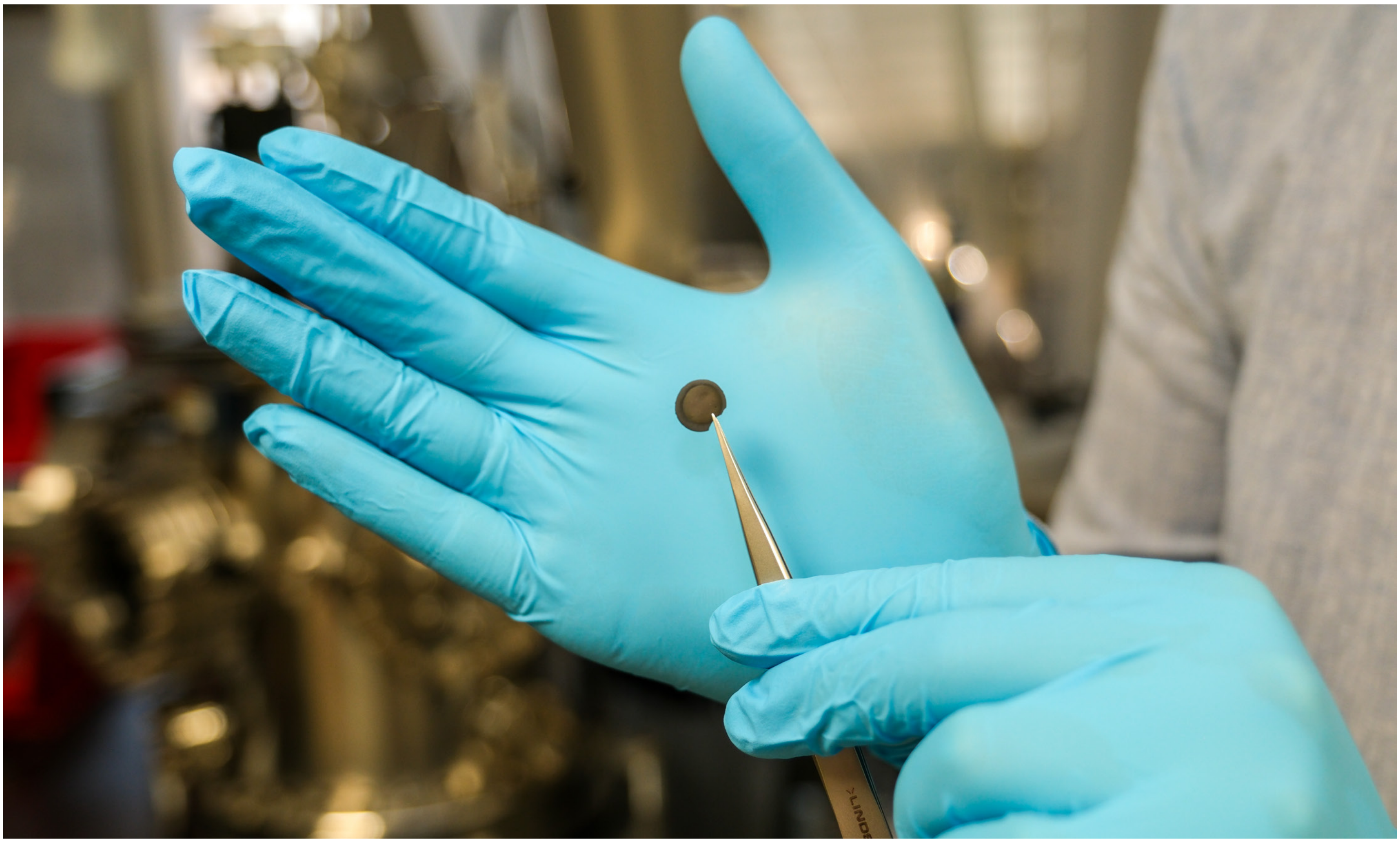
BATTERIES REDUCED TO THE ESSENTIALS

A good battery has high energy density, short charging times, is safe to operate, and can withstand extreme temperatures. Solid-state batteries are a new generation of lithium-ion batteries that do not require liquid components and combine many of these properties. An international research consortium, including the Swiss Federal Laboratories for Materials Science and Technology, or Empa, is working on the development of anode-free solid-state batteries in combination with thin-film technology. Potential application areas include the industrial Internet of Things sector, with additional potential uses in mobile areas such as drones, robotics, and aerospace.



Functional model of the hybrid battery. Photo: Empa

A technical report about the results of a research project in the field of batteries, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine Strassenverkehr Schweiz (issue November 2024).

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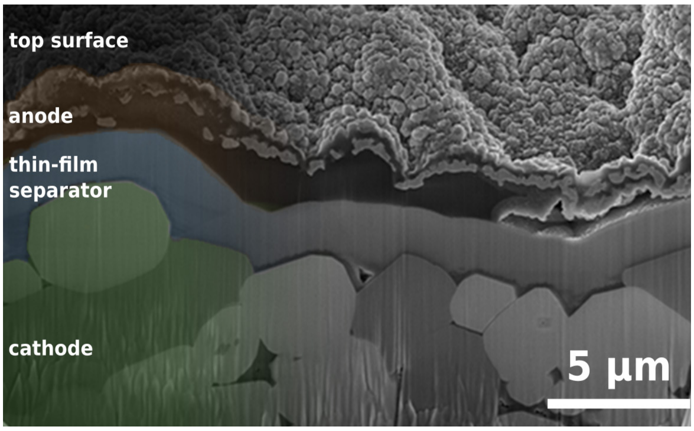
The Swiss Federal Institute of Technology (ETH) and the research institutes of the ETH regularly spinoff startups that aim to commercialize innovative ideas. One of these companies is called BTRY (pronounced: battery). The company was founded in April 2023 by Abdessalem Aribia, Moritz Futscher, and Yaroslav Romanyuk. All three scientists at the time have worked together at Empa, which is part of the ETH. The goal of BTRY is to build a small battery that can be charged very quickly – in just one minute – for use in applications such as sensors, medical devices, or watches.

This fast-charging cell is made possible by vacuum coating technology, a manufacturing process in which Empa has special expertise. Vacuum coating allows for the application of extremely thin material layers that are only a hundredth of a millimeter or less in thickness. The technology comes partly from the production of solar cells and is now being used for the production of safe, environmentally friendly, and long-lasting thin-film batteries. The "battery revolutionaries," as the BTRY founders are called in an Empa publication, plan to start pilot production in 2026.

Empa researches solid-state batteries

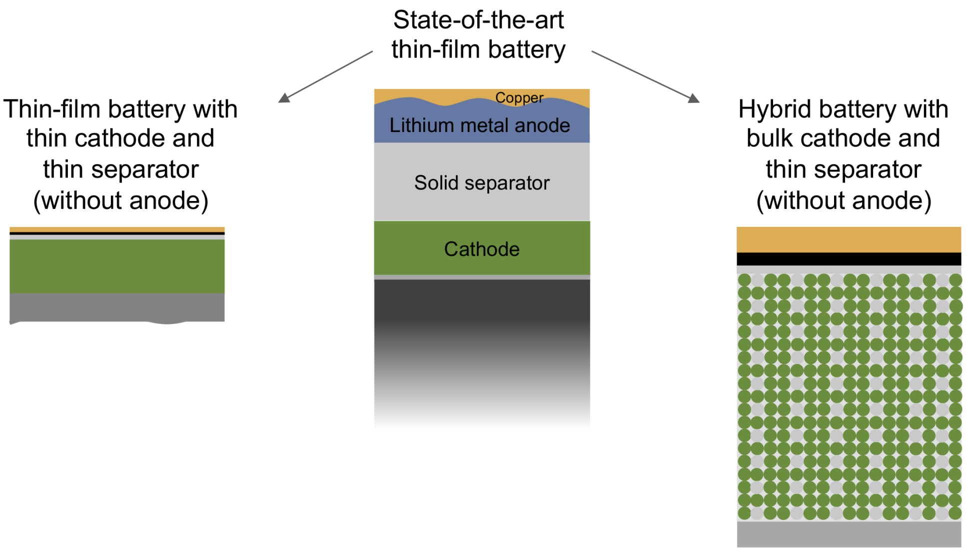
BTRY's battery is a solid-state battery (also referred to as a solid electrolyte battery). It works like the lithium-ion batteries commonly used in mobile phones and electric vehicles but does not contain any liquid. It consists solely of solid materials. Solid-state batteries are safer because the liquid electrolyte in conventional lithium-ion batteries is responsible for their flammability. Furthermore, batteries with non-liquid electrolytes are less sensitive to low temperatures. These advantages explain why scientists are currently conducting intensive research on solid-state batteries with lithium-ion chemistry.



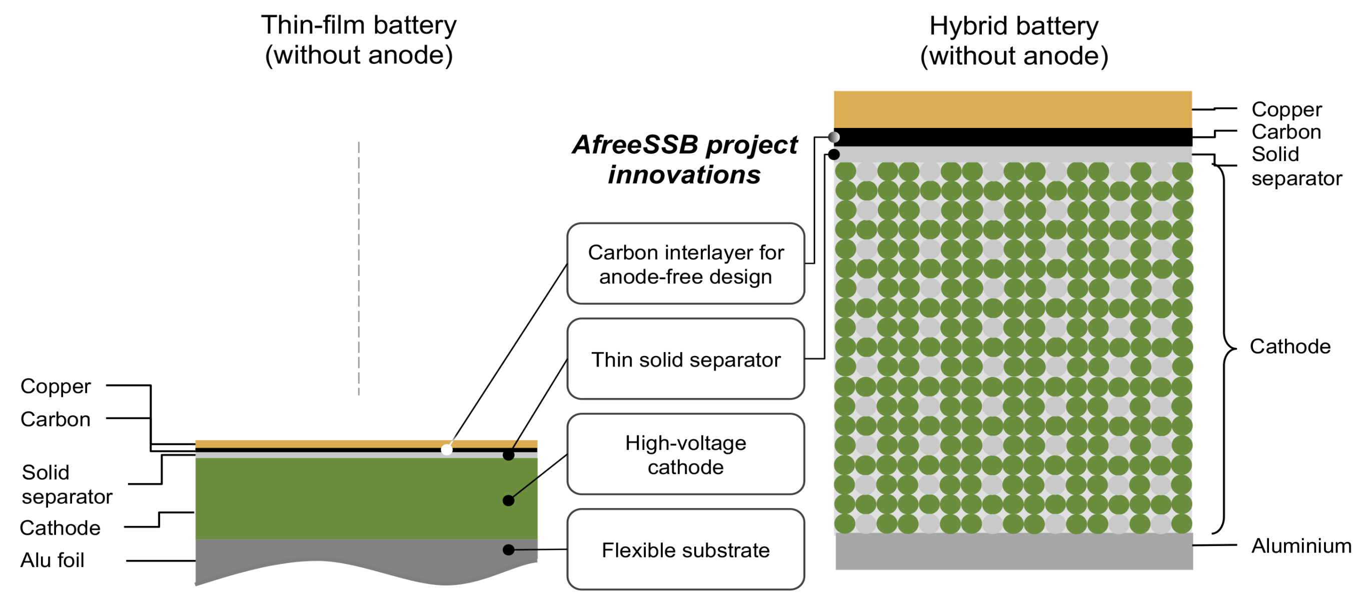
Scanning electron microscope cross-section of a hybrid battery. The cathode from Forschungszentrum Jülich was coated with a thin-film separator and an anode at Empa to complete the cell. Photo: Empa

Empa has been dedicated to the research of solid-state batteries for years. The Empa spinoff BTRY, with its thin-film solid-state batteries, is a product of these research activities at the Empa Laboratory for Thin Films and Photovoltaics. In 2022, the laboratory, together with partners from Germany and Spain, launched the two-year research project: Anode-free all-solid-state batteries: From thin film to bulk (AFreeSSB), which is co-funded by the SFOE.

Hybrid Battery of Thick and Thin Layers



A conventional thin-film solid-state battery (center) and two novel batteries that are being developed in the AFreeSSB project. An anode-free thin-film solid-state battery (left) and a hybrid battery (right) with a thick cathode, as they are used in conventional solid-state batteries, together with a thin separator, as used in thin-film solid-state batteries. Illustration: Empa/edited B. Vogel



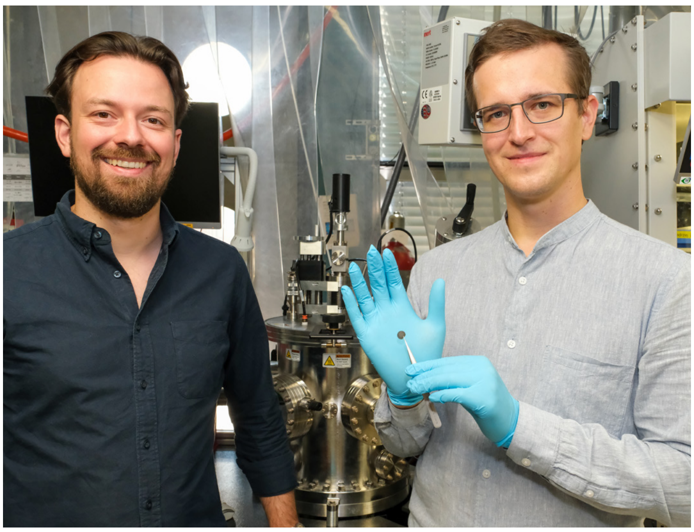
The innovations within the AFreeSSB project are aimed at improving both thin-film batteries (left) and hybrid batteries (right). Illustration: Empa

Solid-state batteries can be made entirely of thin material layers, as in the case of BTRY. Such batteries are lightweight and compact, but limited in storage capacity. To build batteries with large storage capacities for electric vehicles, for example, thick material layers are required that can store a lot of energy per area. The AFreeSSB project, therefore, explores the concept of a hybrid battery that combines the advantages of both battery types. The hybrid battery consists of a thick cathode, as used in a conventional solid-state battery, and a novel thin separator as a spacer between the two electrodes. To manufacture the hybrid battery, the cathode is coated with a material that serves as a separator. This may sound simple but it is a technical challenge. For the cathode to be coated, it must have a very flat surface. The Empa researchers use a cathode from the German Forschungszentrum Jülich, which specializes in manufacturing cathodes for solid-state batteries. A layer of lithium phosphorus oxynitride (LiPON), only a few thousandths of a millimeter thick, is applied to the cathode, which serves as a solid separator. This layer is at least 10 times thinner than in a conventional solid-state battery. To ensure it is uniform and without holes, the so-called magnetron sputtering process is used. The coating is done in a vacuum, incorporating magnetic fields.

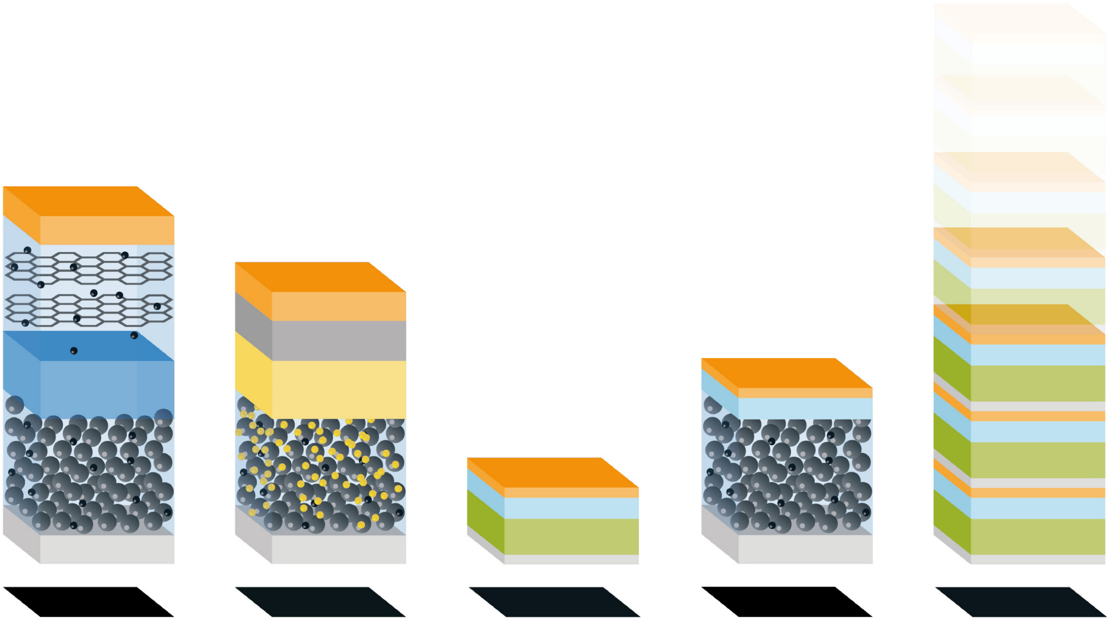
"We were able to generate a stable open-circuit voltage on a functional model of our hybrid cell and also move lithium ions from the cathode towards the anode, which is typical for the charging process of a lithium-ion battery," summarizes Empa scientist Moritz Futscher, a key result of the AFreeSSB project. "Even though our coating basically works, further research is needed to achieve a complete charge-discharge cycle. We hope to present a functional prototype by the end of the project."

Thin-Film Battery Without Permanent Anode

Another subproject of AFreeSSB focuses on the research of solid-state batteries that, like BTRY batteries, consist solely of



Moritz Futscher (left) and Jedrzej Morzy are developing new types of batteries in the Empa laboratory. Photo: Empa



The hybrid battery developed in the project (4th from left) combines the cathode of a solid-state battery with components (separator, anode) of a thin-film battery. On the far right, a stacked thin-film battery developed by BTRY. Illustration: BTRY

thin layers. The research goal is to build a thin-film solid-state battery without an anode. This would mean a battery that does not have an anode in its discharged state and can therefore be manufactured more cheaply and with fewer resources. Only by charging the battery does an anode form by the accumulation of charge carriers made of lithium metal. When the battery is discharged, the anode dissolves again.
To build an anode-free battery, a so-called seed layer is inserted between the separator and the current collector, where the charge carriers of lithium metal accumulate during the charging process. The Empa researchers examined various seed layers that best support the growth of the anode during charging. They found that gold, platinum, and amorphous carbon as seed layers improve lithium deposition. In particular, the amorphous carbon layer facilitated the growth of a lithium metal anode and proved to be a possible cost-effective alternative to precious metals.

Battery Measuring Device

The Fluxim AG (Winterthur) was involved in the AFreeSSB research project. It used the project collaboration with experienced battery researchers to develop a battery test device for research institutions developing new batteries. The innovative compact measuring device combines established measurement methods, such as charge and discharge cycles, with additional methods for characterizing material parameters, such as impedance spectroscopy. A prototype of the measuring system was created during the project, which measures currents with a strength of 100 mA to 1 µA with 8 channels and operates within a temperature range of 5 to 80 °C. "Thanks to the insights gained from the AFreeSSB

THREE COUNTRIES UNITED

The international research project AFreeSSB is conducted under the umbrella of M.ERA-NET, a network of 49 public funding organizations from 39 EU and non-EU countries, in which Switzerland also participates. M.ERA-NET focuses on researching materials and battery technologies that support the EU›s sustainability policy (European Green Deal).

The AFreeSSB research consortium (short for: Anode-free all-solid-state batteries) includes partners from three countries. From Switzerland, the participants are Empa and the company Fluxim AG (Winterthur); from Germany, the Forschungszentrum Jülich GmbH and the company AIXTRON SE, a manufacturer of coating equipment for the semiconductor industry; and from Spain, the Catalonia Institute for Energy Research (IREC) and the microelectronics company AEInnova. The research partners are funded by national funding agencies; in Switzerland›s case, this is the Swiss Federal Office of Energy.

project, Fluxim can incorporate measurement routines and analyses into the measuring system to accelerate the long-term development of new cell types," says Beat Ruhstaller, founder and CEO of Fluxim AG.

- Further information on the **research project** "Anode-free all-solid-state batteries: From thin film to bulk" (AFreeSSB): www.aramis.admin.ch/Grunddaten/?ProjectID=51129.

- For more **information**, contact Stefan Oberholzer (stefan.oberholzer@bfe.admin.ch), Head of the SFOE Battery Research Program.

- Further **articles** on research, pilot, demonstration, and flagship projects in the field of batteries can be found at www.bfe.admin.ch/ec-batterien.

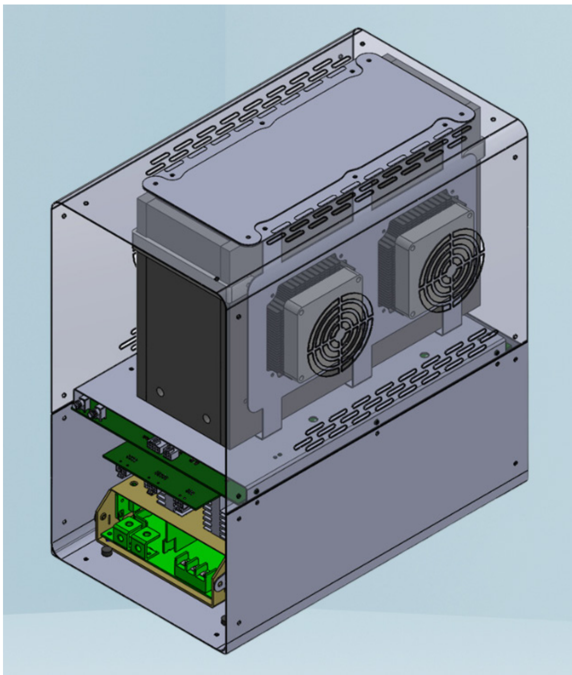


Illustration of the battery measurement system developed by Fluxim as a prototype in the AfreeSSB project. Illustration: Fluxim

Author: Benedikt Vogel, on behalf of the Swiss Federal Office of Energy (SFOE)
Version: December 2024