Sustainable energy storage using egg shells

In 2018, Germans consumed 235 chicken eggs per head. While egg white and egg yolks are processed into cakes, pasta or scrambled eggs, the shell predominantly ends up as organic waste. This despite the fact that eggshells are complex composites of lime and protein fibres. “It has repeatedly been shown over recent years that natural products are excellently suited for energy storage,” explains Professor Maximilian Fichtner from the Helmholtz Institute Ulm, a facility that comes under the Karlsruhe Institute of Technology (KIT) in Karlsruhe.

Together with Australian researchers, Fichtner is studying the electrochemical properties of chicken eggshells. The eggshells are 0.2 to 0.4 millimetres thick and are composed of three layers: a cuticle, a calcified shell and an inner and outer eggshell membrane, which consists of a close-knit network of protein threads. The researchers found that eggshells can be used to make electrodes for lithium-ion capacitors (LIC). This involves washing, grinding and heating the eggshells in the absence of air. The eggshells turn black as the protein fibres transform into coal, enabling them to conduct electrically. “This is the basic prerequisite for being able to carry electric current into the electrode, in other words, to enable energy to be stored," explains Fichtner. The resulting eggshell powder is mixed with a plastic, brushed onto a metal foil and left to dry – the electrode is ready.

Capacitors can be charged and discharged ten times faster than batteries

Prof. Dr. Maximilian Fichtner

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There are many different types of capacitors used in almost all electronic devices. The capacitor of a camera flash unit, for example, can be charged from a battery within seconds. After the flashtube is triggered, the capacitor discharges within a few microseconds and delivers a few kilowatts of power. The battery cannot provide that much power within such a short time. "A capacitor stores ten times less energy than a battery, but can be charged and discharged ten times faster," says Fichtner. In addition, capacitors survive many more charge and discharge cycles. And there's another difference: capacitors store energy as an electric field. Batteries store electrical energy in chemical form.

LICs (lithium-ion capacitors) belong to the group of super-capacitors with the largest capacitance, meaning that they can store far more energy than conventional capacitors. That makes them interesting for quite a few applications. "In China, they have developed the first buses that use capacitors instead of batteries," says Fichtner. When the bus stops at a traffic light or a bus stop, the capacitor is charged without cables within seconds via an induction loop in the ground. The bus can then carry on to the next charging station a few kilometres away where it is charged again. "This works very well for buses with a fixed route but capacitors are not yet suitable for cars. "In addition, LICs are cheaper than large batteries, which often also contain acids and heavy metals. LICs do not contain acids and heavy metals. They are environmentally friendly and contain much less lithium than lithium-ion batteries.

Like an electronically conductive sponge

LICs consist of two

Schematischer Aufbau eines Lithium-Ionen-Kondensators und Verteilung der Ionen im entladenen Zustand. Genauere Erläuterungen im Text.
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different electrodes, which are connected by a lithium-containing electrolyte. An electrolyte is a solvent that contains de-solvated salts. The electrodes are separated from each other by an electrically permeable membrane, a so-called separator, which prevents short circuits. "The electrodes are like an electrically conductive sponge, i.e. a structure with a large surface," explains Fichtner. When voltage is applied to the capacitor, the charge carriers in the electrolyte separate into positive and negative charges. When the capacitor is charged, a so-called Helmholtz double layer forms on the positive eggshell electrode, in which a layer of positive ions forms; a layer of solvated negative ions forms in the electrolyte. As a result, an electric field forms between these layers, resulting in double-layer capacitance.

At the negative electrode, the electrical energy is stored electrochemically.The electrochemical storage of electricity in an electrochemical capacitor is called pseudocapacitance. For this purpose, positively charged lithium ions are incorporated into the activated carbon or graphene electrode during production. The individuallithium ions transfer one electron each to the electrode in what is known as a redox reaction. This generates a bias voltage. The capacitor is only charged when the voltage applied to the capacitor is greater than the bias voltage. During the charging process, further positive lithium ions migrate from the electrolyte to the negative electrode, become lodged and release a charge in the form of an electron. As the capacitor is discharged, the electrons are transferred to the lithium ions and all ions are redistributed in the electrolyte.

Potential further research work with industrial partners

Bei über 1000 Lade-und Entladezyklen hielt die Testzelle eine Kapazität von 92 Prozent aufrecht.

After over 1000 charge and discharge cycles, the test cell maintained a capacity of 92 percent. “This is quite good when compared with battery materials, but compared to capacitors, 92 percent capacity is only in the midfield,” says Fichtner. He is convinced that this can be improved and envisages driving forward the research in a cooperative project with industry partners. He has already received offers from raw material suppliers who want to dispose of some of the 200,000 eggshells that are generated every day. Now he needs a company that is looking to produce eggshell capacitors. "It's not a high-performance system, but has the appeal of a renewable raw material that does not require expensive or rare raw materials."

Original publication:

Minakshi, M.; Visbal, H.; Mitchell, D. R. G.; Fichtner, M.: Bio-waste chicken eggshells to store energy. 2018. Dalton transactions, 2018 (47), 16828–16834. doi:10.1039/c8dt03252a.

Article

04-Jul-2019
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renewable energy | sustainability | waste | bioeconomy | value chain