SOLiD: building a sustainable future for high-performance solid-state lithium-metal batteries

How the EU's SOLiD project revolutionises the next generation of battery manufacturing for safer, greener and more efficient electric mobility.

In the ongoing push for a climate-neutral Europe, electrification—especially in transportation—plays a pivotal role. At the heart of this transition lies the need for robust, safe and sustainable energy storage solutions. While lithium-ion batteries have enabled the first wave of electric mobility, they are nearing their physical and chemical performance limits. This has sparked a wave of research into next-generation battery technologies. Leading that charge is the EU-funded SOLiD project (Sustainable manufacturing and optimised materials and interfaces for lithium-metal batteries with digital quality control), a Horizon Europe initiative that aims to establish a sustainable, safe and scalable pilot line for manufacturing solid-state batteries (SSBs).

Launched in September 2022, with a consortium of 14 partners across nine countries, SOLiD aims to bridge the gap between lab-scale innovation and real-world production, laying the foundation for the EU's future battery manufacturing.

A new generation of batteries

Traditional lithium-ion batteries rely on liquid organic electrolytes that are volatile and flammable. These materials raise both safety concerns and long-term sustainability issues, especially as demand for electric vehicles (EVs), grid storage and portable electronics grows. Moreover, current batteries are heavily dependent on critical raw materials like cobalt and lithium elements that are not only finite but often sourced under environmentally and socially challenging conditions.

Solid-state lithium-metal batteries offer a paradigm shift. By replacing liquid electrolytes with solid ones and using lithium metal instead of graphite anodes, SSBs promise:

- higher energy densities (up to 70% more than current Li-ion batteries)
- improved safety with non-flammable materials
- longer lifespan and better performance at high voltages
- reduced reliance on critical raw materials
- potential for more compact, lightweight battery designs.

Yet despite these advantages, SSBs face a fundamental hurdle: scalability. Most solid-state battery research has been limited to lab settings. Transitioning from proof-of-concept to industrial-scale production remains a difficult challenge—one that the SOLiD project is tackling head-on.

SOLiD's vision and objectives

The predominant ambition of SOLiD is to develop a sustainable, pilot-scale production line for solid-state lithium-metal batteries, with the following goals:

1. Develop a dry and solvent-free electrode fabrication method to reduce energy usage and environmental impact during manufacturing.
2. Establish scalable methods for applying ultra-thin lithium metal and protective coatings using physical and chemical vapour deposition techniques.
3. Create solid polymer electrolytes that offer ionic conductivity comparable to liquid electrolytes while enabling mechanical stability and safety.
4. Integrate digital quality control tools, including real-time sensors and AI-driven defect detection, to ensure high yields and safe operation.
5. Incorporate recycling-by-design principles, ensuring batteries are easier to dismantle and materials are easier to recover at end-of-life.

The project is particularly focused on Generation 4b battery cells, which incorporate lithium-metal anodes, solid electrolytes and high-voltage cathodes—all within a compact, recyclable package.

Technical breakthroughs and innovations

1. Dry electrode fabrication

Traditional electrodes are made using wet processes that require significant amounts of toxic solvents and energy-intensive drying stages. These steps not only create emissions but also increase production costs and fire risks. SOLiD is developing pioneering dry coating techniques, particularly extrusion-based methods, that eliminate the need for solvents altogether. This makes production both safer and more environmentally friendly.

In collaboration with several industrial partners, pilot lines are being set up to test dry-coated cathodes and anodes. Early results have demonstrated promising mechanical properties and electrochemical performance on par with traditionally fabricated electrodes.

2. Thin-film deposition for lithium-metal anodes

Lithium metal is an ideal anode material due to its high specific capacity, but it's reactive and difficult to handle. SOLiD is scaling up pulsed laser deposition (PLD) processes for applying ultra-thin lithium layers (~3–10 µm); these layers form the heart of the anode. They must be uniform and defect-free to prevent dendrite formation, which can lead to short circuits.

The PLD system allows for precise control over deposition rates and layer composition. This is crucial not only for battery safety but also for integrating lithium-metal layers into high-throughput manufacturing systems.

3. Protective coatings and interface engineering

One of the main challenges in SSBs is managing the interface between solid electrolytes and electrodes. Without proper engineering, these interfaces can degrade, increasing resistance or causing mechanical failure.

SOLiD researchers have used atomic layer deposition (ALD) to apply ultra-thin, conformal protective layers on the cathode particles. These coatings improve chemical stability and reduce side reactions, especially at high voltages. Materials like lithium niobate and lithium phosphate have been tested, offering enhanced interface stability and performance.

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4. Advanced solid polymer electrolytes

Solid polymer electrolytes (SPEs) are at the core of the SSB design. The SOLiD consortium has developed a range of SPE materials using different lithium salts. These electrolytes exhibit high ionic conductivity (up to 10^{-4} S/cm) and are compatible with the dry processing methods used for electrodes.

In combination with plasticisers and nano-fillers, these polymers maintain flexibility and thermal stability across a wide temperature range. These properties are essential for maintaining contact between electrodes and electrolytes during battery cycling.

5. Inline inspection and digital quality control

To ensure production quality, SOLiD is developing inline inspection tools capable of detecting deviations in layer thickness, composition and real-time particle distribution. This is paired with AI-based data analytics that flag defects early and allow for process adjustments without human intervention.

These systems are being tested on pilot lines to verify their ability to support high-volume manufacturing without sacrificing performance.

Sustainability and recycling

SOLiD goes beyond just improving battery performance. One of its guiding principles is recyclability. Today's batteries are notoriously difficult to dismantle, and their recycling processes are both costly and inefficient.

By applying recycling-by-design principles, SOLiD ensures that batteries are engineered from the outset for easier disassembly and more sustainable end-of-life processing. Electrodes are designed with specialised binders and coatings to simplify material separation, while non-toxic, modular housing materials help minimise waste. Additionally, software tools track material composition, enabling more intelligent and efficient recycling workflows. These integrated design strategies support the efficient recovery of valuable elements such as lithium, nickel and cobalt, significantly reducing the battery's overall environmental impact.

Early outcomes and project status

Now, well into its second year, SOLiD has achieved a number of key milestones:

- Established detailed cell specifications, including size, voltage, cycling durability, safety and energy density targets.
- Demonstrated dry electrode coating on a pilot line with promising scalability metrics.
- Synthesised and characterised SPEs and lithium coatings with consistent performance.
- Validated inline sensing technologies under near-industrial conditions.
- Published findings at several major battery conferences and peer-reviewed journals.

The next phases of the project will involve assembling full cell prototypes using the developed processes and benchmarking them against state-of-the-art lithium-ion counterparts. The goal is not only to match performance but also to exceed current safety and sustainability standards.

Looking ahead

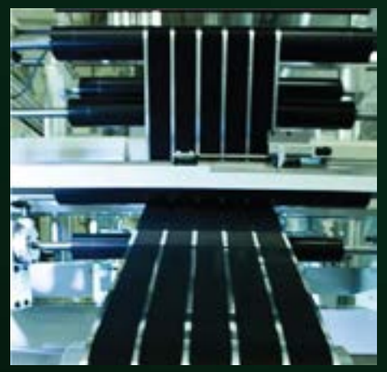
SOLiD is on track to make a profound impact in three key areas:

- **Battery technology:** by advancing solid-state lithium-metal batteries, SOLiD sets a new benchmark for safety, performance and recyclability.
- **Manufacturing innovation:** the development of dry processing techniques and real-time digital quality control sets the stage for greener and more cost-effective battery production across Europe.
- **Environmental responsibility:** with recyclability and resource efficiency baked into the design, SOLiD aligns with the European Green Deal and the EU's strategic goal of battery sovereignty.

As global battery demand is expected to grow 14-fold by 2030, initiatives like SOLiD are crucial not just for meeting that demand but for ensuring that Europe can do so sustainably, competitively and independently.

About the consortium

VTT Technical Research Centre of Finland Ltd coordinates the SOLiD project. It includes a powerful blend of academic, industrial and SME partners throughout the battery manufacturing value chain, starting from materials and ending in the automotive industry, supported by professional dissemination and exploitation experts.



Final thoughts

The SOLiD project is more than just another research initiative. It is a blueprint for how next-generation battery technologies can be scaled and industrialised responsibly. By fusing sustainability with cutting-edge science, SOLiD is not only driving the future of batteries but also the future of clean mobility, smart grids and a truly circular European economy.

For further information, visit the project website at **www.thesolidproject.eu**.

SOLiD

PROJECT SUMMARY

SOLiD is an EU-funded project whose main objective is to create a sustainable, cost-efficient pilot-scale manufacturing process for a high-energy density, safe and easily recyclable solid-state Li-metal battery. The roll-to-roll (R2R) dry extrusion coating and cost-efficient R2R PLD methods enable the sustainable manufacturing of Gen. 4b solid-state batteries with a minimised amount of critical raw materials (Co and Li).

PROJECT PARTNERS

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PROJECT LEAD PROFILE

VTT Technical Research Centre of Finland is an impartial, multidisciplinary expert organisation. VTT's unique strength lies in its capacity to develop new, globally competitive technologies and innovations by integrating knowledge and expertise from various fields. With its expertise, VTT provides research, development, testing and information services to the public sector, companies and international organisations.

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