that are incompatible or of unknown type.

5.2.3 All Battery Technology Charging

For complete charging procedures for all battery and charger technologies consult the operations manuals as supplied by the manufacturer

5.3 Charger Compliance (RCM/EMC etc)

Ensure that the charger supplied has an Australian 'Compliance Mark' (RCM/EMC tested).

The Regulatory Compliance Mark (RCM) is a trade mark owned by the electrical regulator (Regulatory Authorities (RA's)) and Australian Communications Media Authority (ACMA) .

www.eess.gov.au/rcm/regulatory-compliance-mark-rcm-general/

5.4 Energy Requirements for Charging

5.4.1 Electricity Mains Connection

Before selecting a battery and charger, its essential to first determine the energy throughput for your specific application. This will define the appropriate battery size, expected intermediate charging times or battery changes and the necessary charging current required.

Lead-acid chargers are available in various power ratings depending on battery size, while lithium-ion chargers may range from low to high power, depending on the application and required charging speed. Since output power is directly related to input current, it's advisable to consult with the supplier early to identify the most suitable charger for your needs and ensure compatibility with the available wall sockets. In some cases, an electrical upgrade may be necessary, with the cost depending on the nature of the work required.

Always consult the industrial truck manufacturer to confirm the most appropriate battery and charger combination for your specific application.

5.4.2 Building Power Requirements

When planning battery and charger infrastructure, it's important to consider the maximum number of trucks charging simultaneously across all battery and charger technologies. This is essential to accurately assess total power requirements and the maximum demand on your building's electrical supply, including any localised sub-boards.

If switching to lithium-ion technology requires higher charging power, a revised charging strategy may be considered. Since lithium-ion trucks can be opportunity charged at any time, new possibilities such as staggered fleet charging, can help avoid costly upgrades to the electrical infrastructure. Furthermore, some suppliers can offer advanced charging management systems to control peak loads

However, since each application is unique and chargers are variable with various power ratings, it is essential to consult the manufacturer to determine the most suitable and viable solution for each application.

5.4.3 Charge Area Setup

A safe location should be identified where equipment and cables do not create obstructions or block access. Emergency exits, escape routes, and traffic routes must always remain clear. For lead-acid batteries, adequate ventilation, either natural or technical, must be provided.

Australian Standard AS 2402.1.2 outlines ventilation requirements for battery charging rooms. Specifically, it mandates that hydrogen concentrations must not exceed 2%. To achieve this, rooms should be designed with sufficient natural ventilation featuring diagonal airflow: air should enter at ground level, pass over the top of the batteries, exit as high as possible, and release exhaust air outside the building.

If natural ventilation is inadequate, appropriately rated mechanical ventilation may be required to prevent hydrogen accumulation and safely discharge charging gases outside. Ventilation rates should be calculated in accordance with the relevant Australian Standards (AS2402.1.2, AS2402.2.2), battery manufacturer requirements, and site risk assessment.

Additionally, advice should be sought from battery suppliers. They can provide precise calculations tailored to specific battery, cell, and charger combinations, whether for a single battery or hundreds, ensuring compliance and safety.

Lithium-ion batteries do not normally emit hydrogen during charging, so the ventilation requirements for hydrogen control in vented lead-acid charging areas generally do not apply. This may allow more flexible charger placement, but charging locations (regardless of battery chemistry) still need to be subject to a risk assessment. Items to be assessed could include electrical safety, electricity supply availability, fire risk, access/egress, impact protection, cable management, smoke or heat detection, and manufacturer or insurer requirements.

Existing charging rooms can still be used; however, if the location is too far from the operational area for opportunity charging, a battery with similar energy content to a lead-acid system may be required. This is application-specific, so consultation with the supplier is recommended to determine the optimal battery system and charging location.

Clearance distances at charging stations remain the same as for lead-acid systems, for example, 1.0 m between the battery and charger or spark-producing equipment, and 2.5 m from any flammable materials. Where dangerous goods are located nearby, a clearance of 3.0m is required.

The use of certain PPE, such as safety glasses and gloves recommended for charging lead-acid batteries, may be reconsidered for lithium-ion batteries, as they are sealed and eliminate the risk of electrolyte contact under normal use. Charging ports are usually positioned in a convenient location away from the battery compartment.

Always ensure staff are trained in correct charging procedures and refer to the equipment's user manual for specific guidance.

5.4.4 Lifting

In some applications where battery depletion is rapid (heavy use, low temperatures, etc.), it may be necessary to remove a battery from a truck and replace it with a charged one, as there is not enough time to properly charge the battery before the truck needs to be used again. This usually only applies to lead-acid battery types but can apply to lithium ion. Competent and authorised people must be used for this task.

In most cases, lithium-ion batteries do not require lifting or changing like lead-acid batteries. However, if lifting is necessary, the same safety principles apply to both:

Use Proper Lifting Equipment:

Ensure appropriate lifting tools are available, such as:

- Forklifts or pallet trucks with battery pallets or adapters or spreader bars
- Dedicated pallet truck with push/pull rollers
- Overhead cranes with rated spreader bars

Safety Requirements:

- Use correctly rated, safety-tagged, and well-maintained lifting equipment
- Ensure lifting capacity matches the battery weight
- Avoid contact between metal objects (e.g., chains) and the battery
- Never allow personnel to stand under or near a lifted battery

Always follow the user manual instructions and consider purchasing lifting equipment directly from the OEM to ensure compatibility and safety.

5.5 Hot and Cold Working Environments

Lithium batteries are more sensitive to the extremes of temperature. Degradation of operation time and reduced performance can occur. When operated in extreme conditions, precautions must be taken.

In cold stores, the forklift should not be stored or left for extended periods. Irreversible damage may occur. It is recommended that the battery is brought to a normal room temperature and environment before charging.

Conversely, in a hot environment, a battery should be brought to a cooler area for charging.

The operating and charging temperature range for batteries is specified by the manufacturer and can be found in the relevant datasheets and user manuals. Because of this, it is essential to consult these documents when selecting a battery technology to ensure it is suitable for the intended environment.

For lithium-ion batteries, there is no universal temperature limit; the acceptable range depends on the specific cell chemistry and whether the supplier offers additional features such as cold-store heating elements. It is important to note that the Battery Management System (BMS) regulates both operation and charging processes. If temperature extremes are encountered, the BMS is likely to reduce driving and charging speeds or even stop operation entirely. This highlights the importance of consulting with the supplier to confirm that the chosen battery system is appropriate for your application.

In contrast, lead-acid batteries generally do not have a BMS installed, but it is recommended to request temperature-controlled charging options for extreme conditions to help extend battery life by reducing charging power. It is important to note that this may result in longer charging times, which should be carefully considered when evaluating whether battery-electric technology is the right fit for the application.

6 - Storage

All batteries will slowly discharge over a period of time.

The battery should be inspected regularly (e.g. every 3-6 months or as per the user manual), and protected against short circuit or damage. Follow the manufacturer's storage instructions.

If a lead-acid battery is to be stored / unused for a long period of time, it should be fully charged before storage.

If a lithium-ion battery is to be stored / unused for a long period of time, it should be stored between 40-60% state-of-charge (SOC).

The storage area should be indoors, clean, dry and as a recommendation less than 40°C (avoiding high humidity). Check the operation manual for specifics, especially with specialist batteries.

Position the batteries such that they will not be exposed to damage. This may mean storing them off the floor away from potential moisture or flooding.

The batteries should not be stacked directly on top of each other causing load to be applied to the lower battery.

7 – Transporting Equipment and Batteries

As all industrial truck fuel sources (batteries of any kind, LPG, Diesel, CNG, etc) are classed as "Dangerous Goods", there are specific rules and standards in place for the transportation of them all. These requirements can vary between different fuel sources and how they are packaged.

Transportation within a complete industrial truck, as standalone power systems (i.e. complete batteries) or as components (dry cells, liquid electrolyte, wet cells, bottled gases, fuel in tanks of varying sizes, etc.) may carry different requirements.

It is imperative to use reputable transport providers, with up-to-date knowledge and qualifications in the transportation of these dangerous goods when moving them.

Always check with the manufacturer of both the truck and the fuel source to ensure requirements are understood and met.

Lithium-ion batteries are classified as Class 9—Miscellaneous Dangerous Goods under international UN model regulations and the Australian Dangerous Goods Code (ADG Code). Key transport codes depend on battery type: UN3480/UN3481 (Lithium-ion) and UN3090/UN3091 (Lithium-metal), requiring strict packaging, labeling, and documentation for road, sea, and air transport.

Key Transport Classifications (UN Numbers)

- **UN3480:** Lithium-ion batteries (shipped alone)
- **UN3481:** Lithium-ion batteries contained in or packed with equipment
- **UN3090:** Lithium-metal batteries (shipped alone)
- **UN3091:** Lithium-metal batteries contained in or packed with equipment
- **UN3551:** Sodium-ion batteries

Core Transport Regulations

- Road & Rail (Australia): Must follow the most current edition of the Australian Dangerous Goods Code (ADG Code), currently edition 7.9 (at time of drafting).
- Air: Governed by IATA Dangerous Goods Regulations (usually Packing Instructions 965–970).
- Sea: Regulated under the International Maritime Dangerous Goods Code (IMDG), overseen by AMSA

8 - Fire Risk

8.1 All Power Sources

It's important to note that residual risk is present across all industrial truck power sources. Lead-acid or lithium-ion batteries and internal combustion engines using flammable liquids or gases can pose safety risks if mishandled.

This paper does not aim to promote fear or bias toward any technology. Instead, it emphasises that all power sources carry some level of risk, and the same safety principles should apply:

- Prepare an emergency response plan.
- Coordinate with local fire authorities.
- Notify relevant stakeholders (site owner, insurer).
- Consider the OEM user manual instructions.

8.2 Lithium-ion

There is a trend of concerns about the safety of lithium-ion technology, which primarily relates to the use of low-quality lithium systems in low-value, unregulated consumer goods and lack of experience in using the technology.

Lithium-ion batteries used in industrial truck applications are generally built with multiple layers of protection, including cell-level controls, battery management systems, temperature monitoring, current control and protective housings. These systems significantly reduce the likelihood of failure when the battery is used as intended. However, they do not remove the risk entirely.

As part of a comprehensive risk assessment, fire protection measures may be reviewed and implemented. In the event of mishandling or physical damage to a lithium-ion battery, it is possible for the chemical energy stored to be converted into thermal energy. For this reason, it is advisable to draw up an emergency preparation plan, coordinate fire protection measures with the local fire department and notify the site owner & properties insurer. Insurer experience with different technologies can be inconsistent, so it may be prudent to review insurance partners if considering changing energy source for your industrial truck.

9 Emergency Response

9.1 Emergency Response Plan

Site emergency response plans should be updated to include the management of all fuel and energy types used on-site. This includes, but is not limited to, internal combustion-powered equipment (diesel, LPG, CNG), electric-powered equipment (lead-acid or lithium-ion), and hydrogen-powered systems.

9.2 Safety Data Sheet

A Safety Data Sheet (SDS) must be available for all fuel / energy types. This SDS must conform to the Australian requirements for SDS's (WHS Regulation) and detailed in the "Code of Practice – Preparation of safety data sheets for hazardous chemicals".

9.3 Information to Emergency Services

The site manifest should be updated to include the presence, number and location of powered mobile plant with the associated energy type.

10 – End of Life Management

10.1 Industry Recycling

For industrial batteries there is a ban on disposal via landfill and they must be collected and recycled. Contact the OEM or battery supplier.

Recycling of industrial truck lithium-ion batteries is in its infancy in Australia but with the rapid growth of electric cars the industry will grow fast. The EPA dictates that no lithium battery should go to landfill. Damaged, end-of-life or waste lithium batteries can present fire and handling risks, so they should be appropriately stored, transported and recycled.

Lead-acid industrial batteries have a well-established recycling pathway in Australia. They are routinely collected and recycled, with the lead, plastic casing and acid recovered through existing recycling processes.

10.2 Recycling a Damaged Battery

Caution should be taken with damaged batteries as they could be unstable. Never try to transport a damaged battery without specific approval of the competent transport company. The battery manufacturer should be contacted for possible guidance on safe removal.