Industry -Academia Consortium
PEFC Project
To Shed Light on Fuel Cell Mechanism
Fuel cells are attracting increasing attention as a promising technology to address global environmental challenges as well as other issues. By displacing fossil fuels that are normally used for vehicles, fuel cells are expected to help reduce carbon dioxide (CO2), nitrogen oxide (NOx), sulfur oxide (SOx), and particulate matter (PM) emissions. In the latter half of the 1980s, Canadian scientists demonstrated high-power density electric generation by using fluorinated ion-exchange resin membranes; this resulted in increased interest in PEFCs. Since the 1990s, intense competition to develop fuel cells for practical use in the transportation and commercial/residential sectors has been growing, especially in Japan and the United States. In Japan, since 1999, efforts to develop PEFCs under national projects have intensified. Aiming for practical application, various activities are currently underway to develop elemental technologies, systems and infrastructure, and to review existing regulations on emissions, formulate relevant standards, and conduct experimental research.

However, there are high hurdles that must be overcome in order to commercialize PEFCs; costs will have to be sharply reduced, and product quality and durability will have to be dramatically improved. This will require major technological breakthroughs. For example, fuel cell vehicles, like existing gasoline-powered vehicles, will need to have a service life of more than 100,000 kilometers and residential stationary fuel cells will need to be as durable as household appliances. Also, costs need to be reduced to less than one-tenth the current level.

Against this backdrop, in 2005 NEDO launched Strategic Development of PEFC Technologies for Practical Application, a five-year project (FY2005–FY2009). The aim is to put fuel cell technology into full-scale practical application and ultimately create a globally competitive industry in Japan built around domestically developed environmental and energy technologies. To achieve a breakthrough in fuel cell technology, industry/academic consortiums involved in this project are developing fundamental technologies relating to reactions, mass transfer phenomena, analysis and evaluation of degradation mechanisms inside cells, and elemental technologies relating to cell stacks in order to improve the performance, durability and cost-performance of PEFC systems, electrode catalysts, reformers and peripheral equipment.

NEDO Senior Program Manager Seizo Miyata conducts research leader meetings for four particular research activities relating to basic and common issues on a regular basis to help advance the research effectively and efficiently by allowing research findings about cell stack degradation mechanisms and other issues to be shared among related research themes. This brochure is intended to provide an easy-to-understand summary of four research themes relating to basic and common issues and seven research themes relating to elemental technology. In addition, information on research and development achievements made through the end of FY2008 for ongoing NEDO projects is provided. NEDO is committed to making its best efforts to collaborate closely with industry and academia to develop fuel cell and hydrogen technologies, with the objective of putting fuel cells into practical application.
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Polymer electrolyte fuel cells (PEFCs)

Fuel cells can provide higher overall efficiency than conventional internal-combustion engines, while greatly reducing carbon dioxide emissions. Because a variety of feedstocks, including natural gas and methanol, can be used, fuel cells represent an oil-alternative option. Furthermore, from an environmental perspective fuel cell systems operate very quietly and their use reduces the emission of air pollutants such as NOx and SOx. Because PEFCs, in particular, have high output density and excellent starting and stopping performance, they are expected to become fully commercialized as next-generation energy supply systems for fuel cell vehicles and stationary cogeneration systems. In NEDO’s Strategic Development of PEFC Technologies for Practical Application project, technological development focused on solutions to break through the barriers that impede the full commercialization of fuel cells is being promoted.

**Major technical challenges with PEFCs**

- **Electrode (platinum catalyst)**
  - Reducing platinum content (for cost reduction)
  - Preventing the degradation of cell performance (power generation efficiency and cell durability) due to platinum content reduction
  - Developing low-cost alternatives to precious metal catalysts (for cost savings)
  - Developing low-cost catalysts that are as active as platinum catalysts
  - Understanding of degradation mechanisms and development of degradation prevention methods

- **Separators**
  - Developing metal separator (for cost reduction)
  - Developing a metal separator that is free from electron conductivity degradation due to metal surface corrosion.
  - Developing ion separator (for cost reduction)
  - Establishing a carbon separator molding method to ensure a high level of processing accuracy and satisfactory surface electron conductivity

- **Balance of plant (BOP)**
  - Reducing platinum content in reformer (for cost reduction)
  - Preventing the degradation of reforming ability (efficiency and durability) due to platinum content reduction
  - Downsizing through modularization
  - Understanding of degradation mechanisms and development of degradation prevention methods

- **Polymer electrolyte membrane**
  - Developing low-cost, highly durable electrolyte membrane
  - Developing a low-cost, highly durable electrolyte membrane (for use under severe conditions involving frequent starts and stops, humidity, and/or temperature fluctuations, etc.)
  - Understanding degradation mechanisms and development of degradation prevention methods
  - Understanding the mechanisms of membrane degradation and developing methods to prevent membrane degradation in operation at high-humidity/high temperature and starting at low temperature (below zero)

**NEDO’s commitment to PEFC technology development**

**Strategic Development of PEFC Technologies for Practical Application**

- Strategic promotion from basic research to practical applications
- Coordination of three projects
  - Developing measuring and analysis methods and understanding the reaction and mass transport mechanisms
  - Developing innovative materials and understanding the degradation mechanisms

**Fuel Cell Cutting-Edge Scientific Research Project**

- Project term: FY2008 - FY2009
- FY2009 project budget: 850 million yen
- Project leader: Dr. Hiroshi Hasegawa, Director, FC-Cubic, Polymer Electrolyte Fuel Cell Cutting-Edge Research Center, AIST
- Innovative measurement, evaluation and analytical techniques for fundamental PEFC technologies, such as electrolyte materials, catalysts, and mass transport phenomena, will be developed in this project. The objective is to fully understand electrode catalysts, electrolyte materials, mass transport, and reaction mechanisms, and thereby apply this knowledge and the innovative technologies developed in this project to PEFC development.

**Strategic Development of PEFC Technologies for Practical Application/Research on Nanomaterials for High Performance Fuel Cells**

- Project term: FY2008 - FY2014
- FY2009 project budget: 2.0 billion yen
- Project leader: Prof. Masahiro Watanabe, Director, Fuel Cell Nanomaterials Center, University of Yamanashi
- This research and development project combines the knowledge of reaction and degradation mechanisms with cutting-edge technologies, including nanotechnology, to study new materials to be used for catalysts, polymer electrolyte membranes, and membrane electrode assemblies (MEA). The aim of this project is to establish basic technology for advanced cells that can simultaneously achieve high performance, high durability, and low cost, thereby contributing to the full-scale dissemination of PEFCs.
Strategic Development of PEFC Technologies for Practical Application

This project promotes the development of technology for practical application during the initial introduction stage, the development of elemental technology for the full introduction stage and the development of next-generation technology for the full dissemination stage in order to comprehensively develop highly efficient, highly reliable and low cost PEFCs.

(1) Development of technology on basic and common issues
NEDO is carrying out research to address basic and common issues, such as clarifying PEFC degradation mechanisms, including those for vehicles, in order to improve the durability, economic efficiency and performance of individual unit cells, fuel cell stacks and entire systems. In addition, the development of basic analysis evaluation technology that contributes to the research and development of fuel cells is being conducted.

(2) Development of elemental technology
In order to improve the advanced elemental technology required for the practical application of fuel cells for vehicles and stationary fuel cells, NEDO is undertaking the development of high-risk elemental technology for PEFC electrodes, electrolytes (including MEAs), separators, balance of plant (BOP) components and reformers that markedly improve durability and efficiency and reduce costs.

(3) Development of technology for practical application
To establish a market for stationary fuel cells, NEDO is developing production process technology for PEFC separators and other components, as well as basic material production technologies for commercial mass production.

(4) Development of next-generation technology
NEDO is undertaking pioneering and basic research to develop new electrolytes and non-platinum electrocatalysts in order to produce highly efficient, highly reliable and low cost fuel cells and promote the commercialization of fuel cell vehicles. In addition, research is being carried out to develop high-performance fuel cells that differ significantly from conventional fuel cells. Basic research for advanced analysis evaluation technology that can contribute to the research and development of fuel cells is also being conducted.

This brochure introduces four industry–academia consortia research activities being carried out under the theme, Development of technology on basic and common issues, and seven research activities being carried out under the theme, Development of elemental technology, as part of NEDO’s project, Strategic Development of PEFC Technologies for Practical Application.

Study of cell degradation prevention through water management

Understanding cell degradation mechanisms with respect to cell water management, proposing cell degradation prevention measures

❖ Objective
This research is focused on PEFCs for vehicles, targeting commercialization between 2020-2030. The objective is to analyze cell water management to gain an understanding of degradation mechanisms of electrolytes, electrode catalysts, and resin/metal separators in order to propose degradation prevention measures to help achieve fuel cell durability targets.

❖ Project leader
Michio Hori, Professor, Engineering Department, Daido University

❖ Project period
FY2005 -FY2009

❖ Project overview
In the first stage of this research, which was carried out from FY2005 to FY2007, the degradation mechanisms of electrolytes, electrode catalysts, and carbon-resin composite materials were examined in relation to water management at room temperature and high temperatures. With a focus on improving the durability of PEFCs for vehicles, methods to manage water in cells were proposed, including cell construction and cell operating methods. During and after FY2008, the focus has been on the freezing and unfreezing phenomena of MEA under low-temperatures, clarifying the degradation mechanisms of MEA, and conducting research and development activities to obtain knowledge to develop MEA degradation prevention measures.

❖ Project promotion scheme

❖ Make up of this consortium
Professor Hori of Daido University has been providing technical support to automobile manufacturers, drawing on his twenty years of experiences at a private company that developed PEFC and MCFC stacks. This consortium is comprised of a network that Professor Hori has built over the years from various companies and organizations specializing in electrolytes, electrode catalysts, and gas diffusion layers.
**Progress and results**

**Results from FY2005 to FY2007**

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**Schedule**

**Expected results**

This research is expected to help improve the durability of fuel cells substantially by shedding light on the behavior of water (humidity) in a cell in relation to the electrolyte membranes, electrode catalysts, and separators, which play a large role in determining the durability of PEFCs.
Basic research of cell degradation factors and analysis of MEA durability

Analyzing fuel cell degradation mechanisms with a focus on three-phase interface, developing guidelines for producing highly-durable membrane electrode assemblies (MEAs)

❖ Objective
The objectives of this research are to clarify the degradation mechanisms of PEFC electrodes (primarily the cathode electrode) and to thereby come up with an effective proposal to improve PEFC durability.

❖ Project leader
Yoshiharu Uchimoto, Professor, Graduate School of Human and Environmental Studies, Kyoto University

❖ Project term
FY2005-FY2009 (Interim evaluation in FY2007)

❖ Project overview
Efforts will be made to look into and make a deductive observation of the degradation phenomena of membrane electrode assemblies (MEAs) in fuel cells at the three-phase interface*. This will be done to clarify under what operating conditions and in which particular parts of the three-phase interface the electrolyte and electrode catalyst degrade in order to obtain a clear understanding of the degradation mechanisms and to thereby come up with a proposal for producing highly durable MEAs.

*The area where electrode reactions of a fuel cell take place (the surface where the electrolyte, catalyst, and reacting substance [oxygen or hydrogen] coexist).

Project promotion scheme

Kyoto University
Degradation mechanisms using a model three-phase interface

Kyoto Institute of Technology
Synthesis and degradation mechanisms of fluoride ion-exchanged model molecules

Tohoku University

Kyushu University
Multi-scale computational chemical analysis related to electrolyte degradation

Nagaoka University of Technology
Understanding of electrode degradation mechanisms using magnetic resonance spectroscopy

Toray Research Center, Inc.
Electrode catalyst performance and degradation evaluation technique using 3D electron microscope

National Institute of Advanced Industrial Science and Technology (AIST)
Assessment of degradation mechanisms for accelerated degradation model

Waseda University
Degradation state analysis using impedance method

❖ Make up of this consortium
Collaborative efforts are being made among the participating organizations to deductively clarify the mechanisms of catalyst and ionomer degradation in the three-phase interface. Complex degradation mechanisms will be analyzed by consolidating cutting-edge measurement techniques and technologies such as degradation evaluation using accelerated deterioration test protocol, in-situ evaluation using electrochemical impedance techniques, degradation testing of the three phase interface using structurally controlled electrode models, particle beam analysis, transmission electron microscopy analysis, magnetic resonance, and electron spin resonance. Furthermore, the analyzed mechanisms will be confirmed theoretically using computational chemical prediction.
To understand the degradation mechanisms of PEFCs, it is essential to conduct a cell-level degradation factor analysis based on scientific evidence. The work being carried out under this research theme is expected to help improve the durability of fuel cells dramatically, a major challenge for the fuel cell industry, by elucidating the cathode electrode degradation phenomenon, in particular, and to then develop degradation countermeasures.

Analysis of degradation mechanism using computational chemistry

Bonding energy of C-O is lower than that of C-C

 Ether binding affects degradation

Analysis using three-phase interface model

Oversaturation of Ptz+ leads to growth of Pt particles by Ostwald ripening mechanism.

Transmission electron microtomography (TEMt)

Three-dimensional observation of catalyst layer Precise measurement of platinum particle size distribution

Detection of hydroxyl (OH) radical formation using fluorescence probe method with coumarin

Amount of OH radical formed on anode side is larger than amount formed on cathode side

Amount of OH radical increases with platinum dispersed membrane

Schedule

Expected results

To understand the degradation mechanisms of PEFCs, it is essential to conduct a cell-level degradation factor analysis based on scientific evidence. The work being carried out under this research theme is expected to help improve the durability of fuel cells dramatically, a major challenge for the fuel cell industry, by elucidating the cathode electrode degradation phenomenon, in particular, and to then develop degradation countermeasures.
Analysis of degradation mechanisms and development of cell life estimation methods for polymer electrolyte fuel cells

Analyzing PEFC degradation mechanisms, establishing accelerated test method, forecasting service life

❖ Objective
The purpose of this research is to gain an understanding of the degradation mechanisms of PEFCs and to develop an accelerated durability evaluation and service life estimation method in order to accelerate the practical application and broad adoption of fuel cells.

❖ Project leader
Kenichiro Ota, Professor, Faculty of Engineering, Graduate School of Engineering, Yokohama National University

❖ Project term
FY2005-FY2009 (Interim evaluation in FY2007)

❖ Project overview
In the actual usage environment of fuel cell vehicles, various trace elements that affect fuel cells exist, such as sulfur compounds and a wide variety of organic substances. Under this research, PEFC degradation mechanisms caused by these elements will be evaluated by using various membranes and electrode materials under different operating conditions. Evaluation techniques capable of testing the durability of fuel cells at the laboratory level in conditions that are similar to a practical use environment will then be developed. In addition, a pressurized acceleration test method, to speed up durability testing, as well as a technique to forecast the service life of PEFCs will be established. Through this work, the phenomena of catalysts adsorbing these trace airborne elements and the resulting performance degradation mechanisms such as platinum catalyst dissolution will be analyzed using electrochemical and surface analysis methods. The results of these activities will be fed back to the above-mentioned research efforts to develop accelerated testing and service life estimation methods.

❖ Project promotion scheme

❖ Make up of this consortium
With Professor Kenichiro Ota of Yokohama National University serving as the research leader, this consortium has been established to analyze the mechanisms of PEFC degradation and to develop a service life estimation method assuming the actual operating environment of fuel cell vehicles by combining a PEFC performance evaluation technology developed by the Japan Automobile Research Institute, high temperature and pressurized operating technology developed by the Central Research Institute of Electric Power Industry, and analysis techniques developed by Yokohama National University and the Shibaura Institute of Technology.
### Progress and results

**Japan Automobile Research Institute**

**Analyzing influence of airborne trace elements on PEFC performance**

Performance degradation caused by the existence of sulfur compounds and ammonia depends not on the additive concentration but on the amount supplied. This means that performance degradation can be accelerated by increasing the volume supplied. On the other hand, performance degradation caused by nitrogen dioxide depends on the additive concentration.

**Analysis of PEFC performance degradation mechanisms caused by airborne trace elements**

![Graph showing correlation between addition of trace elements and dissolution of fluorine](image)

Effect of the addition of trace components (SO$_2$) on the cell performance and F-dissolution for the MEA with hydrocarbon electrolyte membrane and PFSA ionomer in the catalyst layers. By adding trace elements (SO$_2$) to hydrocarbon electrolyte membrane/ PFSA ionomer-based MEA, the rate of dissolution of fluorine increased.

**Development of performance formula using results of degradation mechanism analysis**

\[
\eta = 0.0721 + \frac{1}{\exp(-0.0069t)} \times (0.035 - 0.041 \ln(m_{SO_{2}}/m_{SO_{2}O}))
\]

Using the performance formula to forecast performance degradation caused by the addition of SO$_2$.

Initially, discussions were held on whether or not it was possible to expand the influence of trace elements into the performance formula and succeed in forecasting the level of performance degradation caused by the addition of SO$_2$ by adding to the formula a term to represent the surface area decrease caused by the catalyst’s adsorption of SO$_2$.

**Central Research Institute of Electric Power Industry**

**Development of PEFC performance evaluation technique**

A high precision PEFC performance formula was developed by introducing time dependent term

\[
\eta = E_{oc} - 0.045U_{a} + 0.37v_{o} - 0.35
\]

Anode representation formula: \( \eta = 0.05 \)

Cathode representation formula: \( \eta = -24.100 \eta_{a} - 0.14 + 0.0335c + 0.0065a(m_{SO_{2}}/m_{SO_{2}O}) \)

\[
\begin{align*}
E_{oc} &= 0.4 \exp(0.0001/0.364) \times 0.06 \times (m_{SO_{2}}/m_{SO_{2}O}) \\
E_{a} &= 0.05 \\
E_{c} &= 0.05 + 0.065 + (m_{SO_{2}}/m_{SO_{2}O})
\end{align*}
\]

**Understanding PEFC performance degradation mechanisms under pressurized conditions**

![Graph showing effect of pressurization on PEFC performance](image)

**Yokohama National University/Shibaura Institute of Technology**

**Understanding performance degradation mechanisms**

- **Hydrogen peroxide production ratio (%)**
  - Reaction with trace elements
  - Coverage ratio of trace elements

**Degradation of electrolyte membrane**

- **Hydrogen peroxide generation of hydrogen peroxide**
  - Adsorption of trace elements and degradation of performance

### Schedule

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### Expected results

This research is expected to make it possible to evaluate the durability of fuel cell vehicles under conditions that resemble an actual operating environment. This will help promote the development of technology to address fuel cell contaminants. Furthermore, the development of a method to conduct accelerated testing of cells operating in a pressurized state and a service life estimation method are expected to improve durability evaluation technologies.
Mass transfer phenomena visualization technology

Developing technology to visualize water distribution and examine its transfer within fuel cells

Objective
The objective of this research is to develop and establish techniques and tools to visualize water distribution and examine its transfer within fuel cells.

Project leader
Yasuhiko Fujii, Manager, Quantum Beam Science Directorate, Japan Atomic Energy Agency

Project period
FY2008 -FY2009

Project overview
Technologies to build a new measurement system with high spatial resolution using neutron radiography (NRG), small-angle neutron scattering (SANS), and magnetic resonance imaging (MRI) will be developed. These technologies can be used very effectively to visualize the inside of a fuel cell and to examine how water behaves in fuel cells, especially in its micro regions such as electrolyte membranes. Furthermore, new visualization technologies using potentially promising pulsed neutron radiography and soft X-rays will be tested and evaluated for their effectiveness in observing the inside of a fuel cell.

Project promotion scheme

Make up of this consortium
The comprehensive development of sophisticated mass transfer visualization technologies using NRG, SANS and MRI is being promoted through this research. These technologies have been studied by the Japan Atomic Energy Agency, Kobe University, Tokyo City University, and Tokyo Institute of Technology. By effectively using multiple technologies possessing such different characteristics, water distribution can be multidimensionally and complementarily evaluated, and mass transfer phenomena within fuel cells can be precisely understood.
Developing neutron radiography technology featuring super-high spatial resolution
Developing micro CT and dynamic CT technology
Evaluating and modeling the correlations among power generation properties,
pressure loss, and water distribution
Neutron small-angle scattering and imaging consolidation technology
MRI technology development
Developing MRI technology featuring high spatial resolution
Neutron imaging technology
FY2008
FY2009

Next-generation visualization technology (Feasibility study)
Visualizing water content inside fuel cells by means of soft X-rays
Water visualization in MEA under operation
• visualization of water formation under ribs
• visualization of water formation in catalyst layer
Developing pulsed neutron imaging technology
Confirmation of discriminable ability of ice from water by resonance absorption imaging

Cross-section visualization of water in a fuel cell
3D water visualization of a large size fuel cell stack

Water distribution in membrane under operation (Resolution on cross-section of membrane
thickness: Left: 15µm Right: 5µm)

Ion channel size increases in correlation to amount of water in membrane

Schedule

Expected results
This research will explore water behavior in fuel cells at high spatial resolutions in order to understand the water transport mechanism between electrodes, which would affect the polarization under high current density while the fuel cell operates with steady and varying loads. It is also intended to clarify water transport in fuel cells during transient operations (starting/stopping at sub-zero temperatures). Understanding detailed water transport phenomena that can influence the performance of fuel cells will facilitate the practical use of fuel cells for vehicles. In addition, a structure for research organizations to make full use of the developed visualization technologies will be established.
Technology development of BOP components for residential fuel cell systems

Developing balance of plant (BOP) components through collaborative efforts of system manufacturers

Objective
The objective of this research is to develop high-performance, high-functionality BOP components required for fuel cell systems in order to promote residential fuel cell cogeneration systems (aka “Ene-Farm”) and to reduce costs in order to facilitate their widespread use.

Project leader
Yuji Nagata, Chief Engineer, Toshiba Fuel Cell Power Systems Corp.

Project period
FY2005 - FY2009

Project overview
This research consortium is comprised of Japan’s leading fuel cell system manufacturers, each having specific development assignments. With cooperation from technologically qualified specialized manufacturers, the basic functions, durability and cost required for BOP components, which control fuel cell systems, will be determined. Elemental technologies to meet these requirements and to improve the performance and functionality of BOP components will then be developed.

Project promotion scheme

Make up of this consortium
Through the cooperative efforts of Japan’s leading fuel cell system manufacturers possessing state-of-the-art technology related to BOP components, elemental technologies to improve the performance and functionality of BOP components required to control fuel cell systems will be developed.

With Mr. Yuji Nagata of Toshiba Fuel Cell Power Systems Corp. serving as the research leader, each committee entrusted with elemental technology development themes, such as water treatment equipment, heat exchangers and inverters, meets monthly to discuss the progress and to ensure mutual collaboration. The equipment being developed under this research is tested and evaluated with actual operating fuel cell systems, with the objective of mass commercialization.
Progress and results

From 2005 to 2007, the consortium’s research and development efforts focused on setting standard target specifications for the mass production of blowers, pumps, valves, and sensors. As a result, the following achievements were made:

a. Performance: Developed components that fulfilled common specifications and achieved auxiliary equipment power loss targets.
b. Durability: Attained durability target of 40,000 hours
c. Cost: Reduced costs from original estimate of ¥410,000 to ¥110,000, based on production volume of 10,000 units/year
d. Practical use: Each system manufacturer incorporated the devices developed in this research into 70% of their systems
e. Mass production: Device manufacturers completed preparations necessary for mass production

In FY2008 and FY2009, the efforts outlined below are being made to develop devices aimed at expanding the use of residential fuel cells:

a. Setting common target specifications
b. Development of low-cost, maintenance-free water treatment equipment
c. Development of a low-cost, durable (40,000 to 90,000 hours) heat exchanger condenser
d. Development of a high-efficiency, inexpensive, low-voltage (15V-class), high-current inverter

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Expected results

For residential fuel cell systems to be widely used, it is essential to achieve a dramatic improvement in system durability as well as a substantial cost reduction. To address this engineering challenge requires developing innovative technologies for BOP components, fuel cells and reformers, as well as the establishment of mass-production technology.

Considering that these BOP components account for a large percentage of the current cost of the fuel cell system as a whole, it is expected that a technological breakthrough related to these BOP components, if realized, will result in a substantial reduction in system costs. Also, developing highly-durable components will help improve system reliability and reduce life cycle costs.
Objective
Significant cost reductions are required for residential PEFC cogeneration systems to become fully commercialized. One aim of this research is to improve the reliability and robustness of major cell stack components, which in turn will simplify the whole system. The ultimate objective is to achieve higher performance (heat recovery at higher temperatures and higher conversion efficiency), while simultaneously reducing system costs.

Project leader
Haruhiko Adachi, Chief Researcher, Fuel Cell Project, The Japan Institute of Energy

Project term

Project overview
This consortium is comprised of Japan’s leading stationary fuel cell manufacturers and system installers. They, in cooperation with academic societies, universities, and research institutes, exchange and share the latest technical information, PEFC stack components (electrolyte membranes, electrode catalysts, MEAs, etc.) and evaluation tools (single cells and stacks), and engage in basic research and development activities to improve the reliability and robustness of major cell stack components.

Project promotion scheme

Make up of this consortium
Under the leadership of Mr. Haruhiko Adachi of the Japan Institute of Energy, the members of this consortium, including materials manufacturers, system builders, and fuel suppliers, cooperate on research and development activities to improve the reliability and robustness of PEFC stack components. Professor Yohtaro Yamazaki and others from the Tokyo Institute of Technology analyze the behavior of water and trace impurities in cells operated under higher temperature and lower humidity conditions. Dr. Tsutom Ioroi of the National Institute of Advanced Industrial Science and Technology are attempting to improve the durability of the cathode catalyst support. Also, under the guidance of Professor Michio Hori of Daido University research is underway to build a database of data on the influence of impurities and to analyze cell degradation mechanisms.
Progress and results

Expansion of allowable temperature and humidity ranges
- By applying polymer C to membrane and electrode binders, Asahi Glass and Panasonic developed a new MEA that can be used with a low humidification catalyst.
- The cell voltages of the newly developed MEA maintained high cell voltage over a wide range of temperature and humidity. (Fig. 1)

Long-term reliability under higher temperature and lower humidity conditions
- Asahi Kasei E-materials produced a prototype membrane with substantially improved chemical tolerance. The cell voltages of the newly developed MEA are maintained by using thinner membranes and lower EW binders.
- ENEOS CELLTECH confirmed the potential long-term reliability of the new MEA under higher temperature and lower humidity conditions by optimizing the quantity of ionomer in the catalyst layer.

Influence of impurities on cell voltages
- Research is underway to build a database on the influence of various impurities and to analyze cell degradation mechanism. A method to reduce the influence of impurities is being studied.

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<td>① Prioritized improvement of MEA reliability</td>
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<td>② Prioritized improvement of MEA robustness</td>
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<td>③ Research on behavior of water and trace impurities in the cell</td>
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<td>④ Development of a database on the influence of impurities and analysis of degradation mechanisms</td>
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<td>⑤ Improvement of reliability and robustness of major cell stack components</td>
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Expected results

To prevent degradation, it is necessary to precisely control the temperature, humidity, and impurities in the cell stack of a stationary fuel cell system. This necessitates the use of various kinds of devices such as high-precision sensors, fluid meters, filters, and high quality valves and pumps, which naturally drive up the cost of the system. This research is expected to establish fuel cell stack technology that can improve the reliability and robustness of fuel cell stacks operated under higher temperature and lower humidity environments. This would, in turn, realize a drastically simplified system with a reduced number of controllers and other auxiliary devices, thereby contributing greatly toward cell cost targets necessary to be reached for stationary fuel cell systems to be widely used.
Development of basic elemental technology for stationary fuel cell reforming catalysts

Developing a catalyst that dramatically decreases reformer costs

❖ Objective
To drastically reduce the cost of reformers, target catalyst specifications will be defined and used to develop catalysts with long-term dependability and the ability to endure frequent starts and stops.

❖ Project leader
Hiroto Matsumoto, FC Project Group Leader, New Business Promotion Office, Idemitsu Kosan Co., Ltd.

❖ Project term
FY2005 - FY2009

❖ Project overview
Because developing innovative technology is time-consuming, a practical approach should be followed for technology development efforts. Through this research, target catalyst specifications will be defined on the basis of the expertise and knowhow that individual participating companies have accumulated through their efforts to improve the durability and reduce the cost of reformers. The expertise and knowhow will become shared research knowledge. Three types of catalysts—reforming, CO conversion, and CO removal—will be developed for the purpose of verification with actual reformers in order to develop inexpensive catalysts with long-term dependability and the ability to endure frequent starts and stops.

Project promotion scheme

❖ Make up of this consortium
Leveraging the technological capabilities of the consortium members, development teams for three types of catalysts and one reforming system evaluation team have been assembled under the leadership of Mr. Hiroto Matsumoto of Idemitsu Kosan Co., Ltd. The consortium is striving to reduce overall reformer costs by sharing information among the catalyst development teams and the system evaluation team.
Progress and results

- **Standardization of reforming catalysts**
  Development targets (cost, product life, durability) and evaluation conditions (gas composition conditions, temperature) were prioritized and shared among consortium members.

- **Development of innovative long-life CO conversion catalyst**
  In the process of developing inexpensive Cu-based non-precious metal catalysts with a focus on aggregation control, a highly active new catalyst (Cu - Zn - Al) with high durability in start and stop (SS) operations was identified. Efforts will be made to establish mass production technology for the catalyst and further improve its activity under low temperature.

- **Development of steam reforming catalyst**
  Efforts have been made to develop an inexpensive Ni-based non-precious metal catalyst with a focus on Ni aggregation control through the use of vapor oxidation. In addition, a new Ni-based non-precious metal catalyst (Pt (very small quantity) - Ni - Mg(Al)O) highly durable in start and stop operations was identified. Efforts will be made to establish mass-production technology for the catalyst and further strengthen catalyst formation.

- **CO removal catalyst**
  A CO selective methanation method, which will result in a more drastic cost reduction by simplifying the overall reforming system as compared to the conventional CO selective oxidation method, is being developed. Several catalysts with high activity and selectivity have been identified.

  Looking forward, the aim is to establish design technology for the reforming process and a reformer for a CO selective methanation catalyst.

- **Reforming system evaluation**
  In order to evaluate the practicability of the development of the catalysts mentioned above, actual reformers have been produced for evaluation, which will be carried out in FY2009.

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<td>① Standardization of reforming catalysts</td>
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<td>② Development of innovative long-life CO conversion catalyst</td>
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<td>③ Development of steam reforming catalyst</td>
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<td>④ Development of CO removal catalyst (selective CO oxidation catalyst) (selective CO methanation catalyst)</td>
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<td>⑤ Catalyst reforming system evaluation (catalyst consolidation system) (actual reformers)</td>
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Expected results

The starting and stopping of a PEFC system produces residual gases that can accelerate the degradation of catalysts. To compensate, it is necessary to use relatively expensive precious metal catalysts with an adequate level of tolerance or to control degradation by means of a complex operating control system. These options, however, increase system costs. To address this problem, efforts will be made to develop inexpensive, long-life reforming catalysts and processes to produce less expensive reformers.
Objective
The aim of this research is to develop anode catalysts and MEAs capable of operating with reformed gases having a CO concentration of 500 ppm (about 2,000 ppm at transient phase of operation), a concentration assumed when the selective CO oxidization catalyst is omitted. The goal is to develop a simplified fuel reforming system that can eventually help reduce the cost of PEFC stationary systems.

Project leader
Hiroyuki Uchida, Professor, Clean Energy Research Center, University of Yamanashi

Project term
FY2008 - FY2009

Project overview
(1) Development of highly CO-tolerant and highly active catalysts, and analysis of mechanisms to tolerate CO gas and improve catalyst activity
- The composition and structure of platinum alloy–based catalysts will be optimized. Highly CO-tolerant and highly active hydrogen-oxidizing catalysts will be developed by using carrier interactions. Rh-porphyrin-based catalysts capable of oxidizing CO at a low overpotential will also be developed.
- Voltage drop mechanisms resulting from CO poisoning will be analyzed in new and existing catalysts from various aspects to develop performance guidelines. The findings of the research will then be fed back to other participating members to help develop catalysts with much higher functionality.

(2) Development of highly CO-tolerant, catalyst recycling operating methods
- A highly CO-tolerant MEA will be developed using the catalysts described above and optimal operating conditions will be identified for reformed fuels containing a CO gas concentration of 500 ppm.
- Operating methods will be developed that can restore the performance of highly CO-tolerant MEA even if the efficiency falls when 2000 ppm CO is temporarily mixed in at start-up or when loads vary.

Project promotion scheme

Make up of this consortium
With Professor Hiroyuki Uchida of the University of Yamanashi serving as the research leader, this consortium has two development groups: a catalyst development group, which is tasked with developing highly CO-tolerant catalysts and MEAs, and an operating method development group, which is responsible for developing optimal operating methods. The catalyst development group is working on the standardization of evaluation methods for CO-poisoning-tolerant hydrogen-oxidization activity so that catalysts can be compared under standardized criteria. The need for a standardized evaluation method, for which there had been calls, is fully addressed during this research for the first time. Also, the catalysts that are developed are supplied to the operating method development group for verification. That group then provides feedback of the verification results to further improve performance.

The liaison meetings that are conducted regularly with the participation of all member organizations manage the progress of the research, share information on the latest technologies, and discuss achievements in order to effectively advance the research.
Japan leads the world when it comes to developing stationary PEFCs. Following the full-scale demonstration tests that were concluded in FY2008, sales of PEFCs to the general public were actively commenced in FY2009. The efforts to develop highly CO-tolerant catalysts, MEAs, and operating methods through this research will greatly contribute to cost reductions, and improve the durability of stationary PEFCs. The efforts are also expected to promote the full-scale introduction of PEFCs to the market. Furthermore, new anode catalysts and their working mechanisms are expected to result in new knowledge that promotes the advancement of electrochemistry and catalytic science.
Objective
The objective of this research is to develop catalytic technology capable of dramatically reducing the platinum content in PEFCs in an effort to address platinum cost and scarcity issues, which are major barriers to promoting the use of fuel cells.

Project leader
Minoru Inaba, Professor, Faculty of Science and Engineering, Doshisha University

Project term
FY2008 - FY2009

Project overview
Under this five-year research effort, which began in FY2008, attempts will be made to develop catalytic technology that allows the amount of platinum used in catalysts to be reduced to one-tenth of the current level. Specifically, elemental technologies for electrode catalyst materials capable of maintaining performance and durability despite dramatically reduced platinum content will be developed. Research will also be conducted to improve performance and durability and reduce costs by incorporating the developed elemental technologies into the electrode catalysts.

Project promotion scheme

Make up of this consortium
Reducing the amount of platinum used on the catalyst requires improving the activity and durability of the catalyst itself and reducing the polarization of the catalyst layer, while simultaneously addressing a wide variety of mutually conflicting challenges. This consortium is comprised of major universities involved in fuel cell catalyst development, the National Institute of Advanced Industrial Science and Technology, and leading Japanese manufacturers of stationary and motor vehicle fuel cell stacks. Under the leadership of Professor Minoru Inaba of Doshisha University, the assigned research and development will be conducted in close mutual collaboration among the universities, and between companies and universities, in order to accelerate the development of fuel cell catalyst technology for practical use.
Platinum costs and scarcity are a major barrier to promoting the use of fuel cells. If a dramatic reduction in the usage of platinum for catalysts can be attained through this research, this would help resolve platinum cost and scarcity problems, thereby opening the way for the widespread use of stationary fuel cell systems and fuel cell vehicles. This would also contribute to the development of key new energy industries centered on fuel cell technologies and promoted in Japan’s Cool Earth 50 initiative.
Carbon alloy catalysts
Reducing costs by developing alternative catalysts

❖ Objective
The aim of this research is to develop the world’s first carbon alloy catalysts with performance and durability that are satisfactory enough to replace the present platinum catalysts. Knowledge obtained through this research is expected to have an impact on the science of carbon alloy catalysts.

❖ Project leader
Seizo Miyata, Senior Program Manager, New Energy and Industrial Technology Development Organization

❖ Subleader
Junichi Ozaki, specially assigned professor, Tokyo Institute of Technology

❖ Project term
FY2008 - FY2009

❖ Project overview
Under this research, a collaborative effort of four universities and two corporations assembled at a research office at the Tokyo Institute of Technology, the following four R&D subjects with the objectives of establishing a method to manufacture carbon alloy catalysts and assessing the feasibility of using carbon alloy catalysts practically will be pursued:

I . Establishing a method to manufacture carbon alloy catalysts
   ① Clarify the correlations between the molecular structure of raw materials, carbonization conditions, and the structure of the produced carbon alloy materials
   ② Control carbonization

II . Assessing the feasibility of using carbon alloy catalysts practically
   ③ Analyze carbon alloy catalyst functions
   ④ Characterize and develop structural analysis of carbon alloy catalyst and identify mechanism

❖ Make up of this consortium
This research incorporates the collaborative efforts of researchers specializing in fuel cells, material science, synthetic chemistry, spectroscopy, and theoretical chemistry from four universities and two corporations (Tokyo Institute of Technology, The University of Tokyo, Japan Advanced Institute of Science and Technology, Gunma University, Nisshinbo Industries, Inc., and Teijin Ltd.), with a research office located at the Tokyo Institute of Technology. The research leader devotes his full attention to managing the research so that researchers can concentrate on their assigned research and development work.
Progress and results

Carbon alloy catalysts consist of graphene with several percent of nitrogen. There are five possible positions where the nitrogen atom can be located, as numbered on the accompanying graphene figure. Using an X-ray spectroscopy at Spring-8, it has been shown that catalyst activity is highest when there is a nitrogen atom at position 5 on the zigzag edge. Moreover, using computational simulation and theoretical analysis, it was discovered that the carbon atom next to nitrogen in position 5 becomes a catalytic site.

Research subjects

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<td>① Characterization and structural analysis of a carbon alloy catalyst</td>
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<td>② Control of carbonization</td>
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<td>II. Assessing feasibility of using carbon alloy catalysts practically</td>
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<td>③ Analysis of carbon alloy catalyst functions</td>
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<td>④ Characterization and structural analysis of the carbon alloy catalyst</td>
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Schedule

Electronic density of states for carbon at zigzag edge
By using nitrogen to increase the number of electrons located just below the Fermi level, catalytic performance can be stimulated.

Expected results

The significant amount of platinum used in PEFC catalysts is a major economic and resource challenge that inhibits promoting the practical and widespread use of PEFCs. It is important, therefore, to develop non-platinum catalysts to facilitate the practical application of PEFCs. To this end, proactive research and development efforts are being made in Japan, as well as in the United States and other countries. Success in this research is expected to result in a dramatic cost reduction and to boost the use of PEFCs. Carbon alloy catalysts developed in Japan will help establish a more environmentally sustainable economy. Furthermore, since a carbon alloy is an unprecedented and innovative type of catalyst, clarifying its mechanisms could open a new horizon of catalyst science.
Non-precious metal oxide based cathode for PEFC
Reducing costs by developing alternative catalysts

Objective
This goal of this research is to develop non-precious metal oxide-based catalysts and cathodes for PEFCs capable of replacing platinum catalysts in an effort to promote the widespread use of PEFCs.

Project leader
Kenichiro Ota, Professor, Faculty of Engineering, Graduate School of Engineering, Yokohama National University

Project term
FY2008 -FY2009

Project overview
To develop non-precious metal catalysts for cathodes capable of replacing platinum catalysts for use in vehicles and stationary PEFCs, transition metal oxides, which contain nitrogen and carbon, are being studied to identify high-performance and durable catalyst materials. Efforts are being made to improve the performance, analyze the mechanisms of how catalysts work, develop catalyst manufacturing technology, make and optimize fuel cell electrodes, and ensure that fuel cells using the developed catalysts will be realized.

Make up of this consortium
The Group 4 and Group 5 transition metal oxides, including nitrogen and oxygen, identified by a research group at Yokohama National University are more stable and capable of catalytic oxygen reduction than platinum in an acidic solvent. In particular, tantalum and zirconium oxides can deliver performance comparable to platinum when used as catalysts. This research applies these transition metal oxides to fuel cells in order to smooth the way for full-dissemination of fuel cell vehicles. With Professor Kenichiro Ota of Yokohama National University serving as the research leader, the participating universities and material manufacturers, who specialize in basic research, and other universities and organizations who have successful achievements in catalyst evaluation and electrode/cell stack manufacturing, are cooperating to develop the world’s first non-precious metal cathodes for PEFCs.
Due to its cost and scarcity, it is necessary to eliminate the dependency on platinum for fuel cell catalysts, in order for fuel cells to be used widely for motor vehicles and stationary applications. The aim of this research is to eliminate the use of platinum in polymer electrolyte fuel cells. If successful, this research is expected to create a truly environmentally sustainable economy based on the utilization of hydrogen and fuel cells.

Though platinum and other precious metal catalysts are widely used in practical applications at present, it is expected that the principle for the development of catalysts capable of replacing precious-metal catalysts can be identified by applying the results of this research. Also, by using newly-developed catalysts that are completely different than existing catalysts, it is expected that new insights regarding the mechanisms of oxygen reduction reactions can be obtained, which would greatly contribute to the establishment of an electrode catalyst theory.

**Progress and results**

**Fig. 1 Solubility in 0.1M H2SO4 at 30°C**

Stable material with a lower level of solubility than platinum

**Fig. 2 Performance of developed oxide catalysts**

In FY2009, one catalyst achieved oxygen reduction target

**Schedule**

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<td>② Understanding reaction mechanisms</td>
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<td>③ Developing manufacturing technology</td>
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<td>④ Improving catalyst performance</td>
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<td>⑤ Manufacturing and evaluation of cells</td>
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**Expected results**

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