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# NEXT-GENERATION SUSTAINABLE BATTERIES:

Insights from the  
**GRAPHERGIA** and  
**PHOENIX** Projects



# NEXT-GENERATION SUSTAINABLE BATTERIES: INSIGHTS FROM THE GRAPHERGIA AND PHOENIX PROJECTS

As the global transition toward clean and secure energy accelerates, **demand for sustainable, high-performance batteries is growing** at an unprecedented pace. **Batteries lie at the core of Europe's strategy to achieve climate neutrality**, enabling the expansion of renewable energy, the electrification of transport, and the stabilisation of modern energy grids. Yet, meeting this demand requires more than simply scaling up existing technologies: **it calls for innovative materials and smarter, more efficient battery architectures.**

**Graphene and other advanced materials are emerging as key enablers in this transition.** With exceptional mechanical strength, conductivity, and chemical stability, graphene offers new opportunities to **enhance battery performance, improve durability, and reduce environmental impacts** across the battery lifecycle. When paired with **sustainable design principles and circular-economy** approaches, these innovations contribute directly to Europe's goals for **resource efficiency, reduced dependency on critical raw materials, and long-term technological sovereignty.**

In this context, **EU-funded initiatives and projects, such as [GRAPHERGIA](#) and [PHOENIX](#), play a crucial role.** By pushing the boundaries of materials science and integrating sustainability at every stage, from design to end-of-life, **these projects are shaping the next generation of battery technologies that will power a climate-neutral Europe.**

Both are part of larger initiatives. In the case of **GRAPHERGIA**, the project belongs to the **[Graphene Flagship initiative](#)**, working to advance Europe's strategic autonomy in technologies that rely on graphene and other 2D materials; meanwhile, **PHOENIX** is a member of **[BATTERY 2030+](#)**, an essential part of the European battery ecosystem, inventing the sustainable batteries of the future.

## The PHOENIX Project

### Supporting the Development of Smart, Technologically Advanced and Sustainable Batteries by Embedding Sensors and Self-Healing Functionalities



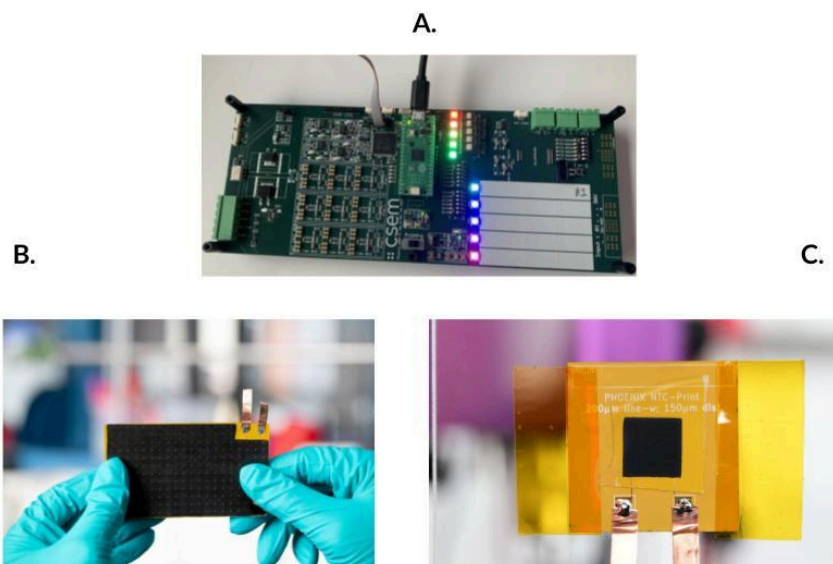
[PHOENIX](#) is a European research and innovation project launched in May 2023 with the ambitious goal of **rethinking lithium-ion batteries** from the inside out. Part of the broader [BATTERY 2030+ initiative](#), PHOENIX focuses on developing smart, self-healing, and sustainable battery technologies that can significantly extend battery lifetime, improve safety, and reduce environmental impact. By integrating sensing, triggering and self-repair mechanisms directly into the battery cell, PHOENIX aims to unlock a new generation of intelligent energy storage systems designed for a circular and climate-neutral future.

### PHOENIX Technology and Methodology

[PHOENIX](#) develops an integrated technological framework that combines **advanced materials, embedded sensors, self-healing polymers** and an **intelligent Battery Management System (BMS)**. The project explores innovative self-healing solutions for key battery components, including silicon-based anodes, polymer electrolytes, metal organic frameworks (MOFs) coated separators and core-shell NMC composites cathode, enabling autonomous recovery from mechanical and electrochemical degradation.

A wide range of sensors (thermal, mechanical, gas and electrochemical) are being developed to monitor battery health in real time. These are connected to a next-generation BMS that acts as the “digital brain” of the battery, enabling early detection of failures and activation of self-healing responses when needed. **Sustainability is embedded into the technology design through life cycle assessment (LCA)**, recyclability strategies and alignment with European recycling infrastructures. A strong **human-centric approach** guides PHOENIX toward **safer batteries** for everyday use in **mobility, energy storage** and **critical applications**.





A. BMS V1 CSEM - PHOENIX project.  
 B. Pressure-sensitive elastomer sensor for monitoring cell expansion and State of Health - PHOENIX project.  
 C. Printed temperature sensor on flexible substrate for SoH monitoring - PHOENIX project.

## Socio-economic Impact of PHOENIX's Batteries

The PHOENIX batteries could target high-impact sectors where battery reliability, safety and lifetime are critical. These include **electric vehicles, stationary energy storage for renewable energy integration, medical devices, aerospace and remote infrastructure applications**. By prolonging battery lifetime and reducing failure rates, PHOENIX contributes to lowering operational costs, reducing dependence on critical raw materials, and minimising environmental footprint.

Self-healing batteries can enable safer fast charging, reduce risks related to gas evolution and thermal runaway, and enhance the economic viability of next-generation high-energy materials such as silicon anodes. In the long term, **PHOENIX supports Europe's strategic autonomy in battery manufacturing** and contributes to the transition toward **climate-neutral energy systems**.

## Who's Behind? The PHOENIX Consortium

PHOENIX is a multidisciplinary [consortium](#) bringing together leading research centres, universities and industrial partners from across Europe. The consortium includes experts in materials science, cell manufacturing, electronics, software development and sustainability assessment. This strong collaboration across disciplines ensures that innovations developed in



PHOENIX are not only scientifically advanced, but also scalable, manufacturable and aligned with real industrial needs.



The PHOENIX project partners - PHOENIX project

## PHOENIX and BATTERY 2030+

PHOENIX is part of the [BATTERY 2030+](#), a large-scale initiative that aims to accelerate the discovery and development of **sustainable, safe and high-performance batteries through radically new approaches**. It brings together a vast ecosystem of research projects, infrastructures, industry players and policymakers under a shared vision: **enabling the future of clean energy and electric mobility through breakthrough battery technologies**.

Within this framework, **PHOENIX contributes to key BATTERY 2030+ research pillars**, including self-healing materials, smart sensing, advanced BMS, manufacturability and circularity. By operating within this coordinated European ecosystem, PHOENIX benefits from knowledge exchange, joint scientific actions and strong alignment with European battery strategies and policy objectives.



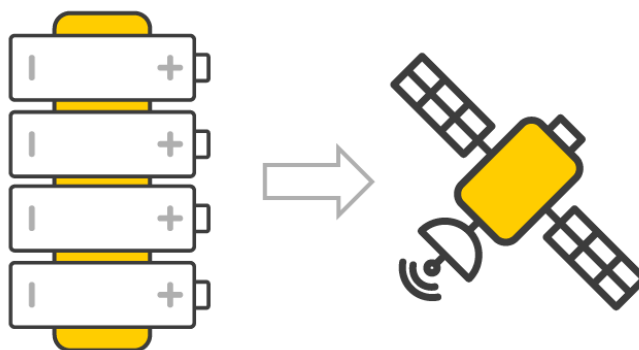
## The GRAPHERGIA Project

### Innovative Pilot Lines for Sustainable Graphene-based Flexible and Structural Energy Harvesting and Storage Devices



With the aim of transforming the energy landscape, [GRAPHERGIA](#) is a Research and Innovation Project spanning 3.5 years, initiated in October 2023, part of the [Graphene Flagship](#) initiative. The project focuses on developing **eco-friendly “dry-electrode” fabrication for energy storage devices**, leveraging the potential of **lasers in graphene synthesis** to enable climate-neutral production, with applications piloted in two key areas: **lithium-ion (Li-ion) batteries** and **micro-flexible supercapacitors integrated energy-autonomous smart textiles**.

### GRAPHERGIA Technology and Methodology



DEMO CASE #3: Advanced graphene-based LIB module prototype for space applications - *AUSTRALO* (GRAPHERGIA)

[GRAPHERGIA](#) develops next-generation electrodes for Li-ion batteries (LIBs) that incorporate two-dimensional (2D) materials, grounded in the principles of eco-design.

The outcome is a **dry-electrode fabrication** approach for producing **advanced graphene/Si-based electrodes for structural next-gen LIB cells** to support space-related applications, led by **Pleione Energy**. A comprehensive method is employed, integrating 2D materials and process-oriented methodologies, utilising **cost-effective raw materials** and **scalable fabrication** techniques to ensure economically viable and **environmentally sustainable solutions** for one of its three key [demo cases](#):



**Advanced graphene-based LIB module prototype for space applications**, focusing on a module prototype that will be designed, manufactured and tested to validate the capabilities and advances of the developed laser-assisted fabrication technology at TRL 5 (Technology Readiness Level) on the system level based on the optimal laser-scribed graphene-based electrodes and LIB cells.

Moreover, in order to **develop autonomous self-powered e-textiles, laser-scribed solid-state micro-flexible supercapacitors (SCs)** will be designed, fabricated and **coupled with energy harvesters such as triboelectric nanogenerators (TENGs)**, a task led by **German Aerospace Center (DLR)**.

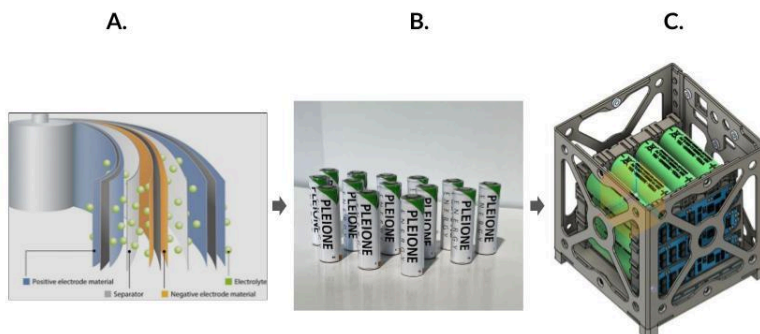
**Self-powered smart clothing will be able to harvest and store energy** in micro-flexible SCs, powering **wearable electronic devices for medical, sports, well-being and Internet of Things (IoT)** applications. All-in-one, self-charging power textiles with integrated electronic systems will provide a **human-body-centric technology** and interface of the user to the IoT through wireless transmission of sensor signals. Gel polymer electrolytes based on highly ion-conductive, high voltage and non-flammable ionic liquids incorporated into castable polymer matrices will be developed to match to the laser ascribed electrodes for fabricating the solid state micro-flexible SCs.

### **Socio-economic Impact of GRAPHERGIA's Batteries**

Achieving scalable, cost-effective, and climate-neutral production of graphene-based materials will accelerate the development of high-market-uptake products for the energy sector, contributing to economic, environmental, and social impact.

GRAPHERGIA's energy solutions will contribute to **creating forefront knowledge** in the area of green, sustainable, carbon-neutral and high-quality, large-scale synthesis of **graphene-based materials**. They will also maintain **industrial leadership in the 2D materials** value chain; support **job growth and competitiveness** in the materials, smart clothing and battery industry; **fight climate change** by employing less energy-intensive processes for fabricating graphene electrodes, and, in general, improve the quality of life for EU citizens.





- A. Internal structure of a Lithium-ion battery, showing the layered electrodes and separator design - *New advances in imaging and microanalysis of lithium-ion batteries* - Best Magazine: <https://www.bestmag.co.uk/new-advances-in-imaging-and-microanalysis-of-lithium-ion-batteries>
- B. Graphene-based Lithium-ion cylindrical battery cells - Pleione Energy GmbH.
- C. Battery module assembly integrating multiple Lithium-ion cells for space applications - Pleione Energy GmbH, design for Demo #3 for GRAPHERGIA activity.

## Who's Behind? The GRAPHERGIA Consortium

GRAPHERGIA is formed by a [consortium](#) of 11 research and industrial partners from six European countries, coordinated by the **Institute of Chemical Engineering Sciences of Foundation for Research and Technology Hellas (FORTH)**. Together, the consortium brings expertise on graphene and 2D materials, smart e-textiles, next-generation Li-ion batteries, and sustainability and eco-design methodologies.



The GRAPHERGIA project partners in a consortium meeting in Université Gustave Eiffel (Paris) - AUSTRALO (GRAPHERGIA)



## GRAPHERGIA and Graphene Flagship

GRAPHERGIA is part of the [Graphene Flagship](#) initiative, which works to **advance technologies that rely on graphene and other 2D materials**. The Flagship brings together 126 academic and industrial partners in 13 research and innovation projects (including GRAPHERGIA) and one coordination and support project.

In the Graphene Flagship, GRAPHERGIA is part of four different working groups, focused on topics such as coordination, associating mechanism to onboard new members, and dissemination and standardisation. This allows the project to join a broader community to find synergies, collaborate and exchange ideas and know-how through joint publications, workshops and events, increasing the project's visibility and impact.

## The Importance of EU Research for the Future of Sustainable Batteries

Sustainable batteries will be a cornerstone of the future energy system. By enabling cleaner mobility, stabilising renewable power, and reducing dependence on critical raw materials, **advanced battery technologies can significantly accelerate Europe's transition toward climate neutrality**. Yet reaching this vision requires more than technological breakthroughs: it demands a coordinated effort across research, industry, and policy.

Projects like **PHOENIX and GRAPHERGIA demonstrate how collaboration can drive meaningful progress**. By combining novel materials, smart sensing, self-healing capabilities and next-generation graphene-based solutions, such initiatives push the boundaries of what batteries can achieve in terms of performance, lifetime, safety, and circularity.

As Europe strengthens its commitment to sustainable energy systems, continued innovation and an active, interconnected research community will be essential. **Working together, we can shape battery technologies** that not only power the devices and vehicles of tomorrow, but also contribute to a **resilient, resource-efficient, and climate-neutral future**, both in Europe and worldwide.

