Lithium batteries and their safe storage, transport, use and disposal, including re-use and re-cycling

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1 INTRODUCTION

This paper is one of three related published papers which look at current EV technology, issues around recycling batteries used for motive power in electric vehicles and, in more detail, issues surrounding the recycling of lithium-ion batteries in the wider industrial and commercial sectors.

Lithium batteries come in a variety of shapes, sizes, designs, materials, and chemical compositions. Besides the use of small lithium button cells used in watches, digital cameras and other consumer appliances, there are many specialised batteries for scientific, military, aerospace, automotive and commercial applications. There are two basic categories of lithium battery, or LIB: (1) Lithium-ion battery: non-rechargeable batteries containing lithium metal, and (2) rechargeable batteries containing salts of lithium. Rechargeable lithium ion (Li-ion) batteries are used in mobile phones and laptops, and larger versions power electric vehicles (EV) and cars in particular. Lithium polymer batteries are a category of Li-ion rechargeable batteries, which have a range of laboratory and scientific applications, as well as being used in consumer electronics such as laptops and tablets.

Lithium rechargeable batteries are used mainly to provide the private individual or business consumer high-end luxury electronic and electrically powered devices, such as lap-top computers and smartphones. The use of even disposable lithium composition batteries is commonplace, including in small photo and electronics applications in all aspects of everyday use. In safety terms LIB have a ‘poor press’ in the light of recent fires. These included fires that have occurred while charging smartphones, fires during waste disposal operations and the involvement of on-board aircraft systems lithium power batteries in the loss of two Boeing 787 Dreamliner aircraft. There have been instances reported in lithium battery recycling operations and also fires reported in motor vehicles during recharging operations.

1.1 Environmental factors

In the life cycle of these components there is seemingly little in the way of the primary environmental concept of **reduction** in the use of lithium. Consequently, there is a widespread and unhindered introduction of lithium batteries in the reuse, recycling, reclaiming and disposal routes in the lifecycle of these products.

Current battery technology depends on potentially hazardous materials and chemicals to produce electrical current from a small portable package. Recycling diminishes the environmental harms by diverting from disposal, but recycling may create other environmental issues in the process, such as increased transportation costs and more energy intensive methods to reprocess batteries.

The increased demand and pressure for improving battery performance have intensified the need for battery performance modelling. For a battery manufacturer, models and simulations help to improve the selection of materials and the design of the battery power system and composition. Subsequently, for device manufacturers who incorporate batteries into products and systems, modelling permits better understanding and simulation facilitates improved performance at a wider range of relevant operating conditions.

However, it seems that little ‘modelling’ has been done into the safety and environmental impact and/or sustainability aspects of use and how to manage the battery at the end of its operational life, on the way to the dis-assembly / dismantling plant which reclaims the individual metals used in the original composition of the product.

2 DEFINITION AND SCOPE

The term lithium battery refers to an entire family of battery types, with varying chemical compositions. The common properties of these chemical constituents are that the negative and the positive electrode materials serve as hosts for lithium ions, and that the battery contains a non-aqueous (organic) conductive electrolyte.

2.1 Battery types

Lithium batteries are manufactured principally in two main types: (1) ‘Primary’, also known as non-rechargeable battery types and (2) ‘Secondary’ rechargeable type. Batteries used for high-power or commercial, automotive and aerospace applications rely on rechargeable technology.

2.2 Focus

This guidance is mainly focussed on rechargeable lithium batteries with additional commentary on non-rechargeable lithium batteries, in the context of their transport and disposal.

3 COMPOSITION OF 'LITHIUM' BATTERIES

Despite the use in common language of the term 'lithium battery' there are several types in popular use, with differing technologies. Each type or chemical composition has its own performance characteristics.

3.1 Lithium-thionyl chloride ($LiSOCl_2$)

These are non-rechargeable and can be high capacity. The main physical risk is a short circuit from inadvertent contact with the terminals. Many types have fuses built in to limit the effect or severity of a short circuit. However, some do not, and consequently can present a serious fire risk. They can have very low internal resistances so that, if shorted, very high currents can flow which can result in rapid heating and temperature escalation which gives rise to the consequent risk of explosion. If subsequently there are attempts at repeatedly re-charging a 'shorted-out' battery, there is also a risk of explosion.

The other main risk to $LiSOCl_2$ cells is corrosion by saltwater since they are often used in marine applications. The inadvertent introduction of saltwater provides a contaminant which can catalyse decomposition, the separation of a single chemical compound into its two or more elemental parts or to simpler compounds. Ironically this effect is used extensively in safe neutralisation of lithium cells prior to transport to disposal.

3.2 Lithium manganese dioxide ($LiMnO_2$)

Rechargeable versions are available, but most are non-rechargeable. They are the type of lithium cells often used as small current devices in watches and memory backups in computers etc. The hazards from these batteries are unintentional polarity changes, or reverse charging when overheating will cause failure and possible fire or explosion. Effects can be minor and risks imagined to be trivial but they must never be ignored.

3.3 Lithium ion (Li-ion)

Li-ion is a recent technology that is now prevalent in the consumer portable electronics market. These batteries are rechargeable and present the most severe consequences of any rechargeable battery failure if charging is not carried out using the correct charging technology or procedure. Lithium-ion batteries cannot tolerate overcharging and cannot be trickle charged continuously because of this. Overcharging can result in the deposition of lithium metal on one of the electrodes, which then becomes a fire hazard. The battery must be charged using a charger that follows a rigid charging regime and has both overheat protection and time-out protection.

3.4 Lithium iron phosphate ($LiFePO_4$)

These have a lower energy density so are more stable and therefore safer than most other lithium batteries. This performance is illustrated in Figure 1. These batteries also have a longer lifetime (1400 or more charge-cycles). They can be configured as much lighter replacements for 12-volt lead acid batteries (e.g. often operationally dormant Tracker batteries) so may have applications for field work where formerly car batteries were used with consequent positive benefits for manual handling and in protection from sulphuric acid (H_2SO_4) spillage.

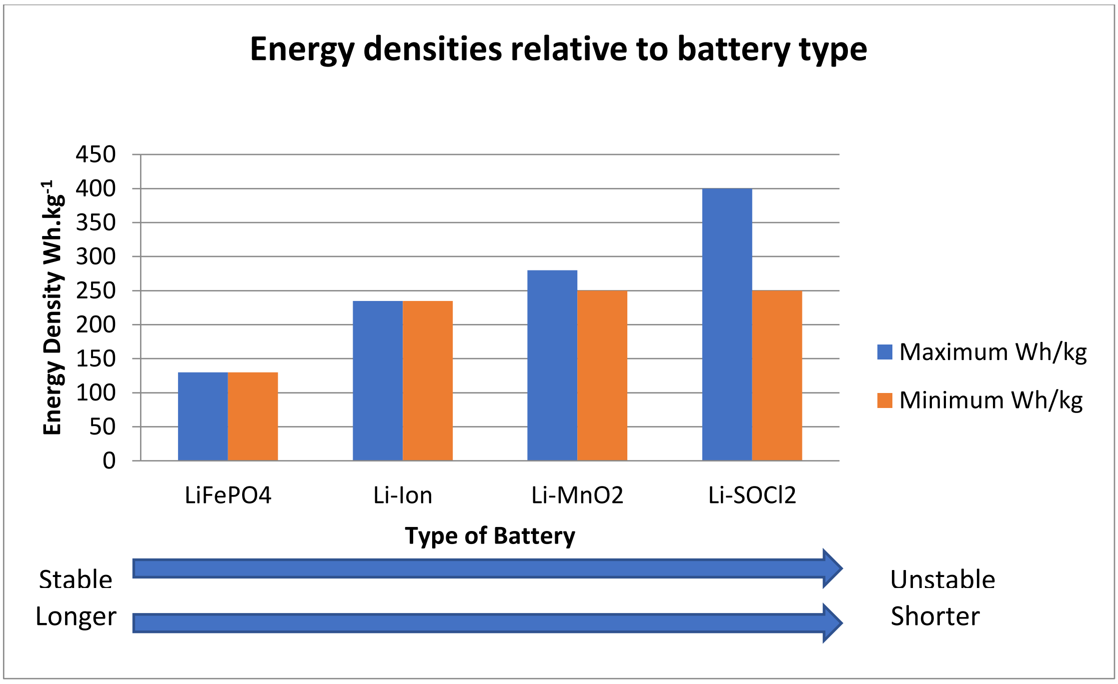

Figure 1: The varying relationship between Energy Density, Size and Stability for each of the four battery types. (Powerstream, 2017) (Land, 2010) (Li, 2017)

4 RECHARGABLE BATTERIES

4.1 Uses

Rechargeable batteries are used in a wide variety of scientific, technical and industrial equipment and personal electrical / electronic equipment and have become the most popular rechargeable batteries for consumer electronics and automotive applications due to their high energy and power densities, relatively high cell voltages, and low weight-to-volume ratios. They are particularly useful in all industrial and domestic applications because of their high charge density which gives them a power advantage over other types of battery and makes them successors in the re-chargeable field to nickel cadmium batteries, which suffered from ‘memory effects’ and alkaline non-rechargeable batteries, which had less impressive performance although they were ‘cheaper’ to produce and buy.

Larger machines and portable equipment, which tend to be used remotely or wirelessly, such as lap-top computers or scientific or industrial equipment, with higher operating voltages, higher power output and consequently higher current drain, are invariably powered by rechargeable cells or larger batteries.

Figure 2: Waste $LiFePO_4$ batteries in a poor storage arrangement

Figure 3: Waste standard $LiFePO_4$ battery

4.2 Hazards

Lithium ion rechargeable batteries have the lithium incorporated in a compound or 'intercalated' with another material. The effects of lithium-based malfunction or the severity of the consequences of the abuse will depend on the type of battery.

OPERATIONAL HAZARD	POSSIBLE CONSEQUENCES
Over charging	Venting, fire, explosion
Forced discharge	Overheating, venting
Short circuit	Overheating, venting, fire, thermal runaway
Incineration/overheating	Venting, explosion (if heating is excessive)
Physical damage	Release of potentially hazardous materials & spontaneous ignition. Short circuits
Leaving for a long term uncharged or unmanaged	Venting

Table 1: Operational hazards and consequences

Venting in this context describes release of gases from the battery, with some designs having pressure release devices to allow 'safe' venting in case of over-heating or decomposition. Other designs **do not** have pressure release devices in which case they may explode if they become over-pressurised.

In some instances, this venting effect in a sealed cell is seen as bulging or swelling of the battery casing. **In these circumstances the battery MUST NOT be reused or recharged.** The battery has passed the end of its useful life and should be safely disposed of.

Lithium batteries start to decompose and vent or 'gas-off' at the end of their useful life causing swelling of the battery case. If this heating starts as a result of impact damage, such as in waste collection, handling or waste processing machinery internal damage could occur, and the battery could spontaneously start a ‘runaway reaction’.

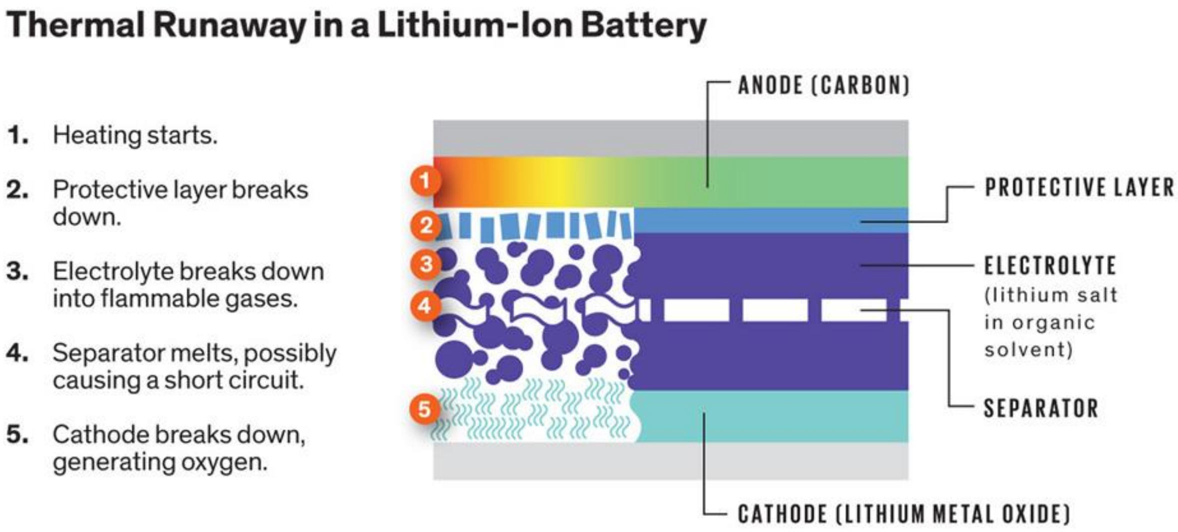

Figure 4: Typical exothermic thermal runaway reaction

In terms of fire safety, occupational and public health one issue is that many lithium-ion batteries contain fluorine, which readily combines with hydrogen to generate hydrogen fluoride (HF). In unintentional battery fires, HF is noxious, corrosive to silicates, dangerous to the skin and tissue, and is a very serious respiratory hazard through inhalation.

West Yorkshire Fire & Rescue Service have reported that they have attended a number of incidents involving lithium type batteries stored in battery recycling boxes. The most likely cause of these incidents is that the terminals of a lithium battery have caused a short circuit, with subsequent heat build-up in the near spent battery and ultimately starting the thermal runaway responsible for initiation and development of the fire.

These are the most common type of rechargeable lithium battery and are widely used in many types of portable electronic equipment including laptops, mobile phones and many other devices.

Lithium polymers (abbreviated to the acronym of LiPo batteries) are a type of lithium ion battery that is usually not enclosed in an outer rigid containment case but rather in a flexible plastic skin. LiPo batteries pose similar risks to other lithium ion batteries but also have some additional ones. They are very useful because they are light, normally do not have a rigid outer case, which together with their high charge density makes them an ideal battery to use in remote/radio controlled unmanned devices such as Unmanned Aerial Vehicles (UAVs, also known as ‘drones’), unmanned ground vehicles (UGVs) and submersibles. LiPo batteries are also very versatile in their design and configuration and can be made very thin and flexible. The risks shared between rigid lithium ion batteries and LiPo are very similar in principle, except that LiPo batteries are more susceptible to damage in use if they have a non-rigid case to protect against damage caused by penetration by sharp objects / improper mounting / impact leading to internal damage and short circuiting within the battery. Some new forms of LiPo battery used in UAVs have rigid cases and built-in power management to record charge cycles and automatically discharge batteries.

4.3 Saltwater

Saltwater immersion is sometimes recommended as a means of rendering damaged lithium ion cells safe for disposal. Care is required before following this disposal route to make sure the battery does not still contain enough energy to short circuit or explode.

4.4 Standard precautions

- Only use a charger that is designed for the equipment being charged, that incorporates the necessary safety / protective features and is a lithium ion battery charger.
- Do not use a NiCd (Nickel Cadmium) or NiMH (Nickel-Metal Hydride) charger with lithium ion batteries or damage and failure may occur.
- Do not crush, break open or physically abuse the batteries or the equipment that contains them.
- Take precautions to avoid short-circuiting.
- When charging batteries do not leave them on charge unattended / in an unoccupied area in case, through a latent defect, they burst into flame during the process. There needs to be someone present who knows how to deal with an emergency.
- The only exception is a proprietary device such as a laptop or mobile phone charged using its supplier’s charger. Although, it is prudent to not leave lithium ion / LiPo batteries to charge overnight unattended.
- Consider creation of dedicated and segregated charging stations / areas.
- Charge batteries on a non-combustible surface, preferably in an isolated area on a concrete or ceramic surface but if necessary, a metallic one although steps to avoid short

circuits by contact with terminals must be in place in such cases. Ensure there are no other flammable or combustible materials close to the charging operation.

- Special protective, non-combustible battery charging cases are available that can be used for charging small batteries.
- After charging has completed and the charger disconnected, delayed chemical reactions and failures may still occur so they should remain observed or retained in an occupied area for a period of an hour or more after charging has ceased.
- Regularly observe the LiPo batteries during charging and for 15 minutes afterwards to check there are no signs of swelling, curvature, distortion or failure.
- Have suitable firefighting and emergency equipment available. Strictly for a lithium metal fire a Type D, special metal fire-fighting extinguisher must be used (usually graphite is specified for lithium). As it is debatable whether a lithium ion battery fire involves elemental lithium metal, a more general-purpose extinguisher may be suitable such as dry powder. Copious (flooding) supply drench water or a bucket of dry sand may be suitable.
- Do not expose lithium ion batteries to extreme heat (above 50 °C) or extreme cold (below -10 °C). Storage in vehicles in direct sunlight that may become very hot should be avoided.

4.5 Charging conditions

- Batteries must be cool and at ambient temperatures before charging.
- Do not overcharge or discharge at too low a rate. Check the manufacturer's specification for the exact battery type used and for small cells in some case it may be within the range 3.2 volts (v) to 2.7 v.
- Do not store batteries fully charged for extended periods of more than 24 hours. Discharge to about 50-60% capacity for storage for long periods.
- Do not use excessive charge rate currents. Keep below the capacity of the battery pack.
- Use protected connectors / terminals that cannot be short-circuited when being handled (e.g. cover with insulating plastic tubing when not in use)
- With multiple battery installations, use a balanced battery charger as it is important that all the cells in a battery pack are maintained at the same voltage. If the voltages vary by too much (5 mV ~ 10 mV), the battery may become unstable.

- Never overcharge a LiPo battery and do not 'trickle' charge one. The lifetime of a LiPo battery is between 300 – 500 cycles. Leaving them fully charged, depleted / dead or exposing them to high temperatures will considerably shorten this useful life cycle.

4.6 Power rating

The accepted method for expressing the power of a lithium-ion battery is now 'Watt-hours' (Wh). When applied to a lithium-ion battery, watt-hour rating is a measurement of how much power (in watts) the battery will expend over one hour and is a product of voltage and current.

The Wh rating may affect transport requirements for the battery and should be marked on newer batteries or be found in the battery specification.

- Observe the battery polarity.
- Do not install lithium batteries next to a source of heat. Their performance will suffer badly.
- Ensure that any power pack is marked 'Lithium Battery'.
- Report any incident involving lithium batteries to your local safety adviser.
- Do not try to charge a primary (non-rechargeable) cell.
- Do not encapsulate lithium batteries without first consulting the manufacturer's advice.
- Before disposal, cells and batteries should be fully discharged using a circuit that incorporates a suitable load to prevent a short circuit.

4.7 Safe storage

There are no **specific** health and safety requirements for storing batteries, but normal health and safety rules apply. This includes that the responsible person should assess health and safety risks. In a workplace, the 'responsible person' is the employer or person who occupies or owns the premises or alternatively the 'responsible person' will be the person or people in control of the premises.

The Health and Safety Executive considers the risks from storing small quantities of portable batteries to be very low if sensible precautions are taken. But these should be considered in a business's health and safety risk assessment.

4.8 All battery types

- Ensure you discharge your duty of care for waste and store batteries separately from other hazardous materials.
- Batteries should be stored and disposed of in accordance with the manufacturer's instructions where these are available. Segregate special and non-special waste batteries but note the specific provisions for lithium-ion batteries. Segregate automotive, industrial and portable batteries as each have different disposal routes.
- Batteries should be separated from other materials and stored in a non-combustible, well ventilated structure with sufficient clearance between walls and battery stacks. If possible, lithium batteries should be stored on racking outside the premises in a secure, cool, well ventilated, dry storage area and away from sources of heat including direct sunlight.
- Protect against physical impact damage such as being crushed or punctured.
- Tape terminals or provide plastic covers for lithium batteries to prevent short circuiting
- Do not store in areas that are fire escape routes
- Ensure waste batteries are regularly removed from premises to avoid significant accumulations.

4.9 Automotive batteries

Producers of automotive batteries must collect waste automotive batteries from final holders of the batteries. This is not the end user and the end user must fund and arrange the transfer to a final holder (such as a suitably licensed recycling facility, a local authority waste facility or a garage that accepts automotive batteries). In selecting a final holder, you must discharge your Duty of Care and ensure that they may legally accept this type of waste.

4.10 Portable batteries

In the case of mixed loads or loads containing only batteries that are special waste (such as NiCd and mercury (Hg) containing batteries) a special waste consignment note should be retained for at least three years. For consignments of batteries that are not special waste (such as alkaline batteries) a controlled waste transfer note should be retained securely for a minimum of two years.

4.11 Safe transport

The rules governing the carriage of lithium cells and batteries are complex, and subject to frequent change. If you anticipate transporting equipment that contains lithium batteries, lithium batteries packed with equipment in the same box, or lithium batteries on their own, you are advised to seek early advice from a professionally qualified HSES adviser.

Lithium batteries of any type are designated as dangerous goods for all modes of transport and are classified in Class 9 – Miscellaneous dangerous goods and articles as:

- UN 3090 lithium metal batteries (including lithium alloy batteries), and
- UN 3480 lithium ion batteries (including lithium ion polymer batteries)

or, if contained in equipment or packed with equipment, as

- UN 3091 lithium metal batteries contained in equipment (including lithium alloy batteries), or
- UN 3091 lithium metal batteries packed with equipment (including lithium alloy batteries), and
- UN 3481 lithium ion batteries contained in equipment (including lithium ion polymer batteries), or
- UN 3481 lithium ion batteries packed with equipment (including lithium ion polymer batteries).

The restrictions on taking lithium batteries on aircraft change at very regular intervals so it is difficult to give specific advice that will remain valid for any long-term period. Personal proprietary portable electronic consumer goods such as mobile phones, cameras, laptops, notebooks, tablets etc. containing lithium batteries are usually allowed in carry-on baggage on passenger aircraft, but this situation can change rapidly as several events in 2016 with respect to aircraft fires demonstrated. One should check with the airline carrier before travelling. At the time of writing guidance on what you may carry in baggage on aircraft that includes sections on spare batteries and items containing batteries may be found on the Civil Aviation Authority (CAA) website. But this advice could be liable to change in reaction to circumstances.

A new Class 9 hazard label for all types of lithium batteries, and a new lithium battery handling mark for packages containing any type of lithium battery came into force on 1

January 2017 for all transport modes. These are shown below. The former hazard label and handling mark were only valid until 31 December 2018.

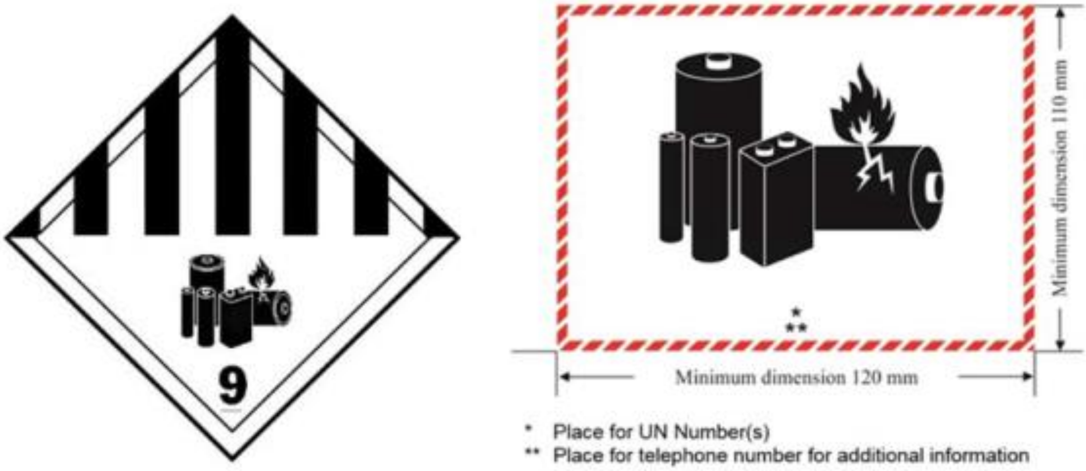

Figure 5: Lithium batteries transport labels

Figure 6: Recycling location logo

Note: There is a new 30% state of charge level for shipping Li-ion batteries as cargo on aircraft and new training requirements for people preparing lithium batteries for air cargo

4.12 Safe disposal

Lithium metal heats up when exposed to water and can easily combust. Lithium-ion batteries were implicated in a plane crash in Dubai in 2010 and consignments of these batteries are now banned from UK and US aircraft, although individual passengers are still allowed to take their laptops and spare batteries on board.

In the workplace be aware that batteries containing metallic lithium become hazardous when the outer casing is damaged, and the contents exposed or the damage is extensive enough to allow contaminants to enter, especially water. If waste is improperly processed or disposed to landfill, the batteries can catch fire below the surface of the landfill. Landfill fires can burn for a long period and are very difficult to extinguish. However, most consumer batteries still end up in landfill and this is not regarded as a serious risk to the environment. Lithium batteries should never be incinerated directly due to the risk of explosion.

Ideally, all waste batteries should be collected separately and sent for recycling. Free collection services are offered by the battery compliance schemes and waste contractors. With lithium batteries, care must be taken to ensure that the batteries are not damaged while awaiting collection. On no account should these batteries be incinerated.

Special precautions and procedures are necessary for lithium polymer (LiPo) batteries. Undamaged batteries should be discharged and stored safely in saltwater; the detailed procedure is given below.

- Place the lithium polymer battery in a fireproof container or bucket of sand.
- Connect the battery to a lithium Polymer discharger and discharge safely until its voltage reaches 1.0V per cell or lower. For resistive load type discharges, discharge the battery for up to 24 hours.
- Prepare a bucket or tub containing 25 litres of cold water and mix in 1 kg of common salt (sodium chloride). This container should have a lid, but it does not need to be airtight.
- Immerse the battery into the saltwater. Allow the battery to remain in the tub of saltwater for at least two weeks.
- Remove the lithium polymer battery from the saltwater and dispose of as hazardous waste.
- Damaged batteries should be placed directly into saltwater and disposed of as hazardous waste.

4.13 Waste classification

Lithium is detailed in the Environment Agency's guidance on hazardous waste as a substance whose presence as a source or contaminant could render a waste hazardous on account of its flammability.

Waste management companies are likely to err on the side of caution where batteries are concerned. For example, Wastecare, which is a partner in the Batteryback scheme, consigns all batteries as hazardous waste. Where lithium batteries are mixed inadvertently with other types of battery the whole consignment should be classified as hazardous waste.

Before any type of disposal route is taken the batteries should be discharged completely. Tape the contacts with electrical tape and package to prevent contacts accidentally coming together at any time. Disassembly and processing must be performed by an approved and permitted waste treatment facility that handles lithium ion batteries. If you are not sure if your waste facility can handle lithium ion batteries, contact them and verify if they are permitted or not.

For home or office disposal, many suppliers or retailers offer free recycling of rechargeable batteries. If no waste collection facility is available in your area, contact the local authority to determine if it is safe to dispose of these batteries in normal domestic waste. As always, check first if there is a local collection and recycling facility.

Recent advances in electronic technology have been accompanied by demands for enhanced battery performance, resulting in increased energy stored within the battery casing. There have been reported battery fires in kitchen drawers, shop recycling bins and electric vehicles during charging.

4.14 Recycling

With the exception of lead acid vehicle batteries, battery recycling has not been an economic option in the past as it costs much more to recycle a battery than to dispose of it to landfill. Furthermore, although battery recycling conserves valuable metals recycled lithium is five times more expensive than lithium obtained as a raw material through mining and uses six times as much energy as the processing of virgin ore. Lithium-ion batteries only contain a very small percentage of lithium, which is not economic to recycle.

One of the key justifications for recycling waste electrical and electronic equipment is that it conserves valuable metals such as rare earths, which are either scarce or can only be found outside the EU. In the case of lithium batteries, there is not such a strong rationale for recycling.

Lithium is not included in the EU's list of critical raw materials because, compared with other metals, both the supply risk and economic importance are relatively low. However, it was classified as a strategically important metal by the UK Government's Science and Technology Committee on account of the projected growth in demand for vehicle batteries. In 2011, the University of Michigan carried out a study into the availability of lithium and concluded that global resources are adequate to meet the demand for electric vehicles throughout this century. Looking further ahead, though, an EU study predicted that reserves could be exhausted by 2050 if there is high market penetration of electric vehicles. Over 40% of the world's lithium reserves lie in Bolivia and Chile, but Bolivia has not yet allowed overseas companies to mine the salt flats in which the deposits are found.

Specialist lithium battery recycling is well established in the USA by following the following general process description:

Lithium ion batteries are recycled in a specialised 'room temperature, oxygen-free', mechanical process during which the battery components are separated into three end products. These items are cobalt and lithium salt concentrate, stainless steel and copper, aluminium and plastic. All these materials are then put back on the market to be reused in new products.

5 NON-RECHARGEABLE BATTERIES

5.1 Uses

Non-rechargeable batteries are used as the routine power supply of small hand-held articles of domestic equipment such as portable radios or torches.

An advantage of non-rechargeable lithium technology is the ability for them to be stored for long periods of time before being used. This gives them great advantages for use in emergency equipment which is not constantly under power or in situations of infrequent use or application, such as emergency use in marine hand-held radios or in life rafts. Some storage lives of small, but high-powered cells, are certified for over 10 years.

5.2 Hazards

Lithium is an alkali metal that, in its elemental state, can react violently with water and ignite readily, particularly when finely divided or when the metal has a large surface area/volume ratio (such as the configuration in metal foil). In batteries, due to flammability with water, lithium is used with non-aqueous (organic solvent) electrolytes. Primary lithium batteries have lithium anodes, i.e. elemental metal

The following table describes typical forms of abuse suffered by batteries and, consequence seen.

ABUSE	CONSEQUENCE
Charging non rechargeable batteries	Venting, fire, explosion
Forced discharge	Venting
Short circuit	Overheating, venting, fire
Incineration/overheating	Venting, explosion (if heating is excessive)
Physical damage	Release of potentially hazardous materials & spontaneous ignition
Leaving for a long term uncharged or unmanaged	Venting

Table 2: Abuse and consequence

The types of lithium batteries used in proprietary consumer goods are usually matched to the use intended and are safe by design, especially if used with the manufacturer's specified charging devices. Unless integrated with the device great care should be taken to maintain the parity between the charger and device. Not all chargers will safely work with all types of batteries! Numerous product recalls and incidents show that safety cannot be taken for granted. If used correctly there is only a small risk of serious malfunction, and it is therefore important to follow the manufacturer's recommendations when using electrical equipment containing lithium batteries. **Follow the disposal advice of the manufacturer and any internal waste management guidance.** Primary battery cells that are disposed of should be protected against short circuit in the waste stream and exposed terminals should be covered with insulating tape before disposal.

5.3 Saltwater

Saltwater on any of these batteries can be a major hazard. Prolonged exposure can result in corrosion of the casing, exposing the battery components to the air. Lithium-thionyl chloride batteries are often used in marine applications but if saltwater ingress into a battery chamber occurs (due to a failed pressure seal, for example), the batteries inside can become corroded resulting in extremely hazardous hydrogen chloride and sulphur dioxide vapours being produced. This can also happen if the internal electrolyte is exposed to air due to the water vapour in air. Both hydrogen chloride and sulphur dioxide are corrosive and toxic, and intensely irritating to the respiratory tract even when present in low concentrations.

5.4 Safe storage

Lithium batteries should be stored at room temperature. If in cold conditions take care as removal to a warm moist area may cause internal condensation of moisture leading to a short circuit.

5.5 Automotive batteries

Most automotive batteries are of a lead acid type, so are treated as special waste. On consignment to a waste facility, special waste consignment notes should be retained for at least three years.

5.6 Industrial and vehicle (EV) batteries

In the case of any industrial batteries that are special waste a **special waste consignment note** should be retained for at least three years. For those that are not special waste a **controlled waste transfer note** should be retained for a minimum of two years.

5.7 Safe disposal

In waste management operations, processing lithium batteries can provide extremely high currents and the batteries can discharge very rapidly when short-circuited. A too-rapid discharge of a lithium battery can result in overheating of the battery, thermal runaway, rupture of the casing or containment and fire and explosion. Lithium-thionyl chloride batteries are particularly susceptible to this type of discharge. Consumer batteries have lower intrinsic risks as they incorporate overcurrent or thermal protection or vents in order to prevent a fire or a physical explosion.

5.8 Waste classification

Lithium batteries are not classified as hazardous waste by the Hazardous Waste Regulations 2005. The European Waste Catalogue lists NiCd and mercury-containing batteries as hazardous, but there is no specific category for lithium batteries, merely a category of “other batteries” classified as non-hazardous.

The Environment Agency, in its guidance on battery returns, explains that although non-hazardous in terms of the 2005 Regulations, lithium batteries still present a risk to safety and the environment. Lithium batteries should not be put in the post (and are banned from air mail) and are subject to dangerous goods legislation when transported by road, rail or sea. Lithium batteries are classified by the ADR Regulations as Class 9 (other dangerous goods) and must be packaged in a UN container conforming to Packing Group II specifications.

Batteries for commercial use should be in a discharged condition prior to their disposal. Generally, a primary lithium cell is considered to be discharged once its voltage reaches 2 volts or less under a current of C/100 (C is the rated capacity of the battery in ampere-hours). Once discharged, large quantities of lithium batteries can be shipped to a hazardous waste facility for end-of-life processing, which is often incineration, if there is no materials recovery planned. There are a few companies that recycle lithium batteries in the UK, including AEA Technology and Veolia.

5.9 Recycling

To recycle batteries containing lithium metal, ferrous and non-ferrous metals are recovered using an alkaline solution, and the lithium is converted to lithium carbonate, which can be used again in batteries.

Liquid nitrogen may be used to freeze lithium-based batteries before shredding, crushing and removal of the lithium, as well as other battery components. The lithium is dissolved in a solution to make the metal non-reactive and is sold for producing lubricating greases. Similarly, the cobalt is separated, collected and sold.

6 RISK ASSESSMENT METHODS

All rechargeable and non-rechargeable lithium battery technology presents high energy power sources and so are potentially hazardous, especially if damaged, exposed to fire or electrical short circuit when they may, in extreme circumstances, cause fires or explosions. Additional control measures over and above those for standard consumer equipment such as laptops and mobile phones must be applied when using specialist equipment. This is especially the case for equipment designed / constructed / specified or modified and serviced in house. The risks associated with lithium batteries must be included in the risk assessment for the work. Where the total weight of lithium batteries exceeds 1 kg in one area then a specific risk assessment is needed. The written risk assessment must address the hazards, determine the consequences and the severity and define the control measures needed to eliminate or reduce the risk of fire or explosion, and specify the transport measures and eventual disposal procedures.

As detailed in a specimen risk assessment below, the hazards are widespread and not simply related to the electrical energy available. This residual or final charge of energy may be low for spent batteries, although it is never zero. This final charge relates to the hazardous properties of component parts and the collective chemical and mechanical hazards which are present if a fire engulfs individual batteries, stores of new batteries or stockpiles or stillages or bins of expended batteries.

In formulating a basic risk assessment of the storage, transport, use and disposal of lithium batteries the following aspects should be considered.

6.1 Generic risk assessment

6.1.1 Hazards and consequences

Hazards fall into occupational, environmental and human related hazards.

Occupational hazards relate to the work being undertaken or the use to which the battery is put, or the processing procedures and include:

- Electrical power, electrical shock (> 50 volts direct current)
- A source of ignition to flammable and combustible materials
- Outbreak of fire, and communication to structures, buildings and equipment
- Exposure to lithium metal, lithium salts and HF, hydrogen fluoride
- Physical damage to batteries through contact with vehicles and equipment, contact with process machinery and abrasion on conveyors

Environmental hazards include fire and explosion, pollution and leakage of electrolyte and additionally refer to public safety hazards such as theft of metal and water ingress leading to battery corrosion.

Human factors hazards include occupational health effects, toxicity and burns, skin contamination and eye damage.

6.1.2 Top event

The top event is a fire or explosion of materials initiated by decomposition, discharge or an electrical short-circuit from a large lithium composition battery.

6.1.3 Controls

The following controls may be considered.

6.1.3.1 Engineering and technical controls

- Provide dedicated battery storage containers or racking for each type of battery
- Ensure that there is adequate ventilation, with forced air flow if necessary
- Ensure that lighting is adequate to identify products and materials correctly
- Use hand trucks or similar for moving quantities of material that provide Manual Handling Operation (MHO hazard
- Provide stillages that are designed to minimise risks from fire and explosion, preferable in a secure space in the open air

6.1.3.2 Procedural control

- Batteries should be stored in places which are easily accessible for handing
- Containers which are clearly labelled
- Stillages and storage containers located well away from sources of heat &/or sunlight &/or sources of fire
- Ensuring, so far as reasonably practicable, that batteries are discharged below 40% of capacity
- Suitable separation and segregation of batteries from uncontained or unregulated sources of combustible or flammable materials. In waste processing this will inevitably be Liquefied Petroleum Gas (LPG) cylinders or containers of fuels and flammable liquids such as petrol or chemical solvents

6.1.3.3 Behavioural control

- Regular monitoring and supervision of storage location and conditions to ensure that no further damage occurs and that risk in storage is managed
- Provide appropriate safety signs and labels
- Provide appropriate information and training to staff and contractors where relevant

6.1.4 Frequency or probability of a top event

The most accurate way to gauge the probability or likelihood of a serious fire or explosion is to base the evaluation on past incident history. A value of the likelihood can be gauged from how many lithium battery fires occurred during the past year. Consequently, accurate data should be maintained on incidents and near misses or hazard observations as they occur. Anecdotally, in normal routine use, storage, transport, processing or operations (including charging batteries) there are very few incidents, except perhaps with battery chargers. However, in waste processing of lithium batteries there could be four or more incidents per annum of fires in processing work which may be attributable to lithium battery decomposition during receipt, storage or processing..

7 EMERGENCY PRECAUTIONS FOR ALL TYPES

In the event of an emergency such as a fire or decomposition of lithium batteries the following precautions should be considered as part of an emergency plan.

1. Clear everyone from the area.
2. If you are trained to do so and can do it safely with the correct equipment, deal with the emergency using an extinguisher, fire blanket, bucket of sand etc.
3. In the event of a fire the material inside the battery may be released. This may be toxic and corrosive. One recommendation is to fight small lithium fires with a Type D special metal fire powder extinguisher, but these are very special, need specialist application techniques and may not be generally available.
4. First Aid information on specific chemicals contained in the lithium battery can be found in the manufacturer's MSDS (material safety data sheet).
5. If a Type D extinguisher is not available, use copious amounts of fresh water as a fine spray to swamp the fire. This will not extinguish the fire immediately and will result in the lithium generating hydrogen. This may in turn fuel a fire or explosion if the firefighting or drench process is not managed properly. Continue to use plenty of water until the fire is extinguished and the batteries are cooled. Be aware of the possible risk of explosion and maintain a safe distance. Where possible use water spray or drench equipment remotely.
6. Call the local authority fire and rescue service. Tell them the fire involves lithium batteries.
7. Evacuate non-essential personnel from processing buildings.

8. If it is not possible to safely transfer the battery / equipment to a safe place in the open air, ventilate the area with fresh air.
9. Use suitable Personal Protective Equipment such as eye protection and gloves while decontaminating surfaces after any fire or spillage incident.
10. Disconnect the cell or battery if practicable in a way that prevents sparks and avoids contact with internal components.
11. Leave the cell or battery in a remote, well ventilated area.
12. Dilute any spillages / residues with plenty of water and wash away spilt liquid that may be corrosive.
13. Report the incident to your local safety adviser and the Health and Safety Executive, as appropriate.

8 KEY LEGISLATION AND GUIDANCE

8.1 Safety legislation

Relevant principal safety legislation comprises:

- The Health and Safety at Work etc Act 1974.
- The Management of Health and Safety at Work Regulations 1999.
- The Control of Substances Hazardous to Health Regulations 2002, as amended.

8.2 Environmental legislation

Several pieces of legislation regulate the management of waste batteries in England & Wales and Scotland.

- Waste Batteries & Accumulators Regulations 2009. These regulations address Compliance Schemes, the organisations that assist battery producers to meet their obligations.
- Waste Batteries (Scotland) Regulations 2009, which transpose parts of the relevant EU Directive (the Batteries Directive), including storage requirements, into Scottish law.
- Environmental Protection (Duty of Care) Regulations 1991 which impose obligations to ensure that waste is managed in a way to avoid harm to the environment.
- Special Waste Regulations 1996 that define special waste and describe the provisions for compliant management.

Since the Battery Directive came into force, batteries are being stored on premises prior to recycling. Recycling stops batteries going to landfill and helps recover thousands of tons of metals, including valuable metals like nickel, cobalt and silver. This reduces the need to mine new materials, cutting CO_2 emissions and saving resources.

8.3 The Batteries Regulations 2009

The EU Batteries Directive, implemented in the UK by the Waste Batteries and Accumulators Regulations, 2009 introduced a producer responsibility regime for batteries by which manufacturers and importers of batteries pay for their collection and recycling. Retailers and other suppliers who sell more than 32 kg of batteries each year must take them back from consumers free of charge, and battery collection bins are now seen in most retail stores, supermarkets and similar locations. The actual recycling is organised by compliance schemes such as BatteryBack, which collects batteries on behalf of its members and ensures that they are recycled to the standards laid down in the directive. For lithium batteries, at least 50% of the collected batteries must be recycled (the targets are higher for lead-acid and NiCad. As disposal of waste **industrial** and **automotive** batteries by landfill and incineration was banned on 1 January 2010 this legislation has created a market for battery recycling and has resulted in the development of new infrastructure. Until recently, all collected batteries were sent to other European countries, such as Belgium, for recycling. However, UK capacity is now set to grow significantly.

8.4 Types of batteries regulated by the legislation

The legislation regulates the following types of rechargeable and single use (expendable) batteries:

- Automotive: usually unsealed lead acid types which provide traction power to start engines. Some types of batteries found in modern cars include AGM (absorbent glass mat) which are essentially spill-proof as the acid is held within the fine glass mat.
- Industrial: those used for industrial use such as emergency power supply, some alarm systems or those used to propel electric vehicles.
- Portable: generally, all other types of battery but typically within the sector these will be sealed batteries and include AA, AAA, C & D types

8.5 Special waste batteries

- Batteries containing nickel cadmium (Ni-Cd) and mercury (Hg) and also lead acid batteries are special waste as a result of the hazardous properties of the chemicals that they contain.
- lithium ion batteries (Li-ion) are dangerous for the purposes of the Carriage of Dangerous Goods Regulations due to the risk of fire as a consequence of the lithium reacting with water or other materials or in the event of an electrical short, but are not considered to be special (hazardous) waste in terms of the European Waste Catalogue.
- In cases where a mixed load of portable batteries is to be disposed or where the types of portable batteries in the waste are unknown then it is necessary to treat the entire consignment of waste as special waste.
- Although lithium-ion batteries (Li-ion) are dangerous, they are not classified as special waste. In this case the nature of the hazard is the risk of fire as a consequence of the lithium reacting with water or other materials or in the event of an electrical short.

8.6 Storage

No registration or other notification is required for storage of a company's own waste. However, any storage must comply with the provisions of the Waste Management Licensing Regulations 1994 Schedule 3 Paragraph 41 which imposes a 12 month time limit and restrict the volume of waste. The waste producer must keep records of disposal for all consignments of waste batteries that are removed from any waste treatment facility.

9 REFERENCES ETC

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9.1 Definitions

Corrosion	Corrosion refers to a natural process which converts a refined metal to a more chemically stable form such as an oxide, hydroxide or sulphide (sulfide). It is the gradual destruction of materials by chemical and/or electromechanical reaction with their environment.
Decomposition	Decomposition refers to the process by which an undesired chemical reaction takes place. It is the separation of a single chemical compound into its two or more elemental parts or to simpler compounds
Hazardous	Activity that involves risk or danger
Intercalated	To insert between layers
Venting	To provide an outlet for air, gas or liquid
Runaway Reaction	Runaway Reaction refers to a process by which an exothermic reaction goes out of control, often resulting in an explosion.
Mechanical Hazards	A mechanical hazard is any hazard involving a machine or process.
Mechanical handling operations	Manual Handling Operations are the operation involved in the movement, storage, control and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption and disposal.
Top Event	The term 'Top event' refers to the point at the end of a fault tree and the beginning of an event tree. In the case of lithium batteries this would be a fire or an explosion.

9.2 Acronyms

HF	Hydrogen fluoride or Hydrofluoric acid, if in aqueous solution
LIPO	Lithium Polymers
MHO	Mechanical handling operations
NiCd	Nickel Cadmium or NiCad, Nickel Cadmium battery
NiMH	Nickel-metal hydride battery
UAV	Unmanned aerial vehicles
UGV	Unmanned ground vehicles