Technology of tomorrow: Searching for the Super Battery

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Increasing storage capacity. Lithium-ion batteries have established themselves as being an efficient and reliable way to store energy, but there's something better: batteries with cathodes made of oxygen can store several times more energy than today's systems can.

By Sascha Rentzing, Freelance Journalist

Not enough charging stations, excessively expensive battery storage – those are the two main reasons that electric mobility has hardly made any headway. At least the cost situation will soon ease up: according to the latest figures from the German Federal Association of eMobility (BEM), the price of lithium ion batteries has decreased fourfold from 800 € per kilowatt to 200 €. Further price reductions are also foreseeable. The American electric car manufacturer Tesla has plans to build a large battery production factory for four to five billion dollars. Starting in 2017, lithium-ion batteries will be manufactured in this factory for a third of the cost of today's systems.

The renewable energy industry also profits from the advances being made in electric mobility. Where does energy come from when there is hardly any wind or sun? Cost-effective lithium-ion batteries offer a solution and are used to store excess green energy in buffers until it is needed. These batteries are particularly suitable for use in households and commercial enterprises that want to be completely self-sufficient using solar energy from systems on their own roof.

However, despite the rapid progress being made on lithium-ion batteries they are still only considered to be an entry-level solution. Shortly after they made their broad-based market launch, scientists already started looking for new, better performing batteries. There is one technology that they are particularly focused on: the so-called lithium-air batteries.

These have an energy density of 1,000 watt hours per kg, which is five times the energy storage capacity of today's lithium batteries. The anode – or positive end – is made of lithium metal instead of graphite or lithium titanate and the air serves as the cathode. Oxygen is sucked in by the battery as needed instead of being integrated as a permanent part of the battery. This makes these batteries lightweight and compact.

High energy density, short-lasting life

Especially the auto industry has shown an interest in lithium air batteries, because that technology would make it possible to significantly increase the driving range of electronic vehicles. This technology is expected to be implemented as early as 2020. „We hope that in the next five to ten years the lithium- air batteries will succeed in being the most efficient solution in the market“, states BEM President Kurt Sigl. However, the technology is also considered to be a promising option as a buffer for the power grid. Thanks to the high energy density, these batteries are able to store large amounts of wind and solar energy in a very small space – this would allow for the size of battery systems to be significantly reduced without having to sacrifice output performance.

However, the major drawback of metal-air batteries is their short life span. The discharge causes electrochemical reactions at the cathode and in the conductive electrolyte, which result in irreversible damage – as a consequence the battery can hardly be recharged. In order to solve this problem, researchers belonging to the project group Electrochemical Storage at the Fraunhofer Institute for Chemical Technology (ICT) are examining the reaction processes that occur at the cathode. The chemical processes taking place are very complex. „If we can understand them, then we will have come a lot closer to commercialization“, explains ICT researcher Kai-Christian Möller.

Batteries learn how to „breathe“

While discharging, the lithium atoms of the anode lose electrons and then travel as lithium ions through an electrolyte to the cathode where a reaction with oxygen from the air will occur. The product of this reaction – lithium peroxide – then settles at the cathode. In order to recharge itself, the cell would have to release the oxygen it gained during the discharge back into the air. So metaphorically speaking, it would have to learn how to breathe.

To achieve such an extension of the battery life, scientists would first have to find a way to reactivate the damaged cathode. In the joint project GLANZ (Anodes and Cells Protected by Glass), the battery research center MEET of the University of Münster, glass specialist Schott and Rockwood Lithium, Varta Microbattery and Volkswagen are all dedicated to solving a different problem.

A lithium-air battery is an open system that constantly has air flowing through it. Since its lithium metal anode is very reactive, it has to be protected from external influences. The microporous polymer membranes used in today’s batteries cannot offer the necessary protection. Therefore, the project participants are working on developing a new separator made of glass ceramics that will prevent any unwanted reactions.

The project, which received funding in the amount of 5.6 million euros from the German government, is supposed to deliver initial results this year already. Meanwhile scientists at the Research Center Jülich (FZJ) are working on the technology associated with the lithium-air batteries.

They are using silicon instead of lithium metal for the anode. This enables the same energy density of 1,000 watt hours per kilogram, but in contrast to the rare metal lithium it is available in inexhaustible quantities, according to the FZJ. The department for fundamental electrochemistry is currently searching for materials that will make the silicon-air battery just as reliable as other types of energy storage.

Technology that is two generations away

Even though the scientists are making good progress, they are warning against premature euphoria. Olaf Wollersheim, leader of the project Competence E at the Karlsruhe Institute of Technology (KIT), does not expect the technology to be commercialized any time soon. In context of Competence E, the experts are examining various types of batteries for e-mobility and the energy industry. „We see metal-air batteries as a technology of the generation after the next generation. We are not yet capable of restoring them to their original condition after the first discharge“, explains Wollersheim.

Other types of batteries that are not garnering a lot of attention nowadays due to the current euphoria surrounding air batteries could very well establish themselves first. Lithium-sulfur batteries could be ready for the market in about ten years, estimates Wollersheim. In everyday usage, lithium-sulfur batteries reach a specific energy of 600 watt hours per kilogram – more than double the capability of today’s lithium ion batteries. The problem with the sulfur storage, though, is its stability and to date, it still has not reached values that can be considered acceptable. Since sulfur expands during charging and contracts again during discharge, the cathode is under considerable stress.

In addition, sulfur dissolves in the electrolyte and the active material is lost as a result. However, researchers at the Fraunhofer Institute for Material and Beam Technology (IWS) have now been able to stabilize the battery. They were able to achieve 1,400 charge cycles and even after that number the cell still had a capacity of 60 percent of its original capacity. This means that the technology still has a shorter life than lithium-ion batteries, which have an average of 7,000 full cycles. However, they are closer to practical implementation than it is the case with air batteries, which are still in the basic research stage.

Goal: Costs of less than $200 per kWh

Sodium-ion batteries could soon be introduced to the market. The US company Aquion Energy, a spin-off of Carnegie Mellon University (CMU) in Pittsburgh, already plans on low-cost mass production of the sodium batteries in 2015. The goal is to achieve a cost of less than $200 per kilowatt hour. This is possible, because Aquion limited themselves in the search for electrode materials to materials that would be inexpensive and readily available, such as sodium and carbon, instead of comparatively rare and expensive materials like lithium. Sodium-ion batteries are said to have many additional advantages: Their storage capacity is retained even in extreme temperatures.

They even work without restrictions in desert areas. They would primarily be used at large solar power plants as these usually are built in the hot regions located on the Earth’s sunbelt. In addition, according to claims made by Aquion, they have improved the performance and life of the sodium-ion technology. The cathode consists of a sodium alloy, the anode is a carbon compound. Between the two ends is a liquid electrolyte which only allows positively charged sodium ions or atoms which are lacking an electron to pass through.

When charging, the ions from the cathode travel to the anode and during discharge this process is reversed. A few years ago the energy storage capacity of sodium-ion batteries was reduced by half after just 50 charges and discharges. Thanks to an improved understanding of the chemical reactions, Aquion has by its own account found a way to handle that problem: the batteries of the American company now achieve 5,000 full cycles and a minimum life of ten years if charged daily.

With that, the sodium batteries have come closer to the level of the lithium-ion technology. The new sodium batteries are also supposed to be especially safe. Unlike the sodium-sulfur battery developed mostly in Germany during the seventies, which had a working temperature of 300 to 400 degrees Celsius and was prone to explosions, Aquion’s batteries operate at ambient temperature – which significantly reduces the risk of fire. Since Aquion has also used a type of brine as the electrolyte, the sodium ion batteries can also be more easily recycled than lithium-ion batteries, which contain an organic electrolyte.

The brine also simplifies production, which in turn reduces costs. The machines used are normally used by food manufacturers. Many energy experts don’t expect an important breakthrough in battery storage until 2030 or later. Given the rapid advances being made in the research and development of storage systems, this estimate may have to be reconsidered.

Author Sascha Rentzing is a freelance journalist who focuses on renewable energy. He writes for trade magazines and public magazines.

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