



Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619- Lot 1

TASK 1 Report

**Scope (Definitions, Standards and Legislation)
For Ecodesign and Energy Labelling**

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Version 1: Version made available in November 2018 for the Stakeholders to comment and discussion in the stakeholder meeting.

Version 2:

- is a review based on the input from the stakeholder comments which resulted mainly in a reviewed and updated scope proposal
- includes several updates on the text and system definitions
- refers to the newly elaborated annex on standards complementary to task 1

Version 2b (final version):

- text correction on the interpretation on p. 42 related to the Battery Directive (2006/66/EC)
- changed scope from ‘.. with lithium chemistries..’ to ‘..with solid lithium cathode chemistries..’
- added in section 1.8 on scope a footnote ‘Batteries with liquid electrodes like ceramic batteries are excluded from the scope because they are not used in electric vehicles and their Ecodesign and recycling is much less challenging due to the used materials’

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ABBREVIATIONS

Abbreviations	Descriptions
AC	Alternating current
AD	Acidification
ADR	European Agreement Concerning the International Carriage of Dangerous Goods by Road
Ah	Ampere-hour
Al	Aluminum
ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
AS	Application service energy
BAT	Best Available Technologies
BAU	Business As Usual
BC	Base case
BEV	Battery Electric Vehicle
BJB	Battery junction box
BMS	Battery Management System
BNAT	Best Not-yet Available Technologies
BOM	Bill-of-Materials
C	Capacity
CAPEX	Capital Expenditure
Cd	Cadmium
CE	European Conformity
CED	Cumulative energy demand
CF	Characterisation Factor
CIT	International Rail Transport Committee
CMC	Carbon methyl cellulose
C _n	Rated capacity
CNT	Carbon nanotube
Co	Cobalt
CPA	Statistical Classification of Products by Activity
CPE	Composite polymer electrolytes
CPT	Cordless Power Tools
CRM	Critical Raw Materials
DC	Direct Current
DEC	Diethyl carbonate
DG	Directorate General
DMC	Dimethyl carbonate
DoC	Declaration of Conformity
DOD	Depth of Discharge
E	Energy
EC	European Commission
EC	Ethylene carbonate
ECHA	European Chemicals Agency
ED	Ecodesign Directive
EDLC	Electrical Double-Layer Capacitor
EEI	Energy efficiency index

Abbreviations	Descriptions
EGDME	1, 2-dimethoxyethane or ethylene glycol dimethyl ether
ELR	Energy Labelling Regulation
ELV	End of Life of Vehicles
EMC	Ethyl Methyl Carbonate
EOL	End-of-Life
EPA	Environmental Protection Agency
EPD	Environmental Product Declaration
EPTA	European Power Tool Association
eq.	equivalent
E_{Rated}	Rated energy
ESS	Electrical Energy Storage Systems
EU	European Union
EU-28	28 Member States of the European Union
EUP	Eutrophication
EV	Electric vehicle
FC	Full cycle
Fe	Iron
FESS	Flywheel energy storage systems
FTP	Federal Test Procedure
FU	Functional Unit
GER	Gross Energy Requirements
GHG	Greenhous Gases
GVW	Gross vehicle weight
GWP	Global warming potential
HDT	Heavy-duty truck
HDTU	Heavy-duty tractor unit
HE	High-energy
HEV	Hybrid Electric Vehicle
Hg	Mercury
HMa	Heavy metals to air
HMw	Heavy metals to water
HREEs	Heavy rate earth elements
HV	High-voltage
I	Current
IATA	International Air Transport Association
ICEV	Internal combustion engine vehicles
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IM	Implementing Measure
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
ISO	International Organization for Standardization
I_t	Reference test current
JRC	Joint Research Centre
kWh	Kilowatt hour
LCA	Life Cycle Assessment

Abbreviations	Descriptions
L _{Cal}	Calendar life
LCC	Life Cycle Costs
LCI	Life Cycle Inventory
LCO	Lithium-ion Cobalt Oxide
LCOE	Levelized Cost Of Energy
LCV	Light commercial vehicles
L _{Cyc}	Cycle life
LFP	Lithium-Ion Phosphate
Li	Lithium
LIB	Lithium ion battery
Li-Cap	Lithium-ion Capacitor
LiFSI	Lithium bis(fluorosulfonyl) imide
LiPF ₆	Lithium Hexafluorophosphate
LLCC	Least Life Cycle Costs
LMNO	Lithium-Ion Manganese Nickel Oxide
LMO	Lithium Manganese Oxide
LMP	Lithium-Metal-Polymer
LREEs	Light rare earth elements
LTO	Lithium-Ion Titanate Oxide
LVD	Low Voltage equipment
MEErP	Methodology for Ecodesign of Energy related Products
MEEuP	Methodology for Ecodesign of Energy-using Products
Mn	Manganese
NACE	Statistical Classification of Economic Activity
NaNiCl ₂	Sodium nickel chloride
NaS	Sodium-sulphur
nC	C-rate
NCA	Lithium Nickel Cobalt Aluminium
NCM	Lithium Nickel Manganese Cobalt Oxide
NEDC	New European Driving Cycle
Ni	Nickel
NiCd	Nickel-Cadmium
NiMH	Nickel-metal hydride
NMC	Lithium-ion Nickel Manganese Cobalt Oxide
NPV	Net Present Value
OCV	Open Circuit Voltage
OPEX	Operational expenditure
P	Phosphor
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
Pb	Lead-acid
PBB	Polybrominated biphenyls
PBDE	Polybrominated diphenyl ethers
PC	Passenger car
PC	Propylene Carbonate
PCM	Protection Circuit Module

Abbreviations	Descriptions
PCR	Product Category Rules
PE	Polyethylene
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PE _m	Primary energy for manufacturing
PEM-FC	Proton exchange membrane fuel cell
PE _r	Primary energy for recycling
PGMs	Platinum Group metals
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
POP	Persistent Organic Pollutants
PP	Polypropylene
PRODCOM	Production Communautaire
PTC	Positive Thermal Coefficient
PV	Photovoltaic
PVD	Physical vapour deposition
PVDF	Polyvinylidene fluoride
PWF	Present Worth Factor
Q _{FU}	Quantity of functional units
R	Internal resistance
R&D	Research and Development
RE	Round-trip efficiency
REACH	Regulation on the registration, evaluation, authorisation and rustication of chemicals
RFB	Redox-flow battery
RID	International Carriage of Dangerous Goods by Rail
RoHS	Restriction of hazardous substances
RRR	Recyclability, Recoverability, Reusability
RT	Room temperature
SASLAB	Sustainability Assessment of Second Life Application of Automotive Batteries
Sb	Antimony
SBR	Styrene-Butadiene Rubber
SD	Self-discharge
SEI	Solid-electrolyte interphase
Si	Silicon
SOC	State of Charge
SOH	State of Health
SOH _{cap}	Capacity degradation
SPE	Solid polymer electrolyte
SVHC	Substances of Very High Concern
T	Time
TIM	Thermal interfacial material
TMS	Thermal Management System
TOC	Total Cost of Ownership
TRL	Technology Readiness Level
UN	United Nations

Abbreviations	Descriptions
UNECE	United Nations Economic Commission for Europe
UPS	Uninterruptible Power Supply
V	Voltage
VAT	Value Added Tax
VKT	Vehicle kilometres travelled
V _L	Voltage limits
V _{OC}	Open circuit voltage
VOC	Volatile Organic Compounds
vPvB	Very persistent and very bio accumulative
V _R	Rated voltage
WEEE	Waste electrical and electronic equipment
WLTP	Worldwide Harmonized Light Vehicle Test Procedure
WVTA	Whole Vehicle Type-Approval System
ZrO ₂	Zirconium Oxide
ZVEI	Zentralverband Elektrotechnik- und Elektronikindustrie e. V.
η_E	Energy efficiency
η_V	Voltaic efficiency

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1. Task 1: Scope, standardisation and legislation

AIM OF TASK 1

The aim of this Task 1 was to analyse the scope, definitions, standards and assessment methods as well as other legislation of relevance to the product group and to assess their suitability for classifying and defining products for the purposes of analysing Ecodesign and Energy Label requirements.

SUMMARY OF TASK 1

The proposed scope for this study and subsequent tasks 3 to 6 is 'high energy rechargeable batteries of high specific energy with solid lithium cathode chemistries for e-mobility and stationary energy storage (if any)'. Herein batteries are either a pack or a system as defined within this study and in line with the international standards. This does not include power electronics neither heat or cool supply systems for thermal management which can be part of what the study defined as a battery application system. The rationale for this scope definition is included in this task report and it took also into account the Task 2 market data. Herein a high volume in total mass of e-mobility lithium batteries are expected to enter the market and therefore also a significant impact could be expected from Ecodesign policy measures, which will be discussed in Task 7. Similar batteries for grid energy storage will also be looked at, especially from the point of view of second life applications. Independent from the proposed scope this Task 1 report introduces the broader range of batteries and their applications on the market.

More details, product categories, applicable regulation, standards and definitions are given in this task report and its annex on standards.

The current version is a reviewed and updated task report based on the first stakeholder meeting held on 20 December 2018 and the comments received on the draft report, amongst others the proposed scope was updated taking into account the various comments received.

Be aware that in parallel to this study the EC hosts a website that provides the latest information for the related regulation making process and that information included in this report can be outdated, therefore please consult also:

https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2018-5951053_en

1.1 General Introduction to the study

The general aim of this study is to support developing of a new Ecodesign Regulation for batteries¹ [1], [2], which means; to set the performance and sustainability criteria that batteries will have to comply to be placed on the EU market. This may eventually be a different regulation using the analyses performed during the complete study.

This study follows the Methodology for Ecodesign of Energy-related products (MEErP)², as established in 2011. It was developed to allow evaluating whether and to which extent various energy-related products fulfil certain criteria according to Article 15 and Annex I and/or II of

¹ http://europa.eu/rapid/press-release_IP-18-6114_en.htm

² http://ec.europa.eu/growth/industry/sustainability/ecodesign_nl

the Ecodesign Directive that make them eligible for implementing measures. This methodology requires to carry out 7 tasks, ranging from product definition to policy scenario analysis; they are:

The tasks in the MEErP entail:

- Task 1 – Scope (definitions, standards and legislation);
- Task 2 – Markets (volumes and prices);
- Task 3 – Users (product demand side);
- Task 4 – Technologies (product supply side, includes both BAT and BNAT);
- Task 5 – Environment & Economics (Base case LCA & LCC);
- Task 6 – Design options;
- Task 7 – Scenarios (Policy, scenario, impact and sensitivity analysis).

This means that specific issues on market, use, technologies, etc. will be discussed in more detail in later tasks and not in Task 1 neither its introduction.

1.2 Preliminary definitions for Task 1

In the following list a set of preliminary definitions and terminology related to batteries is presented. It is useful for the reading of subsequent introductory section on batteries and therefore has been provided preceding this. This is not an exhaustive list but contains basic concepts that are needed in order to understand how a battery can be included in an electric application. The definitions are based on different international standards and regulations like from ISO, IEC, UN. The definitions are written as they have been defined in the standards indicating for each the standard from where they have been taken from. When they are not found in existing standards, the study team will provide its own draft definition. Furthermore, these concepts are implemented in the creation of a functional product and unit defining the boundaries of the system that will be considered in this study. In Figure 1 a schematic representation of the battery pack and system can be observed.

1.2.1 Storage

Electrochemical cell: Electrochemical system capable of storing in chemical form the electric energy received and which can give it back by reversion, i.e. a secondary cell (IEC 60896-21) [3].

Secondary rechargeable cell: Basic manufactured unit providing a source of electrical energy by direct conversion of chemical energy, that consists of electrodes, separators, electrolyte, container and terminals, and that is (IEC 62133) [4], [5]. Cell or battery which is designed to be electrically recharged (IEC 62281) [6]

Primary cell: Any kind of electrochemical cell in which the electrochemical reaction of interest is not reversible (IEC 60730-1) [7]

Flow cell: Secondary cell characterized by the spatial separation of the electrode from the fluid volumes which contain active materials (IEC 61427-2) [8].

Battery: Two or more cells fitted with devices necessary for use, for example case, terminals, marking and protective devices (IEC 61427-2) [8].

Electrochemical battery: An electrochemical system capable of storing in chemical form the electric energy received and which can give it back by conversion (IEC 60050) [9]

Battery with internal storage: Electrochemical batteries that have the active materials in the cells to store the energy; they are in the agreed scope of this study. (Definition from the study)

Flow battery or battery with external storage: Two or more flow cells electrically connected in series and including all components for their use as an electrochemical energy storage system (IEC 61427-2) [10]

Battery lithium cell (secondary): Secondary cell where electrical energy is derived from the insertion/extraction reactions of lithium ions between the negative electrode and positive electrode. The lithium ion cell has an electrolyte that typically consists of a lithium salt and organic solvent compound in liquid, gel or solid form and has a metal or a laminated casing. It is not ready for use in an application because it is not yet fitted with its final housing, terminal arrangement and electronic control device. (IEC 62620) [11]

Ceramic battery: Battery with internal storage characterised by liquid electrodes separated by a solid ceramic electrolyte. They are typically operated around 300°C with sodium-ion passing through a beta-alumina ceramic (definition from the study)

Solid State battery: Battery that is incorporated with solid electrodes and solid electrolytes (definition from the study)

Accumulator: A device that receive, store and releases energy. This energy can be thermal, mechanical or electrical. It is very common to define an accumulator as a battery. The main difference is that an accumulator is always rechargeable while a battery can be also non-rechargeable (definition from the study)

Note: an overview of more battery technologies is included in a later section.

1.2.2 Battery hierarchy

Cell block: Group of cells connected together in parallel configuration with or without protective devices (e.g. fuses/thermal sensors) and monitoring circuitry. It is not ready for use in an application because it is not yet fitted with its final housing, terminal arrangement and electronic control device. (IEC 62620) [11]

Battery Module: Group of cells connected together either in a series and/or parallel configuration with or without protective devices (e.g. fuse or PTC) and monitoring circuitry. (IEC 62620) [11].

Battery Pack: Energy storage device, which is comprised of one or more cells or modules electrically connected. It may incorporate a protective housing and be provided with terminals or another interconnection arrangement. It may include protective devices and control and monitoring, which provides information (e.g. cell voltage) to a battery system. (IEC 62620) [11].

Battery System: System which incorporates one or more cells, modules, or battery packs. It has a battery management unit to cut off in case of overcharging, over current, and overheating. It may have cooling or heating units. (IEC 62620) [11]. Completely functional energy storage system consisting of the pack(s) and necessary ancillary subsystems for physical support, thermal management and electronic control with the thermal management system and protective circuit module respectively [12].

Note: additional definitions about the battery hierarchy is provided in section 1.5

1.2.3 Additional battery components

Battery Management System: Electronic system associated with a battery, which monitors and/or manages its state, calculated secondary data, reports that data and/or controls its environment to influence the battery's safety, performance and/or lifetime. The function of the BMS can be assigned to the battery pack or to equipment that uses the battery. (IEC 62620) [11].

Cell electronics: Electronic device that collects and possibly monitors thermal and electric data of cells or cell assemblies and contains electronics for cell balancing. (ISO 8713) [13]

Protective devices: Devices such as fuses, diodes or other electric or electronic current limiters designed to interrupt the current flow, block the current flow in one direction or limit the current flow in an electrical circuit. (IEC 62281) [6].

Power electronics: The field of electronics which deals with the conversion or switching of electric power with or without control of that power (IEC 60050) [9].

1.2.4 Battery metrology

Gravimetric energy density: Amount of stored energy related to the battery cell, module, pack or system weight expressed in Wh/kg. (ISO 12405) [14]–[16].

Volumetric energy density: Amount of stored energy related to the battery cell, module, pack or system volume expressed in Wh/l. (ISO 12405) [14]–[16].

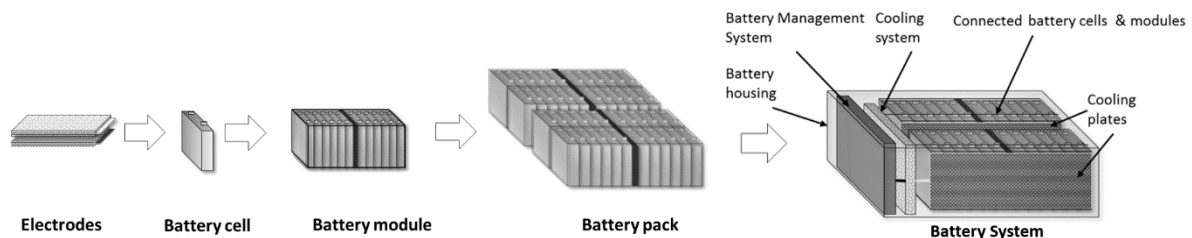


Figure 1: Schematic summary of the key components of a battery pack after [17].

1.2.5 Sustainable, resource-efficient production and consumption

It is needed to establish appropriate definitions and metrics for sustainable and resource efficient production.

The MEErP methodology³ already defined some parameters that will be further explained in subsequent Tasks 3-5. They include amongst other definitions on lifetime, warranty, recoverability of material/product, recyclability of material/product, Recyclability Recoverability

³ <https://publications.europa.eu/en/publication-detail/-/publication/7c3d958d-42cc-4af7-985c-2a3347b66fa8>

and Reusability (RRR) rates (ISO 22628, IEC 62635), reparability of component/product and reusability of component/product.

Apart from the existing MEErP methodology (2013), new definitions on circular economy aspects are also work in progress within a new CEN standardization committee (CEN CLC JTC 10). This means that new terminology and definitions can be expected in future. It is a reply to the EU standardization mandate/543 on Ecodesign requirements on material efficiency aspects for energy-related products. Herein in particular the proposed standard prEN 45555 aims to define general methods for assessing the recyclability and recoverability of energy related products, it is not available (see Annex on Standards).

1.3 Introduction to rechargeable electrochemical battery technologies

The following sections provide a brief introduction to rechargeable electrochemical batteries with internal storage. A comparison of the most common battery technologies found in the market is included, comparing their operational characteristics to each other and the type of electrical application wherein they are commonly incorporated. This is followed by a list of existing definitions of the different components of a battery and their surrounding systems are established. This provides the basis in defining the boundaries, functional unit and parameters of a battery system that is commonly found in electric applications. Finally, the scope of the study is based on the analyses performed for the development of an Ecodesign and Energy label strategy for rechargeable electrochemical batteries with internal storage.

1.3.1 Introduction to electrochemical batteries

A battery is an electrochemical system that can convert chemical energy into electrical energy to power and/or conserve energy for different electrical applications [14], [18]–[22]. This can be single battery cells attached directly to an application or battery cells that are included in modules and packs which are connected to different external power electronics depending on the application. The exact definition of the system will be given in section 1.8 These applications can range from electrical devices as electric watches to portable computers (i.e. laptop), vehicles (i.e. e-bikes, electrical vehicles, buses) to stationary applications such as uninterruptible power supply (UPS), grid support and to store PV energy for self-consumption optimisation.

The first electrochemical battery was developed by Italian physicist Alessandro Volta in 1800 and was made of a stack of copper and zinc plates separated by brine-soaked paper disks. In 1836 a British chemist created the first battery that could power up electrical telegraph networks consisting of a copper pot filled with copper sulphate solution [1], [23]. Rechargeable Nickel-Cadmium batteries were invented in 1899 by Swedish scientist Waldemar Jungner combining nickel and cadmium electrodes under a solution of potassium hydroxide. Following multiple developments in battery technology during the 1970s M. Stanley Whittingham proposed the first lithium battery (main type of battery for electrical and electronic devices) composed of titanium sulphide and lithium metal as electrodes [2]. While in 1989 the first Nickel-Metal hydride batteries and became commercially available.

A main distinction for batteries is made by primary and secondary batteries. A primary battery cannot be recharged and the chemical energy that was initially stored can be turned into electrical power only once. On the contrary a secondary battery can be recharged for multiple uses providing electrical energy over a longer lifetime compared to a primary battery.

A battery cell is composed of two electrodes and its current collector called the anode (negative) and cathode (positive), a separator separating the electrodes and the electrolyte allowing the ions to move [17]. In Figure 2 an example of a structure of a battery cell can be observed.

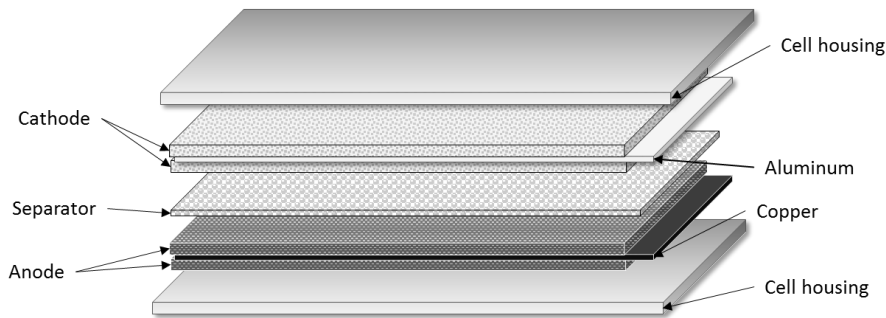


Figure 2: Exemplary structure of a battery cell [17]

The current collectors connect the electrodes to the battery poles. When a battery cell is being discharged electrical energy is provided from the battery to the application attached. Electrons are moving from the anode through the external electrical circuit of the application towards the cathode due to the difference in potential between both electrodes. Inside the battery, through the separator, the current flows as ions. The electrons and ions are combined by electrochemical reactions. The opposite flow of electrons is occurring when a battery is being charged. A higher voltage than the cell possesses under rest is applied, forcing the reverse electrochemical reaction and restoring the energy that is available in the battery cell.

When a battery is fully charged it is denoted as 100% State of Charge (SOC). On the contrary when a battery is fully discharged this is denoted as 0% SOC. This occurs when for a certain current the minimum allowed voltage is attained. The exact definition when a cell is fully charged depends on the cell chemistry. For Li-ion, a cell is fully charged when the current falls below a certain threshold while the potential is maintained at maximum allowed voltage. For lead acid batteries, often a series of charge currents is applied coupled to a duration after being fully charged, maintaining the voltage of the battery stable to account for the full capacity and compensating for self-discharge. For Nickel–metal hydride (NiMH), a cell is fully charged when the cell voltage starts to decrease. A complete discharge and charge procedure defines one operational cycle of the battery system. This should be theoretically from 100% to 0% but in many electrical applications a complete operational cycle is usually performed between an optimized SOC smaller range (e.g. Li-ion battery in electric vehicle) to degrade the battery at a slower rate.

Due to the energetic electric losses during charging, discharging and storage and since the discharge voltage is lower than the charge voltage, the battery cell efficiency is not 100%. It is also possible that more current is needed to charge a cell than can be discharged. This further lowers the efficiency. Furthermore, it should be understood that as the battery is a chemical system, different degradation mechanisms may take place during use and storage. These are affecting the capacity and internal resistance, degrading the energy and power output of the system [24]–[27]. The coulombic efficiency which is the electric efficiency of the battery for a specified charge/discharge procedure will be above 99+% for most its lifetime for Li-ion batteries. This will be further be investigated in Task 3 and 4 of this study.

A typical lithium-ion battery has the three basic functional components like discussed previously for a general cell. These are namely the anode, cathode and electrolyte (Figure 3). There is a thin separator between the electrodes usually made of a micro perforated plastic

foil that allows Li-ions to pass through. Anodes are typically made of graphite pasted on a current collector from copper. The cathode active material is either a layered oxide or a phosphate of spinel type. The different chemistries of the cathode are indicated in Figure 4. The electrolyte is a mixture of organic carbonates containing complexes of lithium ions.

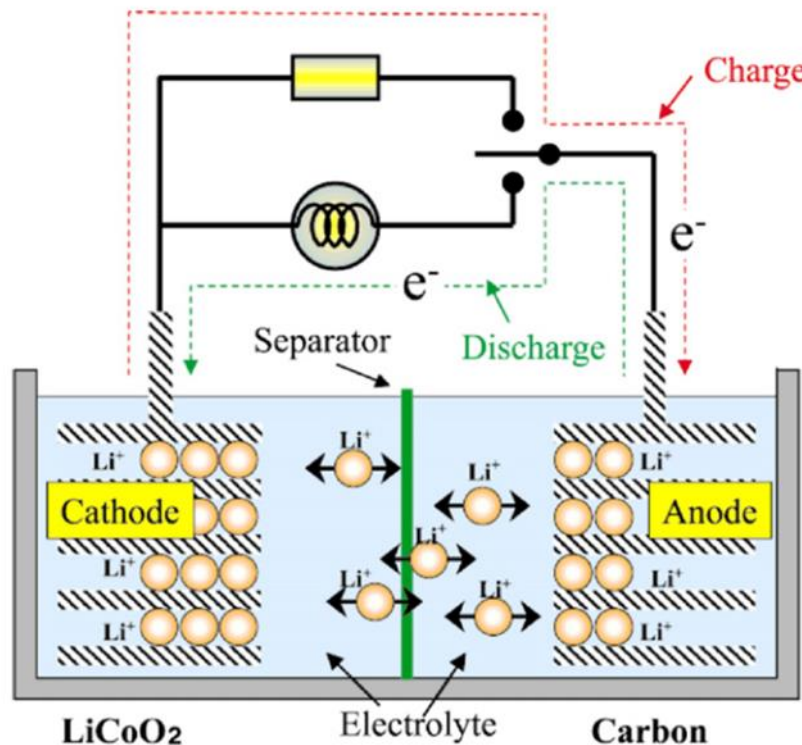


Figure 3: Typical working schematic of Lithium batteries [28]

During the charging process, lithium ions intercalate from the cathode to anode. Intercalation means that the Li-ions are adsorbed in the host material without significantly changing the structure. During the charging process Li-ions and electrons settle themselves between the the graphite layers. During discharge, the process is reversed where the lithium ions go from the anode to cathode and the electron flow direction is also reversed. This is also an intercalation process: the Li-ions settle themselves within the cathodic material, without forming a chemical reaction or an alloying, what would have essentially changed the structure.

1.4 Main product categories of batteries

1.4.1 Rechargeable electrochemical batteries classified according to their chemistry

In Table 1 the most common battery chemistries existing in today's market are compared detailing the advantage that each technology has over the others [29]. Inspecting the different battery technologies, it is observed that each has specific advantages. The lead-acid battery, although it represents one of the lowest in terms of specific power and energy density, has the advantage that its price remains lower with respect to the other technologies for the same energy content. Furthermore, Europe is strong in the manufacturing of lead-acid batteries. Lead-acid batteries are easily recyclable. The lead components of the battery are smelted and refined to be used to make new batteries, in a closed-loop system. Another important

advantage of lead-acid battery is their cold cranking ability at temperatures as low as -30°C . This is one of the areas where until recently Li-Ion batteries had not yet reached parity and one of the reasons why they are still not widely considered for automotive battery applications (i.e. SLI batteries). The presence of cadmium (Cd) in portable batteries is banned through the Batteries Directive (2006/66/EC) due to toxic properties, i.e. nickel cadmium portable batteries are banned for most applications. Although the Batteries Directive provides a few exemptions: portable Ni-Cd batteries are granted for example for emergency batteries. The advantage of the nickel-cadmium technology is that it can be operated in a wide range of temperatures without losing substantially its energy and power characteristics. Due to these intrinsic characteristics, the Ni-Cd technology is the preferred solution for very demanding industrial power back-up solutions. Industrial Ni-Cd batteries have also high recycling efficiency. The nickel-metal hydride on the contrary shows a greater specific energy and power to respect to the lead-acid or nickel-cadmium but still cannot reach the levels of a lithium-ion battery. The main advantage of this technology is its volumetric energy density and a long lifetime if used in a restrained SOC window, i.e. not fully depleting nor fully charging the battery but staying within e.g. 10%-90% SOC. Finally, the lithium-ion battery technology provides the higher energy and power densities in terms of weight and volume. They have a higher cell voltage and a lower self-discharge rate making them a perfect match for e-mobility (high power, high energy), ICT (high volumetric energy density) and stationary (long lifetime and low self-discharge) applications.

Table 1: Comparison of battery technologies advantages to respect to each other after [29]

<div>Advantage of...</div> <div>.....On</div>		Lead acid	Nickel cadmium	Nickel metal hydride	Lithium-ion	
					Cylindrical - prismatic	Pouch
Lead acid			<ul style="list-style-type: none"> • Energy density • Operating temperature • Self discharge rate • Reliability 	<ul style="list-style-type: none"> • Gravimetric energy density • Volumetric energy density • Self discharge rate 	<ul style="list-style-type: none"> • Gravimetric energy density • Volumetric energy density • Voltage output • Self discharge rate 	<ul style="list-style-type: none"> • Gravimetric energy density • Volumetric energy density • Voltage output • Design characteristics
Nickel cadmium		<ul style="list-style-type: none"> • Higher cyclability • Voltage output • Price 		<ul style="list-style-type: none"> • Gravimetric energy density • Volumetric energy density 	<ul style="list-style-type: none"> • Gravimetric energy density • Volumetric energy density • Voltage output • Self discharge rate 	<ul style="list-style-type: none"> • Gravimetric energy density • Volumetric energy density • Voltage output • Design characteristics
Nickel metal hydride		<ul style="list-style-type: none"> • Higher cyclability • Voltage output • Price 	<ul style="list-style-type: none"> • Operating temperature • Higher cyclability • Self discharge rate • Price 		<ul style="list-style-type: none"> • Energy density • Operating temperature • Higher cyclability • Voltage output • Self discharge rate 	<ul style="list-style-type: none"> • Gravimetric energy density • Volumetric energy density • Operating temperature • Design characteristics • Self discharge rate
Lithium-ion	Cylindrical - prismatic	<ul style="list-style-type: none"> • Price • Safety • Recyclability 	<ul style="list-style-type: none"> • Operating temperature • Higher cyclability • Price • Safety 	<ul style="list-style-type: none"> • Price • Safety • Discharge rate • Recyclability 		<ul style="list-style-type: none"> • Gravimetric energy density • Volumetric energy density • Safety • Design characteristics
	Pouch	<ul style="list-style-type: none"> • Price • Safety • Recyclability 	<ul style="list-style-type: none"> • Recyclability • Operating temperature • Higher cyclability • Price 	<ul style="list-style-type: none"> • Volumetric energy density • Higher cyclability • Price 	<ul style="list-style-type: none"> • Operating temperature • Higher cyclability • Price 	
Absolute advantages		<ul style="list-style-type: none"> • Higher Cyclability • Price 	<ul style="list-style-type: none"> • Operating temperature • Price 	<ul style="list-style-type: none"> • Volumetric energy density 	<ul style="list-style-type: none"> • Gravimetric energy density • Volumetric energy density • Voltage output • Self discharge rate 	<ul style="list-style-type: none"> • Energy density • Design characteristics • Voltage output • Self discharge rate

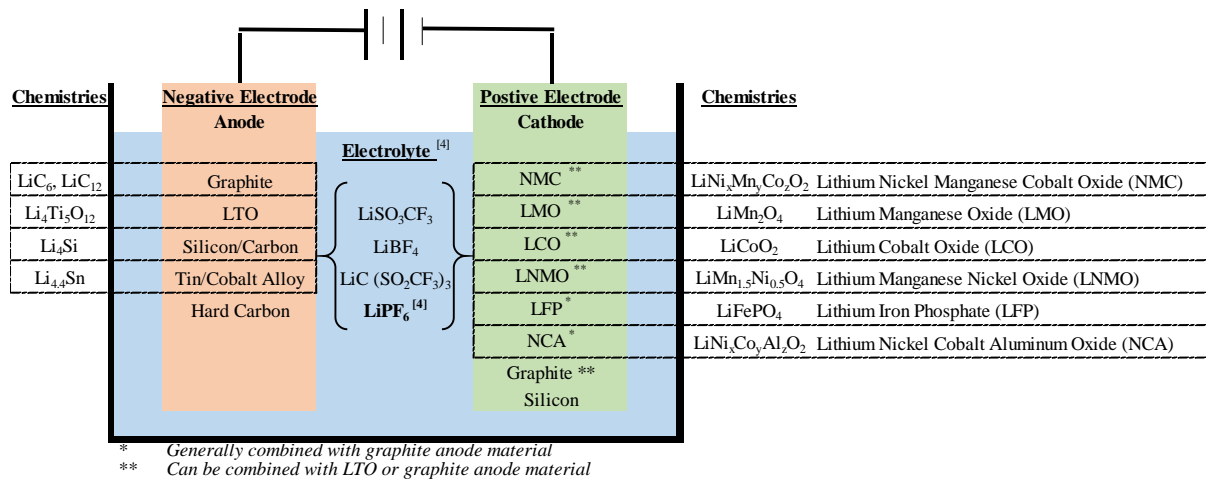


Figure 4: Different types of lithium-ion chemistries [30]–[32]

As illustrated in Figure 4, different types of lithium-ion batteries exist. The materials used in battery cells play a substantial role in the characteristics and performance. In the following list the most common types of lithium-ion cells are denoted. They are mostly designated by the cathode material or anode material (for LTO chemistry), being:

- Lithium-ion Cobalt Oxide (LCO)
- Lithium-ion Nickel Manganese Cobalt Oxide (NMC)
- Lithium-Ion Phosphate (LFP)
- Lithium-Ion Titanite Oxide (LTO)
- Lithium-Ion Manganese Oxide (LMO)
- Lithium-Ion Manganese Nickel Oxide (LMNO)
- Lithium Nickel Cobalt Aluminium (NCA)
- Lithium Metal Polymer (LMP)

In Figure 5 the composition of commonly found materials of a lithium battery system in a mobile application can be also observed [33].

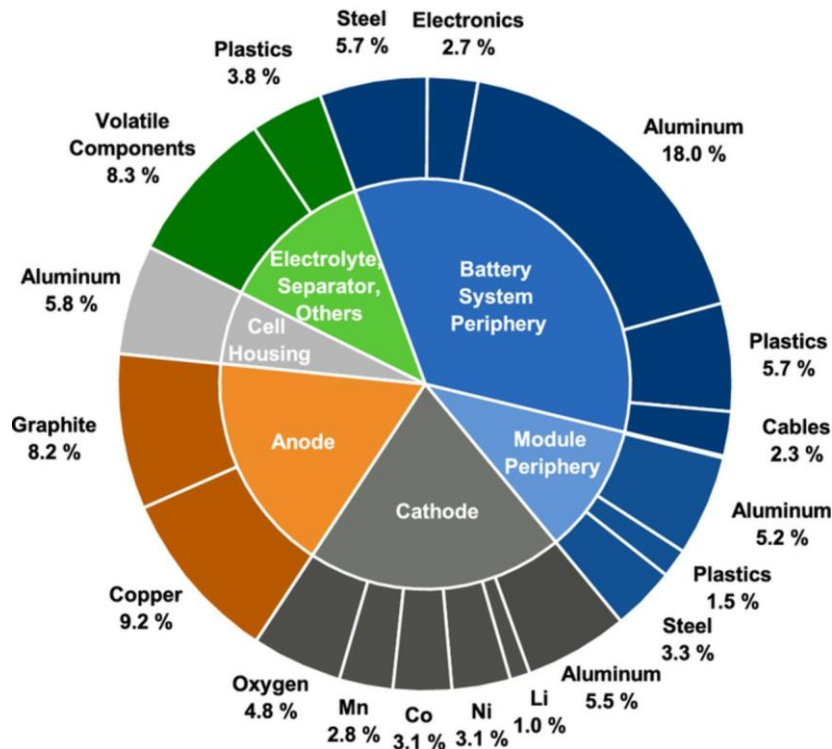


Figure 5: Composition of different materials of a lithium battery system in an mobile application [33]

Li-ion cells are constructed in different forms (Figure 6). Cylindrical cells, being the most widely used formats, are made by winding long strips of electrode into a “jelly roll” configuration. This is encapsulated in a can commonly made of aluminium. In a typical prismatic cell, the cell is created by stacking in a layered approach or winding the electrodes into flat wraps. The casing is a hard structure out of metal or thick plastic. Pouch cells as the name goes, are stacked electrodes typically enclosed in a foil. This is a comparatively weaker structure.

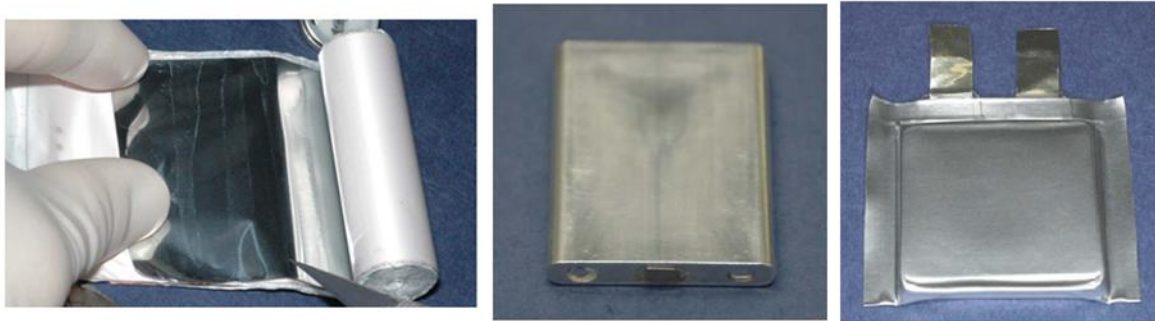


Figure 6: Types of lithium-ion cells : Cylindrical (left), Prismatic hard (centre) and Pouch type (right) [34]

In Table 2 a list of different energy storage systems characteristics including electrochemical batteries is presented. Flow batteries store energy outside the battery. Rechargeability is provided by two chemical components dissolved in liquids that can be stored in two separate storage vessels apart from the battery anode and cathode. They are referred hereafter as batteries with external storage and they are not in the scope of this study. Batteries with internal storage have solid active materials as electrodes that stores the energy. They are in the proposed scope of this study.

The energy output that a battery can deliver, depends on multiple internal and external factors. The useable capacity of a battery strongly depends on the load profile of the application. When a high current is drawn from the battery a lower amount of energy can be extracted from it in comparison to a low current rate. There are two reasons. The voltage drop created by the current increases with the current. Since the energy is a multiplication of voltage, current and discharge time, this leads automatically to a lower energy output. Moreover, the lowest allowed voltage is quicker attained, reducing the discharge time more than linearly. Secondly, the energy output of the battery is directly affected by the ambient temperature at which the battery is operated [35]. At high temperatures the chemical molecules (e.g. ions) in the battery have a greater kinetic energy leading to a lower voltage drop. While this provides a higher energy output of the system, it increases the degradation mechanisms of the battery, reducing the lifetime that it can be operated efficiently and safely. At low temperatures the kinetic energy of chemical molecules is restricted thus raising the voltage drop. As a consequence, the energy output of the system is negatively affected. Therefore, it is important to operate batteries at temperatures that are adequate to efficiently provide the energy required but also restrict the degradation mechanisms. In applications such as destined for e-mobility, grid support or grid and home storage, the temperature of the batteries is directly monitored and managed for optimum performance.

A more detailed technical analysis will be included in Task 4.

Table 2: Energy storage systems main characteristics (own expert assumptions)

Energy Storage Technology	Electro-chemical	Primary - Secondary	Internal - External Storage	[Wh/kg] (range) @ cell level
High-energy LIB (NCA/Graphite, NMC/Graphite)	NCA/Graphite or NMC/Graphite	sec	int	200-300
Mid-energy LIB (LFP, LMO/Graphite)	LFP, LMO/Graphite	sec	int	140-200
High power LIB (LFP, NCA or NMC/Graphite, thin electrode)	LFP, NCA or NMC/Graphite	sec	int	140-200
Heavy duty LIB, high power (NMC, NCA, LFP / LTO)	NMC, NCA, LFP / LTO	sec	int	80-120
Long-life / cycle life LIB (e.g. NMC/LTO)	NMC/LTO	sec	int	80-120
Ultra-high cycle life LIB (e.g. LFP/LTO)	LFP/LTO	sec	int	70-100
Lithium metal polymer	LMP/Carbon	sec	int	100-265
Lead-acid	PbO ₂ / Pb	sec	int	30-45
Lead-acid sealed	PbO ₂ / Pb	sec	int	30-45
NiCd	Cd / Ni(OH) ₂	sec	int	40-60
NiMH	M / Ni(OH) ₂	sec	int	60-120
Li-primary	numerous / Li-metal	pri	int	250-700
Zn-primary	Zn / C, air	pri	int	100-450
Flywheel storage system	N/A	sec	ext	100 - 130
Compressed air storage	N/A	sec	ext	20 - 83
Pumped hydro storage	N/A	sec	ext	Unknown
Redox flow	numerous	sec	ext	25 - 50
Molten salt batteries	Na-S or Na-NiCl ₂	sec	int	130-230

1.4.2 Categories and definitions found in Eurostat PRODCOM codes

The EU's industrial production statistics are compiled in the Prodcom (PRODUCTION COMMunautaire) survey and also in the Europroms database, which includes external trade statistics. The economic activities surveyed by Prodcom are classified according to the Statistical Classification of Economic Activity (NACE). The statistics for production under each economic activity are in turn reported by each member state according to Statistical Classification of Products by Activity (CPA) codes. The link between the NACE and CPA codes is illustrated in Figure 7.

The main indicators of the production sold during the calendar year are collected and published both in monetary units (EUR) and physical units of production (kg, m², number of items, etc.). Data is provided, where available at member state level, for:

- the physical volume of production sold during the survey period,
- the value of production sold during the survey period,
- the physical volume of actual production during the survey period, including any production which is incorporated into the manufacture of other products from the same undertaking.

These statistics provide an outlook on the volume of imports, as well as enabling the actual and apparent production to be estimated based on the balance of EU sales and trade.

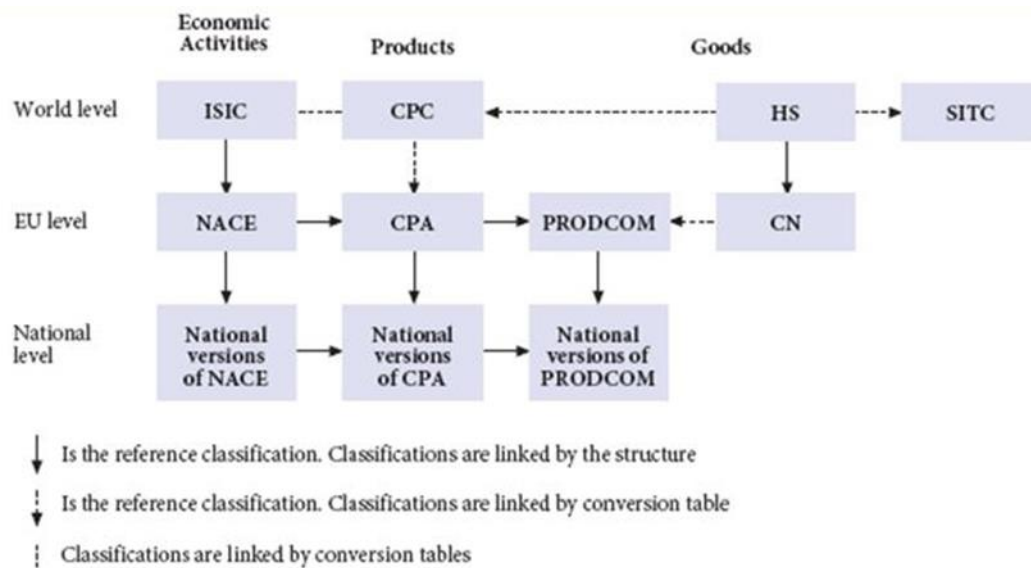


Figure 7: Overview of the revised EU system of integrated statistical classifications. Source: Eurostat (2017)

In Table 3 the Prodcom codes related with battery technologies are listed. In this study the technologies that would be considered are under the 27.20.23 code “Nickel-cadmium, nickel-metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators”.

Table 3: Prodcom categories and codes

Code	Prodcom categories
27.20	Manufacture of batteries and accumulators
27.20.11	Primary cells and primary batteries
27.20.12	Parts of primary cells and primary batteries
27.20.21	Lead-acid accumulators for starting piston engines
27.20.22	Lead-acid accumulators, excluding for starting piston engines
27.20.23	Nickel-cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators
27.20.24	Parts of electric accumulators including separators

The conclusion is that the official Prodcom codes provide little disaggregation of battery products and therefore they cannot be further used in this study for defining the scope in Task 1 neither to source market data in Task 2.

1.4.3 Categories and definitions of battery categories according to the Battery Directive

The Batteries Directive (2006/66/EC) discriminates three battery types according to its application. These are separated in industrial, automotive and portable applications, defined as:

- ‘automotive battery or accumulator’ means any battery or accumulator used for automotive starter, lighting or ignition power;
- ‘industrial battery or accumulator’ means any battery or accumulator designed for exclusively industrial or professional uses or used in any type of electric vehicle;
- ‘portable battery or accumulator’ means any battery, button cell, battery pack or accumulator that (a) is sealed; and (b) can be hand-carried; and (c) is neither an industrial battery or accumulator nor an automotive battery or accumulator;

In the context of this study accumulators are not of interest but have been included in the definitions through the Battery Directive. Thus, accumulators have been incorporated in the battery definition. Furthermore, the Batteries Directive details what kind of batteries can be considered industrial or portable batteries stating that:

- 1) Examples of industrial batteries and accumulators include batteries and accumulators used for emergency or back-up power supply in hospitals, airports or offices, batteries and accumulators used in trains or aircraft and batteries and accumulators used on offshore oil rigs or in lighthouses. Examples also include batteries and accumulators designed exclusively for hand-held payment terminals in shops and restaurants, bar code readers in shops, professional video equipment for TV channels and professional

studios, miners' lamps and diving lamps attached to mining and diving helmets for professionals, back up batteries and accumulators for electric doors to prevent them from blocking or crushing people, batteries and accumulators used for instrumentation or in various types of measurement and instrumentation equipment **and batteries and accumulators used in connection with solar panel, photo-voltaic**, and other renewable energy applications. Industrial batteries and accumulators also include batteries and accumulators used in electrical vehicles, such as electric cars, wheelchairs, bicycles, airport vehicles and automatic transport vehicles. In addition to this non-exhaustive list of examples, any battery or accumulator that is not sealed and not automotive should be considered industrial.

- 2) Examples of portable batteries and accumulators, which are all-sealed batteries and accumulators that an average person could carry by hand without difficulty and that are neither automotive batteries or accumulators nor industrial batteries or accumulators, include single cell batteries (such as AA and AAA batteries) and batteries and accumulators used by consumers or professionals in mobile telephones, portable computers, cordless power tools, toys and household appliances such as electric toothbrushes, razors and hand-held vacuum cleaners (including similar equipment used in schools, shops, restaurants, airports, offices or hospitals) and any battery or accumulator that consumers may use for normal household applications.

Taking into consideration these definitions and examples the batteries that are considered in this study are 'industrial batteries' including energy storage systems for stationary application and batteries for mobile applications according to the current Directive (2006/66/EC).

For more details see section 1.10.4.

1.4.4 Application categories of batteries and relation to battery chemistries

Batteries are used in a multitude of applications such as e-mobility, ICT, computer applications, various consumer electronics, Cordless Power Tools (CPT), Uninterruptable Power Supplies (UPS) and various electrical Energy Storage Systems (ESS), see Table 4. Such applications can have different criteria or priorities related to capacity, specific weight, efficiency, self-discharge, cycle life, etc. As indicated in Table 4 the potential applications and their typical user requirements will be further investigated in later Tasks 3 and 4. Based on our own investigations on battery properties for different technologies they can be linked as suitable candidate to different applications. In Table 4 a list of electrical applications is given. For each application different characteristics based on the importance of low specific weight, efficiency, self-discharge and cycle is provided. It is mainly observed that the energy storage that can be implemented in most of the electric applications is based on lithium-ion technologies. Road-based electric vehicles such as electric buses can have a maximum of 550 kWh under current applications. While electric vehicles can have a minimum of 5 kWh to 20 kWh for plug-in hybrid electric vehicles, 0.9 kWh to 2 kWh for hybrid electric vehicles and 20 kWh to 100 kWh for battery electric vehicles. This could change in the future as newer applications based on advance technologies come into the market. Other applications such as drones and airplanes can reach a battery system capacity of 900 kWh and a minimum of $1 \cdot 10^{-5}$ kWh for electronics and electronic consumer applications.

A more detailed analysis of user requirements and their typical parameters will be in Task 3.

Table 4: Typical electric applications characteristics and the type of battery technologies that can be integrated.

Typical application parameters (See Task 3 on use)	Most typical applications (see Task 2 on market)															
	E-mobility applications									other				Energy Storage Systems		
	Vehicle (BEV)	Vehicle (PHEV)	Vehicle (HEV)	Buses (BEV)	Trucks (BEV)	Rail (BNAT)	Drones / Airplanes (BNAT)	Scooter / E-bikes	Forklift / industrial	ICT	Consumer electronics	CPT	UPS (server, lift, ..)	Residential Energy Storage	Grid support	Grid Energy storage
importance of low specific weight	high	high	high	high	high	medium	high	high	low	medium	medium	high	low	low	low	low
Importance of efficiency	high	high	high	high	high	high	high	high	high	medium	medium	medium	low	high	high	high
importance of self-discharge	medium	medium	medium	low	low	low	low	medium	low	high	high	high	high	medium	low	medium
importance of long cycle life	high	high	high	very high	high	high	high	high	high	medium	medium	medium	low	high	very high	high
Typical electrochemical battery technologies (See Task 4 on Technologies)																
High-energy LIB (NCA/Graphite or NMC/Graphite)	x			x	x	x	x	x	x	x	x	x	x	x	x	x
Mid-energy LIB (LFP, LMO/Graphite)	x			x	x	x		x	x	x	x	x	x	x	x	x
High power LIB (LFP, NCA or NMC/Graphite, thin electrode)		x		x	x	x										
Heavy duty LIB, high power (NMC, NCA, LFP / LTO)		x		x	x	x			x						x	
Long-life / cycle life LIB (e.g. NMC/LTO)															x	
Ultra-high cycle life LIB (e.g. LFP/LTO)															x	
Lithium Metal Polymer	x			x	x										x	x

Typical application parameters (See Task 3 on use)	Most typical applications (see Task 2 on market)															
	E-mobility applications									other				Energy Storage Systems		
	Vehicle (BEV)	Vehicle (PHEV)	Vehicle (HEV)	Buses (BEV)	Trucks (BEV)	Rail (BNAT)	Drones / Airplanes (BNAT)	Scooter / E-bikes	Forklift / industrial	ICT	Consumer electronics	CPT	UPS (server, lift, ..)	Residential Energy Storage	Grid support	Grid Energy storage
Lead-acid									x				x	x	x	x
Lead-acid sealed									x				x	x	x	x
NiCd													x			
NiMH		x	x								x	x				
Li-primary										x	x					
Zn-primary										x	x					
acronyms for electric vehicles (EV):	BEV = Battery Electric Vehicle, PHEV = Plug-in Electrical Vehicle, HEV = Hybrid Electric Vehicle															

1.5 Definition of a battery system and a battery application system for use in this study

In this section the system boundary of a battery system found in different electrical applications is defined. These definitions are important for defining the scope in this Task 1 or market data in Task 2 or the use phase in later Task 3. In the proposed definitions hereafter, we follow the terminology of the IEC standards, see 1.2. Note that in Task 3 however new 'MEErP system scope boundaries' might be defined for further analysis in Tasks 5 to 7 according to the MEErP Methodology, see 15.

A graphical representation of the battery system and overarching battery *application* system definition proposed for use in this study is included in Figure 8. According to this representation, the main components of the battery system can be separated into the following items:

- Battery cell
- Battery module
- Battery pack
- Battery Management System (BMS)
- Cooling/Heating
- Battery system
- Battery application system

Connecting two or more battery cells through their terminals in a parallel and/or series configuration constitutes a battery module. By placing battery cells in series, the total voltage output is the sum of the cell voltage of the cells connected in series while the current passing through each is the same for all battery cells. By connecting battery cells in parallel the voltage level remains the same and the current passing through is the sum of the current output of each cell. Through these configurations additional control over the voltage, current and available capacity of each battery module can be achieved. Each battery module is normally fitted with measurement sensors such as one or more temperature sensors and a control unit wire communicating with the Battery Management System (especially necessary in case of Li-ion chemistry). Through these the BMS can monitor the temperature and electrical behaviour of each battery module and cell.

A battery pack is then formed by connecting the battery modules in series and/or parallel configurations. A battery pack can be incorporated in a protective housing and can be fitted with the terminals connecting the pack to the application if no other voltage or power regulation is needed. The electrical and thermal sensors included inside the battery pack through the battery modules can communicate with the BMS to control the electrical and thermal performance of each battery pack. The electrical supervision of the battery pack is performed through the Protection Circuit Module (PCM) and the thermal control is performed through the Thermal Management System (TMS).

The battery pack is then placed inside a battery system. A battery system can be incorporated with multiple battery packs if necessary, which are supervised by the BMS. The battery system can be also integrated with a temperature control system (cooling/heating) that can be used to adjust the temperature of the battery packs. Depending on the type of application (e.g. e-mobility or stationary application) the battery system is connected to different current or

voltage control systems called power electronics. For example, in electric vehicle applications it is possible to find systems such as DC/DC converters and DC links. These systems are not directly included in the boundaries of the investigated system that will be used in this study. However, the boundaries and focus of the system can be extended depending on the type of application attached to the battery system. These can be introduced between the application and the battery system. By incorporating the power electronics, it is possible to take into consideration the indirect energy losses due to their energy efficiency characteristics. The indirect energy losses can be taken into account during Task 3, where the use phase of the battery system will be modelled.

Furthermore, depending on the application multiple battery systems composed on one or more battery packs can be combined and attached to it to form a battery application system. This is the case mainly with stationary applications where a high capacity and energy is required for grid energy storage.

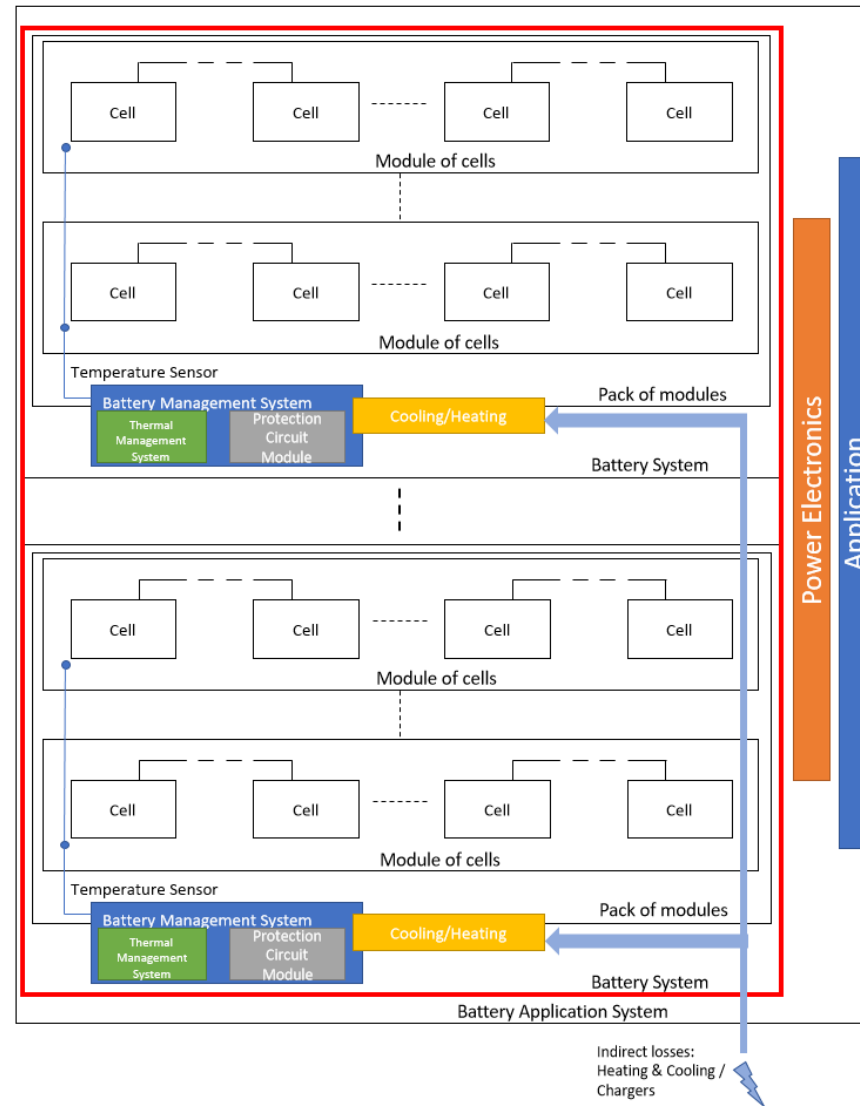


Figure 8: Representation of the battery system components and their system boundaries, forming finally the battery application system.

1.6 Definition of the primary functional parameter and unit

Hereafter is explained what is called the “functional unit” for batteries in the scope of this study.

In standard ISO 14040 on life cycle assessment (LCA) the functional unit is defined as “the quantified performance of a product system for use as a reference unit in life cycle assessment study”. According to the MEErP, the primary purpose of the functional unit is to provide a calculation reference to which environmental impacts (such as energy use), costs, etc. can be related and to allow for comparison between functionally equal battery systems. This is especially important in later Task 6 to consider improvement options. Further product segmentations will be introduced in this study to allow appropriate equal comparison and therefore secondary functional parameters can be added. Note that an Ecodesign preparatory study is always built on a single functional unit and a corresponding product group to allow a consistent analysis according the MEErP in Tasks 3 to 6. As a consequence, considering different applications with different requirements and functional unit is not an option, it would require different studies. This issue has already been addressed within the work done to elaborate a harmonized Product Environmental Footprint (PEF) in Europe⁴. In the pilot phase (2012-2016) batteries have been analysed for both ‘High Specific Energy Rechargeable Batteries for Mobile Applications’ and ‘Uninterruptible Power Supply (UPS)’. This study contract asked for building on the PEF study and to consider e-mobility and therefore it is obvious to build on what the PEF for mobile applications defined as functional unit.

The PEF for ‘High Specific Energy Rechargeable Batteries for Mobile Applications’ is proposed as **‘functional unit (FU)’ of ‘1 kWh (kilowatt-hour) of the total output energy delivered over the service life by the battery system (measured in kWh)’**.

Herein the energy consumption during the use phase of the battery takes into account losses linked to the battery but also the power electronics during charge, discharge and storage. Therefore, the PEF used the delta approach⁵ or main-function approach to take the power electronics losses into account. The delta approach intends to model energy use impact of one product, in this case the battery, with taking into account the indirect losses of another product, in this case the charger. This means that the excess consumption of the charger shall be allocated to the product responsible for the additional consumption which is the battery.

This PEF pilot study for batteries for mobile applications used ‘1 kWh’ instead of ‘total kWh of a battery system’ in the definition of the functional unit for Life Cycle Analysis (LCA). The rationale for this is easy to understand. The consequence is that a real battery system, which can deliver several kWh storage over its lifetime will have to be downscaled to a virtual 1 kWh battery system. For example, a battery storage system providing 2000 kWh of output energy over its service life will be downscaled to 0.05 % (1 kWh/2000 kWh). This might sound complex but the benefit of this rescaling is that life cycle cost (LCC) becomes equivalent to Levelized Cost of Electricity storage (LCOE) (€/kWh) and the calculated impact is per kWh (e.g. CO₂-eq/kWh), which are common metrics to compare energy production and storage solutions. This will become clear in Task 5 and 6 on LCC and LCA.

The PEF study also documented for the proper understanding of their impact modelling some key aspects of their functional unit, see Table 5. This study also defined the reference flow being the amount of product needed to fulfil the defined function and shall be measured in kg

⁴ http://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm

⁵ http://ec.europa.eu/environment/eussd/smgp/pdf/OEFSR_guidance_v6.3.pdf

of battery per kWh of the total energy required by the application over its service life. Which is an important parameter to quantify the environmental impact from batteries.

For the sake of compatibility and harmonization of data **this study proposes to use the same functional unit as the PEF for high specific energy rechargeable batteries for mobile applications.**

Table 5: Key aspects of the functional unit for batteries (source: PEF pilot phase⁴)

What?	Electrical energy, measured in Wh or kWh (current and voltage during a unit of time).
How much?	1 kWh of the total energy delivered over service life (quantity of Wh, obtained from the number of cycles multiplied by the amount of delivered energy over each cycle).
How well?	Maximum specific energy (measured in Wh/kg). Specific product standards and technical properties of the high specific energy rechargeable batteries PEF shall be declared in the PED documentation.
How long?	The amount of cumulative energy delivered over service life of the high specific energy rechargeable batteries (quantity of Wh, obtained from the number of cycles multiplied by the amount of delivered energy over each cycle). The time required to deliver this total energy is not a significant parameter of the service.

Note that the PEF study for UPS⁶ has defined a different functional unit: 'To ensure the supply of power without interruption to equipment with load of 100 watts for a period of 1 year, including a backup time of 5 minutes during a power shortage'. This can be explained because for UPS other battery selection criteria matter, see Table 4 and Table 6. Moreover, these products have already been studied in a previous Ecodesign study 'Lot 27 UPS'. Hence, because UPS batteries have already been studied and have another functional unit it is recommended to exclude them from the scope of this study, see also 39. Also, electrical grid Energy Storage Systems (ESS) can sometimes have the same functional unit as previously defined, however the name ESS is sometimes also used to refer to grid ancillary, which has a different functional unit, e.g. maintain the grid power balancing.

Table 6: Comparing application criteria between BEV and UPS applications

Typical application parameters (See Task 3 on use)	Passenger car (BEV)	UPS (server, lift, light, etc)
Importance of low specific weight	high	low
Importance of efficiency	high	low
Importance of self-discharge	medium	high
Importance of long cycle life	high	low

⁶ http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

1.7 The basic secondary product performance parameters

This section lists some of the basic secondary parameters that are required to describe and characterize the identified product on a functional level. These are important parameters that are mainly provided and defined based on European and International standards and UN manuals. There are some definitions that have been included and are required by the PEF but have not been found to be defined in any standard or regulation. When they are not found on existing standards the study team will provide its own draft definition. Note however that when deemed necessary additional parameters will be added in subsequent tasks.

Capacity: Total number of ampere-hours that can be withdrawn from a fully charged battery under specified conditions. (ISO 12405) [14]–[16]. Strictly the ampere-hours is used in the standards, but this parameter can also be expressed in ampere-hour or kilowatt-hour (Ah or kWh).

Rated capacity: Capacity value of a cell, module, pack or system determined under specified conditions and declared by the manufacturer. (IEC 61960) [36]. This parameter is expressed in ampere-hour (Ah).

Current rate or C-rate: the current that corresponds to the declared capacity by the manufacturer [37]. This parameter is expressed in amperes. For portable and industrial applications this has been defined to be at C/5 [11], [36], for BEV it is defined at C/3 [16], [21] and C/1 for HEV applications [16], [21].

State of Charge (SOC): Available capacity in a cell, module, pack or system expressed as a percentage of rated capacity. (IEC 62660) [19], [20], [38], [39]. This parameter is expressed in percentage (%)

Depth of Discharge (DOD): Percentage of rated capacity discharged from a cell, module, pack or system battery. (IEC 62281) [6] This parameter is expressed in percentage (%).

End of Life (EoL): Condition that determines the moment a battery cell, module or pack does not anymore reach a specified performance in its first designated application based on the degradation of its capacity or internal resistance increase. This condition has been set to 80% for electric vehicle application and 60% for portable applications of the initial capacity. (Study team's own definition, not found in any standards so far) [36], [38]. for electric vehicle application (condition B in the cycle life tests in IEC-62660-1) and 60% for portable applications of the rated capacity (in table 5 of IEC 61960, using the accelerated method). (IEC 61960, IEC 62660) [36], [38].

Full cycle: Means one sequence of fully charging and fully discharging a rechargeable cell, module or pack. (UN Manual of Tests and Criteria) [40]. This parameter is expressed as an absolute value (-).

Specified duty cycle: One or multiply sequences of charging or discharging a battery to a specified state of charge and discharging to a specified depth of discharge under a specified load. The charge and discharge may follow a dynamic profile. This cycle can either be defined by the cell manufacturer or the battery system manufacturer and is typically related to conditions the battery would normally be operated in (study team's own definition, not found in any standards so far). This parameter is expressed as an absolute value (%).

Cycle life: The total amount of specified duty cycles a battery cell, module or pack can perform until it reaches its End of Life condition related to its capacity degradation or power loss (study team's own definition, not found in any standards so far). This parameter is expressed as an absolute value (%).

Calendar-life or shelf-life: The time a battery cell, module or pack can be stored under specified conditions (temperature) until it reaches its end of life condition (study team's own definition, not found in any standards so far). This parameter is expressed in days (-).

Nominal voltage: Suitable approximate value (mean value between 0% and 100% DOD) of the voltage during discharge at a specified current density used to designate or identify the voltage of a cell or a battery. (IEC 62620) [11]. This parameter is expressed in Volts (V).

Voltage limits: Maximum and minimum cut-off voltage limits for safe operation of a battery cell. These limits are also implemented to achieve a complete charge and discharge that leads to the rated capacity under a specified current rate. This parameter is expressed in Volts (V).

Internal resistance: The resistance within the battery, generally different for charging and discharging, also dependent of the battery state of charge and state of health. As internal resistance increases, the battery efficiency decreases, and thermal stability is reduced as more of the charging/discharging energy is converted into heat. [41]. This parameter is expressed in Ohms (Ω).

Open circuit voltage (OCV): Means the voltage across the terminals of a cell or battery when no external current is flowing. (UN Manual of Tests and Criteria) [40]. The OCV depends on the state of charge current rate and state of health of a battery. This parameter is expressed in Volts (V).

Specific energy / Gravimetric energy density: Amount of stored energy related to the battery cell, module, pack or system weight expressed in Wh/kg. (ISO 12405) [14]–[16].

Specific power / Gravimetric power density: Amount of retrievable constant power over a specified time relative to the battery cell, module, pack or system weight expressed in W/kg (study team's own definition, not found in any standards so far).

Volumetric Energy density: Amount of stored energy related to the battery cell, module, pack or system volume expressed in Wh/l. (ISO 12405) [14]–[16].

Volumetric Power density: Amount of retrievable constant power over a specified time relative to the battery cell, module, pack or system volume expressed in W/l. (Study team's own definition, not found in any standards so far)

Coulombic efficiency: Efficiency of the battery, based on electricity (in coulomb) for a specified charge/discharge procedure, expressed by output electricity divided by input electricity. (ISO 11955) [42]. This parameter is expressed in percentage (%).

Energy efficiency: Ratio of the amount of energy provided by a battery during discharge and the amount of energy needed to re-charge the battery to its initial state of charge. This may cover a sequence of charge and discharge rates with a net discharge or charge effect. The storage efficiency on cell level is given by the voltage difference between charge and discharge potential of the cell and its coulomb efficiency. On module, pack or system level, power demand by electronics and supporting infrastructure can also impact the storage efficiency (study team's own definition, not found in any standards so far). This parameter is expressed in percentage (%).

Note that for this study also definitions on **reparability**, **dismantlability**, etc. might be needed, they are under development in proposal for new EN standards from CEN CLC JCT10 and preliminary definitions were already included before in 1.2.5. For the work ongoing see the Annex on standards complementary to this report. Related definitions will be added in later tasks when needed.

1.8 Discussion of the proposed scope of this study

The study aimed at building on the PEF pilot⁷ results and therefore on 'High Specific Energy Rechargeable Batteries for Mobile Applications' with high capacity, see also section 1.6 on the PEF and functional unit. In order to have a consistent and expected significant scope the study team agreed to electrochemical batteries with internal storage and solid electrodes only^{8,9} and the further scoping and focusing explained hereafter. Note that also Tasks 2-5 can according to the MEErP reconsider or reduce the scope for Tasks 6-7 based on their findings. For more information in forecasted market volumes of batteries please read Task 2, it provided the rationale for excluding some applications.

In order to define the scope of the remainder of this study, the following topics were taken into consideration:

- the aim to build on the PEF study for mobile applications and to have a clear single functional unit and a corresponding product group to perform a consistent analysis according the MEErP in Tasks 3 to 6. Considering different applications with different requirements is therefore not an option, it would require different studies.
- Uninterruptable Power Supply systems (UPS) (stationary batteries) were already part of a completed Ecodesign Study (Lot 27). Moreover, UPSs have a complete different functional unit, i.e. provide back-up power during occasional power interrupts, which would lead to an inconsistent study in Tasks 3-6. Therefore, the PEF study for UPS and 'High Specific Energy Rechargeable Batteries for Mobile Applications' had a different and incompatible functional unit compared to UPS.
- Industrial back-up batteries (usually, but not always, stationary) are used in for example nuclear power plants, high speed trains, airplanes, offshore platforms, etc. can have each very different requirements (duration of back-up, service life, ability to withstand temperature, shock and vibrations, ability to perform additional services). A unique functional unit would not adequately cover all these segments. Developing use-specific functional units would require a considerable amount of resources, which are not available, and likely would never adequately capture evolving needs.
- Smaller mobile battery systems were also part of previous Ecodesign studies: Computers and servers (Lot 3) and portable machine tools (Lot 5). Moreover, portable batteries are another category in the battery directive.
- The largest volume of lithium batteries (LiB) is expected for EV applications, see Task 2. According to the MEErP this will therefore also define the base cases or reference systems for impact modelling. Hence accordingly the conclusion for Task 3 to 6 will be to focus on EV E-mobility applications.
- Electric bicycles are complex to model in Task 3 because they have hybrid human/electric power and as explained before referring to Task 2, the total EU mass of batteries sold will be relatively low. Hence, they are not relevant for Tasks 3 to 6.

⁷ http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

⁸ Batteries with external storage are excluded from the scope because the expected niche market (see Task 2) for this application and lack of time to investigate this into detail in this study.

⁹ Batteries with liquid electrodes like ceramic batteries are excluded from the scope because they are not used in electric vehicles and their ecodesign and recycling is much less challenging due to the used materials

- We are aware that other industry/agricultural mobile applications exist and might use also use similar rechargeable batteries (forklifts, garden machinery, mobile floor cleaning tools, etc.). However, here again the Task 3-6 modelling could be very complex and accurate data unavailable today and a relative lower volume to EV is expected, for which they will be excluded from Tasks 3-6.
- Note that despite some the proposed focus for Tasks 2-6 content and work, the policy process can be extended where deemed useful in a later stage of policy making following this preparatory study.
- Taking into consideration that the same LiB batteries can render a useful service as an Energy Storage System (ESS) combined with photovoltaic (PV) modules which are in the scope of the Ecodesign Study on photovoltaic Systems¹⁰. Herein smaller consumers could benefit from further Ecodesign requirements (if any). Also, second life application of EV batteries for ESS could be an option to reduce the carbon footprint, however this still needs to be confirmed if it is technical and economical feasible.
- In their feedback on the draft Task 1 and the first stakeholder meeting several industry federations urged to focus on e-mobility applications because requirements among industrial batteries can be extremely different and each battery technology currently available on the market (lead, lithium, sodium and nickel) can be best suited to serve specific market segments thanks to their different features. This can also be concluded from the introduction in section 1.4.1.
- Taking into account that grid support (mainly ancillary service) and energy storage (mainly photovoltaic energy) function can be very dependent on the local grid circumstances which is not harmonized in the EU (metering intervals, feed in tariffs, grid ancillary services and power reserve market, weather conditions, grid congestion issues, etc.). Therefore, the study will only look at the similar energy storage function but cannot go into the various details of for example grid support (primary reserve, etc.).

Considering all this, the scope herein is: 'High energy rechargeable batteries of high specific energy with solid lithium cathode chemistries for e-mobility and stationary energy storage (if any). Herein batteries are either a pack or a system as defined within this study and in line with the international standards. This does not include power electronics neither heat nor cool supply systems for thermal management which can be part of what the study defined as a battery application system.'

More in detail:

High specific energy is hereby defined by a gravimetric energy density typically above 100 Wh/kg at cell level, this means that several battery technologies are excluded based on this criterium, see Table 4. This is also an elegant and technical way to exclude some types of UPS batteries which have different functional unit and for which weight is of lower importance, see recommendation in section 1.6.

¹⁰ http://susproc.jrc.ec.europa.eu/solar_photovoltaics/index.html

High capacity means that a total **battery system capacity between 2 and 1000 kWh**. Note that as defined in section 1.5 the ‘battery application system’ can be a multiple of the ‘battery system capacity’, e.g. as is the case in large modular energy storage systems for grid support. See also Task 2-3 for market and user data, it appears that few systems above 1000 kWh can be expected due to typical energy use of cars (about 20 kWh/100 km) and houses (about 3500 kWh/year). Battery applications such as grid energy storage that require above 1000 kWh are composed of parallel or multiple smaller systems (<1000 kWh) due to transport and weight constraints. Below 2 kWh is expected a smaller market volume (e.g. cycles), see Task 2, and also ICT (Lot 3) and portable machine tools (Lot 5) having small capacity batteries were already part of previous Ecodesign studies. Below 2 kWh are also the portable batteries which are a separate category in the Batteries Directive(2006/66/EC), see 1.4.3.

Despite this proposed limitation of the scope in Tasks 2-6, in **Task 7 it can be investigated of policy measures can be extended** to a broader scope if the expected impact is unanimously positive.

As a consequence of these energy density and battery system capacity limits, are reducing the scope of this study but **have lithium-ion technologies included**. Given the time constraints in this study this will allow to build on the results from the PEF study for e-mobility available for lithium-ion technology and for which a significant market is expected in the upcoming years (see Task 2).

A battery system and battery application system were previously defined, see 1.5.

As a consequence, the batteries in the proposed scope are according to the definitions of the current Batteries Directive(2006/66/EC) part of the ‘the industrial batteries’. Herein ‘industrial batteries’ are defined as any battery designed for exclusively industrial or professional uses or used in any type of electric vehicle. For more information see section 1.1.12 regarding the Battery Directive.

The proposed scope for this study is thus rechargeable industrial batteries (2006/66/EC) with a high specific density (>100 Wh/kg) and high capacity (2 to 1000 kWh).

1.9 Test standards and/or methods

The general objective of this task is to describe test standards related to the product categories described within the scope of this study. Standards are documents drawn up by consensus and approved by a recognised standardisation body. A test standard describes a method of testing in which no pre-given result is required when performing the test.

The content of this section has been published as a separate annex report due the the extension of the descriptions¹¹.

¹¹ Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619-Lot 1. TASK 1 Scope. Annex: Analysis of available relevant performance standards & methods in relation to Ecodesign Regulation for batteries and identification of gaps. January 2019.

Complementary to the Annex information in related standards can be also be found in: <https://www.batterystandards.info/>¹², the public document of the MAT4BAT project Deliverable 5a 'List of relevant regulations and standards' [43] and the JRC technical report on 'Standards for the performance assessment of electric vehicles batteries' [12].

1.10 Existing legislation

According to the MEERp methodology, EU legislation, Member State legislation and third country legislation relevant to the product group should be screened and analysed.

The most interesting battery regulations can be summarized in the following list:

- Regulation on CE marking
- Regulations on transport of batteries
- European battery directive
- Directive on restrictions of hazardous substances (RoHS)
- Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)
- The battery capacity labelling regulation
- The UNECE vehicle regulation
- Ecodesign Directive (ED)
- The Energy Labelling Regulations (ELR)
- The Framework Directive on type-approval for motor vehicles
- The End of Life of Vehicles (ELV) Directive
- The Waste of Electrical and Electronic Equipment (WEEE) Directive

1.10.1 Regulation on CE marking

Regulation (EC) No 765/2008¹³ on CE marking creates the premise of the internal European Union market. It established the legal basis for accreditation and market surveillance and consolidated the meaning of the CE marking. Therefore, it is of relevance for battery manufacturers. 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;

¹² This website is dedicated in supporting a way through standards on rechargeable batteries and system integration

¹³ REGULATION (EC) No 765/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 July 2008 setting out the requirements for accreditation and market surveillance relating to the marketing of products and repealing Regulation (EEC) No 339/93

- 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: (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 Batteries 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. A complete guide on the implementation of EU product rules is given in the Blue Guide: Commission notice 2016/C 272/01¹⁴.

1.10.2 European Agreement concerning the international carriage of dangerous goods by road (ADR)

The transport of dangerous goods and articles in Europe is arranged in the ADR by UNECE (ECE/TRANS/257)¹⁵. Batteries fall under class 8 (corrosive products) or, for lithium and Li-ion batteries under class 9 (miscellaneous). For lithium (ion) batteries a specific section exists (§2.2.9.1.7) with exigencies to these batteries:

- Lithium cells and batteries have to pass ‘Manual of Tests and Criteria, part III, sub section 38.3’.
- Cells and batteries must have a safety venting device or being designed that no violent rupture can occur.
- Each cell and battery are equipped with an effective means preventing external short circuit.
- Each battery with cells or strings of cells in parallel are equipped with an effective means preventing a dangerous current in the opposite direction, e.g. by diodes or fuses.
- Cells and batteries must be manufactured under a production quality management system.

Table A in the ADR prescribes the needed marking, the special provisions and the packaging possibilities. Chapter 6 prescribes the packaging tests and pass criteria.

¹⁴ https://ec.europa.eu/growth/content/%E2%80%98blue-guide%E2%80%99-implementation-eu-product-rules-0_fi

¹⁵ https://www.unece.org/fileadmin/DAM/trans/danger/publi/adr/adr2017/ADR2017E_web.pdf

For lithium batteries a distinct category is made for damaged or defective cells or batteries, defined as that they do not conform to the type tested according to the provisions of the Manual of Tests and Criteria.

1.10.3 Manual of Tests and Criteria, part III, subsection 38.3

All lithium (ion) batteries that are transported, irrespective of the transport way, have to fulfil the UN38.3 regulation by the United Nations [40]. It prescribes 8 test methods and test 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:

- ICAO: Dangerous goods (DGR), and Li-ion by airplane
- UNECE: Dangerous goods by road: European Agreement concerning the International Carriage of Dangerous Goods by Road, ADR
- UNECE: European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways, ADN
- 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.

1.10.4 European battery directive

Directive 2006/66/EC is the main European regulation on batteries. 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 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.

Note that the Batteries Directive is currently under review¹⁶.

1.10.4.1 Scope

The Batteries Directive discriminates three battery applications:

- Portable battery: any battery, button cell, battery pack or accumulator that:
 - is sealed;
 - can be hand-carried; and
 - is neither an industrial battery or accumulator nor an automotive battery.
- automotive battery or accumulator: any battery or accumulator used for automotive starter, lighting or ignition power;

¹⁶ https://ec.europa.eu/info/consultations/public-consultation-evaluation-batteries-directive_en

- industrial battery or accumulator: any battery or accumulator designed for exclusively industrial or professional uses or used in any type of electric vehicle.

1.10.4.2 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 9: Obligatory labelling for batteries

1.10.4.3 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 and medical equipment.

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.

1.10.4.4 Collection rates for portable equipment

EU member states should achieve the following minimum collection rates:

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

1.10.4.5 Disposal

The EU 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.

1.10.4.6 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.

1.10.4.7 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.

This means that Li rechargeable batteries must 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. Herein 'output fraction'(Art. 2 (5)) means the mass of materials that are produced from the input fraction as a result of the recycling process, as defined in an Annex (I) without undergoing further treatment, that have ceased to be waste or that will be used for their original purpose or for other purposes, but excluding energy recovery. 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, CO₂ emission and/or slags can be included in the recycling efficiency. This concerns mostly oxygen. Carbon can also be used as a reducing agent and therefore CO₂ emission from the battery recycling can be accounted as recycled if it has been used as a reducing agent. An independent scientific authority must 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% O₂ 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 hydro metallurgic processes and/or thermal processes.

Closely related EU legislation on hazardous waste are:

- Council Directive 67/548/EEC¹⁷ on classification, packaging and labelling of dangerous substances determines the substances that are considered dangerous and give provisions on classification, packaging and labelling
- Directive 2000/53/EC on end-of-life vehicles¹⁸. It prohibits the use of mercury, lead, cadmium and hexavalent chromium in vehicle materials and components. It has

¹⁷ [Council Directive 67/548/EEC of 27 June 1967 on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.](#)

¹⁸ [Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles](#)

no additional clauses for battery materials. Batteries must be removed for depollution of end-of-life vehicles.

- Directive 2012/19/EU on Waste Electrical and Electronic Equipment (WEEE)¹⁹. It sets recycling rates for this type of equipment, including selective treatment of batteries included in electrical and electronic equipment.

Note that related to recycling the European Commission has defined a list of Critical Raw Materials²⁰ (CRM). Raw materials are crucial to Europe's economy and access to certain raw materials is a growing concern within the EU and across the globe. To address this challenge, the European Commission has created a list of critical raw materials (CRMs) for the EU, see Table 7, which is subject to a regularly review and update.

Table 7 2017 list of Critical Raw Materials

2017 CRMs (27)			
Antimony	Fluorspar	LREEs	Phosphorus
Baryte	Gallium	Magnesium	Scandium
Beryllium	Germanium	Natural graphite	Silicon metal
Bismuth	Hafnium	Natural rubber	Tantalum
Borate	Helium	Niobium	Tungsten
Cobalt	HREEs	PGMs	Vanadium
Coking coal	Indium	Phosphate rock	

*HREEs=heavy rare earth elements, LREEs=light rare earth elements, PGMs=platinum group metals

1.10.4.8 Member state implementation

Most of the EU members states have national legislation for implementing the Batteries Directive (2006/66/EC). It is related with the chemical restrictions, recycling and collection of batteries and accumulators found in different electrical applications. Table 6 shows a list of the different legislations implemented in specific member states.

¹⁹ [Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment \(WEEE\)](#)

²⁰ http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_nl

Table 8: Member state legislation on batteries and accumulators [45].

Austria	Regulation of the Federal Minister for Agriculture and Forestry on prevention of waste, and the collection and treatment of end-of-life batteries and accumulators
Belgium	Flemish regulations on waste prevention and waste management VLAREA Arrête royal relative aux piles et accumulateurs ainsi qu'aux déchets de piles et d'accumulateurs
Bulgaria	Ordinance on the requirements for placing on the market batteries and accumulators and treatment and transportation of waste batteries and accumulators
Cyprus	The regulations on solid and hazardous wastes (batteries or accumulators)
Czech Republic	Act No. 185/2001, on waste and amending some other laws (Directive 2006/66/EC)
Denmark	Executive order on batteries and accumulators and waste batteries and accumulators
Estonia	Handling requirements for used batteries and accumulators
Finland	Decree on batteries and accumulators
France	Decree on the placing on the market of batteries and accumulators and on the disposal of waste batteries and accumulators and amending the environmental code
Germany	The introduction to circulation, recovery and environmentally-friendly disposal of batteries and accumulators
Greece	Decree on waste management from batteries and accumulators
Hungary	Government regulation No. 181/20098 on the take-back of batteries and accumulators
Ireland	Waste management (batteries and accumulators) regulations 2008 (S.I. No 268 of 2008)
Italy	Recepimento della direttiva 2006/66/CE del parlamento europeo e del consiglio del 6 settembre 2006, elativa a pille e accumulatori e ai rifiuti di pile e accumulatori e che abroga la direttiva 91/157/CEE
Latvia	Waste management law
Lithuania	Law on waste management of the republic of Lithuania
Luxembourg	Loi du 19 décembre 2008 relative aux piles et accumulateurs ainsi qu'aux déchets de piles et d'accumulateurs
Malta	Batteries and accumulators regulations, 2011
Netherlands	Besluit van 4 juli 2008, houdende regels met betrekking tot de mededeling inzake het afvalbeheer en het gebruik van bepaalde gevaarlijke stoffen in batterijen en accu's (Besluit beheer batterijen en accu's 2008)
Norway	Regulation on changes to regulation on recycling processing of waste (Waste regulation)
Poland	The law of 2007 on batteries and accumulators as well as waste batteries and accumulators
Portugal	Decree law 6/2009 transposing the battery directive
Romania	Government decision draft on batteries and accumulators, and waste batteries and accumulators (April 2008)
Slovakia	Slovakian law – Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators
Slovenia	Decree on batteries and accumulators and waste batteries and accumulators
Spain	Royal decree 106/2008 of 1 February 2008, on batteries and accumulators and environmental waste management
Sweden	Proposal for implementation of Directive 2006/66/EC of the European Parliament and of the Council, of 6 September 2006, on batteries and accumulators, and waste batteries and accumulators
United Kingdom	Document on the Implementation of the Batteries and Accumulators and Waste Batteries and Accumulators Directive (2006/66/EC) – Waste Battery Collection and Recycling Provisions

1.10.5 Directive on the Restriction of Hazardous Substance (RoHS)

The RoHS recast Directive 2011/65/EU²¹ 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. Batteries are currently not in the scope of this directive; however it might apply to some parts of a battery system such as the battery management system.

1.10.6 Regulation on capacity labelling of portable secondary and automotive batteries

The Commission Regulation 1103/2010 on rules as regards capacity labelling of portable secondary (rechargeable) and automotive batteries and accumulators pertains the capacity marking requirements of portable rechargeable batteries including specific requirements related to its minimum size and location. 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.

1.10.7 UNECE Electric vehicle regulation

The Economic Commission for Europe of the United Nations (UNECE) has developed the regulation UNECE R100, Battery electric vehicle safety, within committee ECE/TRANS/WP.29 [46]. 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 [47].

Today electric vehicles must specify the battery capacity often only indirectly in a driving range, which is related to standard driving cycles.

Under the UNECE vehicle regulation two driving profiles to assess the CO₂ emissions of vehicles have been developed. These are the New European Driving Cycle (NEDC - E/ECE/324/Rev.2/Add.100/Rev.3) [48] and the Worldwide Harmonised Light Vehicle Test Procedure (WLTP - ECE/TRANS/WP.29/GRPE/2018/19) driving profiles [49]. While these driving profiles have been mainly developed for the assessment of tail pipe emissions of conventional vehicles they can be also be implemented in the context of Electric Vehicles. Electric Vehicle manufactures are implementing these driving cycles to inform the consumer of the total driving range that these vehicles can deliver. These driving cycles are not being executed to establish the capacity of individual batteries but the driving range that a battery system of an Electric Vehicle can deliver all the energy stored is consumed.

Furthermore under the UNECE regulation additional safety aspect have to be considered in relation to Electric Vehicles in UN R100.02 [48]. It aims to protect against electric shock and

²¹ Title here as from previous examples...

therefore: direct contact in connectors and during service of the vehicle, indirect contact and isolation resistance. The UNECE regulation provides also safety in terms of accumulation of gas, functional safety and determination of hydrogen emissions. It will be transposed in the future by the regulation GTR 20 encompassing ECE/TRANS/180/Add.20 [50] and ECE/TRANS/180/Add.20/Appendix I [51].

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

Regulation (EC) No 1907/2006 on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)²² is regulating the use of chemicals in Europe [52]. 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 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 120000 unique substances/entries at the start of 2016 [53].

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 [54] contains at least two substances known for use in Li-ion batteries:

- 1,2-dimethoxyethane or ethylene glycol dimethyl ether (EGDME, $C_4H_{10}O_2$) [55]: electrolyte solvent, very persistent and very bio-accumulative (vPvB)
- 1,3-propanesultone or 1,2-oxathiolane, 2,2-dioxide ($C_3H_6O_3S$) [56]: 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 [57]. Providing a Safety Data Sheet is not mandatory for articles and users of chemicals [58].

1.10.9 The European Ecodesign Directive (2009/125/EC) and its implementing regulations

The Ecodesign Directive provides consistent EU-wide rules for improving the environmental performance of products, such as household appliances, information and communication technologies. The Directive sets out minimum mandatory requirements for the energy efficiency of these products and/or on providing information.

Important content related to battery applications: In Article 1 on 'Subject-matter and scope' it says that it 'This Directive shall not apply to means of transport for persons or goods'. Therefore, it does for example exclude Electrical Vehicles as a product itself and products that

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are exclusively used for cars, such as tyre labels that have their own Regulation (EC) No 1222/2009 and also batteries which are exclusively for vehicles. This is a legal matter but could pose challenges to convert the outcomes of this study into policy based on the Ecodesign Directive. Note however that due to the Vehicle-to-Grid (V2G) technology, EV batteries might also be used as electricity storage for buildings and have a therefore different nature than the solely transport-related one.

So far two EU Ecodesign Regulations are currently in preparation that may cover battery systems:

Commission Regulation (EU) No 617/2013 with regard to Ecodesign requirements for computers and computer servers includes requirements on the extraction and replacement of batteries. The review may include requirements on battery durability (proxy of indication on number of loading cycles that batteries can withstand). A review study of the ecodesign requirements for this product group has been completed in July 2018 [59].

Potential Commission Regulation and/or Voluntary Initiative within the framework of the Ecodesign Directive 2009/125/EC with regard to Uninterruptible Power Supplies (UPS): The status is that a preparatory study has been carried out (Lot 27: Uninterruptible power supplies). The proposed measures are based on UPS efficiency with a material resource bonus, hence taking battery efficiency and materials into account. So far there is no Ecodesign Directive implementing measure yet. However, a voluntary agreement (not under the Ecodesign Directive) has been in place for about ten years, namely the Code of Conduct for AC Uninterruptible Power Systems [60].

Note that parallel to this study an Ecodesign Study on Photovoltaic systems is ongoing²³, that also includes battery storage.

It is the purpose of this study to consider further Implementing Measures (IM) for batteries within the framework of the Ecodesign Directive.

1.10.10 The EU Energy Labelling Framework Regulation (2017/1369)

This EU Regulation sets a framework for energy labelling, simplifying and updating the energy efficiency labelling requirements for products sold in the EU.

Important content related to battery applications:

- In their recitals it says that 'As the energy consumption of means of transport for persons or goods is directly and indirectly regulated by other Union law and policies, it is appropriate to continue to exempt them from the scope of this Regulation, ...'
- In Article 1 on 'Subject-matter and scope' it says that it 'does not apply to: (a) second-hand products, unless they are imported from a third country; (b) means of transport for persons or goods'.

As a conclusion, it does for example exclude Electrical Vehicles as a product itself. It is however unclear whether or not this also applies to components for vehicles such as batteries. This is a legal matter, which goes beyond the scope of this study.

²³ http://susproc.jrc.ec.europa.eu/solar_photovoltaics/index.html

1.10.11 The framework Directive on type-approval for motor and other vehicles

The technical harmonisation of motor vehicles in the EU is based on the Whole Vehicle Type-Approval System (WVTA)²⁴. Under the WVTA, a manufacturer can obtain certification for a vehicle type in one EU country and market it EU-wide without further tests.

It is based on:

- A framework Directive on type-approval for motor vehicles motor vehicles (2007/46/EC)
- Regulation (EU) 2018/858 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending previous regulation
- Regulation for two and three-wheeled vehicles and quadricycles (168/2013/EU)
- Regulation for non-road mobile machinery emissions (Regulation (EU) 2016/1628)

Within WVTA the concept of type approval of components is used which might be relevant to this study:

A 'whole vehicle' is made up of large numbers of components and systems, each of which must conform to corresponding requirements. Suppliers of relevant parts however must ensure that their products meet those requirements. Type approval makes a distinction between 'components for vehicles' - such as lighting components, glazing, rear view mirrors, etc - and 'systems for vehicles', which determine compliance of many components together, such as for braking, steering, crash performance and emissions.

1.10.12 The End of Life of Vehicles (ELV) Directive

Directive 2000/53/EC on end-of life vehicles aims at making dismantling and recycling of ELVs more environmentally friendly. It sets clear quantified targets for reuse, recycling and recovery of the ELVs and their components. It also pushes producers to manufacture new vehicles without hazardous substances (in particular lead, mercury, cadmium and hexavalent chromium), thus promoting the reuse, recyclability and recovery of waste vehicles.

The Commission has an obligation to review the ELV Directive by 31 December 2020.

1.10.13 The Waste of Electrical and Electronic Equipment (WEEE) Directive

Directive 2012/19/EU (WEEE) was issued in 2012 as a recast of Directive 2002/96/EC.

The aim of this directive is expressed by its article 1: 'This Directive lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste from electrical and electronic equipment (WEEE) and by reducing overall impacts of resource use and improving the efficiency of such use.'

The directive puts the responsibility for handling of WEEE on the producers of such equipment. They shall finance the collection and treatment of their WEEE in a harmonised way that avoids false competition. Producers will shift payments to the consumers under the principle that the 'polluter pays', avoiding costs for the general taxpayer.

²⁴ http://ec.europa.eu/growth/sectors/automotive/technical-harmonisation/eu_en

In WEEE:

- Annex VII requires that batteries have to be removed from any separately collected WEEE. For specific treatment reference is made to the Batteries Directive.
- Annex VIII requires that batteries in sites for treatment of WEEE are stored in appropriate containers.
- In its recitals reference is made to the batteries directive that contains more specific requirements for batteries.

1.10.14 Directive on harmonisation of laws on Low Voltage equipment (LVD)

Directive 2014/35/EU regarding Low Voltage electrical equipment (LVD) was issued in February 2014 and repeals the existing directive 2006/95/EC with effect from April 2016. The purpose of this Directive is to ensure that electrical equipment on the market fulfils the requirements providing for a high level of protection of health and safety of persons, and of domestic animals and property, while guaranteeing the functioning of the internal market. The Directive applies to electrical equipment designed for use with a voltage rating between 50 and 1000 V for alternating current and between 75 and 1500 V for direct current. These voltage ratings refer to the voltage of the electrical input or output, not to voltages that may appear inside the equipment. For electrical equipment within its scope, the directive covers all health and safety risks, thus ensuring that electrical equipment will be used safely and in applications for which it was made. For most electrical equipment, the health aspects of emissions of electromagnetic fields are also under the domain of the Low Voltage Directive.

1.10.15 Regulation (EU) No 333/2014 to reduce car CO₂ emissions

Regulation (EU) No 333/2014 amending Regulation (EC) No 443/2009 sets targets to reduce CO₂ emissions from new passenger cars by 2021. By 2021, phased in from 2020, the fleet average to be achieved by all new cars is 95 grams of CO₂ per kilometre. This means a fuel consumption of around 4.1 l/100 km of petrol or 3.6 l/100 km of diesel. Emission limits are set according to the mass of vehicle, using a limit value curve. There are penalty payments for excess emissions. Manufacturers can group together and act jointly to meet the emissions target. The cars Regulation gives manufacturers additional incentives to produce vehicles with extremely low emissions (below 50 g/km). Super-credits will also apply in the second stage of emission reductions, from 2020 to 2022.

The European Commission is currently working on a proposal for setting targets after 2020: https://ec.europa.eu/clima/policies/transport/vehicles/proposal_en.

The proposed framework combines CO₂ targets for 2025 and 2030 with a technology-neutral incentive mechanism for zero- and low-emission vehicles in order to give the market a clear signal for investment in clean vehicles. Herein are defined:

- **zero-emission vehicles** such as battery electric or fuel cell vehicles
- **low-emission vehicles** having tailpipe emissions of less than 50 g CO₂ per km – these are mainly plug-in hybrid vehicles equipped with both a conventional and an electric engine

Important herein worth noting that for defining CO₂ emissions only exhaust emissions are taken into account, based on how data is reported according to the worldwide harmonized

light vehicles test procedure (WLTP) or previously the New (1997) European Driving Cycle (NEDC).

The CO₂ targets of this regulation are based on measurements at the tailpipe to evaluate the in-use emissions performance. This is the so-called 'tank to-wheel' approach, rather than a well-to-wheel or life-cycle analysis approach. These other approaches look further along the emissions chain, e.g. energy involved in producing the fuel/energy used, energy from making the vehicle or its end-of-life treatment. Nevertheless, these are important issues for this study, so far CO₂ emissions from electric vehicles (EV) were not taken into account as there is no consistent methodology in use for such an approach. Hence in the current approach electric vehicles have attributed 0 g CO₂/kWh, in other words it is currently CO₂ emission targets at the tail-pipe used in Regulation (EU) No 33/2014 and not the CO₂-eq GWP targets from life-cycle analysis (LCA).

Hence, this Regulation does not take into account indirect CO₂ emissions that will be modelled later on in this study.

1.10.16 The car labelling Directive (Directive 1999/94/EC)

The aim is to help drivers choose new cars with low fuel consumption, EU countries are required to ensure that relevant information is provided to consumers, including a label showing a car's fuel efficiency and CO₂ emissions. It is complementary to the Regulation (EU) No 333/2014 to reduce car CO₂ emissions, see 1.10.15.

Here again the CO₂ label is based on measurements at the tailpipe to evaluate the in-use emissions performance or the so-called 'tank to-wheel' approach, rather than a well-to-wheel or life-cycle analysis approach. Therefore, electric vehicles have attributed 0 g CO₂/kWh, in other words it is currently based on CO₂ emission at the tail-pipe but not the CO₂-eq GWP targets from life-cycle analysis (LCA).

1.10.17 Weight and dimension limits in road transportation

In Europe regular road transport must comply with certain rules regarding to weights and dimensions for road safety reasons and to avoid damaging roads, bridges and tunnels. This is implemented through the Directive (EU) 2015/719 for the indirect impact on the maximum weight and size laying down for certain road vehicles the maximum authorised dimensions and the maximum authorised weights. This directive limits regular road transport to 40 tonnes (incl. trailer), 2.6-meter width, 4-meter height (incl. trailer) and 12-meter length. As an indirect consequence, in Europe battery application systems as defined in this task for use in applications that require large storage capacity such as grid support are unlikely to become larger. For large storage application most likely a set of parallel battery systems will be installed.

1.10.18 Relevant examples of legislation outside the EU

Looking at the international landscape, different countries have implemented legislation dealing with the recycling and collection of battery materials. This can be related to chemical restrictions (mercury, nickel etc.) during manufacturing of batteries and procedures that have to be followed for the recycling of the battery materials. In Annex A of IEC 60086-6 ED1 Primary batteries - Part 6 Guidance on environmental aspects a list of found international legislations has been included.

Table 9: International legislation related to the recycling and restrictions of chemicals in batteries

China	<p>Restriction of the Use of Certain Hazardous Substances in Electrical and 669 Electronic Products (China RoHS 2)</p> <p>A national standard: Recycling Of Traction Battery Used In Electric Vehicle-dismantling -specification (GB/T 33598-2017)".</p> <p>Manufacturers are responsible for recycling and must set up a traceability systems²⁵ and have a maintenance network</p>
Taiwan	Waste Disposal Act
Japan	Act on Preventing Environmental Pollution of Mercury
	Act on the Promotion of Effective Utilization of Resources
Republic of Korea	Enforcement Decree of the Act on the promotion of saving and recycling of 726 resources
	ELECTRICAL APPLIANCES AND CONSUMER PRODUCTS SAFETY CONTROL 735 ACT
Singapore	Environmental Protection and Management Act
Vietnam	Decision No.16/2015/QĐ-TTg of the Prime Minister
Brazil	CONAMA resolution No.401 of Nov.4, 2008
Colombia	Resolution 1297/2010 - Secondary batteries of following HS code and primary batteries
Israel	Environmental Treatment of Electrical and Electronic Equipment and Batteries Law, 854 5772-2012
Canada	Products Containing Mercury Regulations (SOR/2014-254)
Quebec	Regulation respecting the recovery and reclamation of products by enterprises
British Columbia	Recycling Regulation, B.C. Reg. 449/2004, Environmental Management Act
Manitoba	Regulation 16/2010, Household Hazardous Material and Prescribed Material 872 Stewardship Regulation
USA	Mercury-Containing and Rechargeable Battery Management Act
	New York State Rechargeable Battery Law

1.10.19 Summary and conclusion on legislation for batteries in the scope of this study

The main findings of this review are that the outcomes of this study could:

- Result in Implementing Measures in the framework of the Ecodesign Directive (2009/125/EC), but might require an amendment because means of transport are exempted
- Provide useful input for a future review of the Car Labelling Directive (D1999/94/EC) in the case that full life cycle emissions should be considered instead of tail pipe emissions.
- Define a label for the Energy Labelling Regulation (EU) 2017/1369 for a battery as standalone product, but might require some amendments because means of transport are currently exempted or without amendment for batteries that are not exclusively for mobility.
- Contribute to the review and impact of the Battery Directive (2006/66/EC).

1.11 Other initiatives

Hereafter is a selection of other government supported initiatives that could be relevant for the study.

1.11.1 Product Environmental Footprint

The European Commission services are working on building the single market for green products and therefore also the life cycle environmental performance of products and organisations²⁶.

There are two methods to measure environmental performance throughout the lifecycle, the Product Environmental Footprint (PEF) and the Organisation Environmental Footprint (OEF).

Two pilot studies were done²⁷ related to batteries, one on 'Batteries and accumulators' and another on 'Uninterruptible Power Supply'.

They will provide useful data to this study.

1.11.2 Nordic Swan ecolabelling for primary batteries

The Nordic Swan is a voluntary official ecolabel in Denmark, Norway, Sweden and Iceland. For batteries it focuses on portable primary batteries. Since the market for primary batteries is extensive and since they have differences in environmental and quality properties, the Nordic Ecolabelling is capable to differentiate and to determine the best ones in terms of environmental and quality properties.

The ecolabel prescribes much lower maximum values for toxic metals than the Batteries Directive does. It bans the use of PVC. Clear information on the possible application type must be given and the ecolabel discerns 3 discharge power levels.

²⁶ http://ec.europa.eu/environment/eussd/smgp/policy_footprint.htm

²⁷ http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm#pef

1.11.3 Nordic Swan ecolabelling for rechargeable batteries and portable chargers

The Nordic Swan Ecolabel focuses on capacity and durability of batteries to ensure long battery life thereby reducing the resource consumption. At the same time, batteries and portable chargers must meet recognized quality and safety standards.

The requirements include:

- Threshold values for heavy metals in batteries.
- No use of PVC and a number of flame-retardants in plastic.
- CSR policy to ensure responsible use and sourcing of limited raw materials and “conflict free” minerals.
- Electrical-, safety- and quality testing of batteries/cells, portable- and battery chargers.
- Nickel metal hydride (NiMH) batteries and cells must be fully charged when leaving the production site.
- Recyclable design of the portable charger.

1.11.4 Green Public Procurement in the EU

In 2008, the European Commission adopted a Communication on GPP (COM400, 2008), which, as part of the Sustainable Production and Consumption Action Plan, introduced a number of measures aimed at supporting GPP implementation²⁸ across the EU. Its key features are:

- EU GPP criteria
- Helpdesk
- Studies aimed at monitoring GPP implementation

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