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MAT4BAT

Advanced materials for batteries

FP7-2013-GC-Materials

Theme GC.NMP.2013-1 - Improved materials for innovative ageing resistant batteries

Collaborative project

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Deliverable D5.1

List of relevant regulations and standards

WP	5	Product and market acceptances
Task	5.4	Regulations, Recommendations, Standards

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[1] Dissemination level: **PU** = Public, **PP** = Restricted to other programme participants (including the JU), **RE** = Restricted to a group specified by the consortium (including the JU), **CO** = Confidential, only for members of the consortium (including the JU)

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Deliverable abstract

Task 5.4 has as objective to review the current regulations and standards, the development of proposals for the improvement of regulations and standards with respect to the new state-of-the-art created in this project, if appropriate and necessary for the development and competitiveness of the European economy. The impact of current standards on the developed materials and cell architectures has to be investigated with a differentiation between test standards and regulations.

This deliverable provides a list of relevant regulations and standards. It starts with an overview of the regulation and standardization landscape and shows the main standards related to lithium ion batteries. An overview of test methods for Li-ion battery cells concerning characterisation tests, cycle life tests, abuse & reliability tests and labelling are given subsequently.

Although over 100 battery standards exist, to our knowledge they do not cover material specifiers inside Li-ion batteries. Five standards on nanomaterials mention explicitly nano-enabled energy storage materials. They prescribe methods and are therefore less of use for the Mat4Bat approach.

The European regulation has a clear impact on the way that materials can be used in the battery industry. There exists a specific directive for batteries that prescribes national battery collection mechanisms, oblige the recycling effectiveness of Li-ion batteries to be over 50% and give limits on the use of some heavy metals. These heavy metals are hardly used in Li-ion batteries however. The Reach directive has an annex with substances of very high concern (SVHC) that have to be mentioned if used and ideally they have to be avoided. Some of them are used as an electrolyte solvent in Li-ion batteries and for them the legal prescriptions have to be followed.

Batteries have to be marked by a waste collection symbol and their capacity in Ah must be indicated. Some standards prescribe additional marking. A link to a template for a battery information factsheet provided by RECHARGE (the association for advanced rechargeable batteries) is given in this document.

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1. Introduction: regulation and standardisation landscape

This deliverable provides a list of relevant regulations and standards dealing with rechargeable batteries. In the introduction the difference between regulation and standardisation is covered. Since many standardisation activities exist an overview of the organisations and the working groups is given. After the introductory chapter the regulation and standardisation is discussed separately with an elaborate overview on published standards and those under development. Three themes are covered afterwards to filter the practical information of standards into contents that is of use for the Mat4Bat-project: characterisation tests, cycle life tests and abuse & reliability tests. The report ends with a conclusion.

1.1. Regulation versus standardisation

Many terms are used like regulation, legislation, standards, law and directives. These terms have different meanings and refer to the institution that creates them. For example European regulation is a binding legislative act that must be applied in its entirety across the EU. It is the highest level possible of rules made by the European Commission. On national level on the contrary a regulation is basically the way the legislation is enforced by regulators and they support the requirements of the national legislation which is the highest level.

- **European legal acts**

The European Commission worked out a clear website explaining their legal acts[4].

- A "regulation" is a binding legislative act. It must be applied in its entirety across the EU. For example, when the EU wanted to make sure that there are common safeguards on goods imported from outside the EU, the Council adopted a regulation.
- A "directive" is a legislative act that sets out a goal that all EU countries must achieve. The individual countries have to incorporate into their own laws on how to reach these goals.

The directives are of most importance to bring goods to the European market. Every manufacturer has to decide what directives are valid for its products and to be in compliance with them. If directives are in vigour and they are followed, then the manufacturer can put CE marking on his product. However, since directives are not directly imposed on products, national laws and international standards should be followed. Some directives are:

- Machine directive
- Explosive atmosphere directive
- Battery directive
- Low voltage directive.

- **National legal acts**

The exact legal acts that a country can apply, is country dependent and the differences between legal acts may be subtle. Anyway, countries have at least laws and regulations[5]. Both are obligatory. Laws are made by the government and regulations by government depending authorities. European directives are incorporated in national laws and regulations. For example the

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[4] http://europa.eu/eu-law/decision-making/legal-acts/index_en.htm

[5] http://www.differencebetween.net/miscellaneous/difference-between-legislation-and-regulation/

basic rules in the Low voltage directive are worked out in the Belgian regulation on electrical installations, the 'Algemene richtlijn op elektrische installaties (AREI/RGIE)'. These regulations can cover more subjects than those given in a specific directive. For example the Belgian AREI prescribes rules how to install batteries. This is not part of the Low voltage directive.

- **United Nations**

Apart from the European and national legal acts, the United Nations make also regulation that is compulsory. For batteries is of interest the UN Manual of Tests and Criteria, Lithium Battery Testing Requirements, UN38.3 (this will be discussed in detail later on). The United Nations have region offices like the United Nations Economic Commission for Europe (UNECE). They develop regulation to bring vehicles to the European market. In Europe they also publish the rules on transport of dangerous goods over road (ADR).

- **Transportation organisations**

Since almost all goods have to be transported between basic material and finalised product for the consumer, the organisations that represent the flight, ship and rail companies are important. They make each rule on the transportation of dangerous goods including rules on packaging methods and identification of the goods.

- **Standards**

Standards are not written by a government, but by standardisation organisations. These can be public and private. Typically they refer to product performance or how to do a job. Standards are voluntarily, except if a specific standard is prescribed in a national regulation. This occurs rarely. Standards are recognised as good workmanship. If a standard is not followed then a manufacturer must be able to defend himself to have taken a different route. In Europe, the standards by the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) are made in accordance with the directives. Following the appropriate standards result therefore in a thought of compliance with the directives. Often CEN and CENELEC take over standards by the International Electrotechnical Committee (IEC) and the International Standards Organisation (ISO) and add clauses to bring the standards in accordance with the European rules on *e.g.* environmental protection, safety and consumer protection. A specific class are the harmonised standards[6]. The so-called 'New Approach' represents a way of technical harmonisation by splitting the responsibilities between the European legislator and the European standards bodies. It is based on the following fundamental principles:

- European directives define the 'essential requirements' to ensure a high level of protection of health, safety, consumer protection, or the protection of the environment.
- The task of drawing up the corresponding harmonised standards meeting the essential requirements of products established by the directives is entrusted to the European standardisation organisations (CEN, CENELEC and ETSI).
- Products that comply with harmonised standards are presumed to meet the corresponding essential requirements (presumption of conformity, CE marking) and Member States must accept the free movement of such products.
- The use of these standards remains voluntary. Alternative standards are possible but manufacturers then have an obligation to prove that their products meet the essential requirements.

[6] https://osha.europa.eu/en/safety-and-health-legislation/standards

1.2. The use of standards

Standards are made with dissimilar aims. Unfortunately, often the objectives are not explicitly given. A specific standard can mix several objectives. These can be:

- design
- performance tests
- safety design
- safety tests
- environmental protection
- classification
- guidance
- recommendation.

A standard can thus be found that guides the battery user in the different types of batteries and installation methods. A standard can explain how to design a battery installation, probably stressing safety aspects. Other standards can prescribe performance tests and safety tests.

Closely related to batteries are standards that involve:

- functional safety
- test methods.

Functional safety is about risk containment like the standards on the

- safety of machinery
- safety instrumented systems for the process industry sector
- functional safety of road vehicles.

They are closely related to risk assessments like the Hazard on Operability Analysis (HAZOP) or the Failure Mode and Effect Analysis (FMEA).

Standards that prescribe performance tests and safety tests often refer to standards with test methods that work out specific test conditions.

Standards can cover different life cycle stages being:

- design
- production
- transport
- installation
- use
- return.

1.3. Standardisation organisations

Standardisation on batteries is much broader than the legislation and many bodies are developing standards. The worldwide standardisation organisations that include battery standardisation are:

- International Electrotechnical Commission, IEC
- International Standardisation Organisation, ISO
- Institute of Electrical and Electronics Engineers, IEEE.

At European level the European Committee for Electrotechnical Standardization, CENELEC, is involved regarding batteries. At national level the most active organisations *i.e.* publishing many standards related to batteries, seem to be:

- China
- Japan Electric Vehicle Association Standards (Japan)

- VDE (Germany)
- SAE (United States of America)
- ANSI (United States of America).

Also commercial organisations develop standards on batteries. The most known are:

- Underwriters Laboratory, UL, on all batteries and applications
- Telcordia on storage in telecommunication
- DNV GL on batteries in ships and large Li-ion batteries
- Ellicert on certification EV batteries
- BATSO, aiming at light electric vehicles, LEV.

1.4. Committees in the international and European standardisation organisations active in battery standardisation

Within the IEC the following committees are relevant for batteries:

- **IEC TC21 Secondary cells and batteries**

The committee deals with all batteries and applications, except the electric vehicle at system level. They also include flow batteries. The applications comprise on-grid batteries, air-craft batteries and battery safety. They have general parts and battery specific parts like stationary lead-acid batteries and traction lead-acid batteries.

- **IEC SC21A Batteries with alkaline and other non-acid electrolytes**

This committee makes standards on NiCd, NiMH, Li-ion batteries.

- **IEC TC35 Primary cells and batteries**

It prepares international standards for primary cells and batteries, particularly those relating to specifications, dimensions, performance and guidance on safety matters. They publish a standard on the safety of primary and secondary lithium cells and batteries during transport.

- **IEC TC120 Electric energy storage (EES) systems**

This committee tackles system aspects on grid integration of EES systems. They define unit parameters, testing methods, planning and installation. They guide for environmental issues and system safety aspects.

- **IEC TC113 Nanotechnology standardization for electrical and electronic products and systems**

The committee treats nano-enabled electrical energy storage. Other subjects are: photovoltaics, graphene, luminescent materials and electrotechnical products. They make standards for key control characteristics in nanomanufacturing. Also they make standards on material specifications in nanomanufacturing.

- **IEC TC69 Electric road vehicles and electric industrial trucks**

This committee deals mainly with charging methods. They also publish a standard on ultracapacitor test methods.

Within the ISO the following committees are relevant for batteries:

- **ISO TC22 Road vehicles**

This committee takes the system level of electrically propelled road vehicles into account.

- **ISO/TC 229 Nanotechnologies**

ISO has a committee on nanotechnologies, ISO/TC 229. It cooperates with the IEC counterpart (TC113) (see above) and seems to focus on the characterisation of graphene and carbon nanotubes, not on battery materials.

Other material related committees in ISO and IEC do not seem to be active in battery materials according to the titles of their standards .

In IEEE the Working Group for Energy Storage Subsystems, ESS_WG, is active on battery standards.

At CENELEC committee CLC/TC21X covers secondary battery standards. They mainly take over the standards made in IEC TC21 and IEC SC21A. These standards may receive some specific prescriptions for Europe. They consider environmental requirements from the European directives. The committee prepares hardly standards on their own. CLC/TC301 covers road vehicles including electric vehicles.

2. Regulation

In the introduction an explanation is given on regulation, directives and laws. Also the involved authorities were given. For batteries probably of most interest are:

- the regulations on transport of goods, including batteries
- the CE regulation
- the European battery directive
- the directive on restrictions of hazardous substances (RoHS)
- the regulation on the registration, evaluation, authorisation and restriction of chemicals (REACH)
- the battery capacity labelling regulation
- the UNECE vehicle regulation

An additional survey has been made on nano-materials. Also a link to a template for a battery information factsheet is given.

2.1. Transportation regulation

All batteries that are transported have to fulfil the UN38.3 regulation by the United Nations[7]. It prescribes test methods and criteria that battery cells and batteries have to fulfil before delivery.

The international organisations for the transport modes have their own regulation for the transport of dangerous goods being:

- IATA: Dangerous goods (DGR), and Li-ion by air plane (checklist)
- UNECE: Dangerous goods by road: European Agreement concerning the International Carriage of Dangerous Goods by Road, ADR
- IMO: Dangerous goods by ship: International Maritime Dangerous Goods Code, IMDG
- CIT: Dangerous goods by train: Regulation concerning the International Carriage of Dangerous Goods by Rail, RID.

2.2. Regulation on accreditation and market surveillance

This European regulation[8] creates the premises of the internal European market. Apart from the national accreditation bodies and the market surveillance methods, it describes the CE marking. Therefore, it is of relevance for battery manufacturers. This regulation consolidates the meaning of CE marking. Amongst others it defines the responsibilities of the manufacturer, *i.e.*:

- carry out the applicable conformity assessment or have it carried out, for example verify compliance with applicable European Directives
- draw up the required technical documentation
- draw up the EU Declaration of Conformity (EU DoC)
- accompany the product with instructions and safety information

[7] http://www.phmsa.dot.gov/staticfiles/PHMSA/DownloadableFiles/Files/UN_Test_Manual_Lithium_Battery_Requirements.pdf

[8] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R0765

- satisfy the following traceability requirements:
  - Keep the technical documentation and the EU Declaration of Conformity for 10 years after the product has been placed on the market or for the period specified in the relevant Union harmonisation act.
  - Ensure that the product bears a type, batch or serial number or other element allowing its identification.
  - Indicate the following three elements: his (1) name, (2) registered trade name or registered trade mark and (3) a single contact postal address on the product or when not possible because of the size or physical characteristics of the products on its packaging and/or on the accompanying documentation.
- affix the conformity marking (CE marking and where relevant other markings) to the product in accordance with the applicable legislation, *e.g.* the collection symbol for batteries (see the Battery directive below)
- ensure that procedures are in place for series production to remain in conformity
- Where relevant, certify the product and/or the quality system.

This is applicable to all battery products and devices that use batteries. When a device with an original battery is converted with for example a Li-ion battery retrofit kit the full CE marking procedure needs to be redone including new technical documentation, EU DoC, serial number, etc.

2.3. European battery directive

Directive 2006/66/EC is the main European regulation on batteries[9]. The primary objective is to minimise the negative impact of batteries on the environment. It advocates a high collection and recycling rate for waste batteries and accumulators in the European member states, so as to achieve a high level of environmental protection and material recovery throughout the Community.
Producers have to finance the costs of collecting, treating and recycling all collected batteries minus the profit made by selling the materials recovered.

- **Labelling**

The directive prescribes an additional label to the CE marking. All batteries, accumulators and battery packs are required to be marked with the separate collection symbol (crossed-out wheeled bin) either on the battery or its packaging depending on size. In if the battery contains more heavy metals than prescribed (see below), their chemical symbols have to be added.

Figure 1: Obligatory labelling: the collection symbol for batteries.

[9] http://ec.europa.eu/environment/waste/batteries/

- **Heavy metals**

Batteries are not allowed to contain more than 0,0005 % of mercury by weight; and portable batteries not more than 0,002 % of cadmium by weight. Exceptions are emergency and alarm systems, emergency lighting, medical equipment and cordless power tools.
If batteries contain more than 0,0005 % mercury, more than 0,002 % cadmium or more than 0,004 % lead, they must be marked below the crossed-out dustbin sign with the chemical symbol for the metal concerned: Hg, Cd or Pb.

- **Collection rates**

European member states shall achieve the following minimum collection rates:

- 25 % by 26 September 2012;
- 45 % by 26 September 2016.

- **Disposal**

The European member states shall prohibit the disposal in landfills or by incineration of waste industrial and automotive batteries. However, residues of any batteries and accumulators that have undergone both treatment and recycling may be disposed of in landfills or by incineration.

- **Treatment**

Treatment has minimally to include removal of all fluids and acids. Treatment and any storage, including temporary storage, at treatment facilities shall take place in sites with impermeable surfaces and suitable weatherproof covering or in suitable containers.

- **Recycling**

Recycling processes must achieve the following minimum recycling efficiencies:

- recycling of 65% by average weight of lead-acid batteries and accumulators, including recycling of the lead content to the highest degree that is technically feasible while avoiding excessive costs;
- recycling of 75% by average weight of nickel-cadmium batteries and accumulators, including recycling of the cadmium content to the highest degree that is technically feasible while avoiding excessive costs; and
- recycling of 50 % by average weight of other waste batteries and accumulators.

So, Li-ion batteries have to be recycled for at least 50% by average weight.

According to EC regulation 493/2012 the recycling process stops at the production of output fractions that can be used without further treatment and that are not considered as waste anymore. The mass of the output fractions concerns the dry matter of the elements or compounds expressed in tons per calendar year.

The elements that are incorporated in the alloys or slags can be included in the recycling efficiency. This concerns oxygen and carbon. An independent scientific authority has to certify and publish the recycling efficiency for these cases. The percentage of oxygen and carbon in the output materials are indicated as a percentage. The total recycling rate can be expressed e.g. as 60% from which 20% as functional recycling in alloys and 15% O_2 in the slags.

The recycled materials of batteries include metal alloys and slag that can be used further without extra treatment. A possible plastic fraction can be partly recycled and partly thermally valorised. The light fraction due to the separator material that may be formed during the recycling process can be disposed for final treatment. If black mass is formed out of the electrolyte substances, then it can be used in hydrometallurgic processes and/or thermal processes.

Closely related directives on hazardous waste are:

- Directive 67/548/EEC. It determines the substances that are considered dangerous and give provisions on classification, packaging and labelling
- 2000/53/EC on end-of-life vehicles. It prohibits the use of mercury, lead, cadmium and hexavalent chromium in vehicle materials and components. It has no additional clauses for batteries.
- 2012/19/EU: Waste electrical and electronic equipment (WEEE). It sets recycling rates for this type of equipment.

2.4. Directive on the Restriction of Hazardous Substances (RoHS)

The RoHS recast Directive 2011/65/EU restricts the use of hazardous substances in electrical and electronic equipment. The objective of these schemes is to increase the recycling and/or re-use of such products. It also requires heavy metals such as lead, mercury, cadmium, and hexavalent chromium and flame retardants such as polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) to be substituted by safer alternatives. This is of importance for the electronics like the battery management system in the battery.

2.5. Regulation on capacity labelling of portable secondary and automotive batteries

The European regulation 1103/2010 governs the capacity marking requirements of portable rechargeable batteries including specific requirements related to its minimum size and location[10]. The capacity label shall include both the numeral and its units expressed in Ah or mAh. The capacity label is a marking which has to appear either on the battery label, the battery casing and/or the packaging. The capacity of portable secondary (rechargeable) batteries and accumulators shall be determined on the basis of IEC/EN 61951-1, IEC/EN 61951-2, IEC/EN 60622, IEC/EN 61960 and IEC/EN 61056-1 standards depending on chemical substances contained therein.

Battery standards may contain additional labelling prescriptions about the used battery materials, the power capability and *e.g.* recycling issues. This is covered in chapter 6.

2.6. Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)

The European Union Regulation No 1907/2006 on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) is regulating the use of chemicals in Europe[11]. REACH addresses the production and use of chemical substances and their potential impacts on human health and the environment. It requires all companies manufacturing or importing chemical

[10] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010R1103

[11] http://echa.europa.eu/en/regulations/reach/legislation

substances into the European Union in quantities of one ton or more per year to register these substances with the European Chemicals Agency (ECHA). The ECHA databases contain over 120.000 unique substances/entries at the start of 2016[12].

One of the obligations is to inform customers about the 'Substances of Very High Concern' (SVHC) that are listed on the 'Candidate List' and contained in products in concentrations higher than 0.1% weight by weight per article. These materials may be found in batteries, probably as an electrolyte solvent. A further obligation for these substances is to inform the customer, if necessary, about how to safely use the product. The authorisation procedure aims to assure that the risks from Substances of Very High Concern are properly controlled and that these substances are progressively replaced by suitable alternatives while ensuring the good functioning of the EU internal market.

The Candidate List of substances of very high concern for Authorisation[13] contains at least two substances known for use in Li-ion batteries:

- 1, 2-dimethoxyethane or ethylene glycol dimethyl ether (EGDME, $C_4H_{10}O_2$)[14]: electrolyte solvent, very persistent and very bioaccumulative (vPvB)
- 1,3-propanesultone or 1,2-oxathiolane, 2,2-dioxide ($C_3H_6O_3S$)[15]: electrolyte fluid in lithium ion batteries, carcinogenic

According to the REACH regulation batteries are identified as articles with no intended release of the substances they contain. Battery producers are users of chemicals[16]. Providing a Safety Data Sheet is not mandatory for articles and users of chemicals [17].

2.7. UNECE Electric vehicle regulation

The UNECE has developed the regulation UNECE R100, Battery electric vehicle safety, within committee ECE/TRANS/WP.29[18]. It concerns safety requirements for road vehicles with an electric power train and a maximum design speed exceeding 25 km/h. This regulation comprises safety tests regarding vibration, thermal shock, mechanical shock, fire resistance and charge protection. It is applicable to complete battery systems and battery packs[19].

[12] http://echa.europa.eu/information-on-chemicals

[13] http://echa.europa.eu/candidate-list-table

[14] http://echa.europa.eu/documents/10162/5acc50db-aba1-46f9-87ec-d2cbad906b4b

[15]http://echa.europa.eu/documents/10162/21953237/annex_xv_svhc_214-317-9_1_3-propanesultone_en.pdf

[16] http://echa.europa.eu/support/getting-started/user-of-chemicals

[17] http://echa.europa.eu/regulations/reach/safety-data-sheets

[18] http://www.unece.org/fileadmin/DAM/trans/doc/2010/wp29/ECE-TRANS-WP29-2010-52e.pdf

[19]http://www.tuv-sud-america.com/uploads/images/1421349255360808251207/tuv-sud-requirements-under-r100-lowres-us.pdf

2.8. Regulation on nanomaterials

For nanomaterials the precautionary principle is applicable in Europe[20]. In the waste framework directive, 2008/98/EC, nanomaterials are not treated as a separate category. Also the WEEE directive, the battery directive and the REACH directive (see above) do not mention nanomaterials.

2.9. Battery information factsheet for Li-ion batteries

The European Association for Advanced Rechargeable Batteries (RECHARGE) brings out an interesting document for battery manufacturers: the battery information factsheet for Li-ion batteries[21] (see the hyperlink in the footnote). The document is intended to provide information for the safe handling, storage and transport of lithium batteries by professionals. It offers Good Practice Guidance and Emergency Response Guidance while considering the hazards offered by Lithium-ion batteries. The BIF has been simplified in order to avoid any confusion with a Safety Data Sheet (SDS) (see under the REACH directive above). It also mentions some complementary information regarding the Transport & Environment Protection Legislation. The document can be used as a BIF template for companies manufacturing or placing Li-ion batteries on the market.

[20] http://ec.europa.eu/environment/chemicals/nanotech/pdf/review_legislation.pdf

[21] http://www.rechargebatteries.org/wp-content/uploads/2013/04/Li_Ion-BIF_EN-May-2013-PART-1-2-3-4.pdf

3. Standards

3.1. Standards from IEC committees on batteries

An overview of *famous* standards that are published per committee is given here. Additional information on working area of the committees are also given here.

- **IEC TC21 Secondary cells and batteries**

IEC 61427 series	Batteries for renewable energy storage
IEC 62485 series	Safety requirements for secondary batteries and battery installations (with parts for Li-ion, lead-acid, …)
IEC/EN 60952 series	Aircraft batteries
IEC/EN 60896 series	Stationary lead-acid batteries
IEC/EN 60254-1	Lead-acid traction batteries
IEC/EN 61056 series	General purpose lead-acid batteries (valve-regulated types)
IEC 62660 series	Secondary lithium-ion cells for the propulsion of electric road vehicles

It contains:

- Part 1: Performance testing for lithium-ion cells
- Part 2: Reliability and abuse testing for lithium- ion cells
- Part 3: Safety requirements

Under development	Flow battery systems for stationary applications
Under development	Secondary high temperature cells and batteries
Under development	Marking symbols for secondary batteries for the identification of their chemistry

- **IEC SC21A Batteries with alkaline and other non-acid electrolytes**

IEC/EN 62133 series	Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications.
IEC 62620	Large format secondary lithium cells and batteries for use in industrial applications
IEC 62619	Safety requirements for large format secondary lithium cells and batteries for stationary and motive applications
IEC 61960 series	Secondary lithium cells and batteries for portable applications
IEC/EN 61951 series	Portable sealed rechargeable single cells (NiCd, NiMH)
IEC/EN 60622	Sealed nickel-cadmium prismatic rechargeable single cells
IEC/EN 60623	Vented nickel-cadmium prismatic rechargeable single cells
Under development	Secondary lithium batteries for use in road vehicles not for the propulsion
Under development	Safety requirements for secondary lithium batteries for use in road vehicles not for the propulsion
Under development	Alternative methods for nickel particle insertion method to induce internal short circuit

- **IEC TC35 Primary cells and batteries**

They are out of scope for rechargeable Li-ion batteries, except their transport standard:

IEC/EN 62281	Safety of primary and secondary lithium cells and batteries during transport

It looks being a copy of UN38.3.

- **IEC TC120 Electric energy storage (EES) systems**

All standards under development:

IEC 62933-1	Electrical energy storage (EES) systems - Terminology
IEC 62933-2	Electric Energy Storage (EES) systems - Unit parameters and testing methods of electrical energy storage (EES) system - Part 1: General specification
IEC 62933-3	Planning and installation of electrical energy storage systems
IEC/TS 62933-4	Electrical Energy Storage (EES) Systems - Guidance on environmental issues
IEC/TS 62933-5	Safety considerations related to the integrated electrical energy storage (EES) systems

- **IEC TC69 Electric road vehicles and electric industrial trucks**

IEC 62576	Electric double-layer capacitors for use in hybrid electric vehicles - Test methods for electrical characteristics
IEC 61851 series	Electric vehicle conductive charging system
IEC 61980 series	Electric vehicle wireless power transfer (WPT) systems
IEC TS 62763	Pilot function through a control pilot circuit using PWM (pulse width modulation) and a control pilot wire
Under development	IEC 62840 series Electric vehicle battery swap system

- **IEC TC113 Nanotechnology standardization for electrical and electronic products and systems**

IEC TS 62607 series	Nanomanufacturing - Key control characteristics
IEC 62565 series	Nanomanufacturing - Material specifications
IEC/TS 62876 series	Nanotechnology - Reliability
ISO/TS 80004 series	Nanotechnologies - Vocabulary

Concerning battery materials, some standards on nano-enabled energy storage are under development in:

IEC TS 62607-4 series Nanomanufacturing - Key control characteristics

It concerns:

- Part 4-1: Cathode nanomaterials for nano-enabled electrical energy storage - Electrochemical characterisation, 2-electrode cell method
- Part 4-2: Physical characterization of nanomaterials, density measurement
- Part 4-3: Nano-enabled electrical energy storage - Contact and coating resistivity measurements for nanomaterials
- Part 4-4 Thermal Characterization of Nanomaterials, Nail Penetration Method
- Part 4-5 Cathode nanomaterials - Electrochemical characterisation, 3-electrode cell method

3.2. Standards from ISO committees on batteries

- **ISO TC22 Road vehicles**

ISO 12405 series	Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems

It contains:

- Part 1: High-power applications
- Part 2: High-energy applications

– Part 3: Safety performance requirements

ISO/NP 6469 series	Electrically propelled road vehicles -- Safety specifications
ISO/IEC PAS 16898	Electrically propelled road vehicles - Dimensions and designation of secondary lithium-ion cells
Under development:	ISO/DIS 18300.2 Electrically propelled road vehicles -- Specifications for lithium-ion battery systems combined with lead acid battery or capacitor

3.3. Standards from Cenelec committees

- **CLC/TC21X Secondary cells and batteries**

EN 50272 series	Safety requirements for secondary batteries and battery installations

- **CLC/TC301 Road vehicles**

EN 1987 series	Electrically propelled road vehicles - Specific requirements for safety

For batteries is of interest:

– Part 1: on board energy storage

3.4. Standards from IEEE committees on batteries

Most of their standards concern recommendations and guidance. They have two standards on Li-ion cells. They give guidance and are about use in for use in multi-cell mobile computing devices (IEEE 1625) and in cellular phones (IEEE 1725). Although they have many standards on stationary application, they are no versions for Li-ion batteries.

3.5. Standards from commercial bodies

UL 1642	UL Standard for Safety of Lithium Batteries
UL 2580	Batteries for Use in Electric Vehicles
SAE J2464	Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing
Ellicert Battéries	Certification scheme for battery cells and packs for rechargeable electric and hybrid vehicles – General requirements relating to certification – Application to Lithium based elements
BATSO 01	Manual for evaluation of energy systems for Light Electric Vehicle (LEV)-Secondary Lithium Batteries

3.6. Website with all standards

VITO has developed a website that brings together all standards on rechargeable batteries and system integration around them. This was developed in the FP7 project Stallion: Safety of large stationary Li-ion batteries. It has been reworked within the Mat4Bat project to be up to date. It can be found here:

batterystandards.energyville.be

The standards survey comprises standards that cover batteries and system integration with batteries including grid connection, PV installations, converters and EV charging. Starter batteries (or storage batteries) and primary batteries are omitted. Also country dependent standards like

JIS D 5305-3 or DIN VDE 0110 that are completely based on an ISO or IEC standard have been omitted (in this case resp. ISO 6469-3 and IEC 60664-3). The list includes standards that are referred to specifying test conditions or specific component requirements as well as standards that cover safety design in general like the FMEA (IEC/EN 60812) or the safety of machinery (ISO Guide 78).

The survey wants to alleviate system integration by being a rich source for references. Approximately 400 standards are covered. Specific fields are given per standards like the main application area or the life phase that is envisaged by a standard. The categories are an outcome of the Stallion project. They are not given by the editors in this way. The categories are:

- Target: this is about the main target of the standard like 'batteries' or 'electric vehicle' or even 'test method'.
- Application: this refers to the application with regard to the main target. It can be 'stationary' for 'batteries' and 'converter' for 'PV systems'
- Type: this is a subcategory of the application. It can be 'alkaline' for 'portable [batteries]' or 'safety' for 'automatization'.
- Life phase: this tackles the stage in the lifecycle being 'design', 'production', 'transport', 'installation', 'use' and 'return'. Standards can cover several stages.
- Objective: some standards exist for recommendation purpose, others cover safety design or *e.g.*, performance tests. It is possible that a standard covers several objectives. This classifier enables a quick separation between standards depending on the corresponding stage in the system integration.

Figure 2: Screenshot of website on battery standards

4. Performance testing according to standards

4.1. Material characterisation test

The IEC TS 62607-4 series on key control characteristics in nanomanufacturing, has a published standard to characterise cathode materials via the 2 electrode cell method:
Part 4-1: Cathode nanomaterials for nano-enabled electrical energy storage - Electrochemical characterisation, 2-electrode cell method.

Although officially the standard is for cathode nanomaterials, the test methodology is valid for all battery cathode materials. The aim is to be able to decide whether the cathode nanomaterial is usable and to select a specific material for the wanted application. The standard deals with the sample preparation, pre-treatment of the cathode material and the preparation of the screw or Swagelok cell. The standard comprises the following test methods:

- open circuit voltage
- potentiostatic impedance spectroscopy
- charge-discharge experiment (constant current + constant voltage) with a C-rate of 0,1C and 10 cycles.

4.2. Characterisation test

In the following is a selection of the main international lithium battery performances' testing standards for EV applications:

- IEC 62660-1 (performance testing for lithium-ion cells);
- ISO 12405-1 (lithium batteries for vehicles, high power applications);
- ISO 12405-2 (lithium batteries for vehicles, high energy application);
- DOE Battery test manual for plug-in hybrid electric vehicles (INL/EXT-07-12536).
- IEC 62620: Large format secondary lithium cells and batteries for use in industrial applications

IEC 62660-1:2010: Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 1: Performance testing
It specifies performance and life testing of secondary lithium-ion cells used for propulsion of electric vehicles including battery electric vehicles (BEV) and hybrid electric vehicles (HEV).
ISO 12405-1:2011: Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems -- Part 1: High-power applications
ISO 12405-2:2012: Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems -- Part 2: High-energy applications
ISO 12405-1& 2 specify test procedures for lithium-ion battery packs and systems for use in respectively high-power and high-energy applications.
The specified test procedures enable the determination of the essential characteristics of performance, reliability and abuse of lithium-ion battery packs and systems. They assist the user of ISO 12405-1:2011 to compare the test results achieved for different battery packs or systems.
Battery test manual for plug-in hybrid electric vehicles (revision3-september 2014): The DOE-United States Advanced Battery Consortium (USABC), Technical Advisory Committee (TAC) supported the development of the manual.
A short description of each characterization test of the above cited standards is presented in Table 1.

Table 1: Overview of battery characterisation test according to different standard

Application	**IEC 62660-1:2010**	**ISO 12405-1:2009**	**ISO 12405-2:2009**	**Battery Test Manual For Plug-In Hybrid Electric Vehicles** (Revision3- September 2014)
Capacity test	@ 0°C, 25°C and 45°C Discharge current (A)	@ 18°C, -10°C, 0°C, 25°C and 40°C Discharge current (A)	@ -25°C, -10°C, 0°C, 25°C and 40°C Discharge current (A)	According to manufacturer recommendations
	BEV: 1/3C **HEV:** 1C	1C 10C Imax	1/3C 1C 2C Imax	
Power test :	10sec pulse @ 20%, 50% and 80% SoC @ -25°C, 0°C, 25°C and 40°C Charge and discharge current (A) **BEV:** 1/3C; 1C; 2C; 5C; Imax **HEV:** 1/3C; 1C; 5C; 10C; Imax	several pulse duration @ 20%, 35%, 50%, 65% and 80% SoC @ -18°C, -10°C, 0°C, 25°C and 40°C Charge and discharge current (A) Imax (18s); -0.75Imax (10s)	several pulse duration @ 20%, 35%, 50%, 70% and 90% SoC @ -25°C, -18°C, -10°C, 0°C, 25°C and 40°C Charge and discharge current (A) Imax (18s); 0.75Imax (102s); -0.75Imax (20s)	Hybrid Pulse Power Characterization test: 10sec discharge pulse at Imax and 10sec charge pulse at 0.75Imax. @ each 10 % SoC from 90% 10% SOC with 1 hour rest.
BEV / HEV	Energy efficiency test @ 100% SoC and 70% SoC @ -20°C; 0°C; 25°C and 45°C Charge according to the manufacturer and rest 4 hours	Energy efficiency @ 0°; 25°C and 40°C @ 65%, 50 and 35% SoC 12s Charge pulse at Imax (or 20C) and rest 40s then 16s Discharge pulse at 0.75Imax (or 15C)		Energy efficiency 10s Charge pulses at maximum pulse current.
	BEV: Energy efficiency at fast charging @ 25°C Charge at 2C to 80% SoC and rest 4 hours Charge at 2C to 70% SoC and rest 4 hours		Energy efficiency at fast charging @ 25°C and 0°C Charge at 1C and rest 4 hours Charge at 2C and rest 4 hours Charge at Imax and rest 4 hours	
		No load SOC loss @ 25°C and 40°C @ 80% SoC No load for 24 hours; 168 hours;720 hours	No load SOC loss @ 25°C and 40°C @ 100% SoC No load for 48 hours; 168 hours;720 hours	Self-discharge test @ 30°C for 7 days
				Cold cranking: A pulse train of 2s pulses of either 5 or 7 kW at −30°C. The maximum DoD that still delivers the power has to be found.

4.3. Ageing test

The ageing tests are designed to evaluate the battery performance degradation over time by charge and discharge cycles or by minimal usage. There are two kinds of ageing tests: the calendar life test (also called storage test) and the cyclelife test. The standards related to the use of lithium ion batteries in automotive application and describing the ageing tests are:

– **IEC 62660-1** (performance testing for lithium-ion cells);
– **ISO 12405-1** (lithium batteries for vehicles, high power applications);
– **ISO 12405-2** (lithium batteries for vehicles, high energy application);
– **DOE Battery test manual for plug-in hybrid electric vehicles** (INL/EXT-07-12536).
– **SAE J2288**: Life Cycle Testing of Electric Vehicle Battery Modules. This test refers to battery configuration of several interconnected (typically 12 V) modules.

Outside the automotive standards the IEC has two standards with well-known ageing tests:

– **IEC 61960** (Secondary lithium cells and batteries for portable applications);
– **IEC 62620** (Large format secondary lithium cells and batteries for use in industrial applications)

A short description of these tests according to the standards is presented respectively in Table 2 and Table 3.

Table 2: Overview of life-cycle tests according to different standards (the table covers two pages).

IEC 62660-1:2010	BEV cycle-life Before cycling test: - Capacity test @ 25°C - Dynamic discharge capacity test @ 25°C and 45°C - Power test @ 25°C @ 50% SoC Life cycling: @ 45°C 1- Cycling with the dynamic discharge profile A until the discharged capacity reaches equivalent to 50 % of the initial dynamic discharge capacity measured at 45°C. 2- Cycling with the dynamic discharge profile B 3- Cycling with the dynamic discharge profile A until the discharged capacity reaches equivalent to 80 % of the initial dynamic discharge capacity measured at 45°C. Repeat the test profile 28 days. Every 28 days perform periodical measurement of performance (same as the before cycling test only @ 25°C). HEV cycle-life test Before cycling test: - Capacity test @ 25°C - Power test @ 25°C @ 50% SoC Life cycling: @ 45°C 1- Cycling with the discharge rich profile from 80% SoC to 30% SoC. 2- Cycling with the charge rich profile from 30% SoC until 80% SoC 3- Repeat the test for 22 hours then rest for 2 hours. Every 7 days perform power test @ 25°C @ 50% SoC. Every 14 days, perform capacity test End of test after 6 months or the performances decreased less than 80%.
ISO 12405-1:2009	Before cycling: 1C capacity test @ 25°C @ 25°C Cycling by the discharge-rich until SoC 30% then cycling by the charge-rich profile until SoC 80% for 22 hours then rest 2 hours. Repeat the test 7days Every 7 days: pulse test Every 14 days: 1C capacity test and pulse test
ISO 12405-2:2009	C/3 capacity test @ -10°C and 25°C @ 25°C From 100% to 20% SoC Dynamic discharge profile A + Dynamic discharge profile B + Dynamic discharge profile A Repeat the test 28 days Every 28 days: C/3 capacity test and pulse power @ 25°C. Every 2 months: C/3 capacity test and pulse power @ -10°C and 25°C
Battery Test Manual For Plug-In Hybrid Electric Vehicles (Revision3-	Charge-Sustaining Cycle Life Tests: It is based on the energy efficiency test profile. It takes 9 s. It is repeated for 7500 h being 300k cycles, transferring 15 MWh. It can be scaled to module and cell level. It is performed at a certain, not pre-defined SOC. The profile depends on the target size of the

September 2014)	battery: minimum, medium and maximum PHEV battery. The discharge pulse is 27 kW during 3 s for the minimum size and 23 kW for the maximum size. If the pulses reach the voltage limits before the 300k cycles then it is end of test. Charge depleting cycle life test It is based on a 360 s profile with a 50 kW, 2 s discharge pulse and a 30 kW, 2 s charge pulse for the minimum battery size. It reduces to 46 kW discharge pulse and 25 kW charge pulse for the maximum size. The profile is repeated around 7 times, removing 3,4 kWh for the minimum battery size and around 25 times, removing 11,6 kWh for the maximum battery size. After this, the battery is recharged to certain, undefined, SOC. This is repeated for 5000 cycles. It corresponds to 29 MWh for the minimum and 58 MWh for the maximum battery size
SAE J2288	Discharge to 80% DoD with the dynamic capacity test (SAE J1798) then full charge. Repeat the test 28 days Before cycling and every 28 days, the following measurement shall be performed: 1- Capacity Test at the C/3 constant current rate as defined in SAE J1798. 2- A Dynamic Capacity Test to a maximum of 100% of rated capacity as defined in SAE J1798. 3- A Peak Power Test as defined in SAE J1798 End-of-life limit: a- The measured capacity (either static or dynamic) is less than 80% of rated capacity, or b- The peak power capability is less than 80% of its rated value at 80% depth-of-discharge
	Li-ion cycle life test prescriptions outside automotive
IEC 61960	Endurance in cycles at a rate of 0,2 I_t: Discharge repeatedly a cell or battery at a rate of 0,2 I_t and at 20°C±5°C until final voltage declared by the manufacturer (corresponding to 100% DoD) and using the method declared by the manufacturer as charge method. This until the capacity delivered is less than 60 % of the rated capacity. Cells should be able to pass 400 cycles, batteries 300 cycles. I_t is the C/5 capacity as declared by the manufacturer. Accelerated test procedure: Cells are 400 times discharged at 0,5 It and at 20°C±5°C. For batteries 300 cycles are used. At the end the C/5 capacity should be more than 60% of the declared C/5 capacity.
IEC 62620	The cycle-life test is only for cells and batteries that will be used in cyclic operation. The cell or battery is discharged for 500 cycles at a rate of 0,2 I_t and at 25°C±5°C until final voltage declared by the manufacturer (corresponding to 100% DoD) and using the method declared by the manufacturer as charge method. The capacity at 0,2 I_t is to be determined. If it is above 60% of the declared C/5 capacity then the cycling is repeated with 100 extra cycles until the 60% of the rated capacity is reached. If the manufacturer would like to shorten the time then 0,5 I_t can be used for energy cells (E type); 1,0 I_t for intermediate and power type cells or batteries (M, H type).

Table 3: Overview of calendar tests according to different standards

IEC 62660-1:2010	Charge retention test @ 45°C @ 50% SoC Capacity test every 28 days Storage life test Before cycling - Capacity test - Power density test - Regenerative power test **Calendar life:** @ 45°C @ 100% SoC for BEV and 50% SoC for HEV The 'Before cycling test' is performed every 42 days. The complete procedure is repeated 3 times.
ISO 12405-1:2009	SoC loss at storage @ 45°C @ 50% SoC for 30 days The remaining capacity is measured by a 1C discharge test.
ISO 12405-2:2009	SoC loss at storage @ 45°C @ 50% SoC for 30 days The remaining capacity is measured by a C/3 discharge test.
Battery Test Manual For Plug-In Hybrid Electric Vehicles (Revision3-September 2014)	Calendar life test @ 100% SoC or a target SoC @ at least 3 different temperatures A pulse profile is executed every 24 hours. A reference performance test is applied every 32 days. It consists of a 10kW constant power discharge test and a HPPC test.
SAE J2288	SAE J2288 is only dealing with life cycling
	Li-ion calendar life test prescriptions outside automotive
IEC 61960	Two tests exist. 1 Charge (capacity) retention and recovery test: This test determines firstly the capacity which a cell or battery retains after storage for an extended period of time, and secondly the capacity that can be recovered by a subsequent recharge. The cell or battery have to be fully charged and stored for 28 days at 20°C±5°C. Afterwards it is discharged at 0,2 I_t until the declared final voltage to find the charge retention. A subsequent capacity test shows the remaining battery capacity. The charge retention has to be more than 70% of the original capacity. The remaining capacity has to be at least 85% of the original one. 2 Charge (capacity) recovery after long term storage. The cell or battery is discharged to 50% SOC at 20°C±5°C and subsequently stored at 40°C±2°C during 90 days. Afterwards a C/5 capacity test is performed. It has to be more than 50% of the original capacity.
IEC 62620	The storage test is only used for cells and batteries in stand-by applications. The test verifies the upper limit of the storage temperature specified by the manufacturer in which a minimum capacity of 85% of the rated capacity is maintained after 90 days of storage at a constant voltage corresponding to a 100% state of charge (SOC). The declared temperature should be in the range of the target test temperature and target test temperature minus 10°C. For example in the case of test performed at 57 °C, the declared temperature should be 50 °C.

5. Reliability and abuse testing from the standards

Standards have been developed for reliability and abuse tests of batteries for electric vehicles and for Li-ion cells in special. Both test types are in principle destructive tests, to be sure that no dangerous situations could occur in real life. If the result is really destructive and to which degree, that depends on the quality of the cells and the battery made with them. The difference between reliability tests and abuse tests is small. The first are conditions that should resemble real life behaviour whereas the second is not anymore real life but about foreseeable misuse. UN38.3 classifies the crush test as a mechanical abuse test, leaving it almost open if it is a reliability or an abuse test. Since it is a test for transporting cells and batteries it can be considered dealing with reliability. In IEC 62660-2 it has been formulated more clearly as a reliability test: ‘This test is performed to characterize cell responses to external load forces that may cause deformation’. However, this standard makes no distinction between abuse tests and reliability tests although these categories are in its title. In standard IEC 62619 all tests directly on cells are considered as misuse tests.

IEC 62660-3 makes a division even more difficult. This standard is about safety tests although it uses the same test set-ups as in its brother standard part 2, reliability and abuse tests. Many tests are identical and if they differ then it is mainly with easier test conditions. SAE J2929 calls their tests also safety tests considering the same test subjects as the standards mentioned before. Standard IEC 62619 however contains a section on safety tests that is different. They all belong to testing the battery management system in connection with the battery to verify that it functions correctly. In the standard UL 2580 and in regulation UNECE R100 Annex 8 these tests are called protection test. The ‘FreedomCAR Electrical Energy Storage System Abuse Test Manual for Electric and Hybrid Electric Vehicle Applications’ ((DOE) SAND2005-3123) use a classification of three abuse levels.

Concluding, it is not important to try to make a difference between abuse, reliability and even safety and protection tests since the criteria seem arbitrary and changing from standard to standard. In this document, all these tests are taken into account.

Over 100 standards exist for electric vehicle application. To find the standards that include safety testing and safety requirements, an appropriate tool is to use the website ‘batterystandards.energyville.be’. It gives the worldwide available standards on Li-ion batteries and system integration with them. It tries to be as up to date as possible. The list that is found in this way can be filtered further by omitting standards that do not cover Li-ion batteries or are specifically meant for stationary or portable application. At the end 28 standards seem to be of interest for the Mat4Bat project. The result is given in Table 4 and Table 5. The first table is split in two sections: standards that are applicable on Li-ion cells and on (Li-ion) batteries for electric vehicles. The second table is of secondary interest since the standards here become further away from the Mat4Bat objective. Three sections are given: Li-ion batteries for light weight vehicles, standards on electric vehicle level and rules that need to be followed to transport batteries by air plane, train, lorry and ship.

In the tables, general information is provided on the standards. It is given who made them, on which level they are applicable (world, continent, country, private). UL standards have been indicated here as ‘continent’ since they are extensively used in the United States and Canada. Strictly speaking these are standards of a private organisation that can be used in other regions as well. The application is given in the tables. This can be for batteries in general or for (L)EV batteries in specific or very broad, i.e. for transport means. The life phase is given (design, transport, use) and finally the title of each standard.

Table 4: Overview of standards applicable for Li-ion batteries in electric vehicle application.

Editor	Geography	Reference	Year	Application	Battery or application type	Life phase	Title
Li-ion cells and packs that can be used for EV							
United Nations	World	UN38.3	N.A.	battery	Li-ion	transport	UN Manual of Tests and Criteria, 4th Revised Edition, Lithium Battery Testing Requirements
IEC, CENELEC	World	IEC/EN 62281	2013	battery	Li-ion	transport	Safety of primary and secondary lithium cells and batteries during transport
IEC, CENELEC	World	IEC/EN 62660-2	2010	EV	Li-ion	use	Secondary batteries for the propulsion of electric road vehicles - Part 2: Reliability and abuse testing for lithium- ion cells
IEC	World	IEC 62660-03 NWP	under development	EV	Li-ion	use	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 3: Safety requirements
IEC	World	IEC 62619	under development	battery	Li-ion	design, use	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for large format secondary lithium cells and batteries for stationary and motive applications
UL	Continent	UL 1642	2012	battery	Li-ion	use	UL Standard for Safety of Lithium Batteries (primary and secondary cells)
Japanese battery association	Country	SBA S1101	2011	battery	Li-ion	use	産業用リチウム二次電池の安全性試験
Ellicert	Private	Ellicert Battéries	2012	EV	Li-ion	design, use	Certification scheme for battery cells and packs for rechargeable electric and hybrid vehicles – General requirements relating to certification – Application to Lithium based elements
(Li-ion) batteries that can be used for EV							
ISO	World	ISO 12405-1	2011	EV	Li-ion	use	Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems - Part 1: High-power applications
ISO	World	ISO 12405-2	2012	EV	Li-ion	use	Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems - Part 2: High-energy applications
ISO	World	ISO/DIS 12405-3	under development	EV	Li-ion	use	Electrically propelled road vehicles - Test specification for Lithium-ion traction battery packs and systems - Part 3: Safety performance requirements
UNECE	Continent	UNECE R100 Annex 8	2010	EV	batteries	use	Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train – REESS test procedures
UL	Continent	UL2580	2011	EV	batteries	use	Batteries for use in electric vehicles
SAE	Country	SAE J2929	2011	EV	Li-ion	use	Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells
SAE	Country	SAE J2464	2009	EV	batteries	design, use	Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing
US DoE	Country	(DOE) SAND2005-3123	2005	EV	batteries	design, use	FreedomCAR Electrical Energy Storage System Abuse Test Manual for Electric and Hybrid Electric Vehicle Applications
VDA	Private	VDA	2008	HEV	Li-ion	design, use	Test Specification for Li-Ion Battery Systems: Test Specification for Li-Ion Battery Systems for HEVs

Table 5: Overview of standards of secondary interest, applicable for Li-ion batteries in electric vehicle application.

Editor	Geography	Reference	Year	Application	Battery or application type	Life phase	Title
Li-ion batteries that can be used for LEV							
ISO	World	ISO 18243	under development	LEV	Li-ion	design	Electrically propelled mopeds and motorcycles -- Test specification and safety requirements for lithium-ion battery system
CENELEC	Continent	prEN 50604-1	under development	LEV	Li-ion	use	Secondary lithium batteries for LEV (Light Electric Vehicle) applications - Part 1: General safety requirements and test methods
UL	Continent	UL 2271	N.A.	EV	batteries	use	Batteries For Use in Light Electric Vehicles
BATSO	Private	BATSO 01	2011	EV	Li-ion	use	Manual for evaluation of energy systems for Light Electric Vehicle (LEV)-Secondary Lithium Batteries
Vehicle level							
UNECE	Continent	UNECE R100	2010	EV	batteries	use	Battery electric vehicle safety
ISO	World	ISO 6469-1	2009	EV	storage	use	Electrically propelled road vehicles - Safety specifications - Part 1: On-board rechargeable energy storage system (RESS)
SAE	Country	SAE J1766	under development	EV	batteries	use	Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing
China	Country	GBT 18384.1	2001	EV	batteries	N.A.	Electric vehicles--Safety specification--Part 1: On-board energy storage
Transport of (Li-ion) batteries							
IATA	World	IATA DGR	2013	goods	transport	transport	Dangerous goods regulations (DGR, 54th edition)
IMO	World	IMDG	2010	goods	transport	transport	International Maritime Dangerous Goods (IMDG) Code
UNECE	Continent	ADR	2011	goods	transport	transport	European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)
OTIF	Continent	RID	2012	goods	transport	transport	International Convention concerning the carriage of Goods by Rail, Annex 463 A: International regulations concerning the carriage of dangerous goods by rail (RID)

The standards mentioned in Table 4 will be explored in more detail. The Japanese standard is not available in English, so this one must be skipped. From the second section VITO is not in possession of SAE 2464. The VDA standard is specifically for hybrid electric vehicle application and therefore of less interest. The standards that remain to be investigated are:

- Cells and packs that can be used in EV application: UN38.3, IEC/EN 62281, IEC/EN 62660-2, IEC 62660-03 NWP, IEC 62619, UL 1642, Ellicert Battéries
- (Li-ion) batteries that can be used for EV: ISO 12405-1, ISO 12405-2, ISO 12405-3, UNECE R100 Annex 8, UL2580 , SAE J2929, (SAE J2464 (not possessed)), (DOE) SAND2005-3123

Strictly speaking UN38.3 and UNECE R100 Annex 8 are no standards but regulation (see chapter 2). Ellicert Batteries is a certification scheme. All these three cover test procedures for reliability and abuse testing. In this document all of them will be referred to as standards for ease.

Table 6 gives the tests that are found in the identified standards. This appears to be 29 tests. They have been assembled in four categories being ‘mechanical’, ‘thermal’, ‘electrical’ and ‘environmental’. The first three categories are often used in the standards but a specific test may be ranked in another category then here is done. No standard uses the category ‘environmental’. This class represents influence from outside the battery different from mechanical, thermal or purely electrical. It appears that the standards have quite some differences in the tests that they address. Also a large difference exists in the number of tests. UL2580 and (DOE) SAND2005-3123 contain the largest number of tests, both 16. From the second section only (DOE) SAND2005-3123 contains tests that may be applied at cell level.

The standards on Li-ion cells and batteries (first section) are rough in classifying a battery. They indicate cells, cell-blocks and the battery. A cell-block consists of cells that are placed in parallel to become a higher capacity. The standards of the second section consider more levels between cell and complete system like module and pack. The standards use different wording for these levels. In the first section of the table (Li-ion cells and packs that can be used for EV) tests that cover cell level are simply indicated by an ‘x’. In the second section (Li-ion batteries that can be used for EV) the application is given in words. As said, only one standard contains some tests that may be performed at cell level.

Looking at all tests it appears that 17 can be applied on cells. Most important is the UN38.3 regulation. The described tests have to be fulfilled to be able to transport cells and batteries. It has 8 tests. One test (overcharge) is only applicable to batteries. If the cell is smaller than 20 mm in diameter an impact test is performed, else a crush test. Therefore, it results in 9 tests in the sum at the bottom of the table.

The other standards are not obligatory. It has to be known what test conditions are given. Maybe all tests are almost the same. A short indication of the test conditions is given in Table 7.

Table 6: Tests that are given in the identified standards. If they cover cell level then an ‘x’ is set in the first section, else the applicable level is given. In the second section always the level is given since these standards are not made for cell level, but some can be used at cell level.

	Li-ion cells and packs that can be used for EV							Li-ion batteries that can be used for EV							
Test topic \ Standard	UN38.3	IEC/EN 62281	IEC/EN 62660-2	IEC 62660-03 NWP	IEC 62619	UL 1642	Ellicert Battéries	ISO 12405-1	ISO 12405-2	ISO/DIS 12405-3	UL2580	SAE J2929	*SAE J2464*	(DOE) SAND2005-3123	UNECE R100 Annex 8
Mechanical															
Vibration	x	x	x			x	x	subsystem, pack, system	subsystem, pack, system		module, system	at least subsystem			module or higher
Mechanical Shock	x	x	x	x		x		pack, system	pack, system	pack, system, vehicle	system	battery or vehicle		module	module or higher
Drop		filled package box			x		battery				system	battery		pack	
Impact	x	x			x	x	x								
Crush (mechanical integrity)	x	x	x	x		x	x			pack, system, vehicle	system	battery or vehicle		module	module or higher
Penetration							x							cell or higher	
Roll-over											system			module	
Thermal															
Temperature cycling (shock)	x	x	x	x		x	x	pack, system	pack, system	pack, system		battery		cell or higher	module or higher
High temperature endurance			x	x	x	x	x				system			cell or higher	
Thermal control check					battery					pack, system	system	battery			module or higher
Fire exposure						x	battery			pack, system	module, system	battery		module	module or higher
Propagation of thermal runaway					battery						module, system				
Rapid charging and discharging											module, system			module	
Thermal stability (ARC)														cell or higher	
Electrical															
External short circuit	x	x	x	x	x	x	x	pack, system	pack, system	pack, system	pack, system	battery		module (2 tests)	module or higher
Internal short circuit				x	x										
Overcharge	battery	battery	x	x	x	x	x				system			module	
Forced discharge	x	x	x	x	x	x	x							module (2 tests)	
Imbalanced charge											system				
Overcharge voltage control check					battery			system	system	pack, system		battery			module or higher
Overcharge current control check					battery										
Over-discharge current control check								system	system	pack, system	at least module	battery			module or higher
Environmental															
Altitude simulation	x	x				x	x								
Humidity												battery			
Dewing								pack, system	pack, system	pack, system					
Immersion / Flooding							battery			not specified	module, system	battery			
Salt spray / salt water immersion											module, system			cell or higher	
Rain test															
Electromagnetic susceptibility												battery			
Number of tests	9	10	8	8	11	11	13	7	7	10	16	13	–	16	9

It appears that some tests are close to other ones. Standard IEC 62281 is close to UN 38.3. It comprises three sections: transport tests, packaging test and safety information on packaging and transporting batteries. The transport tests use the same test clauses as found in UN38.3 and have the same test conditions. The packaging test is not on cell level, but is carried out with a box full of cells or batteries like they are transported.

The tests in 62660-3 (safety of Li-ion cells in electrical road vehicles) are often the same as in IEC 62660-2 (reliability and abuse tests). If they differ then the conditions in part 3 are easier than in part 2. Part 3 has an internal short circuit test that is not included in part 2.

The test set-ups and conditions of IEC 62660-2 are often quite different from UN38.3. It is difficult to estimate if one is more severe than the other. For example the short circuit test in UN38.3 can be performed with much lower current, but at elevated temperature and for a long period, whereas in IEC 62660-2 it is maintained only for 10 min. The crush test in the latter is with help of a bar or a hemisphere allowing a maximal deformation of 15%, whereas UN38.3 crushes between plates, allowing a maximal deformation of 50%.

Most short circuit tests create hardly a high current for large cells according to the test conditions. Cells of 2Ah have typically a resistance of 10 mOhm whereas cells of 10 Ah have a typical resistance of 2 mOhm (see G. Mulder e.a. , ‘Comparison of commercial battery cells in relation to material properties’, Electrochimica Acta, 2013, figure 8D). If an external resistance of 100 mOhm is used, this results approximately into 40A or 20 C for a small cell but only 4 C for a 10 Ah cell. The test condition of IEC 62660-2 is with 5 mOhm much harder, but is confined to 10 min. as was stated above.

Table 7: Short indication of the contents of the tests applicable at cell level. Tests that do not exist at cell level are greyed out. (The table covers two pages).

Test topic \ Standard	UN38.3	IEC/EN 62281	IEC/EN 62660-2	IEC 62660-03 NWP	IEC 62619	UL 1642	Ellicert Battéries	(DOE) SAND2005-3123
Mechanical								
Vibration	7-200Hz, 12h, 1 to $8g_n$	acc. UN38.3	10-2000Hz, 24h, 27,8 m/s^2			10-55Hz, 0.8mm, 95 min.	acc. UN38.3	
Mechanical Shock	150 g_n half sine of 6ms, 18x(cell)	acc. UN38.3	500m/s^2 half sine of 6ms, 30x(cell)	acc. Part2		shock from 75 to $150g_n$, 3X	acc. IEC62660-2	(module)
Drop		(package box)			drop from 100cm		(battery)	(pack)
Cell impact	a bar on the cell, falling weight of 9kg, 60cm	acc. UN38.3			close to UN38.3	close to UN38.3		
Crush	crushing surfaces with 1,5cm/s until 13kN, 50% deformation or 100 mV voltage drop	acc. UN38.3	crushing bar or sphere, until 1000X cell weight, 15% deformation or voltage drop of 1/3 of V_{init}	acc. Part2, speed <6mm/min.		crushing surfaces with 1,5cm/s until 13kN	acc. IEC62660-2	(module)
Penetration							acc. SAE J2464	3mm steel rod with 8cm/s
Roll-over								
Thermal								
Temperature cycling	-40 to 72°C, 10X	acc. UN38.3	-40 or $T_{min\ from\ manufacturer}$ to 85°C or $T_{max\ from\ manufacturer}$, 30X, wit or without electrical operation	acc. Part2		close to UN38.3	acc. UN38.3	-40 to 80°C cycling, 5X
High temperature endurance			130°C, 30 min.	acc. Part 2, 6h observation	85°C, 3h	≥130°C, ≥10 min., depending on cell's temperature specification	acc. SAE J2464	storing in 40, 60 and 80°C until 20% capacity decrease
Thermal control check					(battery)			
Fire exposure						cell in flame until explosion or burn-out	(battery)	(module)
Propagation of thermal runaway					(battery)			
Rapid charging and discharging								(module)
Thermal stability (ARC)								30 to 200°C above operational temp. until self-heating

Test topic \ Standard	UN38.3	IEC/EN 62281	IEC/EN 62660-2	IEC 62660-03 NWP	IEC 62619	UL 1642	Ellicert Battéries	(DOE) SAND2005-3123
Electricity								
External short circuit	<0,1 Ohm @55°C, >1h	acc. UN38.3	<5mOhm, 10 min.	acc. Part2	30 mOhm, 6h	80mOhm until 0,2V	acc. IEC62660-2	(module)
Internal short circuit				several methods, preferably an inserted nickel particle	insertion of nickel particle			
Overcharge	(battery)	(battery)	$1I_{t\,(BEV)}$ or $5\ I_{t\,(HEV)}$ until 200% SOC equivalent or 2X Vmax	$1I_{t\,(BEV)}$ or $5\ I_{t\,(HEV)}$ until 1,2 X V_{max} or 130% SOC equivalent	charge until max. voltage of charger that lost control, except if double protection is used.	3X $I_{max.\ charge\ by\ manufacturer}$, for 7h or reaching end of charge condition by manufacturer	acc. IEC62660-2	(module)
Forced discharge	12V source in series	acc. UN38.3	discharging a discharged cell at $1I_t$ for 90 min.	discharging a discharged cell at $1I_t$ for 30 min. Until <0,25X V_{nom}	discharging a discharged cell at $1I_t$ for 90 min. The current is reduced depending on the number of available protections	discharging a discharged cell by the number of charged cells in the application in series and an 80mOhm resistor until V_{tot} <0,2V	acc. IEC62660-2	(module)
Imbalanced Charge								
Overcharge voltage control check					(battery)			
Overcharge current control check					(battery)			
Over-discharge current control check								
Environmental								
Altitude simulation	11,6 kPa, >6h	acc. UN38.3				close to UN38.3	acc. UN38.3	
Humidity								
Dewing								
Immersion							(battery)	
Salt spray / salt water immersion								2h in sea water
Rain test								
Electromagnetic susceptibility								

6. Labelling in standards

Battery standards may contain additional labelling prescriptions about the used battery materials, , the size, the power capability and e.g. recycling issues. The standards covered in chapter 5 concerning characterisation and ageing tests are analysed in this chapter for labelling and marking prescriptions. Also the proposition on Li-ion batteries in a new standard under development of the marking of batteries for the identification of their chemistry is included.

It appears that in the standards on performance of automotive Li-ion batteries, being:

- **IEC 62660-1** (performance testing for lithium-ion cells),
- **ISO 12405-1** (lithium batteries for vehicles, high power applications),
- **ISO 12405-2** (lithium batteries for vehicles, high energy application),
- **DOE Battery test manual for plug-in hybrid electric vehicles** (INL/EXT-07-12536),
- **SAE J2288**: Life Cycle Testing of Electric Vehicle Battery Modules,

there are no labelling clauses included.

- **IEC 61960 (Secondary lithium cells and batteries for portable applications)**

This standard prescribes the following marking:

Each cell or battery shall carry clear and durable markings giving the following information:

- secondary (rechargeable) Li or Li-ion;
- battery or cell designation;
- polarity;
- date of manufacture (which may be in code);
- name or identification of manufacturer or supplier.

Battery markings shall provide the following additional information:

- rated capacity;
- nominal voltage.

The battery or cell designation is defined as follows. Batteries shall be designated with following form:

N1 A1 A2 A3 N2 / N3 / N4 – N5

Cells shall be designated with following form:

A1 A2 A3 N2 / N3 / N4

where

N1 is the number of series connected cells in the battery;

A1 designates the negative electrode system in which

I is lithium ion;

L is lithium metal or lithium alloy;

A2 designates the positive electrode basis in which

C is cobalt;

N is nickel;

M is manganese;

V is vanadium;

T is titanium;

A3 designates the shape of the cell in which

R is cylindrical;

P is prismatic;

N2 is the maximum diameter (if R) or the maximum thickness (if P) in mm rounded up to the next whole number;
N3 is the maximum width (if P) in mm rounded up to the next whole number (N3 not shown if R);
N4 is the maximum overall height in mm rounded up to the next whole number;

If any dimension is less than 1 mm, the units used are tenths of millimetres and the single number is written tN.
N5 is the number of parallel connected cells if 2 or greater (not shown if value is 1).

Apparently, LFP is not covered as cathode material in this standard. No designations are made for the anode.

Two examples:

- ICPt9/35/48 would designate a prismatic Li-ion secondary lithium cell, with a cobalt-based positive electrode, a maximum thickness between 0,8 mm and 0,9 mm, a maximum width between 34 mm and 35 mm, and a maximum overall height between 47 mm and 48 mm.
- 1ICP20/68/70-2 would designate a prismatic Li-ion secondary battery with two parallel connected cells, a cobalt-based positive electrode, a maximum thickness between 19 mm and 20 mm, a maximum width between 67 mm and 68 mm, and a maximum overall height between 69 mm and 70 mm.

- **IEC 62620 (Large format secondary lithium cells and batteries for use in industrial applications)**

This standard has an extensive description of marking cells and batteries. Also the battery designation includes complex cases of nested parallel/series configurations. Here a summary is given about marking and designation.

Each cell or battery that is installed or maintained shall carry clear and durable markings giving the following information:

- secondary (rechargeable) Li or Li-ion;
- polarity(can be deleted if there’s agreement between cell and pack manufacturer);
- date of manufacture(which may be in code);
- name or identification of manufacturer or supplier;
- rated capacity;
- nominal voltage;
- appropriate caution statement.

The model name and manufacturing traceability shall be marked on the cell and battery surface. The other items listed above can be marked on the smallest package or supplied with the cell or the battery.

The following information shall be marked on or supplied with the cell or the battery:

- disposal instructions;
- recommended charge instructions.

The following information shall be marked on the cell or when there is no marking place on the cell, it shall be marked in the manual.

- cell designation

Cells shall be designated with following form:

A1A2A3/N2/N3/N4/ A4/TLTH/NC

where

A1 designates the negative electrode basis in which:

I is carbon;

T is titanium;

X is other material.

A2 designates the positive electrode basis in which:

C is cobalt;

F is iron;

Fp is iron phosphate

N is nickel;

M is manganese;

Mp is manganese phosphate

V is vanadium;

X is other material.

A3 designates the shape of the cell in which:

R is cylindrical;

P is prismatic (including cell with laminate film case).

A4 designates the rate capability of the cell in which:

E is low rate long-time discharge type;

M is medium rate discharge type;

H is high rate discharge type.

The rate capability is defined as follows:

E up to 0,5 I_t

M up to 3,5 I_t

H up to and above 7,0 I_t

Two examples:

– INR50/150/M/-30NA/75 would designate a cylindrical Li-ion secondary cell, with a Nickel-based positive electrode, designed for m edium rate of discharge. Its low temperature grade is -30 ‘C. Its high temperature grade is NA. It applies for cycle use only. Its capacity retention after 500 cycles to rated capacity is 75%. Its maximum diameter is between 49 mm and 50 mm, and its overall height is between 149 mm and 150 mm.
– IMP50/240/150/M/-30+10/NA would designate a prismatic Li-ion secondary cell, with a manganese-based positive electrode, designed for a medium rate of discharge. Its low temperature grade is -30 ‘C. Its high temperature grade is 10 ‘C. It applies for stand-by use only. Its maximum thickness is between 49 mm and 50 mm, its maximum width is between 239 mm and 240mm, and its overall height is between 149 mm and 150 mm.

- **Standard for marking symbols under development**

End 2015 a new IEC working item has been approved, *i.e.* marking symbols for secondary batteries for the identification of their chemistry. A main reason is that lead smelters in both the United States and European Union have reported that increasing numbers of Lithium-ion batteries are finding their way into the Lead-acid battery waste stream. There is actually no clear identification of the battery chemistry by marking symbols. Existing marking (i.e. of heavy metal content) is not sufficient for this purpose.

Besides Lead acid and lithium ion batteries, the labelling scheme will also apply to other battery chemistries (e.g. Nickel Metal Hydride, Nickel Cadmium, Lithium-based batteries). The recycling symbol from the International Organization for Standardization (ISO) will probably be used associated with the chemical symbols indicating the chemistry of secondary batteries. Li-ion batteries can be indicated as Li (referring both to Li-ion and Li-metal) or by Li-ion. The background for this chemistry is proposed to be blue. The symbols have to be fixed on the battery by printing, labelling or moulding.

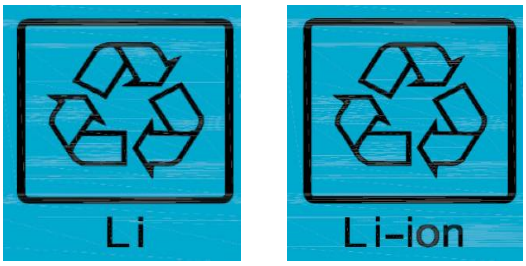

Figure 3: proposed marking for Li-ion batteries

The Li-ion battery designation as given in the previous two standards will not be included in this standard with the argument that additional marking of the different Li-ion chemistries is not necessary for the recycling.

7. Conclusion

- **Analysis on regulation with respect to Mat4Bat**

The regulation gives test exigencies before batteries can be transported, especially UN38.3. The directives on batteries, waste of electronic equipment (WEEE)and hazardous substances (RoHS) give limits in the use of heavy metals. For batteries there is stated explicitly that they are not allowed to contain more than 0,0005 % of mercury by weight; and portable batteries not more than 0,002 % of cadmium by weight. Exceptions are emergency and alarm systems, emergency lighting, medical equipment and cordless power tools.

The European regulation on registration, evaluation, authorisation and restriction of chemicals (REACH) requires all companies manufacturing or importing chemical substances into the European Union iPn quantities of one ton or more per year to register these substances with the European Chemicals Agency (ECHA). It has a 'Candidate List' giving 'Substances of Very High Concern' (SVHC), being carcinogenic, very toxic or very persistent and very bioaccumulative (vPvB). At least two materials concern Li-ion batteries: EGDME and Propanesulfone; both used as electrolyte solvents. If they are used in concentrations higher than 0.1% weight by weight per article, then the customer has to be informed about their use and how to safely use the product.

The battery directive prescribes a recycling rate of over 50% in average weight for Li-ion batteries.

No legislation on nanomaterials has been found but several standards..

The battery capacity has to be given on batteries or the packaging and expressed in mAh or Ah. This is according to the European regulation on capacity labelling of portable secondary and automotive batteries.

A link to an exemplary battery information factsheet template is given. This can be used by battery manufacturers to inform the users according to the European regulation and directives.

- **Analysis on standards with respect to Mat4Bat**

For Li-ion cells some general performance and safety standards exist like:

IEC 62660 series — Secondary lithium-ion cells for the propulsion of electric road vehicles

- Part 1: Performance testing for lithium-ion cells
- Part 2: Reliability and abuse testing for lithium- ion cells
- Part 3: Safety requirements

IEC 62620	Large format secondary lithium cells and batteries for use in industrial applications
IEC 62619	Safety requirements for large format secondary lithium cells and batteries for stationary and motive applications
Under development	Secondary lithium batteries for use in road vehicles not for the propulsion
Under development	Safety requirements for secondary lithium batteries for use in road vehicles not for the propulsion

ISO 12405-1 series Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems

- Part 1: High-power applications
- Part 2: High-energy applications
- Part 3: Safety performance requirements

UL 1642 UL Standard for Safety of Lithium Batteries

UL 2580 Batteries for Use in Electric Vehicles

These standards are not specific for Mat4Bat cells and do not consider specific active materials in the battery cells.

Concerning battery materials, some standards on nano-enabled energy storage are identified and are under development in:

IEC TS 62607-4 series Nanomanufacturing - Key control characteristics

- Part 4-2: Physical characterization of nanomaterials, density measurement
- Part 4-4 Thermal Characterization of Nanomaterials, Nail Penetration Method
- Part 4-5 Cathode nanomaterials - Electrochemical characterisation, 3-electrode cell method

These subjects seem not to have special influences on the Mat4Bat development.

- **Analysis on test prescriptions with respect to Mat4Bat**

Overviews of test prescriptions have been made regarding characterisation tests, cycle life tests and abuse and reliability tests.

- **Analysis on labelling for Mat4Bat**

In automotive standards no labelling clauses were found. In the standard for portable Li-ion batteries and the one for large format industrial Li-ion batteries there exists a marking prescription and a designation of the cell and battery. This can lead to codes like INR50/150/M/-30NA/75. Cells that are made in the Mat4Bat project have to carry the European collection symbol and the ampere hour capacity. This information may be given on the packaging that goes with the cells. A standard is under development to label batteries with the international recycling symbol. For Li-ion cells below the symbol it is proposed to write Li or Li-ion and the total marking should be blue for this chemistry. The symbol has to be fixed on the battery by printing, labelling or moulding.