RA.RE^3

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Executive summary

Ra.Re^3 is a research initiative exploring the repurposing of second-life lithium-ion (Li-ion) batteries originally used in Formula E electric vehicles (EVs) for stationary energy storage applications. By extending their operational life, the project contributes to United Nations (UN) Sustainable Development Goals (SDGs), including affordable and clean energy (SDG 7), industry innovation (SDG 9), responsible consumption (SDG 12), and climate action (SDG 13). Repurposing provides new storage capacity without extracting additional raw materials, lowering lifecycle emissions while supporting energy-intensive infrastructures.
Unlike most second-life initiatives that rely on consumer EV batteries, Ra.Re^3 focuses on high-performance motorsport-derived units developed by Podium Advanced Technologies. These batteries are engineered for rapid discharge, stress endurance, and thermal reliability, making them particularly suited for compact, fast-response applications.

The project aligns with broader EV market dynamics. Global EV sales reached 17 million in 2024 and are expected to exceed 20 million in 2025, with more than 250 million EVs projected on the road by 2030 (International Energy Agency, 2024). Retired batteries typically retain over 70% of their initial capacity, representing a significant opportunity for reuse. With recycling infrastructures still costly and underdeveloped, second-life applications provide an immediate strategy to reduce waste and ease pressure on critical raw material supply chains.

Ra.Re^3 develops two exploratory mission profiles. The first, at NorthC's Eindhoven data center, examines the replacement of obsolete valve-regulated lead-acid (VRLA) batteries in uninterruptible power supply (UPS) systems with Podium's Li-ion modules. The analysis indicates potential cost reductions, substantial volume savings, and compatibility with operators' carbon-neutrality goals. The second profile addresses St. Luke's Hospital in Wolisso, Ethiopia, where substituting existing lead-acid batteries with Podium units would extend backup autonomy from one to over eight hours, reduce reliance on diesel generators, and enable better integration with the on-site photovoltaic system.
These findings confirm the versatility of second-life storage. Motorsport-derived batteries, though limited in availability, offer unique advantages where reliability and responsiveness are critical. Ra.Re^3 demonstrates how second-life deployment is not a fallback but a forward-looking strategy that combines economic rationality, environmental responsibility, and scalability through engineering and cross-sectoral collaboration.

Key words

- Second-life energy storage
- Motorsport battery repurposing
- High-power lithium-ion systems
- Battery end-of-life valorization
- Technological life-cycle extension

Project description

Ra.Re^3 explores the responsible second-life reuse of high-performance lithium-ion battery packs retired from Formula-E racing, assessing their technical, environmental, and organizational fitness for stationary applications. The project's overarching aim is to extend battery lifetimes while advancing key United Nations Sustainable Development Goals (SDGs) on clean energy, responsible consumption, innovation, and climate action. In contrast to the large body of work on consumer EV batteries, Ra.Re^3 focuses on motorsport-derived units, a niche with distinctive power density and traceability advantages. Methodologically, the team built and applied a transparent selection framework to filter multiple candidate applications. Four criteria guided the down-selection: (i) SDG contribution, (ii) stakeholder alignment (iii) performance fit with high-power, short-duration duty, and (iv) practical feasibility (integration, regulation, adoption barriers). This dual emphasis, sustainability relevance and implementability, enabled evidence-based prioritization.

Two illustrative use cases anchor the project: a data-center UPS retrofit and a hospital backup system. For data centers, the work considers replacing conventional lead-acid batteries with second-life lithium-ion units inside standard UPS architectures. The intent is straightforward: improve responsiveness and space efficiency while keeping integration close to established upgrade practices. For the hospital scenario, second-life batteries are combined with the existing solar-hybrid setup to support essential services during grid outages and to limit reliance on diesel generators. Here the emphasis is on reliability, simple operation, and maintainability. Beyond individual cases, Ra.Re^3 clarifies positioning and stakeholder value. For Podium and Formula-E, it demonstrates a credible pathway to extend asset life with verifiable environmental benefits; for operators (data centers, hospitals), it offers faster response, maintainability, and meaningful space and operational advantages typical of Li-ion retrofits; for regulators and communities, it foregrounds certification, safe transport, and end-of-life responsibilities (including recycling after second use). The report recommends piloting both profiles with instrumentation from day one and closing the loop through traceable end-of-life management.

Team description by skill

The project required a multidisciplinary effort, integrating data analysis, system reliability, techno-economic and sustainability assessment, stakeholder engagement and human-centered design to deliver application-ready solutions.
Andrea Coccato, Electrical Engineering, and Francesco Masoero, Chemical Engineering, led the solution selection process and technical feasibility. They contributed technical expertise in data analysis, reliability reasoning and feasibility screening of the proposed applications.
Anna Tardella, Management Engineering, focused on the Eindhoven data-center mission profile. She coordinated stakeholder engagement, explored recycling regulations and required certifications, performed comprehensive technical evaluations, and conducted economic and sustainability analyses for replacing obsolete lead-acid systems with repurposed Formula-E batteries.
Luca Roncari, Management Engineering, led the Wolisso hospital profile by contributing his expertise in economic analysis, sustainability impacts, and a clear technical overview of photovolaic and battery integration under unstable grid conditions.
Niccolò Pecorelli, Management Engineering, conducted the state-of-the-art review and existing case-study analysis, integrating sustainability perspectives and aligning the project's objectives with the United Nations Sustainable Development Goals.
Irene Calvi, Architecture and Urban Design, supported user-requirements elicitation and developed the graphical and spatial visualization of the two reference system architectures, contributing to clear communication and deployable design artifacts.
Across these streams, the team worked iteratively with shared decision gates and integrated reviews, ensuring consistency between technical feasibility, stakeholder needs, and sustainability outcomes in both reference applications.

Goal

The fundamental objective is developing second-life energy storage systems that are technologically and economically viable as well as in alignment with broader environmental objectives, such as lifecycle carbon footprint emission reduction and retention of critical raw materials.

Through the concept of repurposing as a transitional practical phase intervening between first use and final recycle, Ra.Re^3 significantly extends the useful life of batteries within a high-tech circular value system. The program utilizes a multidisciplinary evaluation platform to test repurposing approaches on multiple fronts, namely, performance, certification, operating risks, and environmental implications. Importantly, all these activities are conceived to generate measurable contributions to the United Nations Sustainable Development Goals, ensuring that the project not only delivers technological and economic benefits, but also advances global sustainability priorities.

Understanding the problem

The Formula E championship brought a revolutionary perspective to motorsport through fully electric racing, but the implementation of high-performance lithium-ion battery systems also introduced a critical sustainability challenge: maximizing value extraction from batteries at the end of their championship lifecycle. Crucially, Formula-E batteries retain approximately 90% of their original capability after merely a single racing season, making immediate disposal extraordinarily wasteful and economically irrational. Without considering second-life possibilities, Podium would default to direct recycling, a premature solution that essentially discards 90% of the battery's remaining utility after just one year of motorsport use. This approach represents a profound inefficiency in resource utilization, as recycling processes remain technologically immature, environmentally problematic, and economically burdensome for battery manufacturers.

The stark inefficiency becomes evident when considering that existing recycling methods, particularly pyrometallurgy and hydrometallurgy, consume enormous energy to recover materials from batteries that still possess near-peak performance capabilities. These processes are characterized by high energy intensity, complex logistics, low material recovery rates (especially for lithium and aluminum), hazardous waste generation, and perpetuation of the linear extract-use-dispose resource model.

Given the dramatic waste inherent in immediate recycling and the substantial 90% residual capacity available, second-life applications represent the only rational approach to extract maximum value from these premium battery systems. Podium Advanced Technologies' mission extends beyond profit generation to align with Formula E's sustainability objectives of transforming motorsport into a greener industry. This dual commitment is reflected in the two mission profiles presented: one focused on economic optimization and another emphasizing sustainability and UN Sustainable Development Goals (SDGs) achievement, demonstrating comprehensive value creation through responsible battery lifecycle management.

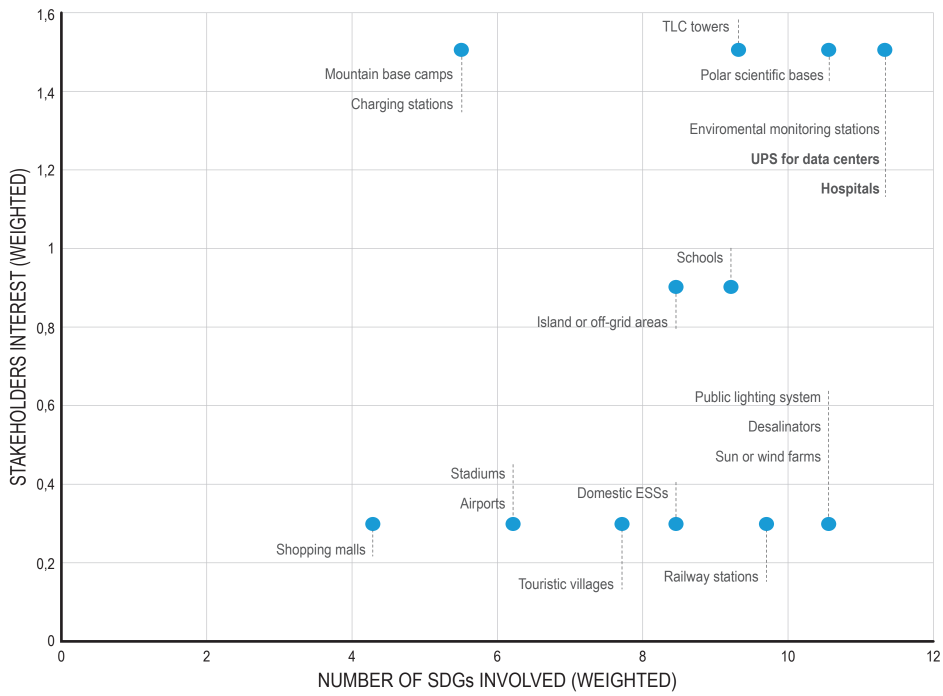
The problem is exacerbated by a lack of developed repurposing pathways for motorsport-oriented high-performance batteries. Unlike mainstream transport-oriented electric vehicle batteries, motorsport batteries feature unusual geometries, different electrical arrangements, and different performance characteristics, all developed in favor of heightened discharge rates and thermal resilience. Such specific properties complicate integration into a common second-use application and contribute in part to there being no bulk-industry paths to reuse. In the meantime, regulatory hurdles are still universal, at least in regard to transport certifications, compliance with safety regulations, and continued liability on the part of the manufacturer at end-of-life despite resale.

Accordingly, technology value-holding components are all too often retired and sent to disposal as waste despite their availability to contribute toward facilitating relief in supply pressures in raw materials and lifecycle emissions mitigation. Ra.Re[3] responds by reframing the high-performing battery as something more than a liability, but as an untapped resource that has calculable technical and environmental value. The project places itself at the intersection of energy storage innovations, resource optimization, and system-centered sustainability and recommends the use of second lives as a necessary interim step before end-of-life material recovery. This way, it challenges the status quo of early recycling and sets up a template for a superior circular value chain specific to motorsport-derived technology.

Exploring the opportunities

In responding to the identified limitations related to immediate recycling, the Ra.Re[3] program utilized a systematic and criterion-based methodology to evaluate possible second-life applications of Formula-E battery sets. A comprehensive evaluation matrix was developed, with four main dimensions being included: compatibility with the Sustainable Development Goals, compatibility with stakeholder expectations, technical compatibility with the performance characteristics of the batteries, and the overall practicality of incorporation into existing infrastructures. Nineteen possible applications were considered in the initial analysis, ranging from residential energy storage applications to renewable integration at the grid scale. However, many scenarios failed to offer sufficient demand-based performance to utilize the power density of the batteries or presented constraints related to scalability and impact.

Following two-stage screening, two mission profiles were identified as both strategically and technically viable: UPS applications in data centers and hybrid photovoltaic–battery applications in hospitals, especially off-grid hospitals. These applications are typified by the need for short-duration, high-reliability energy supply. Both scenarios also present special opportunities for leverage: data centers are high-density energy users with intensifying decarbonization needs, while off-grid hospitals have chronic energy insecurity that undercuts vital services. Emphasis on the two sectors maximizes technical application of battery capabilities as well as the opportunity for positive environmental as well as societal impacts.



Pervasivity Matrix considering stakeholders' interest and SDGs

Generating a solution

Based on the two chosen mission profiles, Ra.Re³ devised in-depth feasibility studies to evaluate the technical, economic, and environmental feasibility of deploying second-life Formula-E batteries in practical energy systems. The initial profile targeted a high-performance Uninterruptible Power Supply (UPS) system within a 4MW data center run by NorthC datacenter in Eindhoven. The application exploits the fast response and low-depth discharge capabilities of the batteries to replace obsolescent UPS batteries in still usable cabinets, which have longer lifespans than the batteries themselves. Through technical modeling, physical site observations, and direct contact with UPS suppliers and site managers, the project demonstrated that Formula-E batteries can deliver significant operational advantages including volume and weight reduction, reduced cooling requirements due to broader thermal tolerance, and up to 14% reduced total cost of ownership with potential revenue from space savings reaching 1.5-2 million euros over a 10-year horizon. Main implementation challenges include guaranteeing battery integrability within UPS supplier cabinets through UL 9540A certification at module level, acquiring additional international certifications as required by UPS suppliers, implementing software modifications for BMS, liquid cooling system deactivation, meeting module-level disassembly requirements, and providing comprehensive SoH data with second-life reliability documentation.

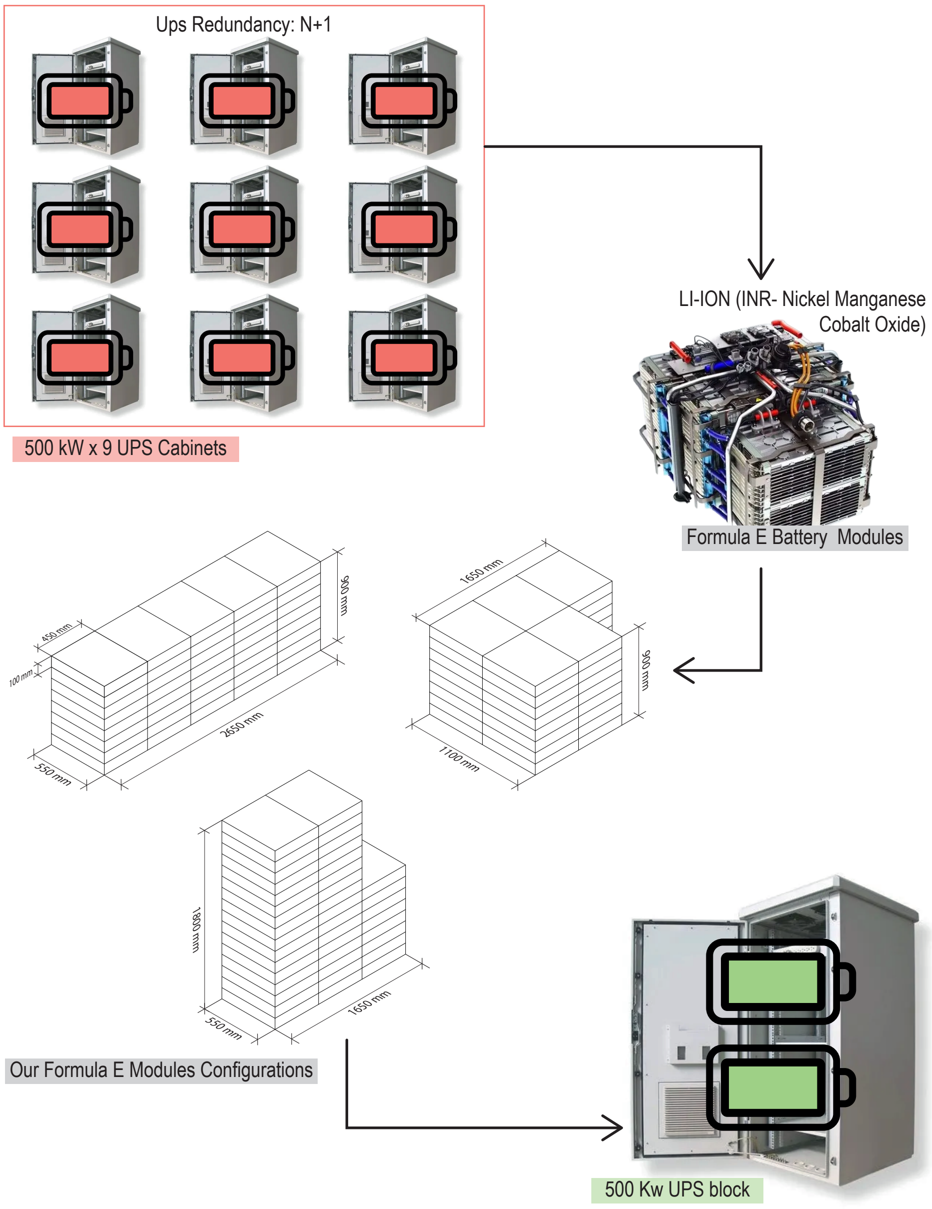


Diagram showing the integration process and our three possible configurations

The second profile investigated energy resilience at Wolisso St. Luke's Hospital in Ethiopia, where repeating outages jeopardize the consistency of vital medical care. The program entailed the replacement of the existing lead-acid battery system with second-life lithium-ion modules repurposed and coupled with local rooftop solar production, thus demonstrating the potential to dramatically increase energy autonomy while decreasing diesel generator dependence. Technical simulations included local solar irradiation conditions, average duration of blackouts, and inverter compatibility requirements. Though the research was confronted with logistical hurdles—in terms of carriage, site management, and regulative limitations—the study indicated mitigation measures through local engagement with non-governmental institutions and phased implementation. Both profiles considered the second life of batteries as no compromise, but as an enriched application phase that maximizes their available working capacity, reduces environmental exposure, and contributes both to the objectives of the sector and societal development goals.

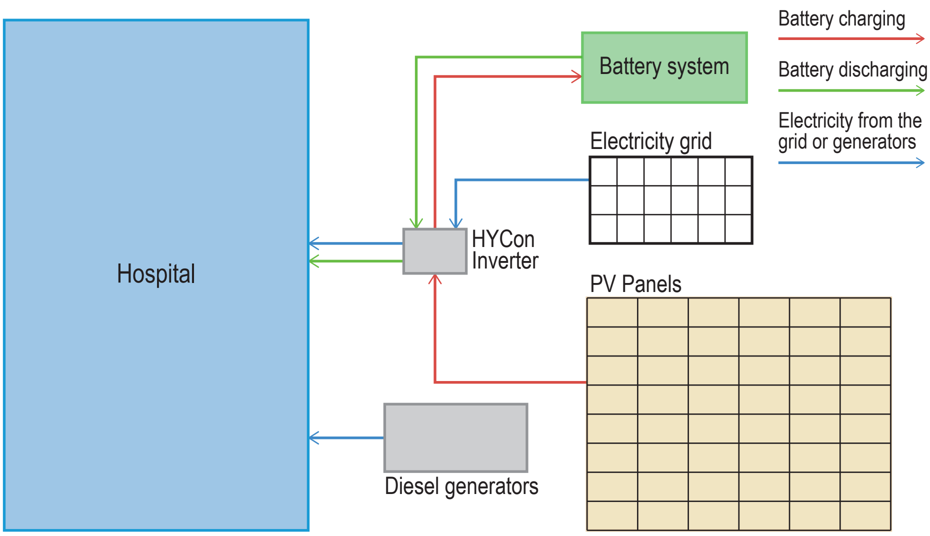


Diagram showing the energy flows

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