Technology Collaboration Programme on Advanced Fuel Cells

International Energy Agency

Annex 31– Polymer Electrolyte Fuel Cells

Introduction of participants

Danish Power Systems participation in the Annex 31 is funded by the Danish Energy Agency (EUDP).

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About IEA's Technology Collaboration Programme on Advanced Fuel Cells (AFC TCP)

Created in 1990, the activities of the AFC TCP are coordinated by the IEA's Working Party on Energy End-Use Technologies (EUWP). The AFC TCP currently has 13 member countries: Austria, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Mexico, Sweden and USA as well as two organizational members (sponsors): VTT Technical Research Center of Finland and CNH2 Hydrogen National Center Spain. Our aim is to advance the state of understanding of all members in the field of advanced fuel cells.
The focus of our work is the eight active Annexes (groups): members of which meet regularly to share technology and policy developments in their countries, companies and research institutions, for the benefit of everyone involved:

- Fuel Cells for Transportation
- Fuel Cells for Stationary Applications
- Fuel Cells for Portable Applications
- Polymer Electrolyte Fuel Cells
- Solid Oxide Fuel Cells
- Systems Analysis
- Modelling of Fuel Cell Systems
- Electrolysis

The Technology Collaboration Programme on Advanced Fuel Cells is overseen by the Executive Committee, who meet twice a year to oversee the collaboration, to share the results generated within the Annexes, as well as to share and learn about developments in all member countries and companies.

This booklet introduces the participants in Annex 31 Polymer Electrolyte Fuel Cells.

More information about annex 31 can be found on www.ieafuelcell.com/annexdescriptions.php

About Annex 31 - Polymer Electrolyte Fuel Cells

Annex 31 is a research and development oriented Annex with the objective to contribute to the identification and development of techniques and materials to reduce the cost and improve the performance and durability of polymer electrolyte fuel cells (PEFCs), direct fuel polymer electrolyte fuel cells (DF-PEFCs), and corresponding fuel cell systems.

Major applications are in the automotive, portable power, auxiliary power (APUs), stationary power (residential, commercial), and combined heat-and-power (CHP) sectors.

The R&D activities in Annex 31 cover all aspects of PEFCs and DF-PEFCs, from individual component materials to whole stacks and systems. These activities are divided into three major subtasks:

1. New stack materials
2. System, component, and balance-of-plant
3. DF-PEFCs

The first subtask comprises research in the new stacks materials that aims to develop improved, durable, lower-cost polymer electrolyte membranes, electrode catalysts and structures, catalyst supports, membrane electrode assemblies, bipolar plates, and other stack materials and designs for PEFCs.

The second subtask addresses stack, system, and balance-of-plant issues in PEFC systems.

The third subtask focuses on the research and development of DF-PEFC technology, including systems using direct methanol fuel cells, direct ethanol fuel cell, and direct borohydride fuel cells.

Subtask 1: New stack Materials

- Membrane materials (new functional groups, cheaper membranes, composite membranes, high-temperature membranes, low-humidity proton conductors)
- Electrode catalysts (lower Pt loadings, CO tolerance, lower-cost higher-performance structures, non-Pt materials)
- Bipolar plates (new materials, improved manufacturability, lower costs)
- Cells and stack assemblies (higher power density, low degradation, light-weight, lower cost, continuous fabrication techniques, >100 ºC operating temperature)

Subtask 2: System, Component, and Balance-of-Plant Issues

End-user aspects (contaminants, humidification and thermal management, operating environments and duty cycles, rapid-start, durability, freeze-thaw cycling, and characterization of materials and components). System-level issues (systems analysis, stack/system hardware designs, fuel processing, and prototypes)

Subtask 3: Direct Fuel Polymer Electrolyte Fuel Cells

Cell materials (anode and cathode catalysts, reduced precious metal loadings, MEA designs and processes for reduced fuel crossover, fuel impermeable membranes, anion-conducting membranes). Operating conditions (pressure, temperature, vapor versus liquid feed, fuel concentration, etc.). Stack and system designs and analyses (modeling, high-temperature operation, high power densities, high efficiencies, performance over duty cycles, etc.)

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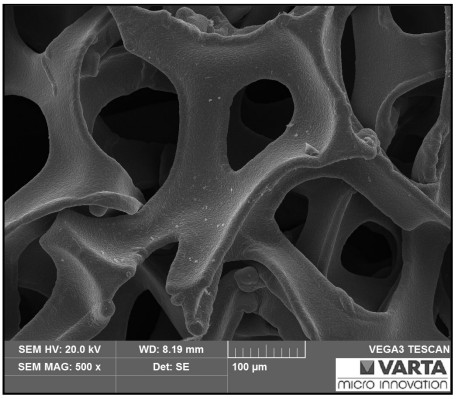
Graz University of Technology

The Fuel Cell and Hydrogen Systems Group of Graz University of Technology at the Institute of Chemical Engineering and Environmental Technology focuses on the development of low temperature fuel cells. The research projects include testing of materials, investigation of degradation, development of monitoring techniques and lifetime tests.

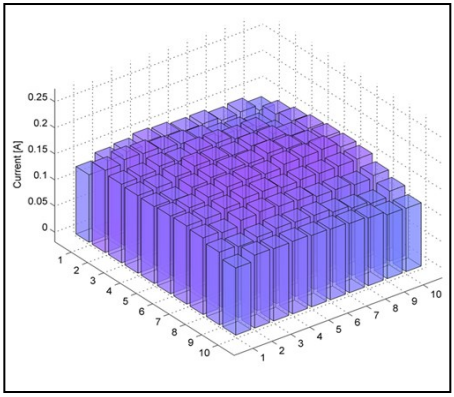
With state-of-the-art material and equipment, phenomena such as membrane degradation, platinum agglomeration and catalyst support oxidation are investigated on single cell and short stack scale by in-situ and ex-situ characterization methods. Electrochemical impedance measurements and analyses of the total harmonic distortion are applied in order to identify local degradation and monitor the operating conditions of the complete system.

To improve the activity and durability of fuel cell catalysts, alloying and functionalization of support materials are investigated. These activities comprise also high-temperature polymer electrolyte fuel cells, alkaline fuel cells, direct fuel cells using borohydride or ethanol as energy carrier and zinc-air cells.

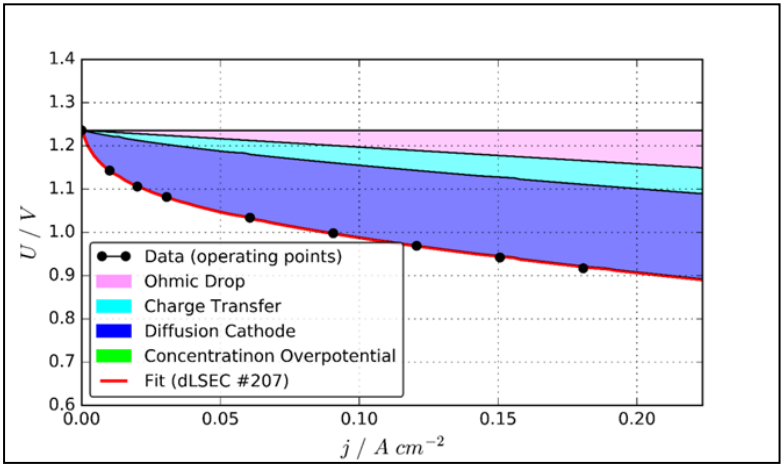
The research activities also cover the development of innovative methods for sustainable hydrogen production and energy storage. An alternative method for the production of ultra-pure, pressurized hydrogen via a chemical looping hydrogen process was developed and materials for efficient storage of hydrogen are investigated to fit the needs for a future hydrogen and fuel cells economy.



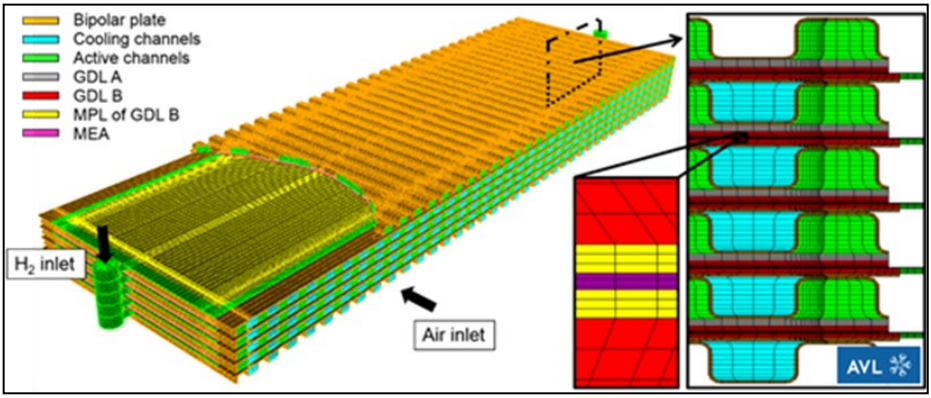
Catalyst support for fuel cell electrodes.



Current and temperature distribution of a single cell.



Fuel cell performance modelled by an innovative equivalent circuit approach.



Modelling and simulation.

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Dalian Institute of Chemical Physics, Chinese Academy of Sciences

DICP is an internationally well connected institution. Today, our faculties are now playing active roles in about 100 international academic communities, including council members of organizations, conference chairmen, members of academic committee, and editors of top S&T journals. In the past five years, nearly 2,000 foreign scientists have visited DICP and more than 1,000 of our staffs and students have gone abroad for international conferences and research collaborations.

Materials for Proton Exchange Membrane Fuel Cell (PEMFC) and Alkaline Anion Exchange Membrane Fuel Cell (AEMFC) have been developed in Dalian Institute of Chemical Physics (DCIP), i.e., alkaline exchange membranes (AEMs) for AEM fuel cells and Membrane Electrode Assemblies (MEAs) for PEM fuel cells and AEM fuel cells. The membranes and MEAs are available for fuel cell stacks.

The MEAs for PEMFCs are manufactured by electrostatic spraying. The power density of PEMFC stacks with the home-made MEAs is higher than 920mW/cm2 at rate output according to the Ministry of Science & Technology reports. Ordered MEAs with low Pt loading are under development. The membranes and MEAs for AEMFCs have already been used in 1 kW stacks without noble metal catalysts.


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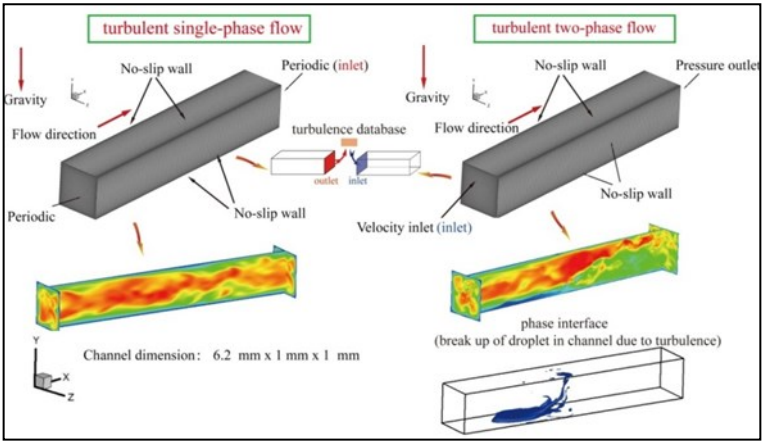
Tianjin University

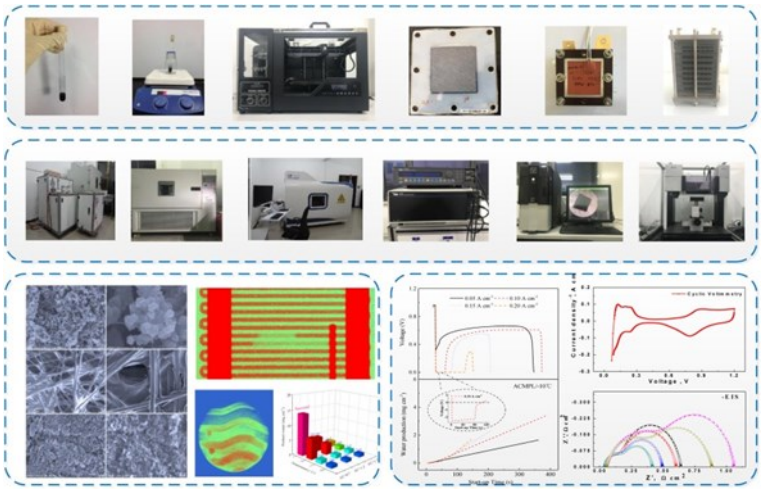
Tianjin University, founded in 1895 as Peiyang University, is the oldest institution of higher education in the modern history of China. The Electrochemical Thermophysics Laboratory of Tianjin University mainly focuses on water and thermal management of fuel cells under both normal and cold start operation conditions based on the knowledge of engineering thermophysics. The research approaches include developing mathematic models and conducting experiments.

A series of numerical and analytical models of fuel cell in different scales (from cell/stack scale to pore scale) and dimensions have been developed to investigate the gas and liquid two-phase flow, phase change, water freeze, electrochemical reaction, electrons and ions transport and heat transfer inside fuel cell. These modeling results are able to help researchers deeply understand the multi-physical processes in fuel cell and can be used in the fuel cell design and performance optimization.

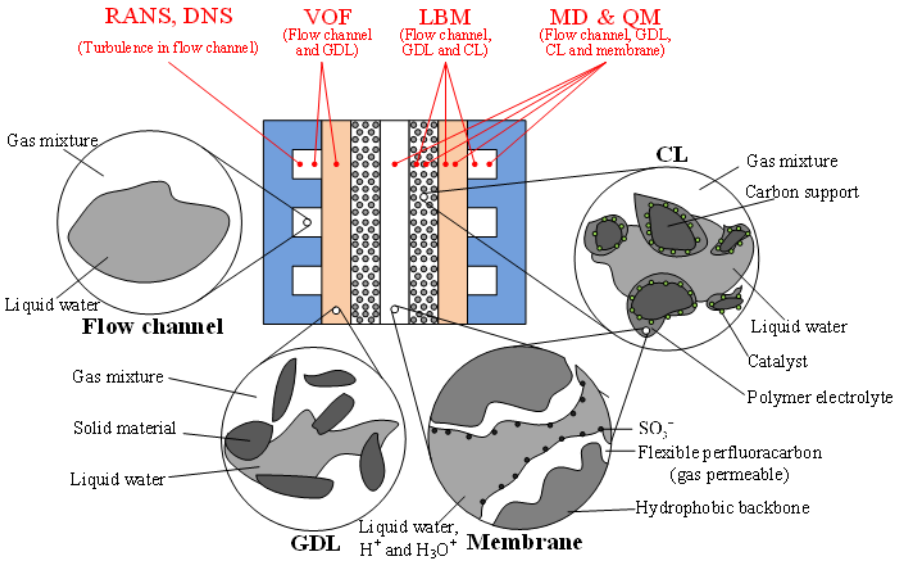
Experimental work have also been conducted in the Electrochemical Thermophysics Laboratory, including performance test, EIS, liquid dynamics visualization, water freeze, MEA (Membrane Electrode Assemblies) manufacture and so on.



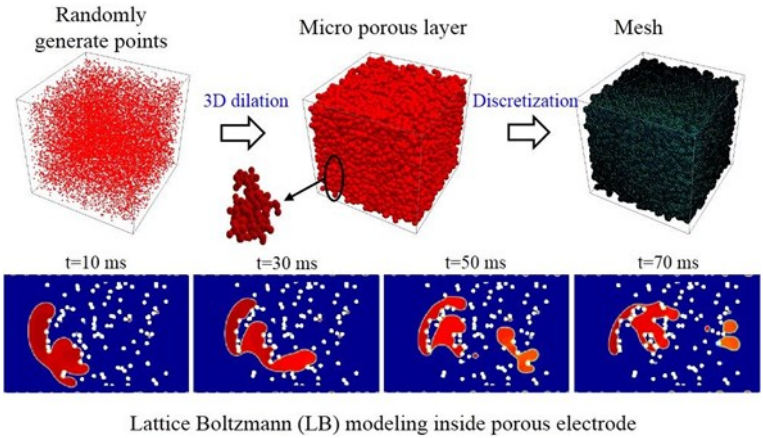
DNS+VOF modeling.



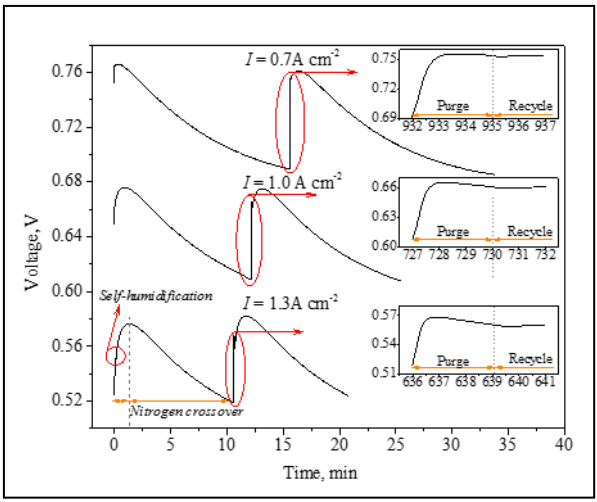
Experimental equipment.



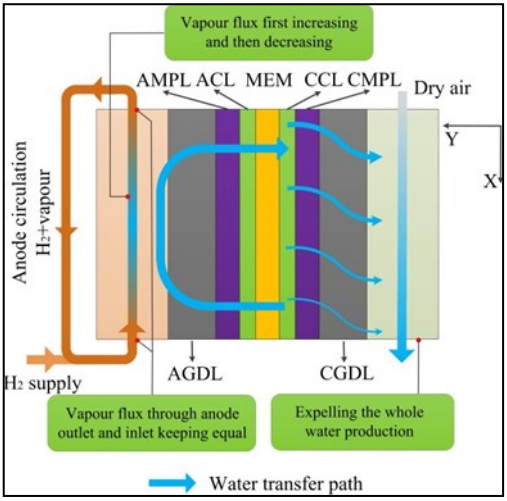
Schematics of various modelling methods for different cell components of PEMFC.



LB modeling.



Transient performance of PEMFC.



Water transfer path at anode circulation.

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Notes

Danish Power Systems

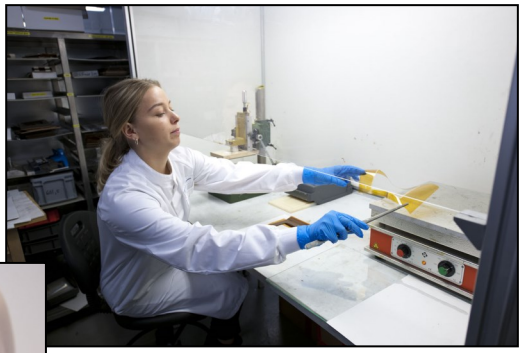
Danish Power Systems is developing and manufacturing Membrane Electrode Assemblies (MEAs) for high temperature PEM fuel cells. The MEAs are available in a number of standard sizes.

Danish Power Systems is actively engaging in several partnerships with leading universities and companies worldwide. This is an important factor for our leading innovation capacity, which is enabling us to deliver continues improvement of the Dapozol MEAs.

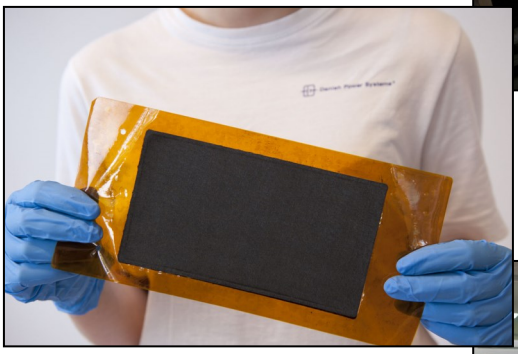
Danish Power Systems has established a production facility and has a number of strategic partnerships in order to bring us closer to the market and therefore understand the individual needs, demands, specifications and requirements of our customers. This facilitates our effort and belief in delivering state of the art and customized technology to the benefit of our customers.

Danish Power Systems has sales agents in Korea, China and India.

Part of Danish Power Systems' testing facilities.



Part of Danish Power Systems' production facilities Denmark.



Sample of 10x18 cm^2 MEA.

Synthesis of the PBI polymer.

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VTT Technical Research Centre of Finland Ltd

With world-class knowhow and constantly developing research facilities, our team provides reliable services and a strategic partnership for stack developers, Balance-of-Plant component developers as well as fuel cell and hydrogen system integrators. Our offering ranges from fuel cell component development and stack characterization to the design of complete systems.

Our research topics include also the quality of hydrogen fuel, that are studied with in-house built 2 kW miniature automotive PEMFC system. In addition to fuel cells, VTT's multi-technological expertise also covers power sources like batteries and ultracapacitors.

These are effectively combined to hybrid power trains, which are especially viable in vehicles. Stationary systems of fuel cell technologies have been successfully designed and demonstrated.

2 kW miniature automotive system, a unique hardware for contaminant studies in realistic conditions.

50 kW PEMFC system, run with by-product H_2 from sodium chlorate production, Äetsä, Finland.

Electric forklift installed with PEMFC triple-hybrid power source.

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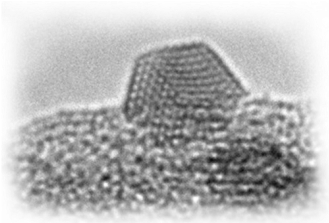
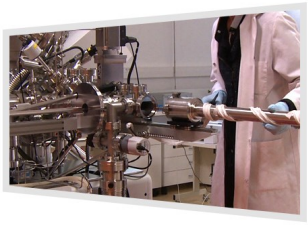
University of Poitiers
Institute of Environmental and Material Chemistry of Poitiers (IC2MP)

IC2MP) is a joint research laboratory (UMR 7285) between CNRS and University of Poitiers, directed by Dr. Sabine Petit. The main research work concern the process efficiency (catalysis, recycling, water treatment, high value-added molecules, etc.), the sustainable management of resources (waters, soils, carbon sources, minerals, wastes, etc.) and the integration of chemistry in future sector (bio-sourced materials, energy storage and conversion, etc.). IC2MP is actively engaging in several partnerships with leading universities and companies worldwide.

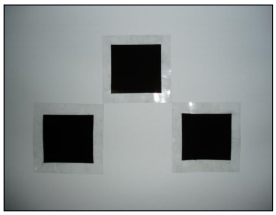
IC2MP has been involved in Fuel Cell development for more than 20 years and is internationally recognized for its expertise in the synthesis/ characterization and evaluation of electrochemical behavior of
nano electrocatalysis in terms of activity, selectivity, tolerance to environmental poison molecules and stability under fuel conditions. Due to these skills, IC2MP has participated and participate to numerous national, European and international projects and is highly involved in the CNRS research grouping HySPAC n° 3652 (Hydrogen, System and Fuel Cells).



Supported catalytic nanoparticles.



Physicochemical characterizations.



Membrane Electrodes Assemblies.

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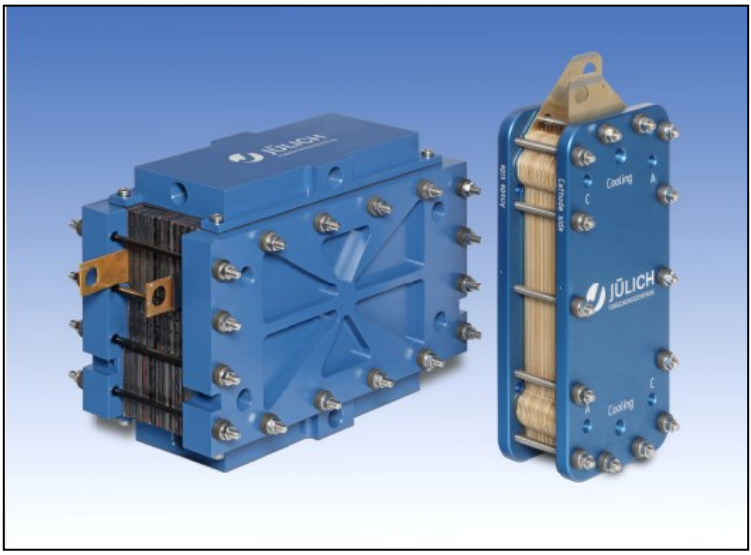
Forschungszentrum Jülich GmbH
Institute of Energy and Climate Research

The transition to a sustainable energy system requires the deployment of a range of efficient technologies for the conversion, storage and distribution of renewably-generated power and heat.

The IEK-3 of the Forschungszentrum Jülich is at the forefront of this endeavour. In collaboration with national and international partners from research and industry, we develop solutions for mobile and stationary applications and conduct groundbreaking research into fuel cells and the use of hydrogen as an energy carrier, including its production, distribution and storage. Additionally, we formulate concepts and models for the energy system of the future.

PEFC test facilities in the IEK-3.



PEFC Stack with graphitic (left) and metallic (right) bipolare plates of the IEK-3. Copyright: Forschungszentrum Jülich.

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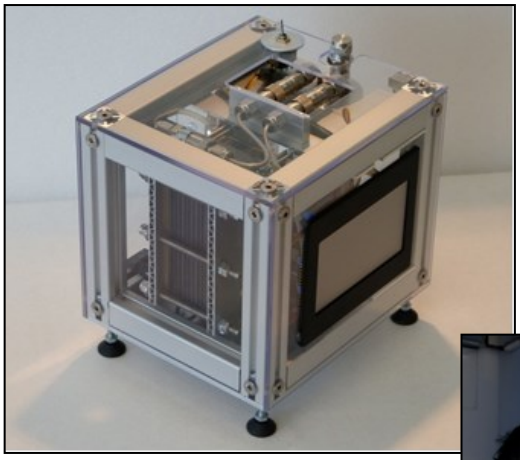
Fraunhofer Institute for Chemical Technology (ICT)

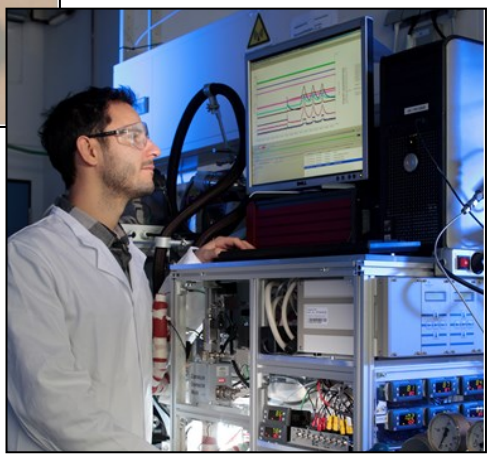
The fuel cell group of Fraunhofer ICT in Pfinztal, Germany develops and characterizes materials for PEM, HT-PEM and alcohol fuel cells as well as PEM fuel cell systems. The research takes place mainly in the framework of national and international projects with leading research institutions and international companies, as well as the German Army.

The catalyst development focuses on acidic and alkaline alcohol fuel cells, PEM fuel cells and electrolysis and sulfur tolerant catalysts for HT-PEM fuel cells. For the characterization of materials a wide variety of equipment is available, such as online mass spectrometry, differential electrochemical mass spectrometry (DEMS) highlighting a test cell for DEMS measurements under HT-PEMFC conditions, rotating electrode techniques (R)RDE and single cell test benches e.g. for MEA performance and durability investigations including a test bed with inline mass spectrometric CO_2 detection for carbon corrosion quantification.
Moreover, facilities and experience of electrode and MEA fabrication based on spraying techniques are available.

The system development focuses on PEM fuel cell system for range extender/APU applications as well as closed systems for underwater usage operating with pure oxygen. The system development also covers the characterization of fuel cell stacks and the simulation of the respective environment.



10 W direct methanol fuel cell system demonstrator.



Fuel cell test bench for differential electrochemical mass spectrometry measurements on single cells.

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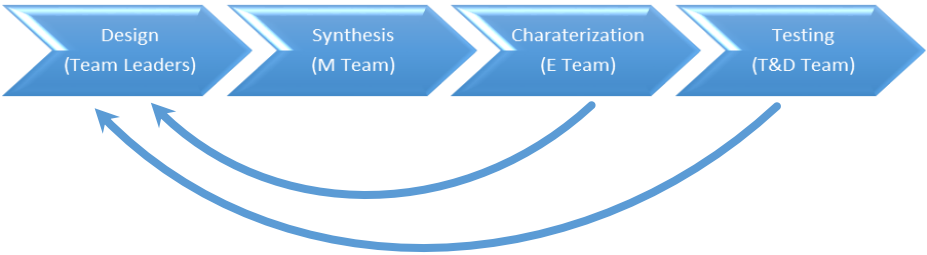
Israeli Fuel Cells Consortium (IFCC)

The Israeli Fuel Cells Consortiums' (IFCC) is part of the Israel Fuel Choices Initiative promoted directly by the Israeli Prime Minister's Office.
Its main task is to bring 12 leading, world-renowned Israeli researchers, with complementing skills and very little overlap, who have been studying fuel cells for years, to have them work synergistically under the direction of the IFCC managing committee. The objectives of this consortium focuses on the three main limiting factors of PEMFC technology: durability, cost and performance (in this order). In the IFCC, all members are expected to reach and go beyond the US-DOE 2020 targets for PEMFCs in their relevant research topic. The IFCC will create a knowledge base and human resources to support the Israeli and world PEMFC industries.



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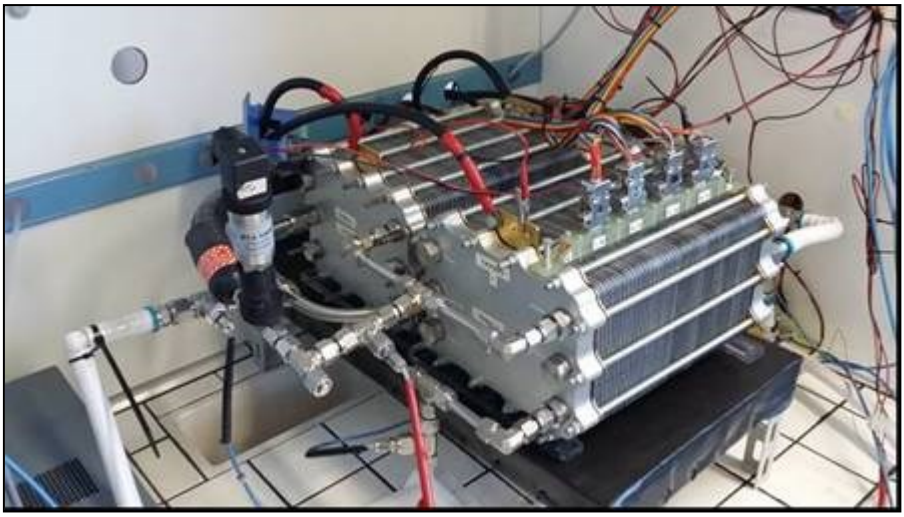
National Council of Research-Institute for Advanced Energy Technologies “Nicola Giordano (CNR-ITAE)”

Since 1980 CNR-ITAE has a worldwide acknowledged experience in all the relevant research areas related to fuel cell technology, from materials development to the stack and system design up to their integration.
Its experience covers portable, automotive, stationary, marine and space applications. It also has a long history of participation in EU-funded projects, both as a partner and coordinator. Its R&D activity in PEFCs topic include: development of new polymer electrolytes, membranes and ionomers with increased conductivity, mechanical and chemical stability and reduced materials cost; integration of membrane and electrodes to optimize mechanical and chemical interactions of catalyst, support and ionomer into MEA; development of catalysts and supports with a reduced precious metal loading and an increased activity, durability and lower cost; extension of MEAs operating range and durability; scaled-up fabrication processes for production of membranes, electrodes, MEAs and bipolar plates.

Scaled-up membrane at CNR-ITAE with a maximum dimension of 600 cm^2.

MEA with a maximum active area of 200 cm^2.



5kW H_2/air PEFC stack for marine application.

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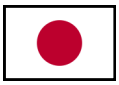

Ishifuku Metal Industry Co., Ltd.

Ishifuku Metal Industry Co., Ltd. develops, manufactures, distributes, and refines precious metals. Since the establishment in 1930, we have solely focused on this material and have created products that exceed customer expectations.

Our distinctions as a business:

1. Sales, buying and refining of precious metals
2. Manufacturing and sales of the following products:

- Wire, plate and powder for industrial use
- Precious metal targets
- Wire, plate, pipe and parts for jewellery
- Thermocouple wire and precious metal products for physics and chemistry
- Precious metal chemical compounds and chloride
- Catalysts and allied products for fuel cell
- Insoluble electrode
- Electronic and communication parts
- Precious metal products for dentistry

Our fuel cell catalysts consist of platinum-based nanoparticles supported on conductive carbon. Platinum-based nanoparticles are developed to achieve high catalytic activity without the increased usage of platinum. The specific surface area of platinum is enhanced through fine dispersion and the specific activity is improved through composition and structure control.

Plant exterior view.

Pictures of industrial products.

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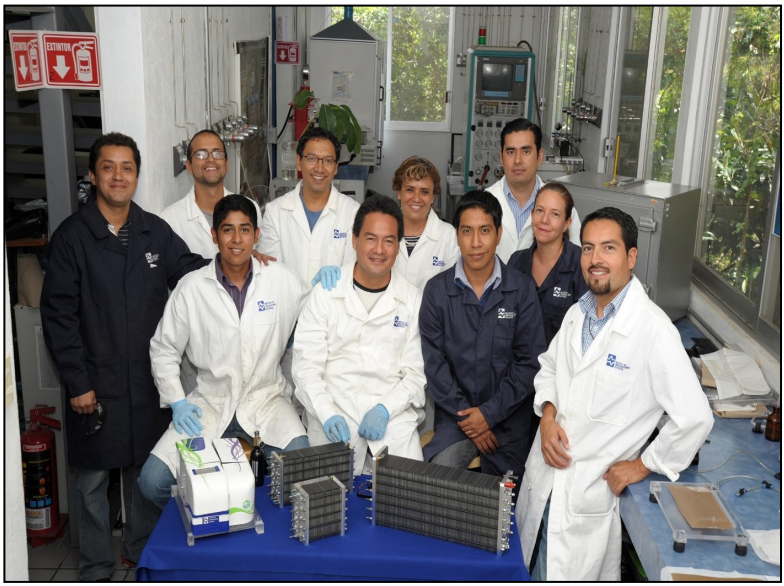
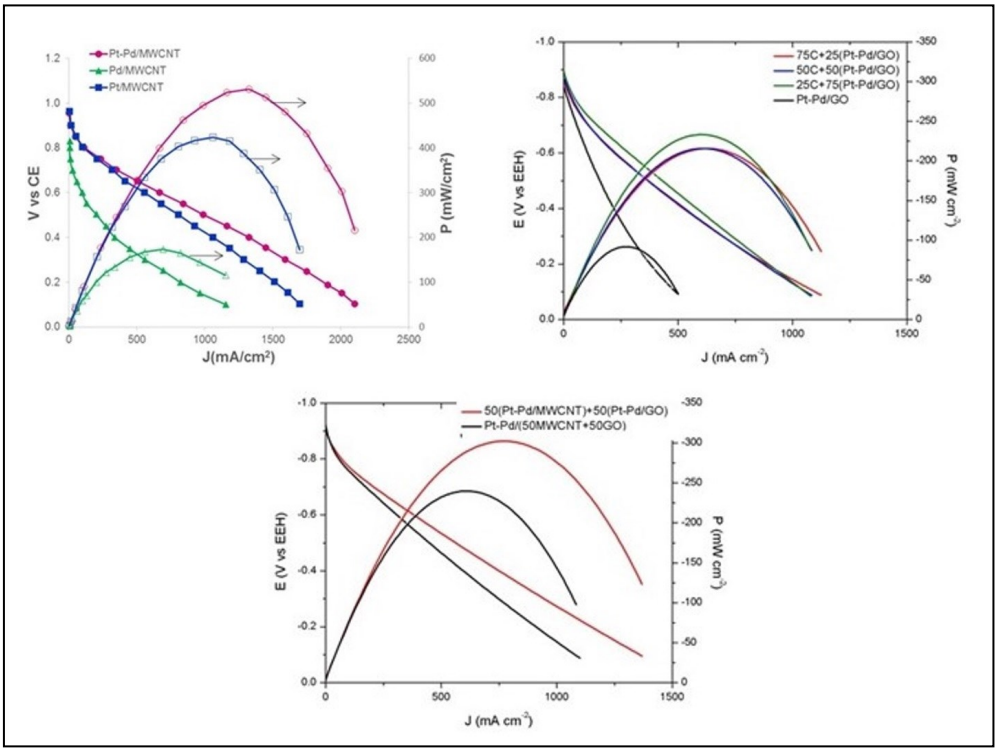
Web: www.ishifuku.co.jp/english/

Instituto Nacional de Electricidad y Energías Limpias

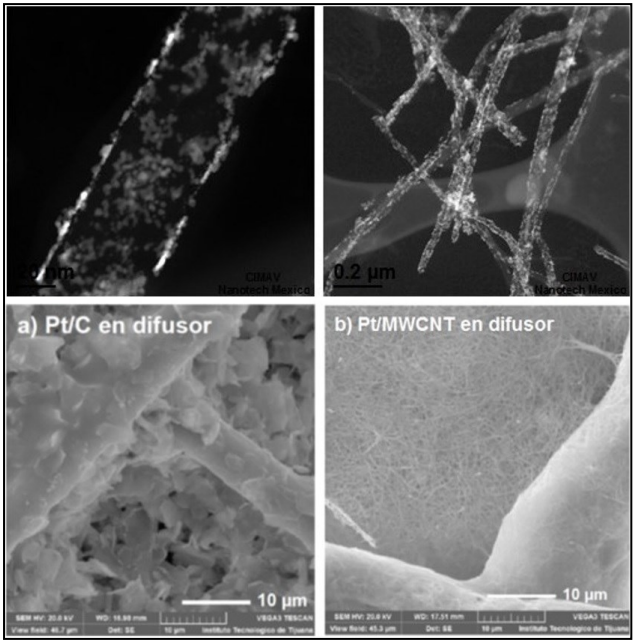
INEEL activities range from energy resources evaluation and electricity generation to its final use. It promotes clean and efficient technologies including hydrogen generation from water and renewables. It has its own PEMFC technology including MEAs, FC stacks and FC systems. Recently, INEEL has focused on transportation applications where FC systems are configured with other technologies like batteries and ultracapacitors to balance pros/cons of each one. At the scientific level, INEEL has collaborated with other institutions such as Instituto Tecnológico de Tijuana (ITT) in order to explore options to reduce platinum load in FCs or improve their performance without added cost, for example by designing catalyst support for better electrochemical processes. As a national institution INEEL is engaged in establishing energy strategy dialogs in Mexico, a country going through an energy restructuring phase, which encourages renewable resources and clean energies through technologies like H2 fuel cells.



Team Members INEEL FC R&D Group.



Performance I-V curves of different catalysts materials and material support: Pt-Pd, Pd and Pt (all supported on MWCN), Pt-Pd supported on GO using Carbon Vulcan as separator, Pt-Pd supported on GO and MWCNT and Pt-Pd supported on a mixture of both supports.



Catalysts and support Micrographs of different catalyst on several support material, including Pt-Pd/MWCNT, Pt/C and Pt/MWCNT, Pt-Pd supported on GO and C-Vulcan as separator, Pt-Pd supported on GO and MWCNT and Pt-Pd supported on a mixture of both supports.

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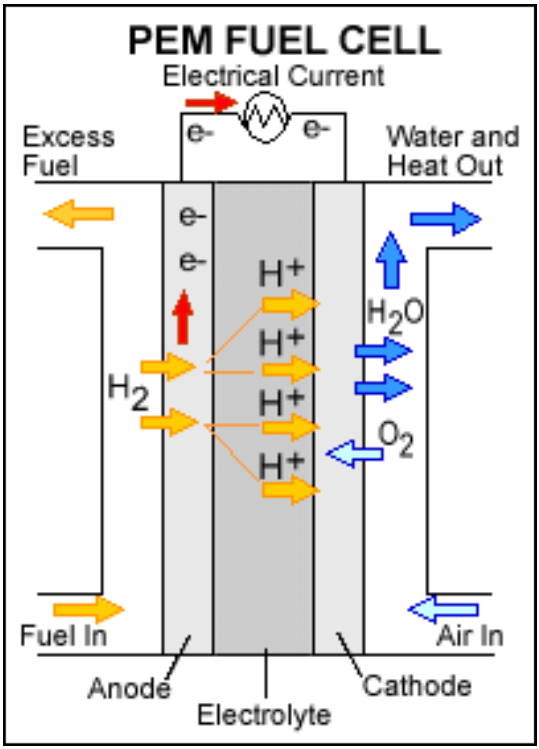
PEM fuel cell principle (from DoE)



Korea Advanced Institute of Science and Technology

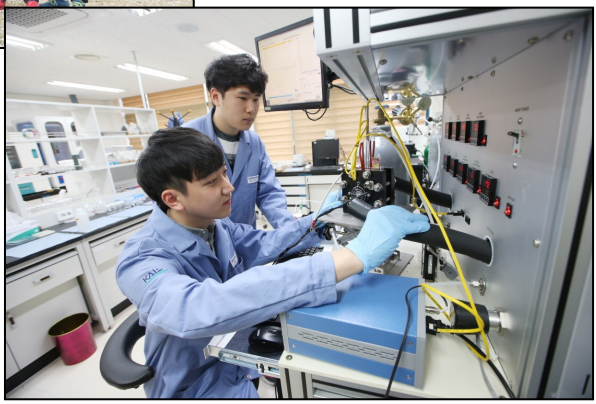
KAIST is a science and technology research university in Korea, founded by the South Korean government in 1971. KAIST aims to promote competitive research convergence based on scientific and technological innovations.

KAIST offers interdisciplinary academic and research programs in the following colleges: Natural Sciences, Life Science & Bioengineering, Engineering, Liberal Arts and Convergence Science, and Business. In particular, KAIST provides innovative education and research with a primary focus on core technologies, including biotechnology, nanotechnology, information technology, robotics, health technology, and EEWS (energy, environment, water and sustainability).

Energy conversion and storage materials (ECSM) lab. at KAIST is currently undertaking research to develop novel electrode materials for fuel cells, electrolyzers and batteries. The ultimate goal of ECSM research activity is to contribute to solve the global energy issues and bring a new paradigm shift in energy technology innovation.

Full view of KAIST, KOREA.

The fuel cell team at KAIST



KAIST lab facility

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Korea Institute of Energy Research (KIER)

Korea Institute of Energy Research (KIER) is a multidisciplinary energy research institution funded by the Korean government. KIER is committed to conducting R&D in the areas of energy efficiency, new and renewable energy, climate change, advanced materials, and marine and offshore wind energy.

KIER started fuel cell researches with PAFC in 1981 and now expanded its activities to PEFCs, DMFCs and SOFCs.

The PEFC research group covers from core materials (electrocatalysts, electrolyte membranes, ionomers and MEAs (Membrane electrode assembly), etc.) to stack and systems. KIER also operates a Test & Evaluation Center for fuel cell systems which has a traceability to the international standards. In recent, the research group is focusing on the block copolymer and reinforced membranes, ultra-low-Pt with highly durable support based electrocatalysts, non-precious metal (PGM-free) electrocatalysts, low-Pt loaded MEAs and special-purpose unmanned vehicles.

Roll to roll MEA fabrication process, 50 kW Stack for Fuel Cells mini-bus and Hydrogen refuelling station of KIER.

KIER KOREA INSTITUTE OF ENERGY RESEARCH
한국에너지기술연구원

Main campus (Daejeon) and 4 branches (Jeju, Buan, Ulasn and Gwangju campus) of KIER.

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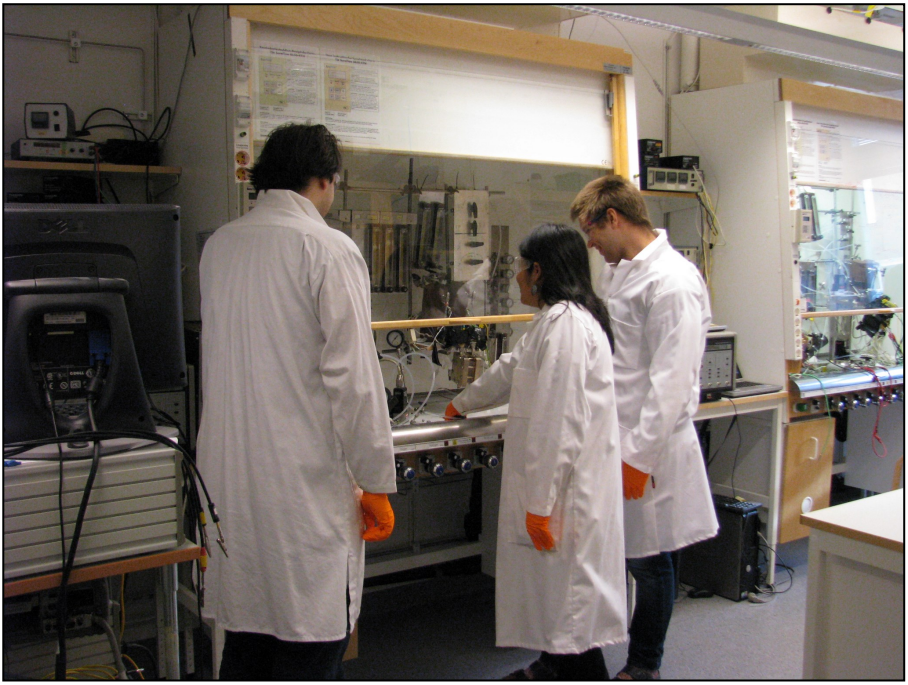
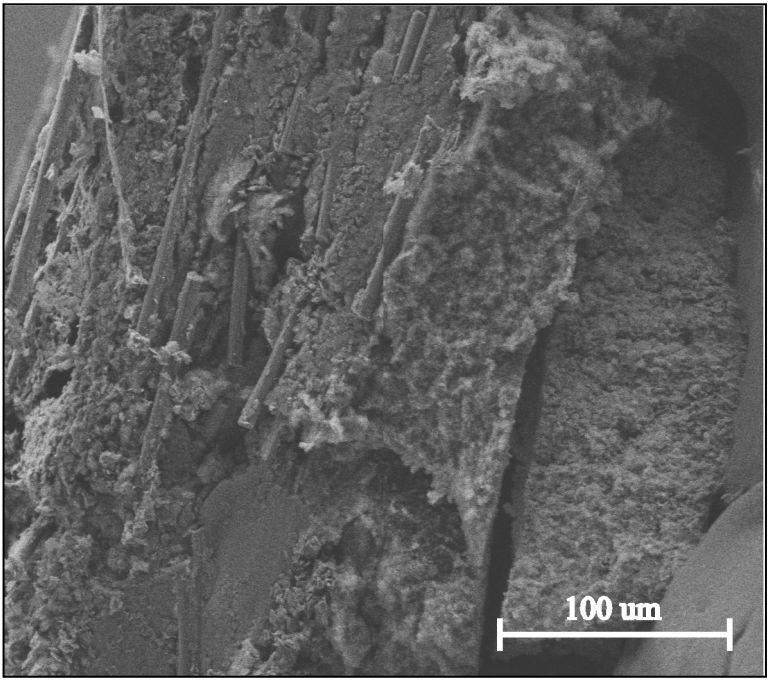
KTH Royal Institute of Technology

The Applied Electrochemistry group at KTH primarily work with in-operando studies of polymer electrolyte fuel cells, PEMFC as well as AEMFC. The research focuses on understanding and improving lifetime, performance, limiting factors, electrode structures, and degradation mechanisms. New materials are obtained through collaboration with universities and companies, while we specialize in electrochemical and physical characterization. The experimental results are further evaluated with physical models to give a more in-depth understanding of the underlying limiting mechanisms. Further, collaboration with key industrial partners enables the formulation of relevant research questions, as well as, insights into current state-of-the-art development. Our competence and broad network allow us to be part of the development of next generation fuel cell components.

Barack Obama during his visit at KTH in 2013.



PEMFC lab at Applied Electrochemistry. KTH.



SEM cross section of a porous electrode.

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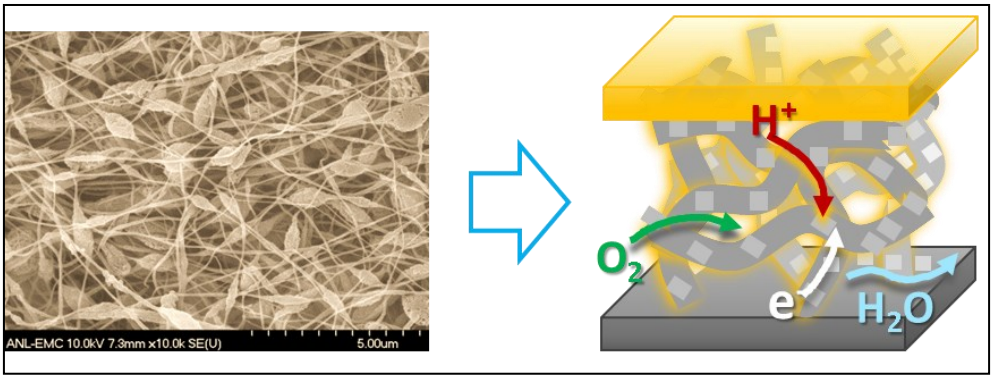
Argonne National Laboratory

Argonne National Laboratory (ANL) is one of the Department of Energy's major National Laboratories for electrochemical research. ANL and has involved in fuel cell development for nearly 30 years, including molten carbonate, solid oxide, and polymer electrolyte fuel cells.

In the transportation sector, ANL supported the design and retrofit of the first U.S. fuel cell bus in the mid-1990s. Argonne pioneered the autothermal reforming of methanol and gasoline for on-board hydrogen production and provided technical support to the U.S. Department of Energy in Fuel Cells for Transportation Program. In the stationary power sector, ANL invented the monolithic solid oxide fuel cell and provided technical support to the U.S. Department of Energy in the molten carbonate and solid oxide fuel cell programs. In recent years, ANL's fuel cell program focuses on synthesizing new catalysts and materials by using rational design concept to prepare highly-active and durable low-Pt and PGM-free electrocatalysts for the oxygen reduction reaction (ORR) in polymer electrolyte membrane fuel cells and the hydrogen oxidation reaction (HOR) for electrolyzers of water splitting; testing catalyst and MEA performance by evaluating ORR and HOR catalysts using rotating disc electrodes or through membrane electrode assemblies in operating fuel cells; characterizing catalyst and mitigating catalyst degradation by using advanced spectroscopic and analytical tools to identify the key physical and/or chemical property changes as guidance to improve the catalyst properties and performance; evaluating and optimizing component performance by using process modeling and simulation tools to analyze individual components in fuel cell, hydrogen storage, or hydrogen production systems and to optimize the system design and the operating parameters for better process efficiency.



New porous nano-network catalyst invented at Argonne improves catalytic efficiency and mass/charge transports for PEMFC.

Energy Science Building of Argonne National Laboratory where fuel cell material research groups reside.

Argonne National Laboratory
Chemical Sciences & Engineering Division
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Latest Annex 31 meetings

In May 2017, a combined meeting was held for the Annex 31/35 in Graz, Austria, a long with a seminar on fuel cells.

- Spring meeting, Seoul 2014
- Fall meeting, Cancun 2014
- Summer meeting, Pfinztal 2015
- Spring meeting, Messina 2016
- Fall meting, Beijing 2016
- Spring meeting, Graz 2017
- Fall meeting, Washington DC 2017

NEWS:

Applications of fuel cells - power for ships

Passenger ferry MS-Innogy on the German Baldeneysee.

MS-Innogy is powered by seven 5 kW methanol fuel cells.

Notes

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- United States Department of Energy (DoE)
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- Danish Power Systems (DPS)

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