November 2024

Recycling batteries: regulation, environmental impacts and key market players

Global Overview and Perspectives

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Battery recycling - Executive Summary

To remain on track with the Paris Agreements, electrification and storage should rely on sustainable batteries.

Climate change imposes states to adopt battery recycling objectives

- Batteries are regarded as one of the available tools to build a trajectory to **reach a net zero for direct & energy emissions** and to contribute to the objective of carbon neutrality across all up and downstream activities.
- The EU has adopted an **ambitious directive on batteries: 65% of a lithium-ion battery weight must be recycled in 2025, increasing to 70% by 2030.**
- As for critical metals, ambitious **recovery rates** were defined for cobalt, nickel, copper and lithium.

Sustainable batteries rely on the recycling industry

- Recycling industry stands as a fast-growing market, with an **8% yearly average growth** until 2030
- The Asia-Pacific concentrates more than **50% of the global market in value**, with China accounting for more of 70% of the region's capacities.
- This growing market is structured with **three categories of players**: recycling pure players, EV manufacturers and energy & raw materials suppliers.

The added value from battery recycling is high and relies on multiple factors

- Recycling represents a real opportunity, with **around 80% of recycling potential** from traditional batteries in electronics and EVs, thanks to recycling technologies already well-known in the mining and metallurgy companies.
- However, the recycling potential depends on the **battery composition** and the critical metal contained in the battery parts.
- The **value added** from recycled batteries remains **volatile**, as it is strongly conditioned by the market value of raw materials and scrap metals.

Source: IEA Electrification; IEA World Energy Outlook 2023; IEA Global Emissions by sector (2019-2022); Xerfi

Summary

1. Regulatory context and technology overview
2. Battery recycling industry forecasts
3. Environmental impact and value added of battery recycling
4. Our related offerings and capabilities
5. Appendix – current key standards and labels

1. Regulatory context and technology overview

Several battery categories co-exist on the market, with an unequal maturity

Li-ion appears as the sole leading technology on the market

Key :
Maturity level :
Low | Medium | High

Focus of this study

	Formula	Technology readiness level (TRL)	Use cases	Battery sub-type	Share of the total capacity in % (Stationary, 2021)
Lithium ion	*Li-ion*	**9 -** Leading technology on the storage market	Marine, railways, aviation, road mobility	LFP LMO, LTO, NMC (disputed), NCA	92 %
Lead acid	*Pb*	**9 -** Oldest technology	- Starter motors, backup power suppliesf or EV / automotive	Hard lead	3,5%
Nickel	*Ni*	**9 -** Mature technology capturing growing **market share**	- Airline industry - EV - Laptops	Ni-Cd Ni-Mh	<0,2%
Redox	✖	**8 -** Mature technology capturing growing **market share**	Solar, wind (renewables)	VRFB	0,7%
Sodium – Ion (Na-ion)	*Na-ion*	**7 -** Emerging technology, still in development phase	- Solar, wind (renewables) - Light EVs	Na ion	3,6%
Lithium – Sulfur (LiS)	*Li-S*	**1 - 5** Technology under development, alternative to Li-ion.	- EV - Drones - Satellites	✖	-
Solids	✖	**1 - 5** Technology under development, replacing liquid electrolyte with solid electrolyte. TRL depends on the use case	Premium auto, heavy trucks	✖	-

Ambitious development goals have been set at both national and EU levels

The development of energy storage stands out as a pillar of the energy transition, established in Europe by the RED III directive and declined at the national scale through various mechanisms

RED III Directive

42.5% of RE in EU consumption *by 2030*

Incorporation of flexibility mechanisms into government strategic plans

EU National Energy and Climate Plans

- Increasing total EU member states' **storage capacity** *from 16GW currently to around 45GW by 2030*
- Proposing **financial incentive measures** to boost current capacities
- **Securing the supply of critical materials** for battery storage

Public support mechanisms

Subsidies

Subsidy scheme, which provides financial support for renewable energy projects, including those incorporating energy storage technologies like stationary batteries
e.g. SDE++, The Netherlands

Capacity Mechanisms

Capacity providers (like stationary batteries) rewarded with a payment for ensuring the availability of electricity generation capacity during peak demand periods
e.g. Capacity Remuneration Mechanism (CRM), Belgium

Tax Incentives

- *Reduction on VAT*
- *Corporate income tax for battery projects*
- *Property tax for battery projects*

Feed-in-Tariffs (FiT)

Financial incentive in which energy producers, including battery energy storage owners, are paid a guaranteed price to feed electricity they generate into the grid from RE
e.g. Smart Export Guarantee (SEG), UK

This financial public support has been paired with more demanding regulations and standards on recycling and waste disposal

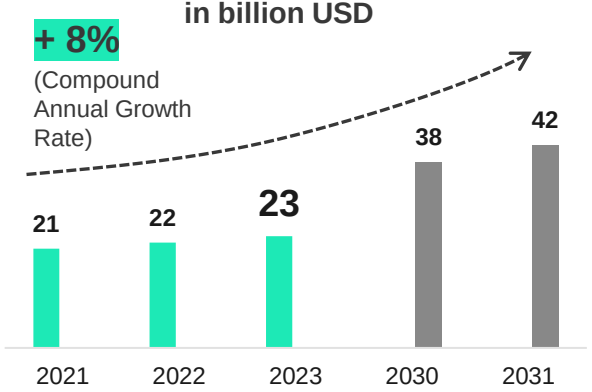
Sources: European Commission: Renewable Energy Directive 2023/2413 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC, revised in 2023; Seban avocats: adoption de la directive n° 2023/2413 du 18 octobre 2023, dite "RED III" : synthèse des modifications apportées au droit européen de l'énergie; Eurelectric : Energy Storage : enabling higher integration and utilisation of variable renewables, October 2023

2. Battery recycling industry forecasts

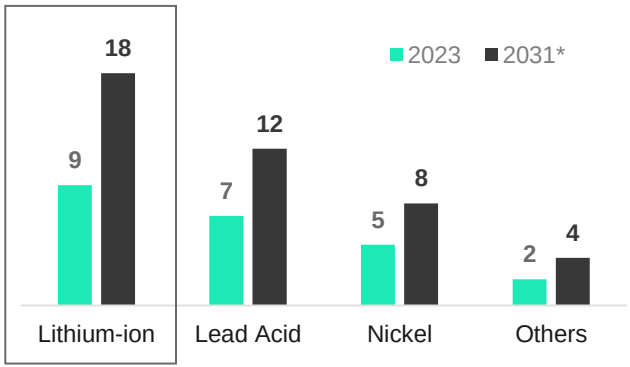
Battery recycling market: promising forecasts

The battery recycling market is experiencing a sharp increase in turnover, driven by the surging li-ion recycling industry.

Global battery recycling market, in billion USD



Global battery recycling market value by chemistry, in billion USD



* forecasts

Factors encouraging a stable growth

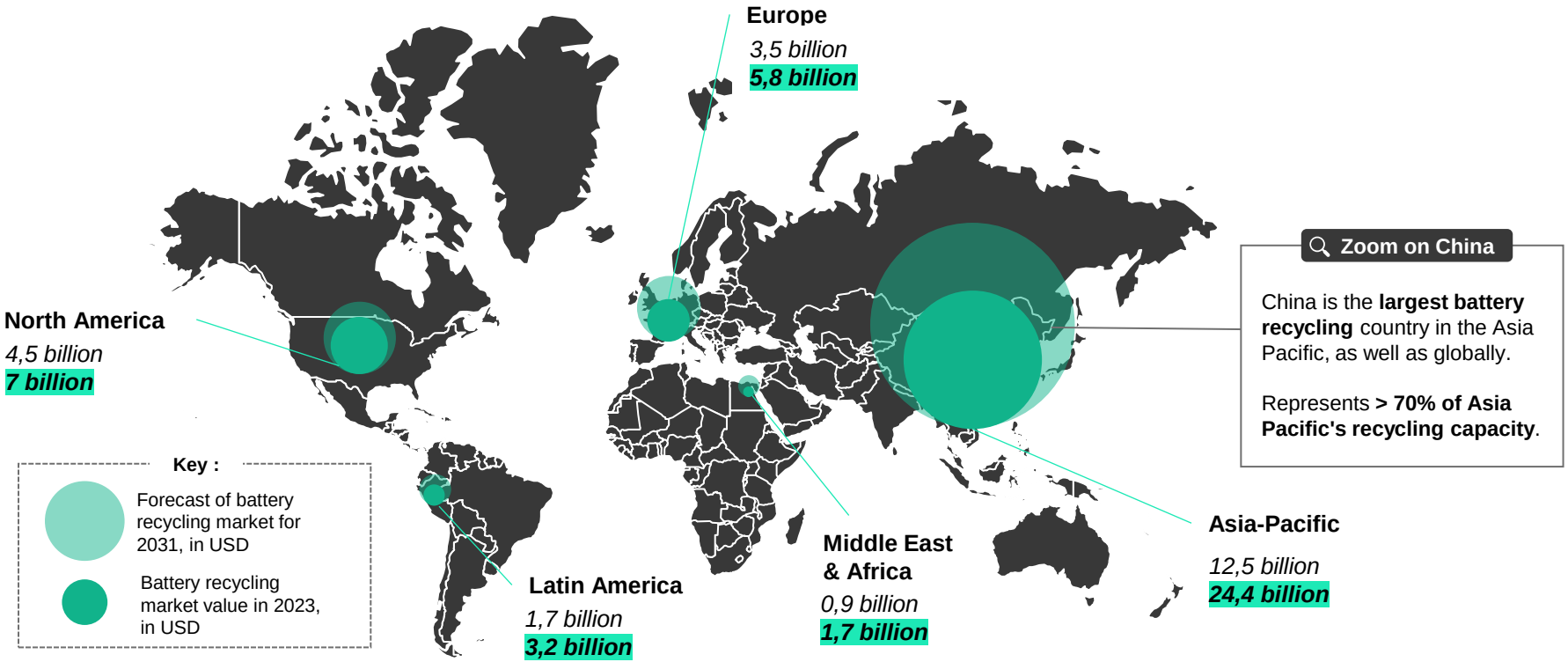
- Stationary battery market growth: **32% by 2032**
- Volume of **battery materials available** for recycling worldwide
- Rising investments in **EV**
- Regulations
- Initiatives to encourage recycling

Recycling **lithium ion** dominates the market with revenue share of more than **40%** in 2023 and is expected to experience the highest growth by 2031.

Source: Extrapolate.com

Battery recycling market: regional split and forecasts

Asia-Pacific accounted for more than **54%** of the global battery recycling market in 2023 and is expected to see the highest growth over the decade



Source: Extrapolate.com

Key:
Current battery recycling capacity per year
Recycling battery projected capacity per year by 2030

Battery recycling market: key actors

Key actors on the battery recycling market fall into three main categories: pure players, battery manufacturers and raw material suppliers

Type of actor	Companies focused on battery recycling	Battery and car manufacturers	Energy and raw material suppliers
Recycling capacity	2,3Mt / 3,4Mt	1,05Mt / 1,1Mt	2,3Mt / 3Mt*
Example of actors (non-exhaustive vision)	ACCUREC, GME, SNAM, Li-Cycle, ATTERO, REDWOOD MATERIALS, ABTC, Primobius, SARPI, VEOLIA, PRINCETON, ACE Green Recycling, STENA RECYCLING	*The extended producer responsibility (EPR) obliges manufacturers to take charge of the entire battery life cycle. Therefore, many battery manufacturers developed their own recycling capacity.* CATL, northvolt, BYD, Mercedes-Benz, TIANNENG, TESLA	* Forecasts extrapolated from other actors' growth capacities THE DOE RUN COMPANY, GRAVITA, eramet, GLENCORE, umicore, endesa, ecobat, orano

The recycling capacity of pure-players is set to grow rapidly due to the arrival of new players with the same positioning. Battery and car manufacturers' own capacity is increasing slightly, mainly because they are concluding agreements with pure-players and developing little in-house capacity.

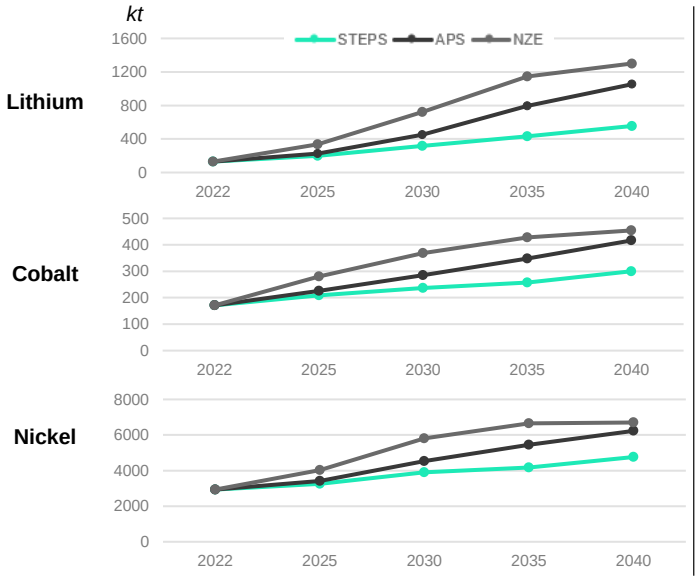
Sources : Companies' websites, Fraunhofer ISI, Arval Mobility Observatory, Conseil national de l'industrie

3. Environmental impact and value added of battery recycling

Growing expectations on recycling as the raw metals demand is soaring

The demand for recycling stems from both constraints on critical minerals and more stringent regulations

Surging increase in critical minerals demand



STEPS: Stated Policies Scenario
Current progress according to public policies in place

APS: Announced Pledge Scenario
Meeting the targets announced by governments

NZE : Net Zero Emission
IPCC international targets for carbon neutrality by 2050

Battery storage **currently accounts for 8% of the increase** in total metal demand on average across the scenarios.

Higher expectations from recycling industry, observable on three layers

Regulation: Set of legal provisions defining the functioning of a sector. Breaches may enforce by the imposition of penalties.

EU Regulation 2023/1542 Focus next page

Guidelines: Act adopted by local or international institutions with a recommendatory nature.

UN 38.3
- Recommendation on environmental tests for Li-ion batteries

Standards: An established norm of quality level set by an industry.

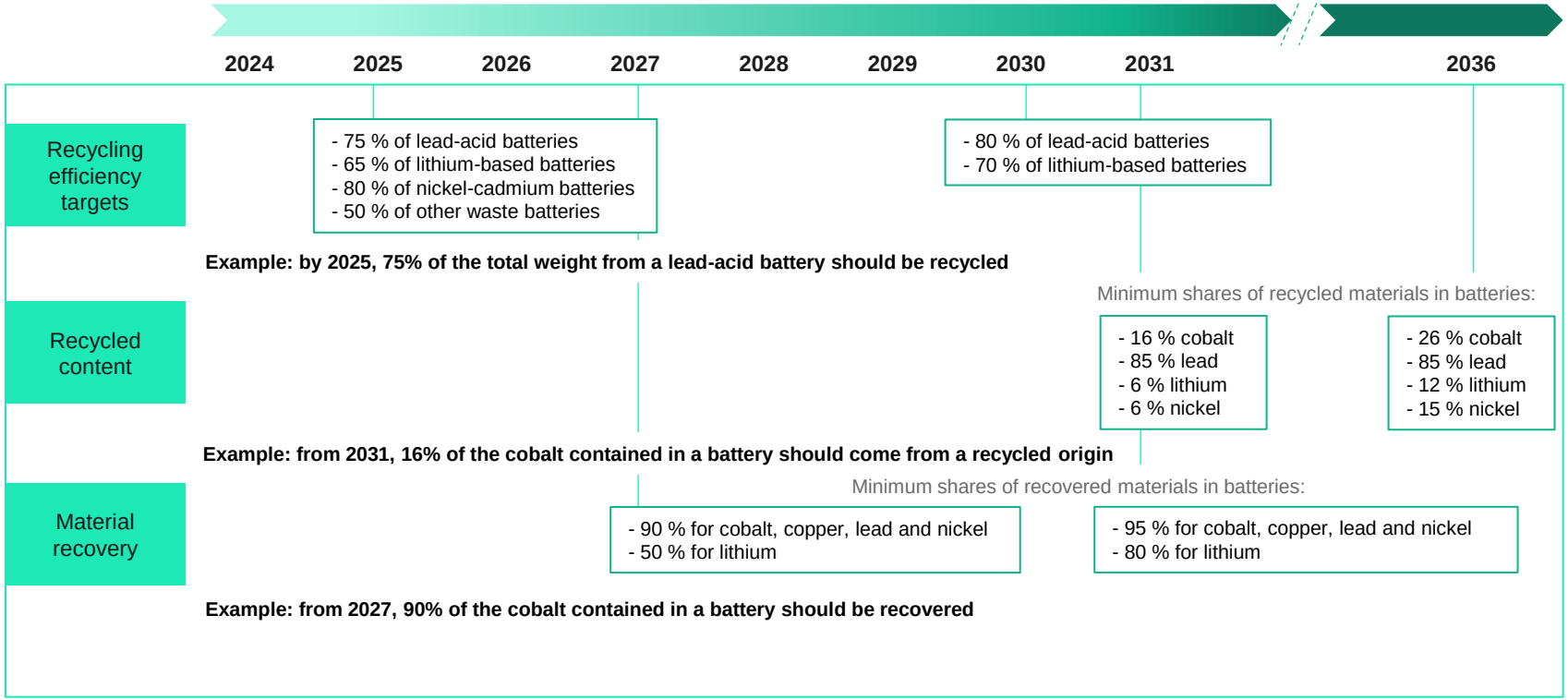
A dozen of established standards for battery production, use and testing (details in appendix)
- International standards: IEC, JIS
- National standards: VDE, UL

Regulations, guidelines and standards aiming to address the **entire battery lifecycle**, from production to waste disposal

Source: Critical Minerals Data Explorer; IEA, 2023

Focus on the EU Batteries regulation (1/2 - Recycling)

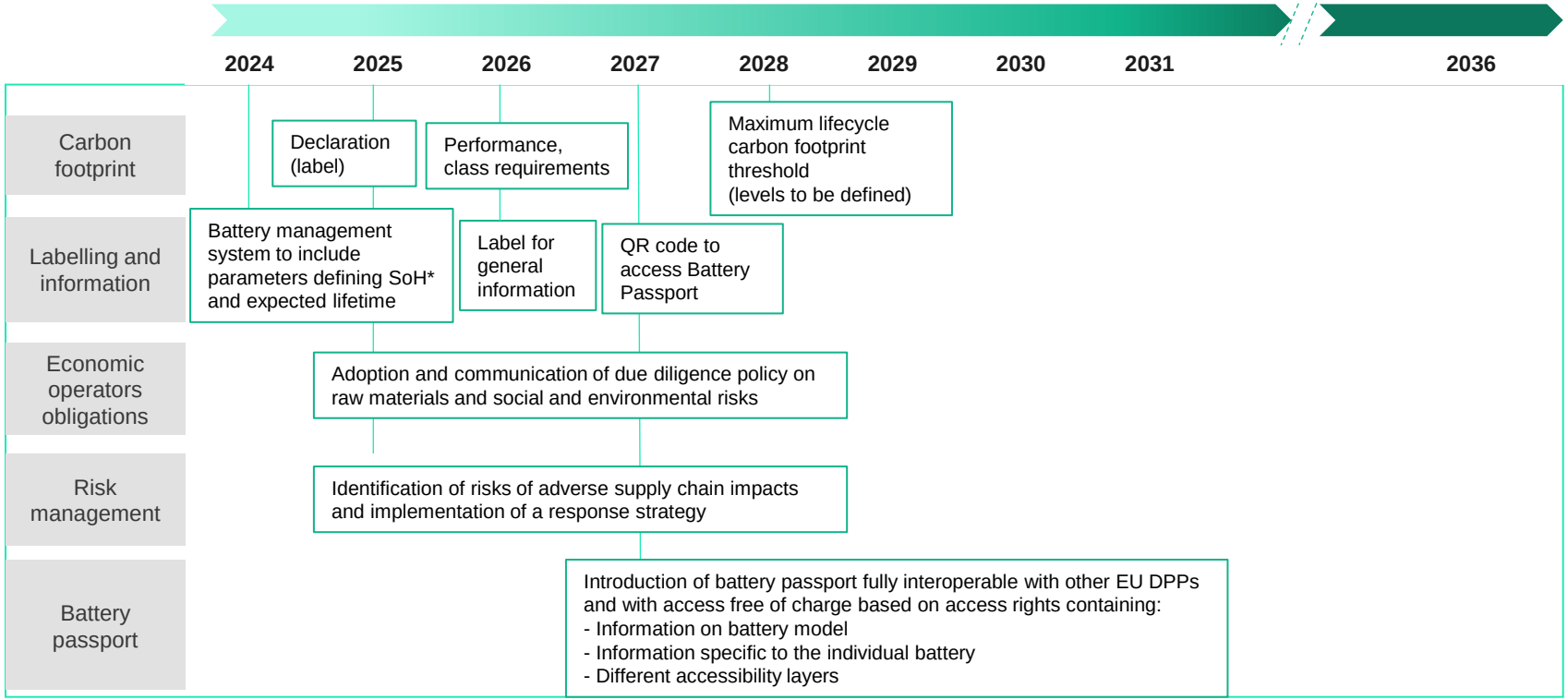
The EU Commission has reinforced the 2006 initial legislative framework in the light of the booming battery market



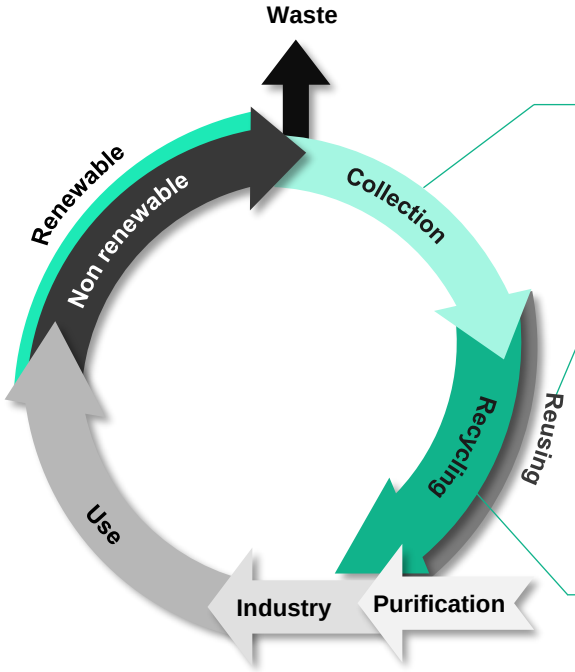
*State of health

Focus on the EU Batteries regulation (2/2 – Climate and environment)

The EU Commission has reinforced the 2006 initial legislative framework in the light of the booming battery market



Different approaches of recycling are currently implemented



- **46% of EV batteries are collected**.
- Collection rates of Li-ion batteries for small electronic appliances varies between 5% and 15% whereas 80% of EV Li-ion batteries are collected.
- **Battery manufacturers are obliged by the EU regulation to collect back batteries** returned by final users, but there is no obligation for returning used batteries.

- Reusing is the main alternative to recycling. However**, less than 37% of batteries are currently re-used**.
- **Used EV batteries can be dedicated to stationary usage** after around 1000-1500 charging cycles.

- **Direct valorization**: produce pure pieces that can potentially be reused in the manufacturing of new batteries (ex: electrode regeneration, electrolyte recovery...)
- **Pyrometallurgy** (melting the module or entire cell at temperatures up to 1 450°C): offers high processing capacity but generates toxic gases and are not able to recover electrolytes (lithium salts) or plastics.
- **Hydrometallurgy**: enables recycling of plastics, electronics, lithium salts, and sometimes solvents, though it is more complex and requires several preliminary stages, including discharge, dismantling, shredding, and grinding.
- **Combined pyro-hydro** process offers two advantages: pyro treatment mitigates safety risks from battery composition and charge variations, while hydro-treatment efficiently separates and processes materials from slags using appropriate chemicals.

Sources: Critical Minerals Data Explorer; IEA, 2023, IFRI 2020

Still, the recyclability and environmental impact strongly differs following the used technology

Key :
Maturity level:
Low | Medium | High

	Raw material recyclability average	Average Lifespan (y)	Stationary storage use	Specific Energy (Wh / kg)	Lifecycle emissions (kg – $CO_{2\ eq}$/kWh)	Average cost per kWh
Li-ion - LFP	46%	5 to 15	✓	170	34 - 39	$139
Li-ion - NMC	40%	5 to 15	Uncommon	220	53 - 56	$132
Lead acid	50%	5 to 15	✓	15 - 50	550 – 1000	$100 to $200*
Nickel metal hybrid	Reusing discarded NiMH has never been commercially realized	5 to 10	Uncommon	30 - 90	-	$350 to $530*
Redox	44%	15 to 20	✓	10 - 35	550 – 1000	N/A
Sodium – ion	-	15	✓	140 - 160	550 – 1000	$87
Solids	-	10 to 15	-	~500	-	$320*

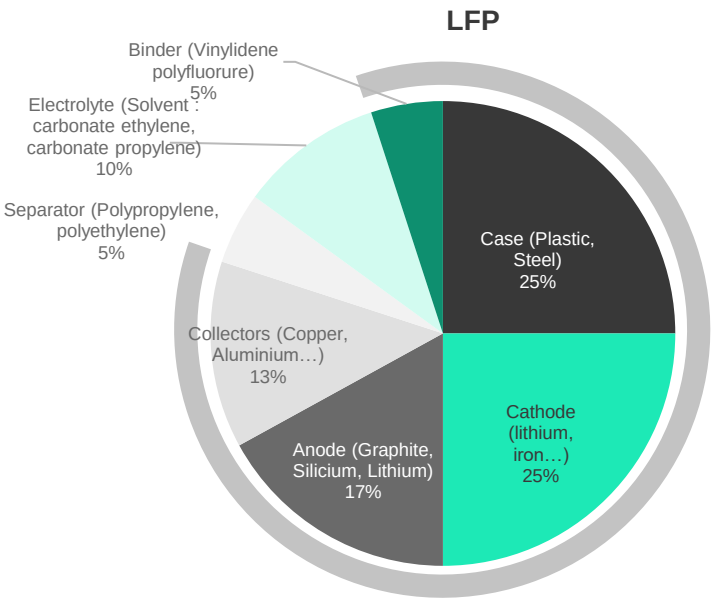
Craddle-to gate emissions in Europe

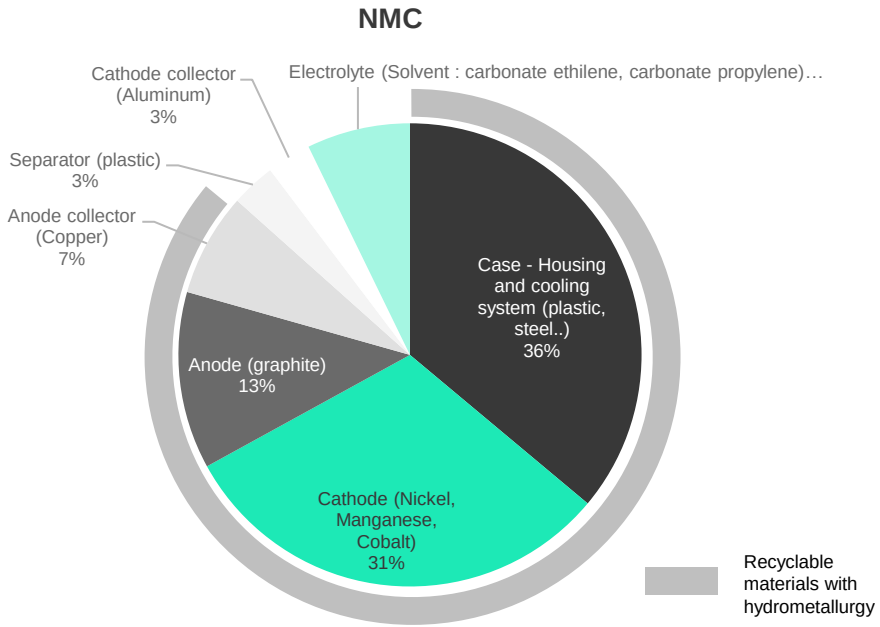
*forecast

Sources: *Comparative life cycle assessment of Li-Sulphur and Li-ion batteries for electric vehicles*

Focus on components recyclability for two key battery types: LFP and NMC

Companies process plastic, copper, aluminum, including lithium-ion battery materials to manufacture their future batteries. However, some pieces such as separators and electrolyte can not always be recovered.
The two leading approaches hydrometallurgy and pyrometallurgy are well-known and have already been used for decades in the metal mining industry. Both allow to recycle a share of the li-ion battery in line with EU objectives: **90% with hydrometallurgy and 65% with pyrometallurgy.**

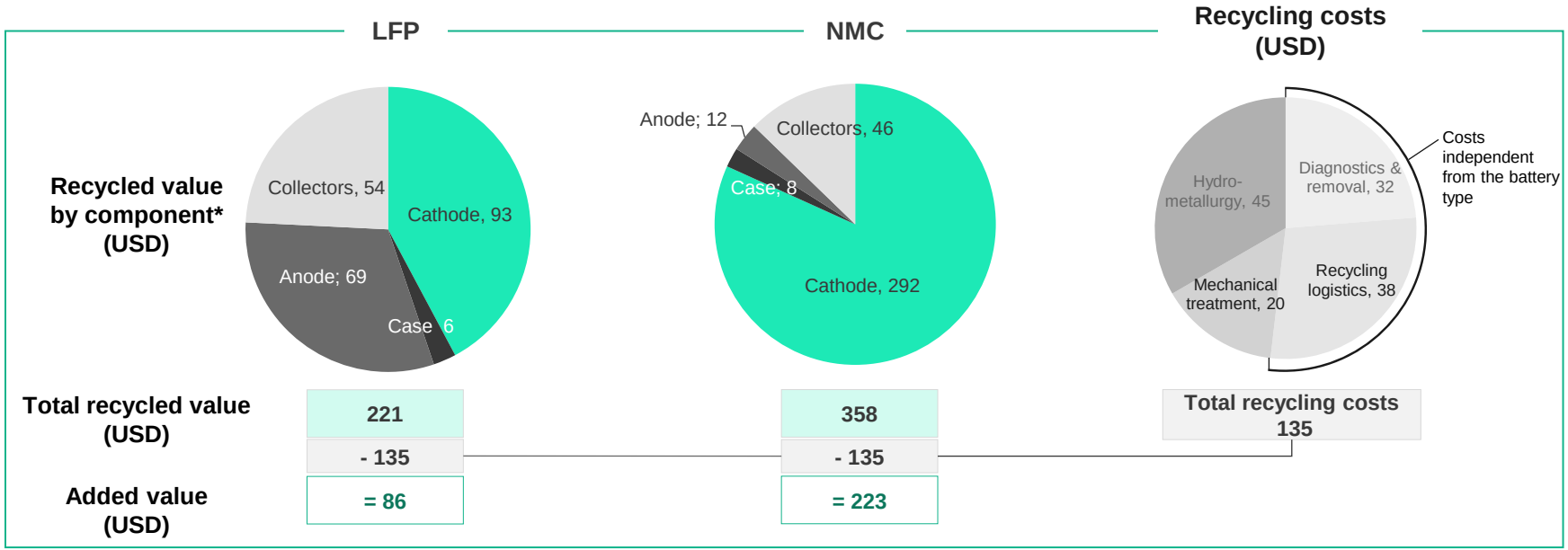




Source: MDPI 2018

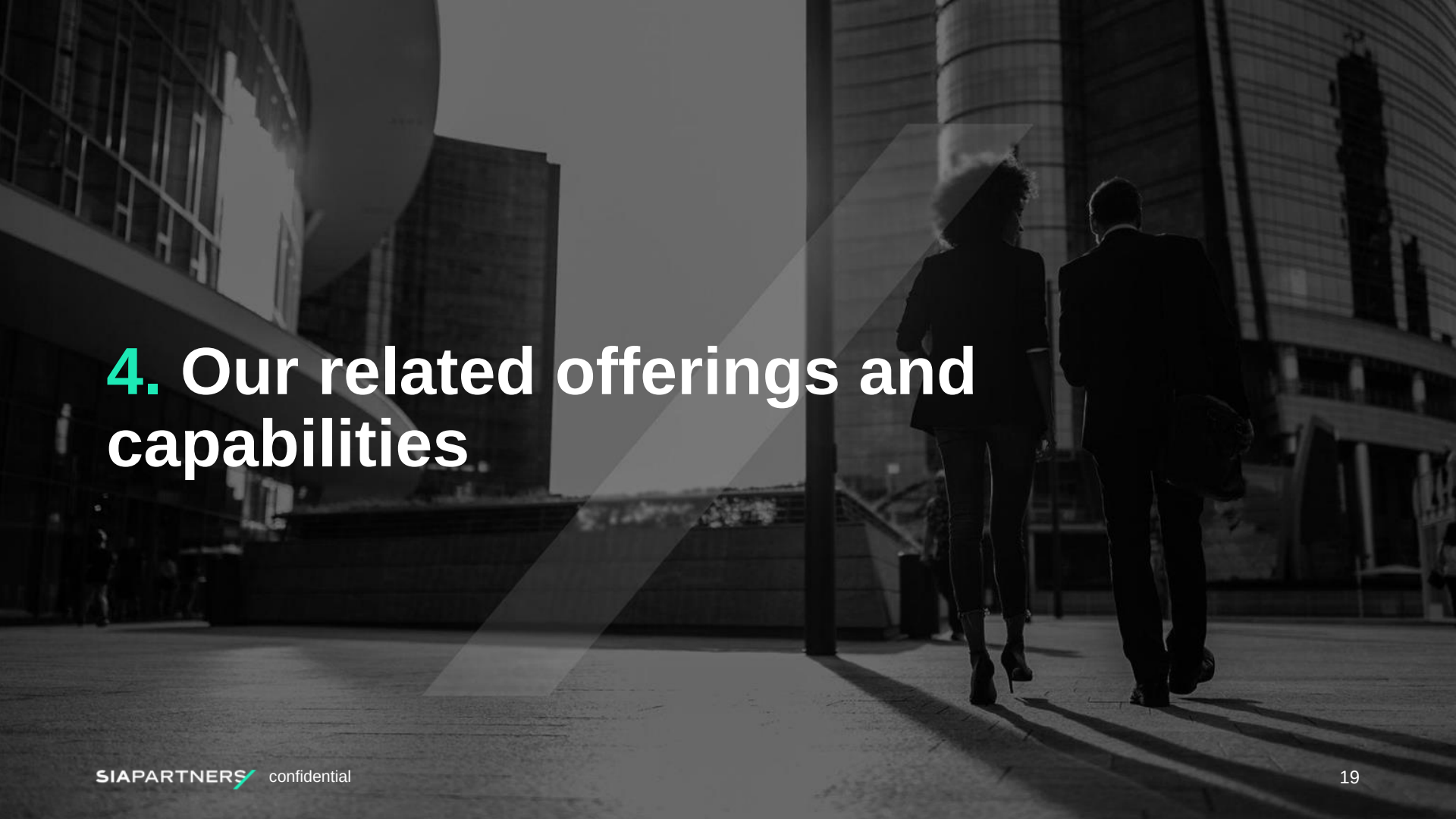
Focus on recycling profitability for two key battery types: LFP and NMC

Assumptions for NMC and LFP battery recycling value and cost. Calculations below assume that the recycled batteries have a **100kg standardized weight**.



Recycling proves being profitable, although its profitability varies strongly depending on the chemical composition

*Value based on 2019 market prize, with 95% efficiency of recycling



4. Our related offerings and capabilities

Sia Partners offers the expertise needed to navigate the battery landscape

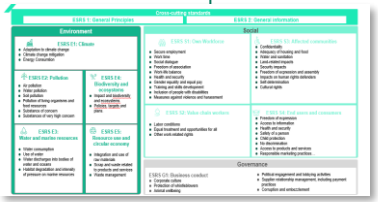
A seasoned combination of operational, regulatory and analytical skills

Low carbon and Net Zero Strategy

- Use of stationary batteries to decarbonize a process
- Improvement of the global GHG assessment with the battery lifecycle carbon footprint

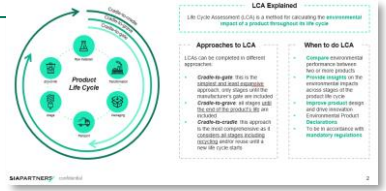
CSRD

- Double materiality assessment
- Data collection and calculation
- Strategic roadmap design
- Strategy implementation



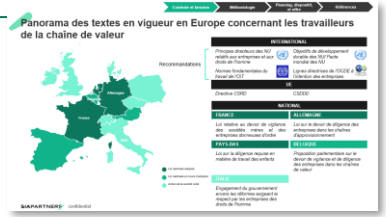
Product Lifecycle assessment

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Results interpretation and improvement report



Market and regulatory studies

- Industry Benchmarks
- Competition survey
- National and international regulatory overview



Sia Partners // end-to-end climate expertise: leveraging our +800 Experts

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- Energy & Utilities
- Automotive
- Technology
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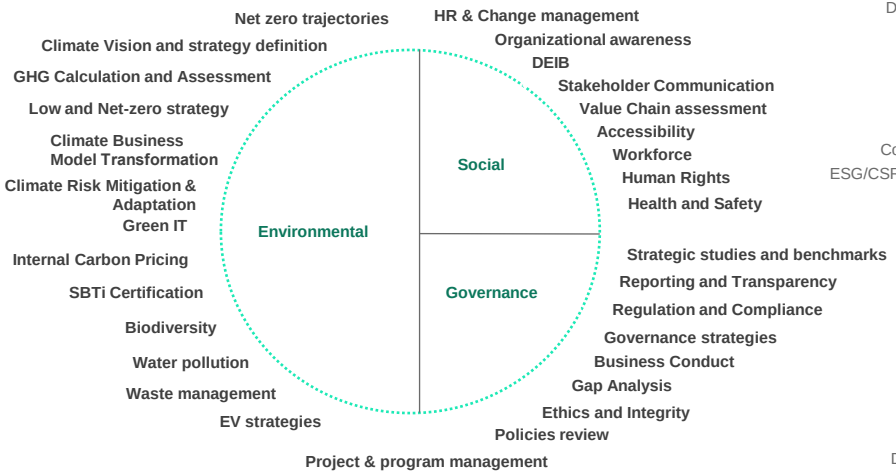
- Healthcare
- Travel & Transportation
- Media & Entertainment
- Real Estate
- Industry & Manufacturing
- Telecomm.

And many more

…with extended consulting capabilities…



…dedicated to ESG

Management Consulting
Dedicated to create impacts
ISO, GHG, CDP, Ecovadis & SBTi net-zero

Corporate Communication
ESG/CSR -Sustainability Reports
Design and marketing

A carbon Management platform leveraging Technology and AI to manage your GHG emissions

Data Science department helping companies with data-related challenges

5. Appendix - current key standards and labels

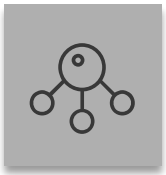
A legislative need and a clear standardization to support the stationary batteries development

A proliferation of certifications and regulations related to this topic has indeed been observed recently.

It is therefore imperative to understand which rules are in force, what are their scope of application, and associated sanction modalities.

Variety of technologies

As mentioned previously, there is a technological multiplicity of batteries. In addition, research and development work suggests that new technologies will emerge.



Multiplicity of use cases

Stationary batteries meet various challenges such as energy production and distribution for commercial, industrial and residential sectors.

The evolving context requires the various players to strengthen their regulation around the use, recycling or manufacturing of stationary batteries.
This study carried out by Sia Partners aims thus to provide a clear, exhaustive and intelligible inventory of the various regulations and certifications concerning stationary batteries. This work seeks to address both constructors and public authorities.

It is important to make a legislative/regulatory state of art of stationary batteries because of its technological and utilization complexity

A diverse and evolving legal framework

Lifecycle stage

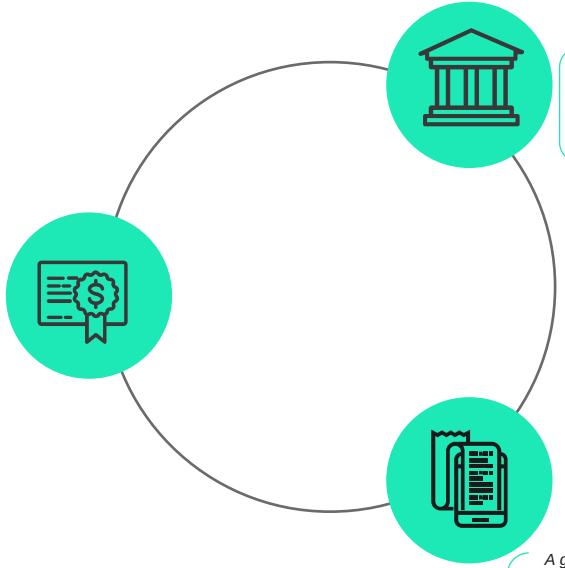
Production | Testing | Operation

- IEC 62619:2017
- IEC/EN 62281
- IEC 62620
- IEC 63056
- VDE-AR-E 2510-50
- JIS 8715-2
- IEC 61427-1
- IEC 61427-2
- IEC 62485
- UL 1973
- JIS 8715-1

Standard

definition

An established norm of quality level given by an accredited organization. May not be free.



Regulation

definition

Regulation is a set of legal provisions that define the functioning of a particular institution

- EU Regulation 2023/1542

EU Battery Directive ambition

- 65% of a lithium-ion battery weight recycled in 2025, increasing to 70% by 2030.
- For metals, a recovery rate of 90% for cobalt, nickel, and copper and 35% for lithium is targeted.
- By 2030 these targets raise to 95% and 70%, respectively.

Guideline

definition

A guideline is a normative act adopted by the institutions of the European Union. It sets out objectives to be achieved by the Member States, with a deadline.

- EU battery pass
- UN 38.3

With a large amount of regulations, guidelines or standards, the legal framework is quite loaded.

VDE-AR-E 2510-50

Targeted applications

Stationary applications (solar PV installation)

Battery types

Primary and secondary lithium cells (Li-ion batteries)

Lifecycle stage

Main features

- Last update: 2017
- Provides with requirements for:
- Isolation tests
- Proof voltage
- Resistance
- Endurance

Fees and sanctions in case of non-compliance

- Purchase fees: 200 USD

JIS 8715-1

Targeted applications

Stationary applications: telecom, uninterruptible power supplies (UPS), electrical energy storage system, utility switching, emergency power…

Battery types

Secondary lithium cells

Lifecycle stage

Main features

- Last update: 2022
- This Standard specifies requirements of performance and marking for lithium secondary cells and batteries used in industrial applications including stationary applications.

Fees and sanctions in case of non-compliance

- Purchase fees: circa 100 USD

UL 1973

Targeted applications

Stationary and Motive Auxiliary Power Applications: PV, Wind turbine storage, Uninterruptible Power Supply, Light Electric Rail

Battery types

Primary and secondary stationary batteries, multiple technologies (li-ion, sodium, lead, nickel)

Lifecycle stage

Production | Testing | Operation

Main features

- Last update: 2022
- Construction requirements
- Safety performance tests : electrical tests, testing of electrical components
- Production tests

Fees and sanctions in case of non-compliance

- Purchase fees: 600 USD

JIS 8715-2

Targeted applications

Stationary applications: telecom, uninterruptible power supplies (UPS), electrical energy storage system, utility switching, emergency power…

Battery types

Secondary lithium cells

Lifecycle stage

Main features

- Last update: 2022
- The second part of the standard provides with guidelines for testing and requirements of safety

Fees and sanctions in case of non-compliance

- Purchase fees: circa 100 USD

IEC 62619:2017

Targeted applications

Industrial applications including stationary applications

Battery types

Secondary lithium cells and batteries containing alkaline or other non-acid electrolytes

Lifecycle stage

Main features

- Specificities requirements and tests for the safe operation of batteries in the scope of stationary applications : telecom, emergency power … also motive applications : forklift truck, golf cart, railway...
- Last update 2022, publication date 2017

Fees and sanctions in case of non-compliance

- Detailed in the full text (restricted access)

UN 38.3

Targeted applications

Testing

Battery types

Li-ion

Details on special provisions for the use of lithium cells and batteries

Lifecycle stage

Main features

- Recommendations on the transport of dangerous goods – manual of tests and criteria (including UN 38.3 lithium-ion battery)
- Lithium metal and lithium-ion cells and batteries shall be subjected to the tests
- Detailed summary tables of required tests for primary cells and batteries

Fees and sanctions in case of non-compliance

- If the cell or battery does not meet one or more of the test requirements, deficiencies that caused must be identified before retesting

EU battery pass

Targeted applications

Portable batteries, starting, lighting and ignition batteries, light means of transport

Battery types

Every industrial or EV battery with a capacity of over 2kWh

Lifecycle stage

Main features

- Identification of the battery, basic characteristics of the battery, statistics on performance and durability, mining and refining companies, carbon footprint declaration, hazardous substances, certifications,…
- As a unique product identifier, the physical battery must have a QR code printed or engraved on it
- Information is selectively shared with three distinct groups : the general public, regulatory bodies and battery service/end of life processors

Fees and sanctions in case of non-compliance

Batteries will be prohibited from sale and recalled if already in the market

REGULATION (EU) 2023/1542

Targeted applications

All applications

Battery types

All categories

Lifecycle stage

Main features

- Circular economy, waste management, durability, security
- Waste collecting objectives through the years : 63% in 2027 and 73% in 2030
- Lithium valorization
- Minimal amount of recycling

Fees and sanctions in case of non-compliance

- Ban on placing a battery on the market/or putting it into service if it does not comply with a requirement of durability, safety, labeling
- Member States determine the system of sanctions applicable to violations of this Regulation.

IEC 62485

Targeted applications

Stationary secondary batteries
Traction batteries with aqueous electrolyte
Lead-acid for portable appliances

Battery types

- Lead-acid & nickel-cadmium and systems with aqueous electrolyte
- Installations < 1500 V DC (nominal)

Lifecycle stage

Main features

- General safety requirements
- Basic system requirements:
  - Safety
  - Reliability
  - Life expectancy
  - Mechanical strength
  - Cycle stability
  - Internal resistance
  - Battery temperature
- Latest version 2020, publication date 2018

Fees and sanctions in case of non-compliance

- Detailed in the full text (restricted access)

IEC 62281

Targeted applications

Transport of batteries, other than for recycling or disposal

Battery types

Primary and secondary lithium cells and batteries

Lifecycle stage

Main features

- Safety tests: specifies test methods and requirements to ensure the safety during transport other than for recycling or disposal
- First version in 2013, last updated in 2019

Fees and sanctions in case of non-compliance

- Detailed in the full text (restricted access)

IEC 621427-1

Targeted applications

Renewable energy storage for off-grid photovoltaic application

Battery types

Secondary cells and batteries for renewable energy storage

Lifecycle stage

Main features

- Information on requirements for secondary batteries used in PV energy systems
- It serves as a kind of benchmark to make a more precise life expectancy estimation of the PV battery, taking seasonal and temperature features into account
- First version in 2013

Fees and sanctions in case of non-compliance

- Detailed in the full text (restricted access)

IEC 621427-2

Targeted applications

Renewable energy storage for on-grid application

Battery types

Secondary cells and batteries for renewable energy storage

Lifecycle stage

Main features

- Information on requirements for secondary batteries used in renewable energy storage systems in on-grid applications.
- Test methods for verification of their endurance, properties and electrical performance in such applications.
- First version in 2015

Fees and sanctions in case of non-compliance

- Detailed in the full text (restricted access)

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- Extensive sustainability and asset management **expertise and experience**
- We offer a **comprehensive suite of services** to address all your climate-related challenges, providing a centralized point of contact for all your needs.

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