



The Magnesium Charge

Designing Safer and more sustainable batteries: Putting safe and sustainable by design (SSbD) into practice

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These challenges highlight the need to consider safety and sustainability from the earliest stages of battery design and development, rather than addressing them only at the end of the value chain (i.e. use phase). Choices made during material selection, cell design, and process steps can significantly influence a battery's environmental footprint, safety, resource efficiency, cost and potential recyclability.

The European Safe and Sustainable by Design (SSbD) approach provides a way to address these issues together. By integrating safety, environmental, social, economic, risk, and circularity considerations into the design process, SSbD can help identify trade-offs early in the design phase and guide the development of batteries that are safer, more sustainable, resource efficient, competitive and circular by design.”

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What does “Safe and sustainable by design” mean?

SSbD is a concept developed by the European Union to integrate safety and sustainability into the development of new materials, products and technologies from the early stages of design and development. For batteries, this means considering the entire life cycle (Cradle-to-Grave), i.e. from raw materials or alternative materials extraction, manufacturing phase (including processes employed), use phase, and end-of-life phase (recovering, recycling, reuse, disposal, etc).

SSbD goes beyond a single measure such as carbon footprint, and considers environmental, human health, safety, social, economic and potential circularity aspects of feedstocks, products and manufacturing processes. It also helps identify benefits, and potential trade-offs, for instance, reducing carbon emissions may increase water use or resource consumption. By considering these factors together, SSbD supports the development of batteries that are safer, more sustainable and circular by design.

How HighMag assess safety and sustainability

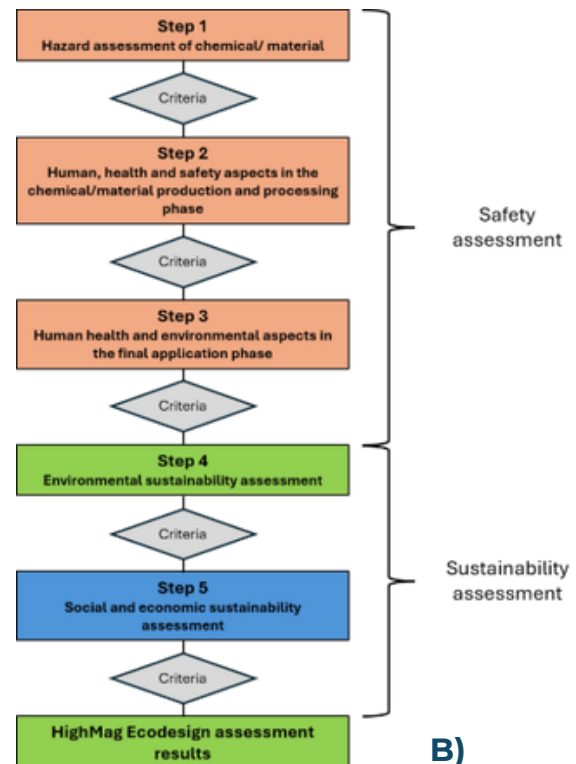
In the HighMag project, safety and sustainability are assessed alongside technological performance from the early stages of battery development. This work is led by Imperial College of London through WP7. The WP7 team first reviewed relevant international, national and regional regulations covering battery manufacturing, use and end-of-life management. Building on this review, an eco-design framework aligned with SSbD principles was developed. The adapted HighMag framework consists of two main stages:

- (1) design/re-design, where eco-design principles (Figure 1A) guide battery pack development, and;
- (2) safety, sustainability and recyclability assessment (Figure 1B), evaluating materials and chemicals across safety (Steps 1–3), environmental impacts (Step 4), and socio-economic sustainability (Step 5).



#	Design Principles
1	Material efficiency
2	Minimise the use of hazardous chemicals/materials
3	Design for energy efficiency
4	Use renewable sources
5	Prevent and avoid hazardous emissions
6	Reduce exposure to hazardous substances
7	Design for end-of-life
8	Consider the whole life cycle
9	Design for recyclability and circularity
10	Design for supply chain resilience
11	Design for electrochemical safety
12	Design for thermal safety
13	Design for mechanical integrity

A)



B)

Figure 1: Adapted HighMag eco-design framework: A) Design principles (Principles 9-13 tailored to the requirements of HighMag battery development) and B) Safety, sustainability and recyclability assessment steps

The framework is applied to innovative technologies developed within HighMag with the safety and sustainability assessment comprising of five steps (Figure 1B). Each step is then assessed according to criteria that follows norms, policies and thresholds, which enable a comparative assessment with competing products and manufacturing processes through a multi-level approach.

Steps 1–3 focus on safety:

Step 1 assessing the intrinsic hazards of chemicals and materials, employing established databases such as REACH (The Regulation on the registration, evaluation, authorisation and restriction of chemicals) for initial screening, ensuring that the safest available chemicals are used.

Step 2 evaluates potential worker health and safety risks during battery production and processing, by performing a risk assessment of the premises, chemicals, etc, and recommending mitigation measures to reduce risks associated with the production environment.

Step 3 assesses potential human health and environmental risks during the use phase by evaluating exposure to hazardous substances, potential releases, and impacts on workers, consumers, and the environment.

Exposure assessments in Steps 2 and 3 use established tools, including the ECETOC (European Centre for Ecotoxicology and Toxicology of Chemicals) targeted risk assessment framework.

Step 4 assesses environmental performance, using life cycle assessment as the primary tool within the framework following ISO 14044 guidelines.

Step 5 evaluates social and economic sustainability using social life cycle assessment and techno-economic assessment, following UNEP/SETAC and ISO/TS 14076:2025 guidelines.

To support practical and consistent decision making, the developed framework to evaluate sustainability, recyclability and safety by design incorporates an SSbD aligned scoring system. This enables materials and technologies to be assessed for inherent safety and systematically compared using safety, environmental, social and economic criteria, either against initial designs or alternative materials, chemicals and components.



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