INFORMATION ON THE USE OF LITHIUM-ION BATTERY BASED ENERGY SYSTEMS IN NON-ROAD MOBILE MACHINERY

1. SCOPE

This document addresses lithium-ion battery-based energy systems and their main differences from lead-acid batteries and internal-combustion engine powered machines. Target groups are end users of-, as well as sales- and service organizations, rescue services, and insurance providers for industrial trucks and construction equipment.

2. LITHIUM-ION BATTERY SYSTEM

A Lithium-Ion (Li-Ion) battery contains electrochemical cells based on the principle of lithium ions to transfer electric charge from the negative electrode (anode) to the positive electrode (cathode). Connecting such a battery to a closed electrical circuit results in an electric current to flow.

Li-Ion batteries provide high energy density and are thereby an efficient way of storing electric energy. Li-Ion batteries also have high power capability, which enables fast charging as well as high working performance. Li-Ion batteries in different forms can for example be found in consumer electronics, mobile telephones, computers, and electric vehicles.

Multiple Battery Cells are connected, arranged, and encapsulated in a Battery Module, which normally also contains logics for cell management and safety.

In many applications, several Battery Modules are in turn arranged and encapsulated in a Battery Pack. Depending on application, addition encapsulation levels may exist.

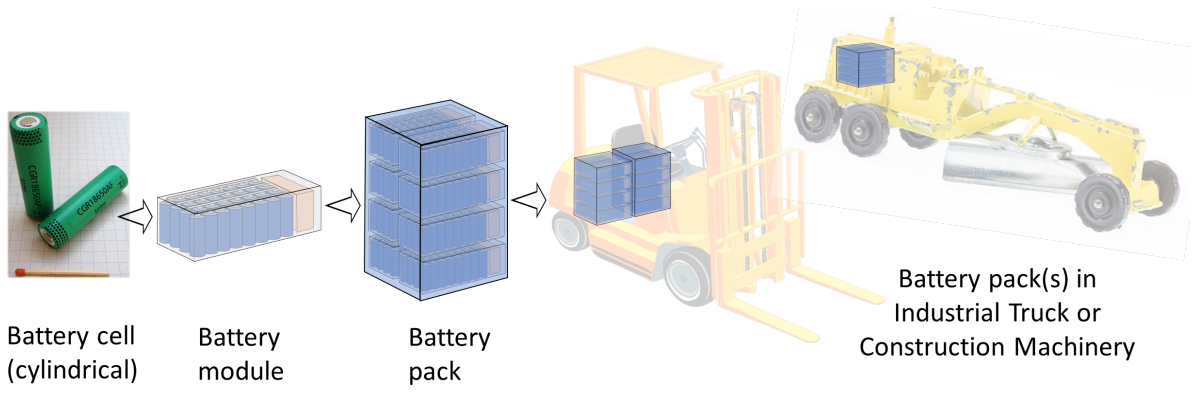

Figure: Conceptual sketch of a Lithium-Ion battery-based energy system.

Properties of some rechargeable Battery types (non-exhaustive):

Type of battery chemistry	Specific Energy		Efficiency[1)]	Usable Energy[2)]
	Wh/kg	Wh/L		
Lead-acid	30–50	50-90	<80%	~50%
Lithium-ion	90–250	125-600	>95%	~80%

1) Percentage of electric energy put into the battery at charging that is later retrieved
2) Amount of electric energy stored in the battery that can be utilized

A Lithium-Ion battery system contains a Battery Management System (BMS), which is central to the safe and efficient operations of the battery. The BMS ensures that the battery cells stay within a safe voltage, current and temperature range.

The BMS monitors the energy flow within the electric machine during driving and regenerative braking, as well as to the electric machine during charging. The BMS manages battery pack voltage, current, battery charge level (SOC), depth of discharge (DOD) and temperature and voltage of battery cells. The BMS monitors large quantities of data related to the operation, performance, and health of the battery, and can be integrated into the vehicle design and its safety functions. The BMS also communicates with the charging infrastructure so that the battery is always charged in a suitable way.

3. LITHIUM-ION, COMPARISON WITH OTHER ENERGY SYSTEMS (LEAD-ACID, DIESEL, LPG)

	Electric drive(s)		Internal Combustion Engine (ICE) drive	
TABLE 1	**Hazards at energy refill (charging / refueling)**			
Risk of	**Li-Ion**	**Lead-Acid**	**Liquid Fuel (diesel)**	**Gaseous fuel (LPG)**
Leakage from Energy System	-N/A-	Acid spillage	Diesel (and similar fuel, urea)	Gas Spillage
Emissions (to ambient)	-N/A-	Acid leakage $2H_2 + O_2$ formation and leakage	Fuel vapour	Gas leakage
Requirements to recharge	External electrical power source If battery exchange, risks associated to handling of batteries	Dedicated charging area, approved ventilation If battery exchange, risks associated to handling of batteries	Dedicated area Refueling outside dedicated area can be done, may need exemption	Dedicated area If gas tank exchange, risks associated to handling of gas tanks
	Explosion / Overheating risk	Explosion risk	Explosion risk	Explosion risk

TABLE 2	**Hazards during DRIVING (at intended ambient conditions)**			
Risk of	**Li-Ion**	**Lead-Acid**	**Liquid Fuel (diesel)**	**Gaseous fuel (LPG)**
Leakage from Energy System	N/A	Acid spill	Diesel (and similar fuel), urea	Gas Spillage
Emissions (to ambient)	N/A	N/A	Fuel vapour, exhaust emission	Gas leakage, exhaust emission
Hot surface (possible ignition source)	N/A	N/A		

Hazard rating
None
None / Minor
Minor
Moderate
Severe

These Lithium-Ion specific hazards are mitigated by warnings and error messages, derating of the machine, and eventually shut-down of the battery. Warnings are sent from the battery to the machine in case of abnormal voltage, temperature, or current. Machines are designed and tested in accordance with applicable standards and legal requirements.

4. FREQUENTLY ASKED QUESTIONS (FAQ) REGARDING LITHIUM-ION

Q: Have the specific harsh requirements for Industrial Trucks and Construction Equipment been considered?
A: Yes. Vibration, shock and mechanical impact/collision, as well as extreme temperatures and reliability needs are fully complied with. Also, washing/cleaning can be performed according to the manufacturer's instruction.

Q: Which risks are associated with Lithium-Ion batteries?
A: See tables 1 and 2 above.

Q: How are these risks mitigated by the machine manufacturer?
A: The manufacturer has considered fire in its risk assessment and implemented risk reduction/protective measures, as described in the machine instructions. By design there are embedded safety systems (mechanical, electrical, and/or thermal/logical layers) to detect safety critical failures (including fire) and protect from their consequences. The user should always have a battery management plan in place in case of emergency.

Q: How to handle fire incidents?
A: When safe to do so, press emergency stop and exit the machine. Call fire services and follow local evacuation instructions. This procedure is not different for a Lithium-Ion battery compared to any other energy system, for example lead-acid, diesel, and LPG. The embedded safety system ensures that the battery is disconnected so that it is safe to exit the machine and extinguish a possible fire.

Q: How to handle a damaged battery?
A: If damage to battery or energy system is detected, remove damaged batteries from service. Follow the manufacturer's instructions.

Q: Is formal authorization or training required for driving a Li-Ion powered industrial truck or construction equipment?
A: No particular training is needed. National laws on occupational health and safety apply. The manufacturer provides relevant documentation and defines skill needs.

Q: Is there a risk in the battery charging process if using the wrong charger?
A: Yes. Only use the manufacturer's recommended battery chargers for the respective machine.

Q: How fast can the charging process be?
A: This is determined by the battery's C-rating (power capacity), SoC of the battery, temperature, and available power supply from the battery charger. Details are described in the manufacturer's instructions.

Q: Any other special considerations for charging the battery?
A: Yes, for example in extreme ambient temperatures. Always follow the manufacturer's instructions.

Q: Which are the responsibilities of the machine manufacturer and the end user?
A: The machine manufacturer is responsible to develop and produce a machine that, as a minimum, meet all applicable safety requirements, and that is accompanied by instructions for safe use and handling of the machine. The end user is responsible for operations and that use of the machine is carried out in accordance with the manufacturer's instructions, and by competent and trained personnel per the manufacturer's requirements.

Q: Any battery transportation and/or end of life considerations?
A: Follow the machine manufacturer's instructions.

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