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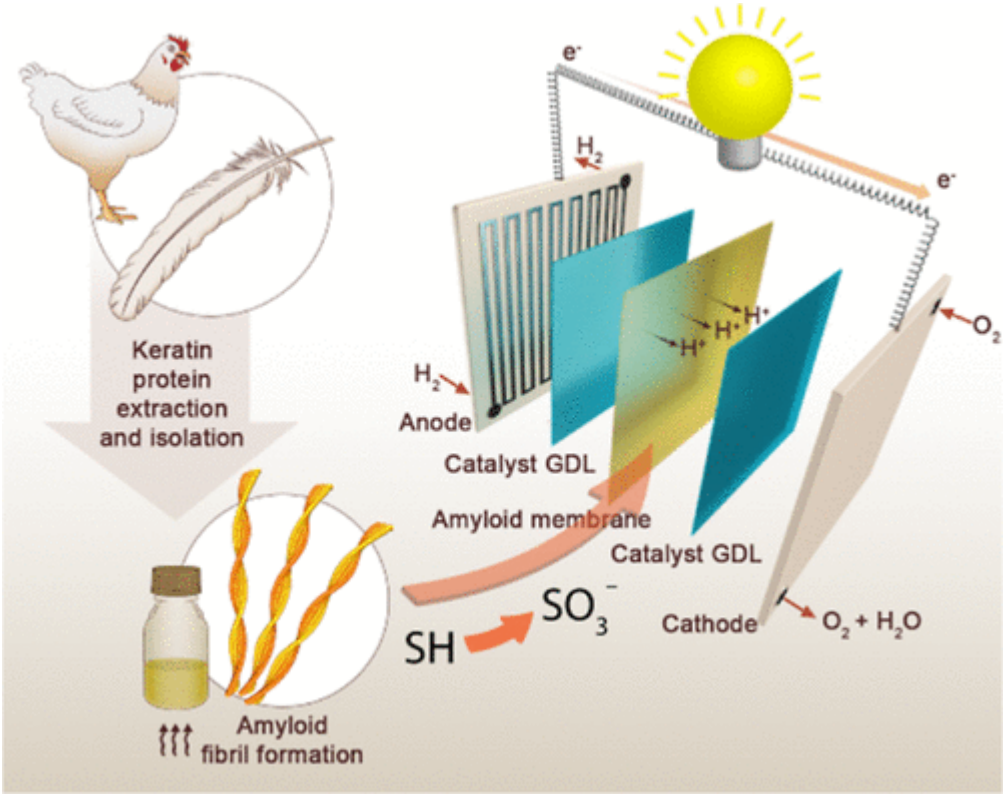
NTU Singapore and ETH Zurich scientists convert waste chicken feathers into fuel cell membrane

22 October 2023

Scientists from Nanyang Technological University, Singapore (NTU Singapore) and ETH Zurich in Switzerland have converted chicken feathers into a clean and sustainable material to build zero-waste fuel cells. By extracting the protein keratin from feathers, then processing it into ultra-fine fibers known as amyloid fibrils, the researchers created a thin membrane capable of conducting protons, which are a vital component of fuel cells.

A paper on their work is published in the journal *ACS Applied Materials & Interfaces*.



Soon *et al*.

Biobased industrial byproducts, such as side streams from the food industry, are attractive alternatives with strong potential for valorization due to their large volume, low cost, renewability, biodegradability, and intrinsic material properties. Here, we demonstrate the reutilization of industrial chicken feather waste into proton-conductive membranes for fuel cells, protonic transistors, and water-splitting devices.

Keratin was isolated from chicken feathers via a fast and economical process, converted into amyloid fibrils through heat treatment, and further processed into membranes with an imparted proton conductivity of 6.3 mS cm^{-1} using a simple oxidative method. The functionality of the membranes is demonstrated by assembling them into a hydrogen fuel cell capable of generating 25 mW cm^{-2} of power density to operate various types of devices using hydrogen and air as fuel.
Additionally, these membranes were used to generate hydrogen through water splitting and in protonic field-effect transistors as thin-film modulators of protonic conductivity via the electrostatic gating effect. We believe that by converting industrial waste into renewable energy materials at low cost and high scalability, our green manufacturing process can contribute to a fully circular economy with a neutral carbon footprint.

—Soon *et al.*

The research team, led by Professor Ali Miserez from NTU's School of Material Science and Engineering and School of Biological Sciences, and NTU Visiting Professor Raffaele Mezzenga, who is also Professor of Food and Soft Materials at ETH Zurich, say that their membrane not only reduces carbon emissions from the burning of unwanted chicken feathers but is also produced in a sustainable manner.

Fuel cells are one of the most promising sustainable energy sources of the future. The poultry industry generates millions of tons of unwanted chicken feather waste, which is burnt off in disposal, releasing large amounts of carbon dioxide and toxic gases such as sulphur dioxide. Our membrane reduces such emissions by repurposing the feathers into further green applications in fuel cells. The membrane not only has a negative carbon footprint from its production, but can operate without further carbon dioxide emissions when used in a fuel cell.

—Professor Ali Miserez

The extraction process is both fast and economical. Chicken feathers are 90 per cent keratin, which is the useful protein we want due to its high cysteine amino acid content. When burnt, cysteine produces highly toxic sulphur dioxide; however, the cysteine itself is crucial in allowing for the membrane's high proton conductivity when treated. We are turning something that is toxic when disposed of into something sustainable when used in this membrane.

—Wei Long Soon, first author

In the study, feather keratin is first isolated from an alkaline extract of chicken feathers. This keratin is heated and converted into protein amyloid fibrils, rope-like nanostructures made of tightly wound proteins. These nanofibrils are then further processed into membranes and treated in acid, where they undergo a chemical reaction that allows them to conduct protons.

The large amount of industrial chicken feather waste produced by the poultry industry also means that the membrane manufactured in the laboratory could be up to three times cheaper than conventional membranes to produce. The researchers say it takes 100g of feathers to make 1 square meter of membrane.

The researchers' next step will be to investigate how stable and durable their keratin membrane is and to improve it. The research team has already filed a joint patent for the membrane and is now looking to partner with investors or companies to develop the technology further and bring it to market.

Resources

- Wei Long Soon, Mohammad Peydayesh, Tym de Wild, Felix Donat, Rinku Saran, Christoph R. Müller, Lorenz Gubler, Raffaele Mezzenga, and Ali Miserez (2023) "Renewable Energy from Livestock Waste Valorization: Amyloid-Based Feather Keratin Fuel Cells" *ACS Applied Materials & Interfaces* 15 (40), 47049-47057 doi: 10.1021/acsami.3c10218

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