Fuel Cell Testing

Degradation of Fuel Cells and its Impact on Fuel Cell Applications

Fuel cells are expected to play a major role in the future energy supply, especially polymer electrolyte membrane fuel cells could become an integral part in future cars. Reduction of degradation of fuel cell performance while keeping fuel cell cost under control is the key for an introduction into mass markets.

Dr. Andreas Pfrang, Scientist in the Cleaner Energy Unit of the Institute for Energy

The Directorate General Joint Research Center is the European Commission's in-house research organization with seven specialized Institutes which provide impartial scientific and technical know-how in areas such as food safety, public security, antifraud, health, chemical products and last but not least also energy to support EU policies.

Institute for Energy of the Joint Research Center

The Institute for Energy has competences and facilities to support the increasing policy needs in the energy area from hydrogen to biomass, and nuclear safety to carbon capture and storage. The Institute focuses on assessing the impact of and overcoming the barriers to the deployment of safer, cleaner and more efficient energy technologies, non-nuclear as well as nuclear. Progress in energy technologies has indeed been globally recognized as indispensable for meeting the world's future energy needs.

Fuel Cells as Key Element in a Hydrogen World

Fuel cells are expected to play a major role in the future energy supply and in the long-term could partly substitute current power generation technologies in all end use sectors. Fuel cells can combine high conversion efficiency with sustainability, especially when hydrogen produced from renewable energy sources is used as fuel. But even in combination with conventional fuels such as natural gas, they have, in the medium and long-term, a high potential for a large reductions of CO_2 emissions and energy savings.

On a European level, the Hydrogen & Fuel Cell Technology Platform (HFP) was established in 2004. Its main goal is to facilitate and accelerate the development and deployment of cost-competitive, world class European hydrogen and fuel cell based energy systems and component technologies for applications in transport, stationary and portable power [1].

With the 7th Framework Program, the European Commission has introduced the concept of Joint Technology Initiatives (JTI) as a new way of realizing public-private partnerships for performing research and development in areas earmarked as critical for EU interest at European level. In 2008, the Fuel Cell & Hydrogen Joint Technology Initiative (FCH JTI) was created to facilitate the commercial deployment of fuel cells and fuel cell technologies in a strong industry-led public private partnership. The European Commission will fund € 470 million from the 7th Framework Program for a period of six years which will be at least matched by industry contributions.

The Institute for Energy of the Joint Research Centre is currently enhancing its existent testing capabilities for fuel cell systems and will act as reference fuel cell testing facility within the Fuel Cell & Hydrogen Joint Technology Initiative.

Operating Principle of Fuel Cells

Fuel cells convert chemical energy in electrical energy and heat by consuming typically hydrogen and oxygen and producing water. At the anode (left hand side) the hydrogen is reduced, whereas at the cathode (right hand side) the oxygen is oxidized.

The protons produced on the anode side have to move through the proton-conducting (but not electron-conducting) membrane to the cathode side. Electrons will be transported via the electrical load outside the fuel cell to the cathode side. Overall, this results in the production of water as 'waste'.

$$2\,H_2 + O_2 \rightarrow 2\,H_2O$$

For some types of fuel cells hydrogen can be replaced by other hydrogen-containing fuels as e.g. methanol. On the cathode side, instead of using pure oxygen also normal air can be used and supply the oxygen necessary for operation of the fuel cell.

Despite the simple basic principle of fuel cells, the operation under real conditions is far from understood in detail and some challenging technological issues, i.e. the optimization of catalyst and gas diffusion layer, have to be solved.

Fuel Cell Degradation

Besides cost reduction, durability is the most important property of fuel cell systems that has to be improved for a successful introduction of fuel cells into markets. The typical lifetime requirements vary with the type of application.

Polymer Electrolyte Membrane Fuel Cells

Polymer electrolyte membrane (PEM) fuel cells are promising candidates for mobile applications e.g. in cars due to the relatively short start-up times and the high flexibility of the delivered power. On the other hand, PEM fuel cells require pure hydrogen as fuel and noble metals as catalyst which results in relatively high cost. The lifetime requirements for mobile applications can be achieved for PEM fuel cells at high loadings of noble metals and under laboratory conditions. At lower noble metal loadings – which is preferable in terms of cost – and under real-world conditions – which includes load cycling, start-stop cycles, varying humidification, fuel starvation, temperatures above 90°C and mechanical vibration – fuel cell degradation is still an important issue.

Typical degradations mechanisms include chemical degradation or mechanical failure of the membrane, loss of electrochemically active surface area (ECSA) of the catalyst and chemical and mechanical degradation of the gas diffusion layer. For a review of the relevant degradation mechanisms in PEM fuel cells see [2, 3].

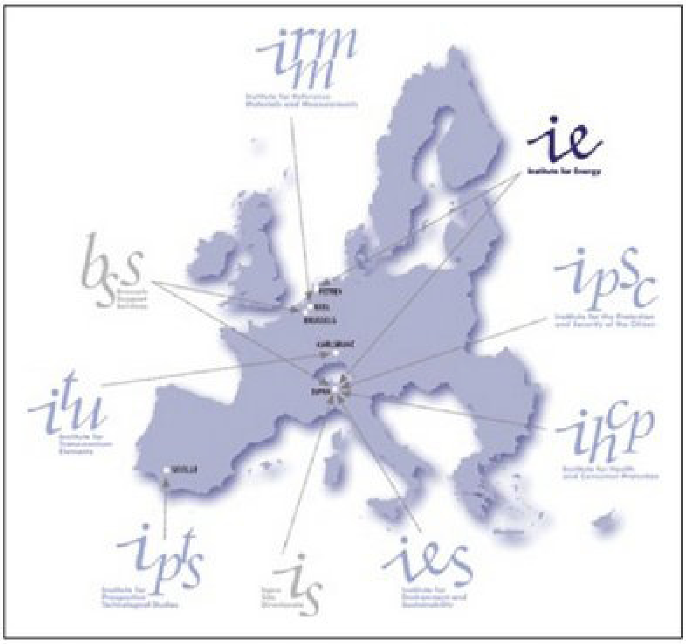

Fig. 1: The seven institutes of the Joint Research Centre of the European Commission

Depending on the mode of operation, different degradation mechanisms can be dominant. Under ideal operating conditions the loss of hydrophobicity of the gas diffusion layer dominates, while for potential cycling the Pt particle growth at the cathode side plays an important role.

While X-ray diffraction allows the fast determination of the average particle size, scanning electron microscopy and especially transmission electron microscopy allow the direct visualization of catalyst particles. These images not only allow to get an impression of the homogeneity of the particle distribution but also of the degree of agglomeration of smaller particles. In the SEM image a non-homogeneous distribution of the catalyst particles is clearly visible while the TEM image shows a tendency towards particle agglomeration.

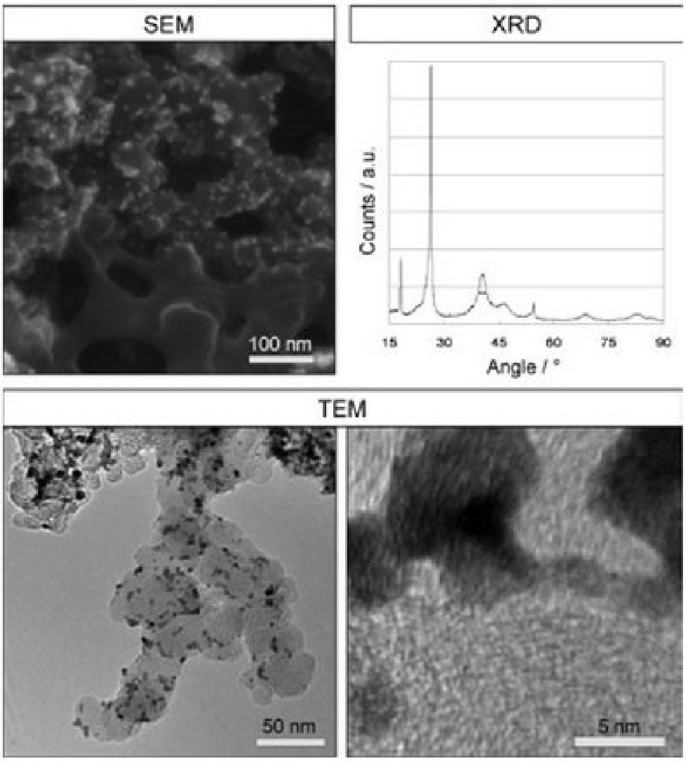

Fig. 3: Size determination and imaging of catalyst particles by X-ray diffraction (XRD), scanning electron microscopy (SEM) and transmission electron microscopy (TEM)

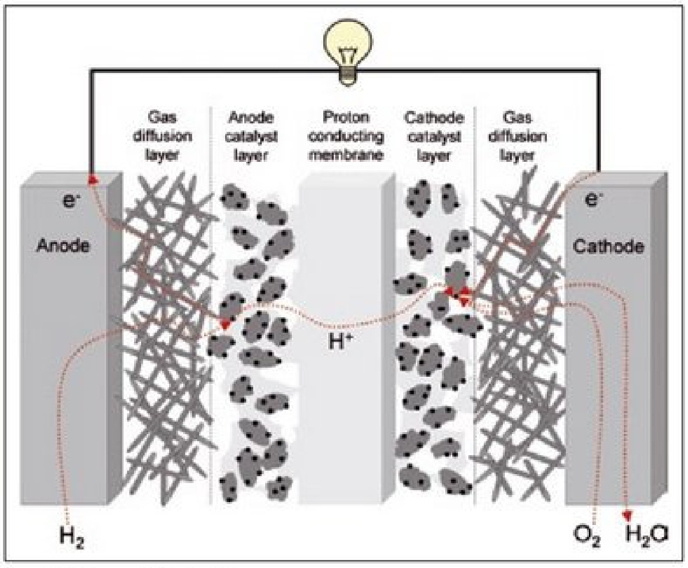

Fig. 2: Scheme of fuel cell

Challenges ahead

On one hand, it seems that membrane degradation in PEM fuel cells can be overcome by chemical modifications and reinforcements without seriously effecting cost. On the other hand, the improvement of electrode durability and especially of the water-removing capacity of the gas diffusion layers still requires much effort.

While degradation – besides other issues like e.g. the necessary installation of a hydrogen infrastructure – currently still hinders the introduction of fuel cells into mass markets, the PEM fuel cell is the most promising candidate for mobile applications. It could become an integral part of any car in near future, allow a reduction of emissions on global scale and – by using renewable energy sources for hydrogen production – make individual transport independent of fossil fuels.

References

[1] European Hydrogen and Fuel Cell Platform: Achievements and Perspectives 2006, Brussels, Belgium, 2006

[2] de Bruijn F.A. *et al.*: Fuel Cells 8, 3–22 (2008)

[3] Wu J. *et al.*: Journal of Power Sources 184, 104–119 (2008)

Contact:

Dr. Andreas Pfrang
European Commission
DG Joint Research Centre
Institute for Energy
Cleaner Energy Unit
Petten, The Netherlands
Tel.: +31 224 565047
Fax: +31 224 565625
andreas.pfrang@ec.europa.eu
www.jrc.nl

Table 1: Typical lifetime requirements for fuel cells

Type of applications	Operating time	Max. performance loss
Stationary	40,000–80,000 hours within 10 years	0.13–0.25 % per year
Mobile	5,000 hours within 10 years	2 % per year
Portable	1,000–5,000 hours within 1–5 years	2–10 % per year