STREAMS
SUSTAINABLE TECHNOLOGIES FOR REDUCING EUROPE'S BATTERY RAW MATERIALS DEPENDANCE

THE BATTERY CHRONICLES

Daniel Dias

Research Associate and Project Management
at Imperial College London

Balancing the scales: How eco-design and economics guide greener batteries

Imperial College London holds a transversal role in the STREAMS project, with a strong focus on technical work packages. Therefore, our role includes understanding the processes involved in the value-chain system through a holistic and detailed approach. This requires open communication between Imperial and relevant partners of the consortium to receive the most relevant and up-to-date data regarding all processes.

As a result of this approach, Imperial has gained a deep understanding of the processes and has thus mapped out the whole STREAMS value-chain and identified integral innovative technologies, which has enabled us to design Eco-Design guidelines. This has allowed us to identify hazardous chemicals, process hotspots, environmental risks, fire hazards, and physical risks, as well as risks related to the manufacturing, use, and end-of-life phases regarding potential STREAMS products.

To complement these outcomes, the Techno-Economic Assessment (TEA) aids the evaluation in order to determine if the proposed solution is economically viable in its current state, or if the changes suggested through eco-design bring further value and sustainability, while increasing or aggravating the economic performance. This tight balance, also considering the Safe and Sustainable by Design (SSbD) principles, allows for Imperial, together with partners of the consortium, to suggest, recommend, and deliver the best product available based on data-driven frameworks and methodologies, considering an economically responsible approach.

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Eco-Design and risk assessment

The Eco-Design guideline, which is integral to the STREAMS overall sustainability strategy, provides a structured framework for integrating safety, environmental, economic, and social considerations into the development of the innovative technologies pursued within the project.

The importance of such a guideline lies in its ability to ensure that technological innovation is not evaluated solely based on technical performance, but rather through a broader sustainability perspective that considers the full range of impacts associated with battery material production and battery system development.

The STREAMS Eco-Design guideline is based on the principles of SSbD, which we believe offers a particularly suitable foundation for projects such as STREAMS, where novel materials, recycling pathways, and process technologies are being developed simultaneously. One of the key strengths of the SSbD approach is that it encourages the integration of safety and sustainability considerations from the earliest stages of technology development rather than treating them as secondary assessments conducted after process optimisation. This proactive methodology is especially important in the battery sector, where the introduction of new materials, novel technologies, and processing routes can create unintended environmental, health, and operational risks if not systematically assessed.

In terms of implementation, the STREAMS Eco-Design guideline was structured around a series of decision gates, enabling a staged and iterative assessment process aligned with the progressive maturity of the innovative technologies under development. This staged approach is particularly valuable because it allows design decisions to evolve alongside technological readiness, ensuring that sustainability considerations remain embedded throughout scale-up and demonstration activities. The guideline acts as a dynamic decision support system that guides technology developers toward a safer and more sustainable process. It will serve as a strategic methodology for guiding innovation toward technologies that are not only technically effective, but also inherently safer, environmentally responsible, economically viable, and socially sustainable across their entire life cycle.

Risk assessment in practice: To support the safety dimension of the STREAMS Eco-Design guideline, we have identified twelve (12) innovative technologies, as well as their pertaining hazards and associated risks. This has allowed us to rate the severity of the risk and suggest mitigation actions in order to reduce those risks. Then the severity of the risk, considering the mitigation recommendations, is re evaluated in order to conclude if they are acceptable or if further mitigation recommendations (e.g., high, medium, or low) are required. The number of hazards per innovative technology varies from one to six, thus requiring the collaboration of all partners involved in a given technology.

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Techno-Economic Assessment (TEA)

The techno-economic evaluation (TEA) activities within the STREAMS project focus on providing a quantitative and systematic assessment of the economic feasibility of innovative technologies developed across the project's circular value chain. This includes recovery, recycling, and upcycling routes for critical materials, where process configurations are assessed using partner-provided datasets representing their respective design and operational conditions. The TEA framework is applied consistently across cases in terms of modelling approach and economic indicators, enabling transparent estimation of capital expenditures, operational costs, and key cost drivers for each process.

The analysis relies on experimental data provided by project partners, industrial-scale projections, and literature-supported assumptions, reflecting different levels of technological maturity and data completeness. The TEA does not aim to redesign or modify the underlying process configurations but instead evaluates the economic performance of each pathway as defined within its respective dataset.

A central aspect of the work is the identification of main cost contributors and economic sensitivities within each individual process, supporting interpretation of scale-up potential and economic viability under stated assumptions. While consistent indicators such as Net Present Value (NPV) and minimum selling price are reported across all cases to ensure transparency, results should be interpreted within the context of each process's specific system boundaries and data basis.

In parallel, the TEA is integrated with SSbD activities, supporting a multi-dimensional assessment framework where economic performance is considered alongside environmental and safety aspects. Overall, this work provides structured economic insight into each individual technology pathway within STREAMS, supporting evidence-based evaluation and future scale-up considerations.

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