Polymer Membrane Fuel Cell Innovation & Patent Review

AI-supported Product Development Decision Making for the Fuel Cells Community

b-science.net is offering a popular information service to facilitate product development decisions in the Li-ion battery community with the help of a supervised AI approach, which leads to an improved chance of successful product launches. We would like to offer this service also to the fuel cells community.

Our AI approach permits for the identification of patent applications with high commercial relevance, which allows for plotting of key technical decisions (decision trees) and processes employed by various players. We also provide inspirations for novel and under-explored product development approaches and benchmarking data.

Our service facilitates the successful launch of new products and is currently relied upon by industrial battery R&D / product management teams, academic research groups and investors based in America, Asia and Europe.

At this time, we prepare triweekly patent updates in the category:

- **Proton-exchange Membrane and Anion-exchange Membrane Fuel Cells (PEMFC / AEMFC) – Electrochemically Active Materials**

This prospectus describes the prospective scope of our offering, preparation of which will start upon receiving sufficient subscriber interest. A quote can be requested here.

Background

Hydrogen has been chosen as a major part of the toolkit required to meet the NetZero decarbonisation goals set as part of the obligations in the Paris Agreement to avoid a greater than 1.5 °C global temperature rise. As a result, innovation for fuel cells and electrolysers has seen exponential growth in the last decade. However, there are many hurdles to overcome, in particular for polymer membrane based technologies, i.e. polymer electrolyte membrane (PEM) and anion exchange membrane (AEM).

The forthcoming review discusses divergent product development decisions taken by key fuel cell industry players.

Scope, Methodology & Visualisation Techniques

Scope

The review will cover PEM based technology for fuel cells. In addition, anion AEM will be covered as a secondary topic. Key areas to be covered will be:

- membrane electrolytes, including the backbone polymer technology, catalyst types and coating methods
- gas diffusion electrodes (GDE), including the gas diffusion layers (GDL), hydrophobic layers and catalysts
- bipolar plate technologies

The structure of this report will be based on the following chapters and content:

- **Executive Summary:** a top line summary with key points and conclusions from each of the chapters contained within the report.
- **Introduction:** an overview of the market needs and technology environment for fuel cells and the challenges faced by the industry to move to cost-efficient commercial technologies at scale, based on which we propose a technology adoption framework.
- **Decision Trees for PEM and AEM Technologies:** decision trees set out the product development approaches described in patents for a set number of developers. Topics covered will include catalyst technology, polymer development.
- **Key Developers of PEM and AEM Technologies:** technology & patent reviews for ≥35 key companies in the areas of catalyst coated membranes, gas diffusion layers and electrodes, polymer electrolyte developments, bipolar plate design.
- **Deep Dives on PEM and AEM Technologies:** based on subscriber input, key challenges will be further explored with the ambition of providing inspirations for novel inventions connected to KPIs.
- **Strategic Summary:** This chapter draws together the findings from the different analyses in the review and views these in terms of the progress the industry is making to meeting its technology goals. Key strengths and gaps in the innovation landscape will be identified and discussed with a view to inspiring product development teams and to providing a guide to potentially fruitful areas for their future projects.

The full proposed table of contents (TOC) is appended to this prospectus.

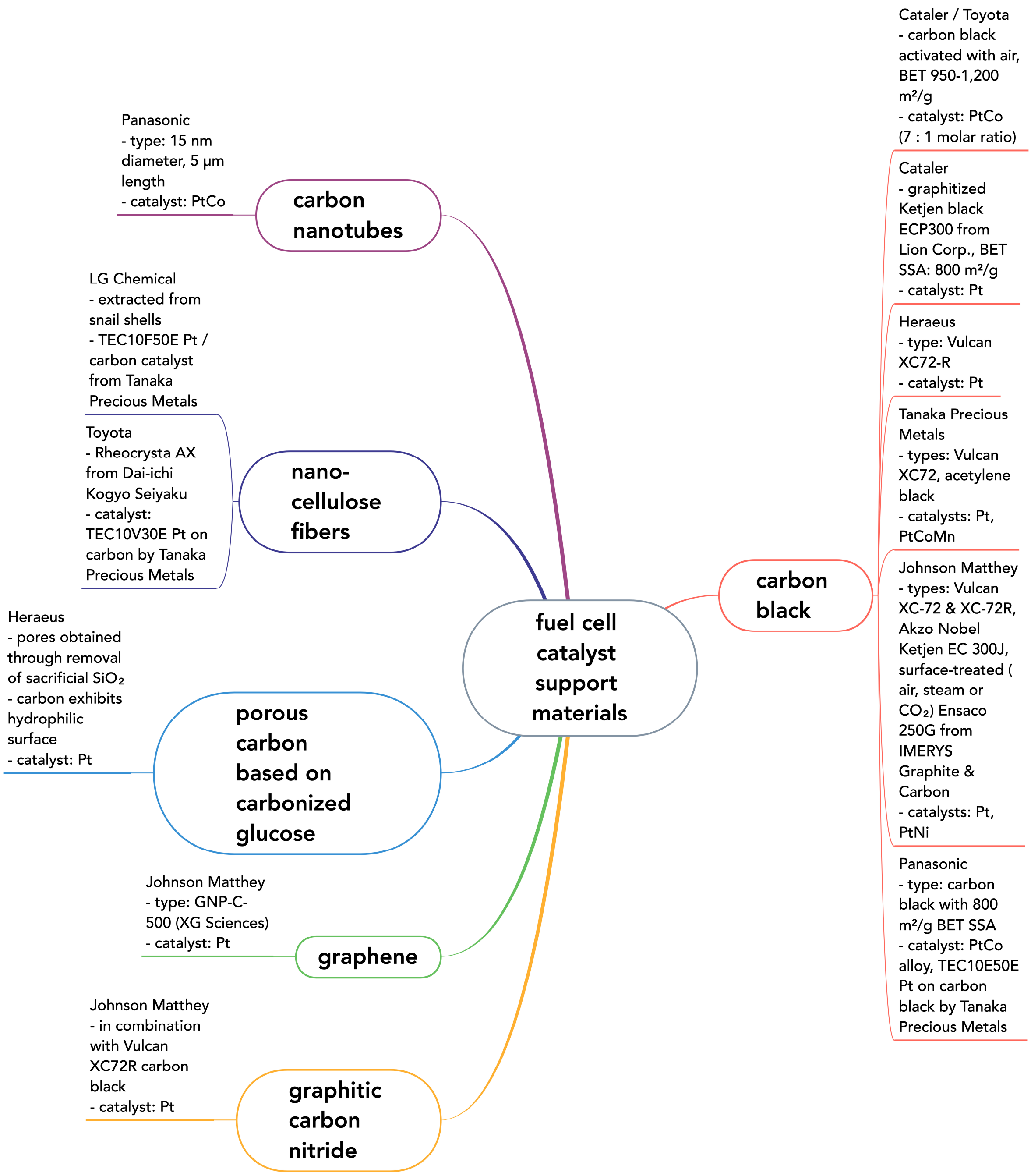
The patent information source for this review and related content is the European Patent Office (EPO), which covers patent filings from more than 100 patent offices around the world. The b-science.net database contains patents relating to fuel cells dating back to 1980, but will focus on patent families published since 2021 (earliest document in patent family) in order to reflect the most current state of the art.

AI-based Methodology for Identification of Commercially Relevant Patents

b-science.net has developed a supervised AI methodology to assess the commercial relevance of patents, combined with an automatic translation framework that makes sure non-English patents are also identified. We focus on patent families by commercial / private companies.

Product Development Decision Trees

Figure 1: technical decision tree – fuel cell catalyst support materials (tentative version)



Product development decision trees visualise how key commercial players take divergent decisions towards launching novel products into the market, which frequently constitutes the key entrepreneurial risk that will determine the competitive position of a company 2-10 years down the road. In Figure 1, a tentative example of a decision tree is given on fuel cell catalyst support materials. Further prospective decision trees:

- Polymer electrolyte membrane fuel cell (PEMFC) catalyst development
- PEM bipolar plate composition and construction
- PEM membrane architecture development
- PEM gas diffusion layer (GDL) development
- Anion exchange membrane (AEM) catalyst development
- AEM polymer architecture development

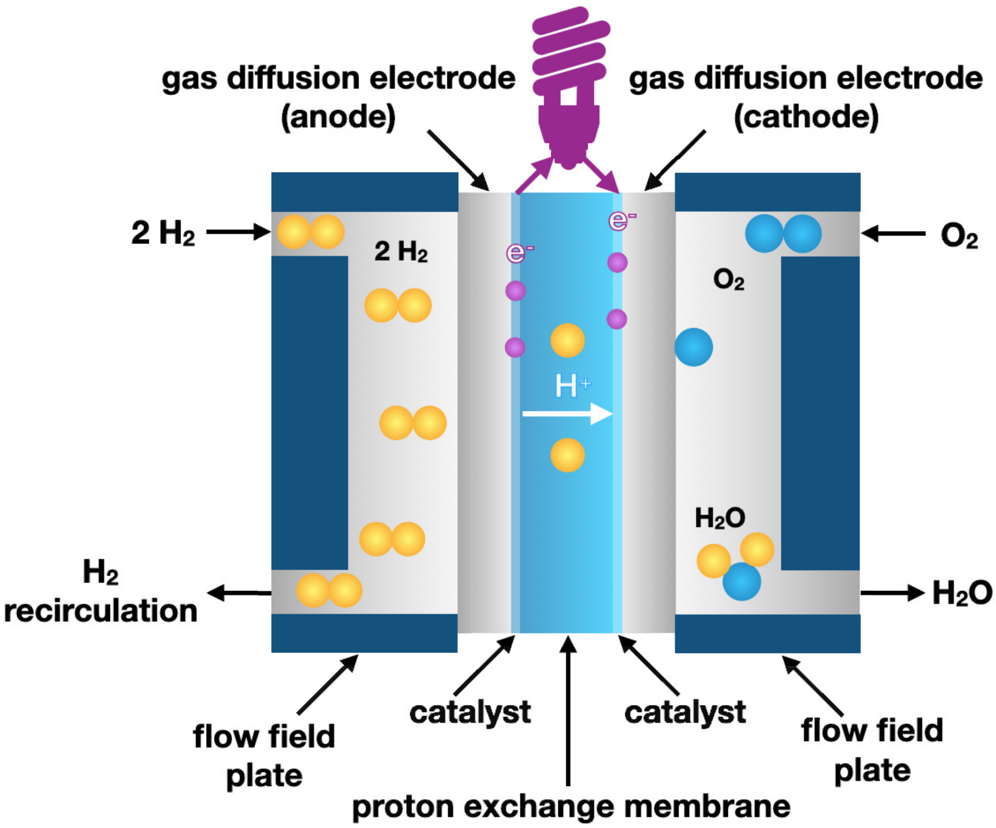
Comprehension of the state of the art & corresponding decision trees allows for identification of promising future product development directions hat have not yet been explored, and for differentiation versus existing players.

Process Diagrams

An example of a process diagram generated based on the analysis of a patent portfolio related to membrane fuel cells is shown below in the chapter excerpt on Heraeus.

Technology Overview

Figure 2: Basic Schematic of a PEM Fuel Cell



Fuel cells are all made up of a cathode, an anode, and a separator / electrolyte layer. Each type of fuel cell looks quite different. If the separator / electrolyte layer consists of a proton exchange membrane (PEM, Figure 2), the electrode catalysts are coated onto either side of a solid membrane electrolyte made of a specially designed polymeric material called perfluorosulfonic acid (PFSA). The industry state of the art uses commercial Nafion PFSA membranes from Chemours. Conventional large scale production methods of depositing the catalyst include spraying, screen printing, knife coating, slot die, and microgravure coating.

The state of the electrode catalysts is clearly at the heart of the fuel cell operation (Figure 2). However the remainder of the cell also needs to be considered, in particular the gas diffusion layers (GDL), and bipolar plates.

Key Performance Targets

Product development goals for fuel cells have been shaped by the key performance indicator (KPI) targets set for instance by the United States Department of Energy (US DOE) and the International Renewable Energy Agency (IRENA). Typical parameters relate to cost, efficiency, lifetime of the cell as well as operating parameters – e.g. pressure, ramp time, current density, area footprint and use of critical raw materials (CRM). The KPI targets are set at different levels along the value chain, i.e. one set for catalysts, GDL and separately for the entire stack and the end-use application, e.g. fuel cell vehicles, trains, buses etc. It is helpful to consider the innovations described in patents in terms of their ability to contribute to meeting KPI targets, e.g. GDL thickness, precious metals loadings, efficiencies, current densities, etc. This approach will be employed in particular as part of the analysis in the deep dives section, e.g. for “meeting the gigawatt scale challenge”.

Internal product development progress can be benchmarked against competitors with the help of our review.

Key Developers

Key Developers Overview

The section on key developers will cover each of the ≥35 companies that make the final selection based on early subscriber feedback. For each company, the patent literature is reviewed and the possible composition of future polymer membrane fuel cells will be highlighted. The unique capability of each of the companies and potential roadblocks will be outlined.

Example – Extract for Heraeus – Germany

Organisation profile

Heraeus (https://www.heraeus.com, catalyst product pages – fuel cells, electrolysers), based in Hanau (Germany) provides precious metal and specialty metal products to the energy, electronics, environmental, health, mobility and industrial sectors. It provides catalyst powders for PEM electrodes.

Innovation profile

5 new patent families by Heraeus related to 'PEMFC / AEMFC – electrochemically active materials' have been published between 2021 and 2024-05-16.

These patent families are largely consistent with the Heraeus PEM fuel cells catalyst portfolio, which accommodate various requirements in terms of catalytic activity, stability, and cell reversal tolerance.

Key inventions towards improved catalyst activity:

- use of carbon or TiO_2 support materials with controlled BET surface area and pore size distribution.
- oxygen plasma treatment of carbon support materials that have been produced in-house or were sourced externally (Vulkan carbon black). Favourable dispersion of the carbon support in water is likely of key importance towards achieving a homogeneous catalyst distribution on its surface.
- careful adjustment of pH and other process conditions during catalyst precursor deposition and reduction.
- careful optimisation of heat treatment after depositing the catalyst on the support material, and after depositing the supported catalyst on the polymer membrane.

Figure 3 illustrates how Heraeus' IP covers substantial vertical integration, including preparation of the carbon catalyst support, metal precursors and preparation of catalyst-coated membranes (CCM).

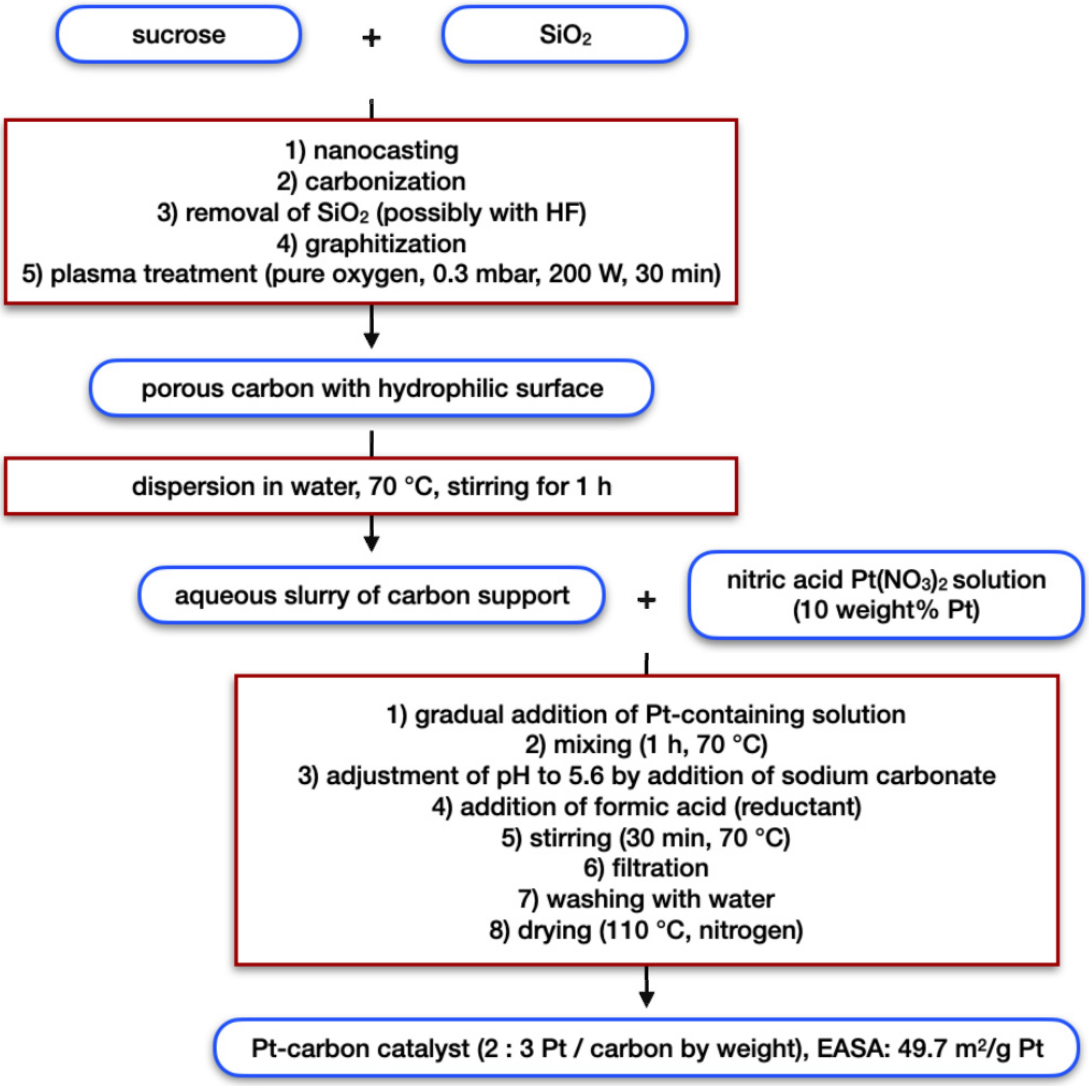
Unique capability: clear focus of R&D resources on catalysts, while controlling all process steps that can affect performance and costs.

Potential roadblock: none identified.

Possible composition of future catalyst products

- FC: Pt on plasma-treated porous carbon (produced in-house, Figure 4) or plasma-treated carbon black (e.g. Vulcan XC72-R by Cabot).

Figure 3: projected manufacturing process for Heraeus (possibly for PEM FC catalyst H2-FC-30Pt-C60T)

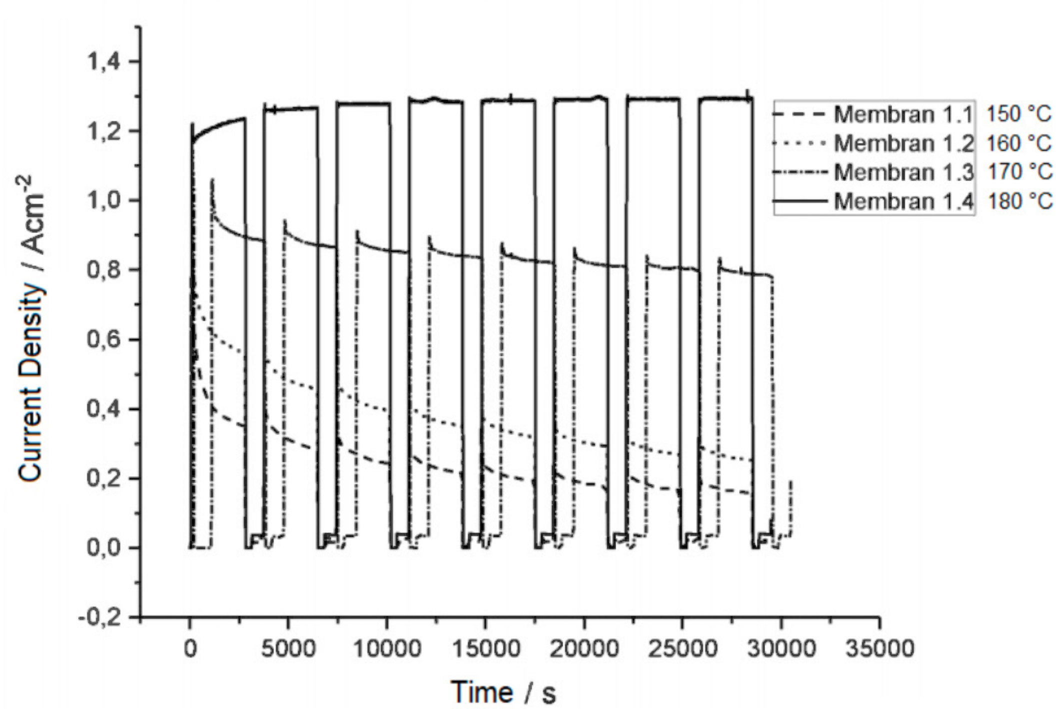


Examples from the patent portfolio

A) PEM Catalysts

- METHOD FOR PRODUCING A CATALYST-COATED MEMBRANE (Google): an aqueous solution was prepared based on an ionomer of tetrafluoroethylene and a perfluorinated vinyl ether containing sulfonic acid groups (MX820.15, Gore, 4.05 mass%) along with a catalyst deposited on a carbon support (7.19 mass%). The CCM was heat treated at different temperatures (see Figure 4 below).
  The thermal treatments lead to a significant increase in performance in humid operating conditions and to a stabilisation of performance that does not only start after several cycles, but very early. A so-called “pre-conditioning” or “break-in” step for activating the membrane can therefore be omitted.

Figure 4: electrochemical performance of CCM upon heat treatment for 4 min at 150-180 °C



- HIGH STABILITY CATALYST FOR AN ELECTROCHEMICAL CELL (Google): a graphitized porous carbon material was produced via nanocasting by impregnating a porous SiO_2 template with sucrose (Figure 4), followed by carbonization, removal of SiO_2 and graphitization of the carbonized material. This material was treated with plasma (pure oxygen, 0.3 mbar, 200 W, 30 min). The resulting material was suspended in water at 70 °C. After 1 h, nitric acid platinum nitrate solution (10 mass% Pt) was gradually added (2 : 3 Pt / carbon support by weight) and further mixed for 1 h. The pH was then adjusted to 5.6 by adding sodium carbonate, followed by the addition of formic acid as reducing agent. After 30 min, the Pt-carbon catalyst was filtered off, washed with water and dried (110 °C, nitrogen). This material exhibits an electrochemically active surface area (EASA) of 49.7 m^2/g Pt.

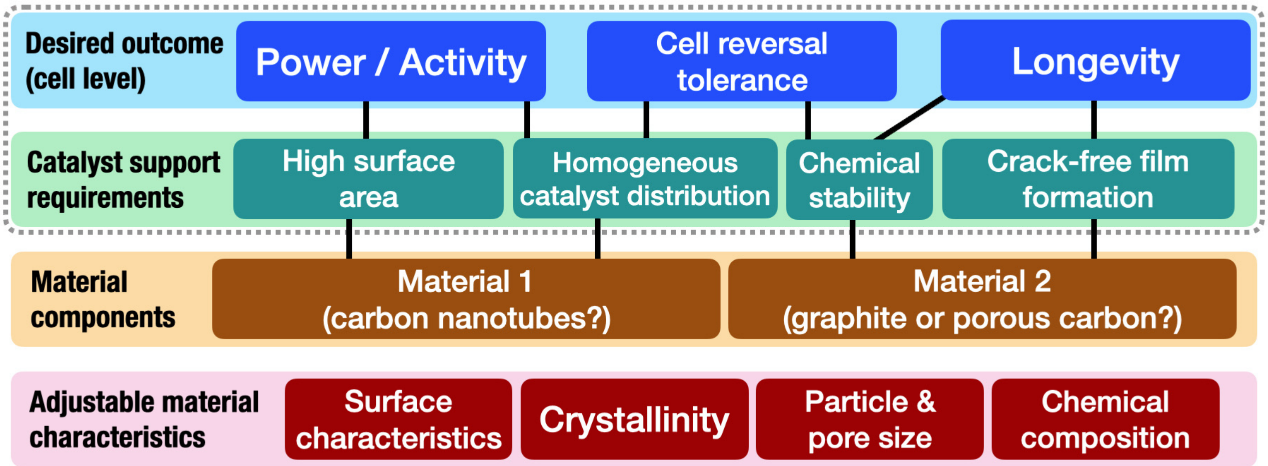
  This work illustrates how a plasma treatment of the carbon support material leads to a substantial increase in the EASA, which allows for a favourable balance between current density and longevity. This EASA value and product features are consistent with Heraeus PEM FC catalyst H2-FC-30Pt-C60T.
- METHOD FOR PRODUCING SUPPORTED PLATINUM PARTICLES (Google): in a similar procedure as in the prior patent, Pt was deposited on conductive carbon black (Vulcan XC72-R by Cabot, BET specific surface area: 250 m^2/g) with H_2PtCl_6 in water at 70 °C, followed by the addition of sodium carbonate to adjust the pH value to 5.1 and reduction with formic acid. This material exhibits an EASA of 65 m^2/g Pt.

  This work illustrates how the EASA was further increased by employing a conductive carbon black support material. Whether or not the increased BET specific surface area as compared to the carbon support in the prior patent (ca. 240 m^2/g vs. ca. 60 m^2/g) can be tolerated depends on stability and cell reversal tolerance requirements. This EASA and product features are consistent with Heraeus PEM FC catalyst H2-FC-40Pt-C240.

Deep Dives

Deep dive chapters provide inspirations for novel inventions by connecting multiple insights from the patent literature in terms of how they apply to solving a specific technical problem. An example is included below (Figure 5).

Figure 5: example of inspiration for novel inventions – CNT-coated graphites as potential catalyst support materials



- In the battery patent literature, CNT coatings are employed on active materials.
- A graphite or porous carbon core might facilitate crack-free film formation.

Deep dive chapters will be produced according to subscriber input, examples:

- Cost reduction methods for PEMFC catalyst coated membranes (CCM)
- Development of novel gas diffusion electrodes (GDE)
- Routes to higher current densities
- Developing improved polymers for anion exchange membranes (AEM)
- Meeting the gigawatt scale challenge

About the Author

Dr Pirmin Ulmann

Pirmin Ulmann obtained a diploma in chemistry from ETH Zurich (Switzerland) in 2004 and a PhD from Northwestern University (USA) in 2009. Thereafter, he was a JSPS Foreign Fellow in an ERATO academic-industrial organic solar cell project at the University of Tokyo (Japan). From 2010 to 2016, while working at IMERYS Graphite & Carbon in Switzerland, he was a co-inventor of 7 patent families related to lithium-ion batteries and was involved in a collaboration on GDLs for fuel cells. He was also in charge of a collaboration with the Paul Scherrer Institute, evaluated outside technologies for corporate strategy, and made customer visits to battery & fuel cell component manufacturers in East Asia, North America & Europe. He holds the credential

Stanford Certified Project Manager (SCPM) and has co-authored scientific articles with more than 1,900 citations.

b-science.net LLC operates as a distributed team in Switzerland, and has premium subscribers in the vertical Li-ion battery technology in key technology clusters across America, Asia and Europe. The company facilitates technical decision making with its unique AI-based approach. Subscribers enjoy a superior understanding of the global state of the art in a time-efficient manner and get a head start towards successfully launching products. Gradually, further energy storage verticals are being pursued, starting with fuel cells.

Proposed Table of Contents

- Hyzon Motors - USA
- Jiping New Energy - China
- Johnson Matthey - UK
- Kolon - South Korea
- LG Chemical / LG Energy Solution / LG Fuel Cell Systems - South Korea
- Panasonic - Japan
- Plug Power - USA
- Sinocat - China
- SinoHyKey - China
- Tanaka Precious Metals - Japan
- Terralix - South Kora
- Toppan - Japan
- Toray - Japan
- Toyota / Cataler - Japan
- Umicore - Belgium
- Vinatech - South Korea
- Volkswagen / Audi - Germany
- WeiChai - China
- Wuhan WUT Hypower - China

Deep Dives

- Cost Reduction Methods for PEMFC Catalyst Coated Membranes (CCM)
- Development of Novel Gas Diffusion Electrodes (GDE)
- Routes to Higher Current Densities
- Developing Improved Polymers for Anion Exchange Membranes (AEM)
- Meeting the Gigawatt Scale Challenge

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