## CONTENTS

### Introduction

- Background .................................................................................................................. 2
- Political Measures and Industrial Trends in Japan ....................................................... 2
- Activities of NEDO’s Fuel Cell and Hydrogen Technology Development .................... 2
- Projects of Fuel Cell and Hydrogen Technology ......................................................... 3

### PROJECT

<table>
<thead>
<tr>
<th>Fuel Cell</th>
<th>Hydrogen</th>
<th>Codes and Standards</th>
<th>Demonstration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Strategic Development of PEFC Technologies for Practical Application ........... 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Strategic Development of PEFC Technologies for Practical Application/Research on Nanomaterials for High Performance Fuel Cells ............... 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Fuel Cell Cutting-Edge Scientific Research Project ...................................... 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Development of System and Elemental Technology on Solid Oxide Fuel Cells (SOFC) ................................................................. 12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Development of Technologies for Hydrogen Production, Delivery and Storage Systems .......................................................... 14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Fundamental Research Project on Advanced Hydrogen Science .......................... 16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Advanced Fundamental Research on Hydrogen Storage Materials ....................... 18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Establishment of Codes &amp; Standards for Hydrogen Economy Society ............... 20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Demonstration of Residential PEFC Systems for Market Creation ....................... 22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Demonstrative Research on Solid Oxide Fuel Cells (SOFC) .............................. 24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Japan Hydrogen and Fuel Cell Demonstration Project ..................................... 26</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### MORE INFORMATION

- NEDO 2008 Roadmap for Fuel Cell and Hydrogen Technology Development
  - Overview of 2008 Roadmaps for Fuel Cell and Hydrogen Technology ............... 28
  - Digest : Polymer Electrolyte Fuel Cells (PEFC) Roadmap (Stationary fuel cell systems) .................. 29
    - Polymer Electrolyte Fuel Cells (PEFC) Technology Roadmap (Fuel Cell Vehicle (FCV)) .................. 30
    - Solid Oxide Fuel Cells (SOFC) Technology Roadmap ................................................. 31
    - Hydrogen Storage Technology Roadmap ......................................................................... 32
    - On-site Hydrogen Station Technology Roadmap .......................................................... 33
    - Off-site Hydrogen Station Technology Roadmap .......................................................... 34
  - TOPICS
  - Industry Results and Trends ...................................................................................... 35
  - Basic Knowledge
    - Hydrogen basics ........................................................................................................ 36
    - Basics of fuel cells .................................................................................................... 38
    - Introduction to the NEDO website .............................................................................. 40
In Japan’s Cool Earth-Innovative Energy Technology Program, which was announced in March 2008, stationary fuel cell systems, fuel cell vehicles, as well as hydrogen production, delivery, and storage systems, were designated as priority technologies. As part of the program’s goal of dramatically reducing carbon dioxide emissions by 2050, the research and development of fuel cells and hydrogen for practical use is being actively undertaken in both the public and private sectors. At the industrial level, a commercialization scenario for fuel cell vehicles and hydrogen stations has been developed, with the aim of commercialization for the general public by 2015.

With the heightened awareness of global environmental issues in recent years, the development of fuel cell and hydrogen-related technologies, centered around the polymer electrolyte fuel cell, has been ongoing and increasingly active worldwide. A number of measures to promote development and commercialization have been proposed and the competition to develop the technology has intensified around the world.

Given the background and trends described above, NEDO’s Fuel Cell and Hydrogen Technology Development Department is promoting technological development projects encompassing basic research, experimental studies, and the establishment of benchmarks and standards in cooperation with industry, academic institutions and government. Currently, NEDO is undertaking 11 projects in three fields: stationary fuel cell systems, fuel cell vehicles and hydrogen infrastructure. In particular, the development of polymer electrolyte fuel cells (PEFC), solid oxide fuel cells (SOFC), and hydrogen production, delivery and storage systems is being promoted. Concerning the development of PEFCs, NEDO is promoting research to significantly improve performance, extend operating life, and reduce costs. An integrated approach is being undertaken for the development of basic production technology, such as mass production technology, and next-generation fuel cell technology.

The Fuel Cell and Hydrogen Technology Development Department is collecting various on-road performance, reliability and fuel cell vehicle fuel consumption data from test runs on public roads. Furthermore, NEDO is involved in reviewing national regulations to encourage the dissemination of these technologies throughout Japan. Aiming to enhance Japan’s competitiveness in international markets, NEDO is also promoting the collection of various data and the establishment of testing/evaluation methods to be proposed for the development of international standards.
Projects of Fuel Cell and Hydrogen Technology

Stationary Fuel Cell System
- Development of System and Elemental Technology on Solid Oxide Fuel Cell (SOFC)
- Demonstrative Research on Solid Oxide Fuel Cells (SOFC)

Fuel Cell Vehicle
- Strategic Development of PEFC Technologies for Practical Application
- Strategic Development of PEFC Technologies for Practical Application/Research on Nanomaterials for High Performance Fuel Cells
- Fuel Cell Cutting-Edge Scientific Research Project
- Development of Technologies for Hydrogen Production, Delivery and Storage Systems

Hydrogen Infrastructure
- Demonstration of Residential PEFC Systems for Market Creation
- Advanced Fundamental Research on Hydrogen Storage Materials
- Fundamental Research Project on Advanced Hydrogen Science
- Establishment of Codes & Standards for Hydrogen Economy Society
- Japan Hydrogen and Fuel Cell Demonstration Project
- Technology Development
- Standardization
- Demonstration
Strategic Development of PEFC Technologies for Practical Application

1 Project overview

Duration FY2005 – FY2009
FY2008 budget ¥4.69 billion

Background Fuel cells can provide higher overall efficiency compared to conventional internal combustion engines and greatly reduce carbon dioxide emissions. The use of fuel cells also represents an oil-alternative form of transportation as various types of fuel, including natural gas and methanol, can be used. Furthermore, the use of fuel cells produces important environmental benefits, such as a reduction in the emission of air pollutants like nitrogen oxides and sulfur oxides and the quietness of the system leads to a reduction in noise pollution.

Objective Given their high output density and superior start and stop capabilities, there are high hopes that PEFCs will be fully commercialized as next-generation energy supply systems for fuel cell vehicles and residential cogeneration systems. This project is focused on establishing the technologies required for the full-scale practical application of PEFCs.

Outline To increase efficiency and reliability, and reduce costs, which are essential for the commercialization of PEFCs, this project comprehensively promotes the ongoing 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. Moreover, in order to encourage further research and development breakthroughs in these technologies, in addition to establishing fundamental technology for the practical application of PEFCs this project will promote fundamental and common research into the clarification of fuel cell stack reaction and degradation mechanisms and measurement evaluation technologies. This will be carried out through an industrial-academic collaborative approach, as well as a vertical collaborative framework incorporating systems, materials and components.

2 Project features

Under Strategic Development of PEFC Technologies for Practical Application, the following four technological development sub-projects are being promoted. The targeted technological advancements for PEFCs are expected to be achieved during the full-scale commercialization stage (2020 to 2030), when fuel cell vehicles, like conventional vehicles, are expected to have a lifespan exceeding 100,000 kilometers and residential stationary fuel cells are expected to be as durable and have a service life comparable to that of home appliances and cost are reduced to several tenths of current costs.

(1) Development of technology focused on basic and common issues

NEDO has formed a number of academic-industry consortia to carry out intensive research focused on clarifying the degradation mechanisms of unit cell and fuel cell stacks and to develop technology to improve the endurance of PEFCs. These represent the basic and common issues that must be addressed for fuel cell vehicles and the residential PEFC systems to be commercialized.

Each sub-project is promoted in an integrated approach; a project leader is assigned to each consortium to manage and promote an individual project while regular meetings of project leaders, chaired by the senior program manager of NEDO, are held to facilitate information sharing and promote discussion on common issues.

A separate brochure "Industry-academic partnership project on PEFC," describes this sub-project in more detail (in Japanese). (See next page for additional information.)
Strategic technological development concerning the practical application of PEFC

1) Basic and common issues (clarifying the reaction and degradation mechanisms)
Formation of consortia through academic-industrial collaboration and implementation of research and development into basic and common issues, in order to achieve breakthroughs in relation to improved durability and lower costs.

2) Elemental technology development
Implementation of cutting-edge elemental technology development relating to electrolyte membranes and electrode catalysts, MEA, peripheral equipment and reformers, with a view to achieving substantial improvements in durability, cost reductions and improved efficiency.

3) Technology development for practical application (development of basic production technology)
Implementation of technology for mass production processes relating to the electrodes, separators, MEA, etc. required for the practical application of PEFC.

4) Next-generation technological development
Implementation of basic and innovative research and development relating to revolutionary approaches to technological issues that should be tackled in order to achieve the technological level required for the full-scale popularization phase of fuel cell vehicles, and basic research and development aimed at scientifically clarifying the various reaction mechanisms and mass transfers within fuel cells stacks thereof.
(2) Development of elemental technology
In order to markedly improve the durability, efficiency, and cost effectiveness of PEFCs, NEDO is undertaking the development of advanced elemental technologies for each fuel cell component, including electrolyte membranes, separators, cell stacks, peripheral equipment, and reformers, setting specific development targets to be achieved for both vehicle and stationary applications.

(3) Development of technology for practical application
NEDO is promoting the development of process technologies and mass production technologies to produce components and materials for cell stacks, membrane electrode assemblies (MEAs), separators, and other peripheral systems.

(4) Development of next-generation fuel cell technology
NEDO is providing support to selected researchers at universities and other institutions who are taking innovative approaches to challenge existing concepts to promote the basic research and development of next-generation elemental technologies that are required when fuel cell vehicles are expected to be fully commercialized (2020-2030). As part of this, NEDO is promoting efforts to search for completely new high-performance materials, to design and control nano-level molecular structures, and to provide scientific clarification of the mechanisms related to the reaction and mass transfer that take place in fuel cell stacks.
Selected research themes are reviewed each year to determine whether they are to be continued for another year. New proposals are also solicited as a means of encouraging additional research themes. This process encourages selection and focus in order to breakthrough barriers impeding the development of next-generation technologies.

Future development

Leveraging the collaborative efforts of the government, industrial, and academic sectors, this five-year project (FY2005-FY2009) is being strongly promoted by NEDO with the aim of ensuring that Japan leads the world in the creation of a PEFC market, thereby building an international competitive advantage. NEDO is supporting the full-scale commercialization of PEFCs in Japan by encouraging technological breakthroughs to improve performance, durability, and reduce production costs.

Introduction to the brochure “Industry-academic partnership project on PEFC”
A detailed brochure that describes the consortium-type projects promoted under this project is available at the website of NEDO’s Fuel Cell and Hydrogen Technology Development Department.
Please visit the site at http://www.nedo.go.jp/kankobutsu/pamphlets/bunya/07nentryo.html. (From the top page of the NEDO website, select “Departments, Branches and Overseas Offices”, “Fuel Cell and Hydrogen Technology Development Department,” and then “Pamphlets and Publications” (Japanese only).
Technology overview

Major technological issues relating to PEFC

**Running conditions**
- Expansion of the scope of conditions permitting running (temperature, humidity)
- Improvement of durability (running in low humidity conditions, etc.)
- Increasing efficiency (running at high temperatures, etc.)
- Starting at low temperatures (starting in the range -40 – 30°C)

**Systems**
- Cost reductions and increased durability of peripheral equipment
- Increased operating life and efficiency of reformers
- Development of reform-type platinum-substitute catalysts

**Polymer electrolyte membranes**
- Development to increase durability
- Maintenance of conductive properties at high temperatures and/or low humidity
- Reducing the cost of the electrolyte membrane
- Clarification of degradation mechanism

**Separators**
- Making separators thinner, lighter in weight and cheaper
- Improved electrical and thermal conductivity
- Improved channel design and corrosion resistance

**Electrodes (fuel electrode & air electrode)**
- Reducing the quantity of platinum used
- Developing catalysts that are a substitute for platinum
- Developing a high-CO poisoning-resistant catalyst (fuel electrode)
- Improved resistance to stop-start operation and the electrical potential cycle
- Clarification of the cell degradation mechanism and technologies for evaluating this
Strategic Development of PEFC Technologies for Practical Application/Research on Nanomaterials for High Performance Fuel Cells

1. Project overview

Duration | FY 2008 – FY 2014
FY2009 budget | ¥2.0 billion
PL | Masahiro Watanabe, Professor and Director, Fuel Cell Nanomaterials Center, University of Yamanashi

Background
There are high hopes in industrial circles that there will be innovative breakthroughs that will satisfy the diverse issues that need to be addressed in order to achieve full-scale commercialization of fuel cells, namely cost reductions and improvements in performance, durability and reliability. Since FY2005, under Strategic Development of PEFC Technologies for Practical Application, NEDO has been conducting basic research into challenges such as clarifying the reaction and degradation mechanisms of fuel cells. In the future, it will be necessary to expand the knowledge gained through this project into the development of innovative materials.

Objective
By blending knowledge about reaction and degradation mechanisms with cutting-edge technologies, such as nanotechnology, this project aims to contribute to the full-scale commercialization of PEFCs by conducting research into new materials, such as catalysts, electrolyte membranes and MEAs, and establishing basic technologies that make the production of highly efficient, high-performance, highly reliable and economic fuel cells practical.

Outline
The goal of this project is to develop, by the end of FY2014, an MEA that can start at temperatures as low as -30% and that can operate at relative humidity levels of 30% and temperatures up to 100°C; with a view to the application of fuel cells in vehicles, this project will seek to reduce the quantity of platinum used in the electrode catalyst to one-tenth of the amount currently used, with a target efficiency rating of 25%, and a low heating value (LHV) of 64%. Additional targets include attaining durability that will permit 5,000 hours of operation and 60,000 starts and stops. In order to achieve these targets, a number of researchers have been brought together under the project leader to carry out comprehensive, integrated research and development into the following four themes within a concentrated research framework:

1) Analysis of degradation mechanisms
2) Development of a highly active, highly durable catalyst
3) Development of an electrolyte membrane that can operate within a wide temperature range and at low humidity
4) Research into creating a high-performance, highly reliable MEA for vehicles

In order to achieve the aforementioned targets, research and development is being conducted with regard to the following themes.

(1) Analysis of degradation mechanisms
In order to feed back the results of the analysis of degradation mechanisms into new materials development, as well as to develop accelerated testing methods for each degradation mode, the degradation speed and degradation mechanism resulting from impurities and changes in the load on electrode catalysts will be analyzed. In addition, the degradation speed and degradation mechanism of hydrocarbon-based electrolyte membranes at high temperatures and low humidity will be analyzed and the degradation mechanism and reaction distribution within the cells will be clarified.

(2) Development of a highly active, highly durable catalyst
In order to combine high activity with the ability to withstand a large number of load changes, highly active platinum-alloy catalysts with low solubility; high-potential, stable substrates and supported catalysts; and highly active, highly durable, low steam/carbon ratio (S/C) fuel-reforming catalysts will be developed and evaluated based on knowledge gained through the analysis of degradation mechanisms.

(3) Development of an electrolyte membrane that can operate within a wide temperature range and at low humidity
In order to respond to a wide temperature range and low humidity conditions in which it is envisioned fuel cells for use in vehicles will operate, highly shape-stable hydrocarbon-based electrolyte membranes with high proton conductivity, and hydrocarbon-based electrolyte membranes with high oxidation and high ability to withstand hydrolysis will be developed and evaluated. In addition, efforts will be made to improve their characteristics under high and low temperatures and low-humidity conditions.

(4) Research into creating high-performance, highly reliable MEAs for vehicles
A hydrogen-based MEA with a high catalyst usage rate and a hydrocarbon-based MEA that is stable under changes in load and temperature cycles will be developed and evaluated, in response to the operating conditions envisioned for fuel cell vehicles.

2. Project features

In order to achieve the aforementioned targets, research and development is being conducted with regard to the following themes.

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(4) Research into creating high-performance, highly reliable MEAs for vehicles
A hydrogen-based MEA with a high catalyst usage rate and a hydrocarbon-based MEA that is stable under changes in load and temperature cycles will be developed and evaluated, in response to the operating conditions envisioned for fuel cell vehicles.
Achieving the objectives related to the production of high-performance and highly reliable materials for components, such as catalysts, electrolyte membranes and MEAs, would mark a breakthrough in Japan’s PEFC technologies and would greatly contribute to the full-scale commercialization of PEFCs.
Fuel Cell Cutting-Edge Scientific Research Project

1 Project overview

Duration FY 2008 – FY 2009
FY2009 budget ¥850 million

PI Hiroshi Hasegawa, Research Center Director, Polymer Electrolyte Fuel Cell Cutting-Edge Research Center (FC-Cubic), National Institute of Advanced Industrial Science and Technology (AIST)

Background In order to achieve technical breakthroughs that will satisfy the diverse issues that need to be addressed for PEFCs to be fully commercialized, including reductions in costs and increases in performance, durability and reliability, research and development that returns to basic science is required.

Objective The aim of this project is to develop innovative measurement, evaluation and analysis technologies related to electrode catalysts, electrolyte materials and material transfer, which are essential technologies for PEFCs; another aim is to promote a fundamental understanding of substances/materials and reaction mechanisms, and, by extension, to establish these technologies as fundamental technologies for PEFCs.

Outline In order to achieve reduction in cost and increases in performance, durability and reliability, challenges that currently inhibit the commercialization of PEFCs, research and development that goes back to basic science will be conducted. With regard to the following three themes that are essential to a breakthrough, this project aims to make extremely precise measurements in situ, envisioning the actual operating situation, and to analyze these in order to establish measurement and analysis technology, as well as provide guidelines for breakthroughs in industrial circles.

1) Clarification of electrode catalyst reaction mechanisms
2) Clarification of material transfer and reaction mechanisms in electrolyte materials
3) Clarification of material transfer mechanisms in cell component elements and interfaces

2 Project features

With the aim of providing guidelines for breakthroughs toward industry, this project will focus on research and development that goes back to basic/elemental science.

With regard to the research topics, efforts will be developed in three areas that are essential technologies for PEFCs: electrode catalysts, electrolyte materials and material transfer. Research will be conducted in the following three areas, incorporating requests from industry.

1) Clarification of electrode catalyst reaction mechanisms
   In order to drastically improve electrode catalyst performance and facilitate potential cost reductions, reaction mechanisms will be clarified by understanding the connection between the structure of electrode catalysts and substrates (including their electron structures) and catalyst activity and durability, as well as establishing techniques for the kinetic measurement of electrochemical reactions in electrode catalysts.

2) Clarification of material transfer and reaction mechanisms in electrolyte materials
   In order to drastically improve the performance of electrolyte materials and facilitate potential cost reductions, material transfer and reaction mechanisms will be clarified by such means as quantitatively understanding the connection between proton conduction, gas permeation and chemical durability, as well as establishing techniques for clarifying the higher order structure in environments equivalent to actual operating environments.

3) Clarification of material transfer mechanisms in cell component elements and interfaces
   In order to achieve improvements in material transfer speeds in cell component elements and interfaces, the structure of the catalyst layer and the gas diffusion layer in environments equivalent to actual operating environments will be clarified. In addition, the material transfer mechanisms will be clarified by such means as quantitatively understanding the impact of those structures on material transfer and thermal and electrical conduction.

3 Future development

This research will lead to an understanding of the limits of current technology, present guidelines for development aimed at overcoming those limitations, and facilitate the realization of new technologies (new materials, new structures, new systems, etc.) that will result in dramatic cost reductions.
Project overview

New Energy and Industrial Technology Development Organization (NEDO)

Project Leader: Hiroshi Hasegawa, Research Center Director, Polymer Electrolyte Fuel Cell Cutting-Edge Research Center (FC-Cubic), National Institute of Advanced Industrial Science and Technology (AIST)

Polymer Electrolyte Fuel Cell Cutting-Edge Research Center (FC-Cubic), National Institute of Advanced Industrial Science and Technology (AIST)

1) Clarification of electrode catalyst reaction mechanisms
2) Clarification of material transfer and reaction mechanisms in electrolyte materials
3) Clarification of material transfer mechanisms in cell component elements and interfaces

University of Texas at Austin 3) (Catalyst modeling)

<Joint Implementation>

Ochanomizu University
1) Reduction in the quantity of platinum, platinum dissolution mechanisms, etc.

Japan Advanced Institute of Science and Technology
1) (Model catalyst synthesis)

Sophia University
2) (Development of hydrocarbon-based model electrolyte materials)

Technology overview

Industry needs
Research issues

Material transfer and reaction mechanisms in electrolyte materials

Ensuring ability to operate at high temperatures (Ensuring ability to operate at low temperatures)
Improving durability
Improving cost potential

Claritying the reaction mechanism of electrode catalysts

Revolutionary reductions in the quantity of catalyst platinum (Non-noble metal catalysts)
Improvement in the durability of catalysts and substrates

1) Establishing techniques for searching for electrochemical reactions on the catalyst surface
2) Clarifying the relationship between electrode catalyst structures and electrochemical reactions

Claritying the material transfer mechanisms in cell component elements and interfaces

Improving performance (water management control technology)
Improving durability
Improving cost potential

Electrolyte Catalyst layer MPL Gas diffusion layer Separators

1) Establishing kinetic measurement techniques
2) Clarifying the transfer phenomenon

Image of higher order structures and water clusters
Project overview

**Duration**  FY 2008 – FY 2012

**FY2009 budget**  ¥1.20 billion

**PL**  Harumi Yokoyama, Invited Research Scientist, Energy Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST)

**Background**  Relative to other fuel cells, solid oxide fuel cells (SOFC) have a high power generation efficiency and can operate with a diverse variety of fuels, such as natural gas and coal gas. As such, there are high expectations with regard to their practical application, as they are highly adaptable and can be used in a wide range of systems within small-scale distributed systems and alternative systems to large-scale thermal power systems. There is a pressing need to establish SOFC system technology in Japan and to establish elemental technologies that are needed for next-generation SOFC systems that will be used in the full market introduction stage.

**Objective**  The objective of this project is to conduct the basic research and elemental technology development required in order to establish those basic technologies and to introduce SOFC systems to the market as soon as possible.

**Outline**  1) Research and development on fundamental common issues

   Through basic research focused on improving the durability and reliability of SOFCs, the prospects for 40,000 hours of operation (voltage reduction rate of 0.25%/1,000 hours) and the prospects for 250 starts and stops will be determined. In addition, the development of technologies to reduce the costs of materials and cell stack modules will be promoted.

2) Technological development for improving practical utility

   Stop-start technology, aimed at improving operability, and high-pressure operation technology, aimed at achieving ultra-high-efficiency operation will be established

2 Project features

Under this project, the following research and development will be conducted.

**1) Research and development on fundamental common issues**

   i) Establishing the foundations for improving durability and reliability

   Durability and reliability are must be improved in order for SOFC systems to be practically applied. Accordingly, using thermodynamic, chemical, and mechanical analyses, efforts will be made to clarify degradation mechanisms, formulate measures, verify results, and establish accelerated tests. In particular, with regard to the triphasic interface, which has a significant impact on performance, this project will seek to establish the correlation between the degradation phenomenon and changes in the microstructure. Moreover, durability evaluation techniques that will enable users to easily assess the remaining life of the cell will be established.

   ii) Technological development aimed at reducing the cost of raw materials and other materials, and at creating a low-cost cell stack module

   Cost reductions will be required for cell stacks to become fully commercialized. Accordingly, stack manufacturers and material manufacturers are collaborating with regard to common raw materials and other materials that will be used, in order to develop low-cost manufacturing methods. Moreover, with regard to cell stacks, development is taking place with regard to designs and manufacturing techniques that will facilitate low-cost manufacturing.

**2) Technological development for improving practical utility**

   i) Stop-start technology for improving operability

   In cogeneration systems in the several tens of kilowatt-class, flexible operability is required with regard to stopping and starting, and load changes. Under this project, the development of cell stack modules that will not result in degradation or breakdown of the cells in such operating states and the development of system configuration and control methods is being undertaken.

   ii) High-pressure operating technology for ultra-high-efficiency operation

   As the temperature of exhaust heat from SOFCs is extremely high, creating a structure based on a combined power generation cycle with gas turbines or other such equipment will, in theory, result in power generation at an efficiency of 60% or higher. Since this significantly surpasses the 40% average power generation efficiency for thermal power systems, there are high hopes for this form of power generation to become a substitute for thermal power generation. Highly pressure-resistant cells that can be combined with gas turbines, and safe stop-start control technology is being developed under this project as infrastructure technologies for SOFCs.
Future development

Because improving the durability and reliability of SOFCs is an important challenge, this project is being conducted applying a multidisciplinary approach. In collaboration with Demonstrative Research on Solid Oxide Fuel Cells (see p. 24-25), this project will clarify degradation mechanisms and countermeasures and promote the practical application of SOFCs.

Project overview

Example of SOFC cell modules

Vertical cylindrical cell bundles

Example of SOFC systems

Cogeneration system in the several tens of kilowatts class

Horizontal cylindrical cells and several hundred kilowatt pressurized module

Several hundred kilowatt combined-cycle system
Development of Technologies for Hydrogen Production, Delivery and Storage Systems

1 Project overview

Duration FY 2008 – FY 2012
FY2009 budget ¥1.36 billion

Background For Japan, a country lacking indigenous energy resources, it is essential to develop next-generation energy technology, by developing, introducing and commercializing innovative energy technology in order to achieve sustainable development. As part of these efforts, the development of fuel cell vehicles is progressing. In parallel, technology is being developed to deliver a safe, efficient supply of hydrogen to fuel such vehicles.

Objective To establish hydrogen supply infrastructure around 2015 in coordination with the coming commercialization of hydrogen energy, under this project the technological development of low-cost, highly durable equipment and systems for hydrogen production, transport, storage and refueling, as well as elemental technological development will be conducted. Next-generation technological development and scenario formulation, as well as a feasibility study, will also be carried out. Through these efforts, technology related to the equipment and systems required for the introduction and commercialization of hydrogen energy will be established.

Outline System technology: With regard to hydrogen storage and transport containers, such as hydrogen station equipment and vehicle-mounted containers, lower-cost, more compact containers will be developed and the durability of systems that combine these will be verified.

Elemental technology: the development and verification of elemental technology aimed at improving hydrogen manufacturing, transport, storage and filling equipment and systems will be conducted, making the equipment cheaper and lighter, and increasing its service life.

Next-generation technological development and feasibility study: This project will focus on the consideration of technology development scenarios aimed at the establishment of a hydrogen-based society and the development of innovative technology based on new concepts (for example, hydrogen production from sources other than fossil fuels), as well as investigating a technology development scenario for the realization of a hydrogen economy.

Development will be conducted in the following three stages, with a view to establishing a market that is envisioned to take shape in 2015.

System technology development: Based on the elemental technology and equipment developed to date and in order to be prepared for 2015, development will be conducted that will lead to cheaper, more compact hydrogen storage vessels, such as vehicle-mounted storage vessels and station equipment that meet the demands of refueling at 70MPa, to build a hydrogen supply chain that encompasses multiple types of equipment; in addition, work will be carried out to establish the necessary technology and to ensure the durability of the hydrogen supply system as a whole.

Development of elemental technology: With regard to elemental technology for hydrogen production, transport, storage and filling equipment and systems, to be achieved by 2015 or thereafter, technological development will be focused on improving performance, reducing costs, increasing service life and improving maintainability, taking into consideration the perspective of the user.

Next-generation technological development and feasibility:

i) Innovative next-generation technologies:
In order to achieve technological development breakthroughs, innovative next-generation technologies will be sought based on new concepts (including international joint research with overseas research institutions), such as producing hydrogen from sources other than fossil fuels, and the utility of such technologies will be confirmed and verified.

ii) Research and development such as a feasibility study related to technological development scenarios for the introduction and commercialization of hydrogen energy:
With a view to the introduction and commercialization of hydrogen energy, a feasibility study will be conducted focused on development scenarios that impose the least cost on society; issues affecting future technological development will be identified and beneficial information supporting the aforementioned development activities will be shared and disseminated.

2 Project features

3 Future development

In collaboration with related industrial sectors and other hydrogen-related projects, focus will be placed on the establishment and realization as soon as possible of hydrogen supply technology in order to ensure that it can be incorporated at the early fuel cell commercialization stage (2015), the target date set by the Fuel Cell Commercialization Conference of Japan (FCCJ).
Development of Technologies for Hydrogen Production, Delivery and Storage Systems

**Project overview**

Relating to hydrogen station technology
- Japan Petroleum Energy Center, Toho Gas Co., Ltd., Tokico Technology Ltd., Hitachi, Ltd., Taiyo Nippon Sanso Corporation, Yokohama Rubber Co., Ltd., Saga University
- Tatsuno Corporation
- Nippon Oil Corporation
- Shimizu Corporation, Iwatani Corporation
- Japan Petroleum Energy Center, Kitz Corporation, Yamatake Corporation, Japan Steel Works, Ltd., Japan Research and Development Center for Metals

Feasibility Study
- National Institute of Advanced Industrial Science and Technology

Consideration of studies of technological trends
- Technova Inc.
- Engineering Advancement Association of Japan

Relating to hydrogen manufacture technology
- Tokyo Gas Co., Ltd., NGK Spark Plug Co., Ltd.
- Mitsubishi Kakoki Kaisha, Ltd.
- Renaissance Energy Research, Kobe University, Kyoto University, National Institute of Advanced Industrial Science and Technology, Mikuni Corporation

Relating to hydrogen storage technology
- Japan Metals & Chemicals Co., Ltd., Sumtec, National Institute of Advanced Industrial Science and Technology
- Toyota Central R&D Labs, Inc., Tohoku University
- Japan Metals & Chemicals Co., Ltd.

Information exchange

- System technology development
- Elemental technology development
- Next-generation technology development

Relating to next-generation technology
- National Institute of Advanced Industrial Science and Technology
- Yokohama National University
- National Institute for Materials Science, Kanazawa University
- University of Tokyo
- National Institute of Advanced Industrial Science and Technology, Tohoku University
- Tohoku University, Tokai University

Technology overview

Example of target equipment and systems
1 Project overview

Duration FY 2006 – FY 2012
FY2009 budget ¥1.12 billion

PL Yukitaka Murakami, Director, Research Center for Hydrogen Industrial Use and Storage, National Institute of Advanced Industrial Science and Technology (AIST)

Background To build a hydrogen economy, it is necessary to devise a means of transporting and storing large quantities of hydrogen in a compact form. In order to do this, it is inevitable that hydrogen will need to be in a liquefied form or under high pressure for efficient handling.

In particular, a clear understanding of the physical properties of high-pressure hydrogen and hydrogen embrittlement in high-pressure or liquefied hydrogen environments is especially important for the production of materials, equipment components, and to evaluate margin of safety. (Hydrogen embrittlement: The phenomenon where the tensile strength of metals is reduced through the absorption of hydrogen.)

Objective The aim of this project is to provide industry with guidelines relating to material and equipment design and degradation evaluation methods in order to use hydrogen more safely and more conveniently.
In addition, the evaluation of hydrogen materials will be carried out with a view to also providing industry with the collected basic data, which will be required when proposing technical standards and standardization to domestic/international standards organizations.

Outline Using advanced research equipment such as material evaluation equipment, which enables the creation of an ultrahigh-pressure hydrogen gas environment, a phenomenon such as hydrogen embrittlement can be recreated. By precisely observing the behavior of hydrogen and the condition of materials, this project aims to clarify the basic principles of these phenomena.

Based on these scientific knowledge about hydrogen and materials, rational guidelines can be provided for equipment design (material degradation countermeasures) and material degradation evaluation methods to support the manufacturing necessary for building a hydrogen economy.

2 Project features

(1) Basic research concerning the physical properties of high-pressure hydrogen
A database will be constructed related to pressure, volume, temperature (PVT), as well as the coefficient of viscosity, thermal conductivity and specific heat of high-pressure hydrogen; in addition, a software tool that can estimate the thermophysical properties of hydrogen will be developed.

(2) Understanding of the basic principles of the embrittlement of metals and other materials exposed to high-pressure or liquid hydrogen and a study of possible countermeasures
This project will observe the influence on materials exposed to high-pressure or liquefied hydrogen and clarify the hydrogen embrittlement mechanism.

(3) Study concerning the strength of metallic materials that have been exposed to pressurized or liquefied hydrogen over an extended period of time or that have been processed (materials that have been molded, welded, or which have undergone surface modifications); material strength research on the effect temperature and other factors have on metallic materials
Simple methods to evaluate the hydrogen embrittlement of materials in a short period of time by accelerating degradation will be proposed. In addition, these methods will be used to evaluate the influence of material processing or the composition of the materials. A database of properties of the materials that are used in hydrogen environments will be constructed.

(4) Study concerning the strength of polymer materials that have been exposed to pressurized or liquefied hydrogen over an extended period of time, or that have been processed (materials that have been molded, welded, or have undergone surface modifications); material strength research on the effect temperature and other factors have on polymer materials
Design guidelines will be established for hydrogen-resistant polymer materials to be used as sealing materials or liner materials that will be exposed to high-pressure hydrogen by observing both the degradation of the macrostructure of materials (e.g. blister fractures), as well as micro level composition or chemical structure changes.

(5) Clarification of tribology in high-pressure hydrogen environments
A database will be constructed of the tribological characteristics of materials used for bearings, valves, and seals in high-pressure hydrogen environments in order to offer suggested design guidelines for a hydrogen-resistant tribological system. (Tribology: the principles of friction, abrasion, and lubrication between the surfaces of two materials)

(6) Simulation study on hydrogen behavior (diffusion, leakage, etc.) in materials
Technology that simulates hydrogen diffusion in solid materials and clarifies the mechanism of the effect of hydrogen on strength and fatigue resistance of a material will be developed. These technologies will support an understanding of the hydrogen embrittlement mechanism and assist the evaluation of the materials to use in hydrogen environments.
Future development

This project is being carried out mainly by the Research Center for Hydrogen Industrial Use and Storage (HYDROGENIUS), which was established on the Ito campus of Kyushu University as a research facility offering an environment for conducting high-pressure hydrogen demonstration experiments and high precision analysis. Japanese and international researchers in this field are being invited to use the facilities at which necessary experimental equipment will be installed. It is hoped that, based on collaboration with NEDO’s hydrogen projects and research institutions within Japan and overseas, the mechanisms by which hydrogen affects various materials and the characteristics of hydrogen in its high-pressure and liquefied forms will be clarified, thereby facilitating the resolution of issues currently faced by industry.

Project overview

Technology overview

Basic physical properties of hydrogen under high pressure

- PVT Data
- Coefficient of viscosity
- Thermal conductivity
- Specific heat
- Solubility, etc.

Used as design data for various systems

Example of hydrogen embrittlement, SUS316 (Tensile test under high pressure)

Advanced Fundamental Research on Hydrogen Storage Materials

1 Project overview

Duration FY 2007 – FY 2011
FY2009 budget ¥1.0 billion
PL Etsuo Akiba, Deputy Director, Energy Technology Research Institute (ETRI), National Institute of Advanced Industrial Science and Technology (AIST)

Background From the perspective of convenience, hydrogen storage materials (alloys that absorb and desorb hydrogen) are attracting a great deal of attention for their potential to provide a safer, simpler, more efficient and cheaper means of storing the required amount of hydrogen on fuel cell vehicles. However, technological development results achieved to date are still insufficient to permit practical application. It is believed that significant improvements will be required for future commercialization.

Objective This project will clarify the basic principles of high performance and highly durable hydrogen storage materials and conduct cross-sectional fundamental research into a wide range of fields related to the knowledge required for applied technology. The aim of this project is to facilitate the development of a hydrogen economy and the dissemination of fuel cell vehicles by providing the results of the research to industry and also producing technological development guidelines for the development of relevant materials.

Outline Through the clarification of the basic principles of hydrogen storage materials and cross-sectional fundamental research conducted in a wide range of fields related to the knowledge required for applied technology, as well as the promotion of research in collaboration with other related hydrogen technology projects currently being implemented in parallel (Development of Technologies for Hydrogen Production, Delivery and Storage Systems and Fundamental Research Project on Advanced Hydrogen Science), the basic principles of hydrogen storage materials and the establishment of basic technology to develop material research using computing science will be clarified in this project.

In this project, the five research groups promote collaborative approaches under the leadership of the project leader.

(1) Fundamental research on metal hydrides for hydrogen storage
Fundamental research based on experimental approaches to metallic materials and the clarification and evaluation of phenomena is being conducted. In addition to analyzing structures related to various scales, such as crystalline structures, local structures and defective structures, this group will identify factors that are important in considering hydrogen absorption and storage properties and clarifying reaction mechanisms and promote more sophisticated measurements and analysis techniques.

(2) Basic research of metal hydrides with light elements
It is believed that hydrogen storage materials consist of lightweight elements, which have a greater hydrogen density by weight than alloys, will contribute significantly to achieving lighter hydrogen storage vessels, but a material that achieves the necessary performance level has yet to be discovered. This group will clarify the reaction mechanisms of non-metallic hydrogen storage materials and will establish the infrastructure technologies for applying them as high-performance hydrogen storage materials.

(3) Advanced research on hydrogen-metal interaction of hydrogen storage materials
A variety of synchrotron radiation analytical equipment installed in the world’s top-performing synchrotron radiation facility (SPring-8) will be used to conduct experimental verification and clarification related to such matters as the structural properties of hydrogen storage materials, the correlation between material properties and chemical controls on material surfaces, and the status and structural changes of local electrons.

(4) Computational study on the properties and microscopic kinetics of hydrogen storage materials
By using a computational science approach to identify the most stable position for a hydrogen atom in hydrogen storage systems, as well as to analyze electron density distribution and electron structure, candidate hydrogen storage materials that can respond to various conditions and clarify their structural characteristics will be identified.

(5) Atomic structure research of hydrogen storage materials with an advanced neutron diffractometer
This group will develop and improve total neutron scattering instruments at the Japan Proton Accelerator Research Complex (J-PARC) and use these to conduct structural research into hydrogen storage materials in order to clarify the basic principles of hydrogen storage mechanisms.
In addition to making effective use of Japan’s leading quantum beam facilities (J-PARC and SPring-8), the technology of leading research institutes, such as the Los Alamos National Laboratory in the U.S., will be used and researchers will cooperate with industry. Through these efforts, the development of guidelines for hydrogen storage materials with the aim for practical application will be facilitated.

Project overview

Technology overview

- **Hydrogen absorption and emission process**
  - Entry and exit of hydrogen atoms
  - Expansion and contraction (distortion) of metal lattice

- **Identification of hydrogen atom positions through a neutron total scattering device that uses a world-class neutron beam**

- **Cutting-edge analytical device**
  - Sample for analysis
  - Scattered neutrons
  - Neutron detector

- **Formulation of development guidelines for hydrogen-storing materials**

**Total neutron scattering instrument; Nova**
Establishment of Codes & Standards for Hydrogen Economy Society

Project overview

<table>
<thead>
<tr>
<th>Duration</th>
<th>FY 2005 – FY 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY2008 budget</td>
<td>¥9.0 billion</td>
</tr>
</tbody>
</table>

**Background**
In order for hydrogen and fuel cells to be widely and smoothly commercialized and to establish a hydrogen economy with a global market closely associated with industry, it will be essential to develop, in addition to technology, soft infrastructure, such as benchmarks and standards. It will also be necessary to review related regulations and improve infrastructure for the promotion of fuel cell vehicles and stationary fuel cell systems.

**Objective**
The aim of this project is to conduct development related to testing and evaluation techniques in order to propose sophisticated technological standards and drafts for standardization to domestic and international standards organizations to ensure safety and to obtain and evaluate data that will confirm this.

**Outline**
In order to achieve the above objective, testing methods are being developed and performance data is being obtained and evaluated with regard to the physical properties of materials and data to confirm safety, which is required for regulatory revisions in line with government policy and industry needs, thereby supporting the formulation of sample standards. Moreover, international standards and regulatory revisions related to such matters as hydrogen supply and fuel cells are being promoted, as is the initial creation of a fuel cell market. In addition, with regard to international standards, testing and research data is being actively provided to international standards bodies such as the ISO with the aim of developing benchmarks and standards within Japan, as well as international standards that are closely aligned with these.

(1) Review of regulations relating to fuel cell vehicles and R&D for standardization
The safety of fuel cell vehicles that use high-pressure compressed hydrogen, liquefied hydrogen, and related technology will be verified, and data that will confirm this will be acquired and evaluated. Moreover, in order to maximize convenience from the perspective of users and enhance travelling performance by extending the range of such vehicles, as well as to ensure their safety and reliability, evaluation techniques will be proposed in line with progress regarding the technological level of fuel cell vehicles. Evaluation and testing devices will be developed, and data relating to safety and reliability will be analyzed.

(2) Review of regulations relating to stationary fuel cell systems and R&D for standardization
As efforts aimed at simplifying the systems while ensuring the safety of fuel cells are ongoing, with a view to future commercialization, relevant supporting data to be used for new regulations and standardization to match such simplified systems will be collected and the results will be reflected in the review of regulations and standardization.

(3) Review of regulations relating to hydrogen infrastructure and R&D for standardization
Data that provides evidence relating to the safety and installation requirements of hydrogen infrastructure equipment that can be used with fuel cell vehicles that use ultra-high-pressure compressed hydrogen, liquefied hydrogen and hydrogen storage materials will be obtained and evaluated. Performance evaluation techniques will be established, evaluation and testing devices will be designed and the utility of these will be verified.

Future development
Data that provides evidence relating to the necessary themes will be obtained and evaluated based on trends concerning international standardization efforts and domestic regulatory revisions relating to fuel cells and hydrogen. It is hoped that this data will be reflected in the formulation of draft international standards and sample standards for the revision of regulations through FY2009, and that deregulation will be promoted as a result.
Establishment of Codes & Standards for Hydrogen Economy Society

Project overview

- **NEDO**
  - Promotion and Advisory Committee (Chairman: Michihiko Nagumo, Emeritus Professor, Waseda University)

- Japan Automobile Research Institute
  - Research and development focused on standardization and the review of regulations concerning fuel cell cars

- Japan Gas Association
  - Japan Gas Appliances Inspection Association
  - Japan Electrical Manufacturers’ Association

- National Institute of Advanced Industrial Science and Technology
  - Research and development focused on standardization and the review of regulations concerning stationary fuel cell systems

- Japan Petroleum Energy Center
  - Mitsubishi Heavy Industries Ltd., Japan Industrial Gases Association, Japan Steel Works, Ltd., Tatsuno Corporation

- Japan Research and Development Center for Metals
  - Aichi Steel Corporation, Nippon Steel Corporation, Sumitomo Metal Industries, Ltd., High Pressure Gas Safety Institute of Japan

- Japan Aluminium Association

Technology overview

- **Hydrogen stations**
  - Gas storage containers for use at hydrogen stations

- **Solid Fuel Oxide Fuel Cell (SOFC) system**
  - Explosion and fire testing equipment
Demonstration of Residential PEFC Systems for Market Creation

1 Project overview

Duration FY 2005 – FY 2009
FY2008 budget –

Background While expectations are high for fuel cells to be put into practical use as energy-efficient, CO2 emission reducing, new power sources, it is necessary to significantly reduce costs and improve durability and reliability before they can be broadly adopted. In this project, issues will be clarified when residential fuel cell systems are being installed in ordinary households, and tasks will be identified in order to commercialize fuel cells as soon as possible.

Objective Under this project, stationary fuel cell systems are being installed on a large scale across a considerable area of Japan. Verification data derived from actual usage in ordinary households is being acquired in order to understand technical and non-technical problems.

Outline Thousands of polymer electrolyte fuel cells (PEFC), supply electricity and hot water, have been installed at ordinary households across a wide area of Japan for the purposes of conducting a large-scale demonstration study. The study allows energy supply companies participating in this project to gain experience from installing the systems in ordinary households and to obtain operating data, including information on defects and efficiency levels. This data is collected, evaluated and analyzed to gain an understanding of the technological and developmental challenges facing stationary fuel cell systems.

2 Project features

This is a large-scale demonstrative research project involving the installation over four years of a total of 3,307 residential fuel cell systems in ordinary households. It is the first such initiative in the world. Given the scale, it is hoped that the project will spur dramatic advances in Japanese fuel cell technology and promote the development of mass production systems and manufacturing cost reductions by system manufacturers, as well as simplified system installation processes and the development of maintenance systems by energy supply companies. The project is considered vital in determining whether a fuel cell market can be established. Moreover, using household electricity and heat usage data, it will be possible to determine the energy saving effect of fuel cells. It is hoped that fuel cells will be recognized as an ecological power source for daily use.

3 Future development

This project, in collaboration with the Strategic Development of PEFC Technologies for Practical Application project (see p. 4-7), has resulted in substantial reliability improvements and cost reductions for systems installed in FY2008. Throughout FY2009, operating data will be collected, evaluated and analyzed. “ENE-FARM” (short for “energy farm”) is a marketing term coined for the residential fuel cell cogeneration systems product category. With financial incentives supplied by the government, these systems have been marketed commercially since FY2008.
Project overview

Energy supply companies

Fuel cell manufacturers

Installation in ordinary households

Energy supply companies

Fuel cell manufacturers

Installation in ordinary households

Energy supply companies

Fuel cell manufacturers

Installation in ordinary households

Fuel cell manufacturers

Cooperating businesses

Installation in ordinary households

Fuel cell manufacturers

Evaluation Committee

Function Deliberation Subcommittee

Technology overview

<table>
<thead>
<tr>
<th>Fuel cell manufacturers</th>
<th>LPG</th>
<th>City gas</th>
<th>Kerosene</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eneos Celltech*</td>
<td>1,062</td>
<td>191</td>
<td>0</td>
<td>1,253</td>
</tr>
<tr>
<td>Ebara Corporation</td>
<td>0</td>
<td>396</td>
<td>314</td>
<td>710</td>
</tr>
<tr>
<td>Toshiba Fuel Cell Power Systems Corporation</td>
<td>554</td>
<td>194</td>
<td>0</td>
<td>748</td>
</tr>
<tr>
<td>Panasonic</td>
<td>0</td>
<td>520</td>
<td>0</td>
<td>520</td>
</tr>
<tr>
<td>Toyota Motor Corporation</td>
<td>0</td>
<td>76</td>
<td>0</td>
<td>73</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,614</td>
<td>1,379</td>
<td>314</td>
<td>3,307</td>
</tr>
</tbody>
</table>

* A new company established by Nippon Oil Corporation and Sanyo Electric

Figure 1 Participating manufacturers and installation sites
Demonstrative Research on Solid Oxide Fuel Cells (SOFC)

1 Project overview

Duration  FY 2007 – FY 2010
FY 2009 budget  ¥720 million

Background  Instead of expensive platinum catalysts, solid oxide fuel cells (SOFC) make use of ceramic technology, for which Japan has extensive development experience and expertise. Because they operate very efficiently and at high temperatures, expectations are high regarding their application in distributed power supply systems. However, sufficient demonstration data, including durability data, has yet to be gathered and there remain a number of unknown areas. It is necessary, therefore, to identify solutions to technical issues as early as possible to facilitate research and development and commercialization efforts.

Objective  Under this demonstrative research project, SOFC systems will be installed in various actual load environments and the operating data will be evaluated and analyzed in order to identify issues impeding the technological development of SOFC systems.

Outline  Compact SOFC systems will be installed in a diverse range of actual load environments, including ordinary households. Technological issues will be fed back into technological development projects such as the Development of System and Elemental Technology on Solid Oxide Fuel Cells project (see p. 19-20), in order to contribute to the swift resolution of these issues and promote the practical application of such systems as soon as possible.

2 Project features

While there are high hopes for the use of SOFCs in distributed power supply systems, little demonstration data has been collected from ordinary households. This project narrows the focus to compact SOFC systems in the range of 1 kW to 10 kW of output power. Data on durability, operation, failure and efficiency under actual load conditions is being collected, evaluated, and analyzed to identify technological issues that must be addressed in order to promote the practical utilization of SOFCs.

3 Future development

In the future, under a new research implementation structure SOFC systems will be installed in a variety of demonstration sites such as actual load environments, in regions with varying environments, etc., with the aim of accumulating additional verification data. Development issues that can contribute to improved durability and reliability for SOFCs will be identified from the collected verification data in order to promote the practical application of SOFCs in collaboration with the Development of System and Elemental Technology on Solid Oxide Fuel Cells project.
Project overview

Identifying issues
- SOFC system and elemental technology

Subsidization
- Operating data
- Subsidization
- Analysis and evaluation of result

Cooperation
- Field test operator
- New Energy Foundation
- Project evaluation committee

evaluation result

Field test Operator: System installation and data collection
New Energy Foundation: Analysis and evaluation of data

Technology overview

Figure 1 External appearance of an SOFC System

Figure 2 Image of a stationary fuel cell system

Main fuel cell unit
Hot well

Operating data
Failure data
Power generation efficiency
This data will be gathered and made use of in technological development

Provision of electrical power
Fuel
Natural gas, LPG, etc.

Hot water supply and underfloor heating
Japan Hydrogen and Fuel Cell Demonstration Project

1. Project overview

Duration FY 2009 – FY 2010

FY2009 budget ¥990 million

Background In the Commercialization Scenario for Fuel Cell Vehicles and Hydrogen Stations guidelines compiled by the Fuel Cell Commercialization Conference of Japan (FCCJ), it is stated that FY2015 will mark the beginning of the commercialization of fuel cell vehicles for general users. In order for this to happen, a review of regulations will need to be completed and a national consensus to promote fuel cell vehicles and hydrogen infrastructure will need to be built through public demonstrations.

Objective Aiming to establish a hydrogen energy economy, research will be carried out in order to demonstrate the usefulness of hydrogen infrastructure and fuel cell vehicles (FCV). Through this project, data will be collected and issues identified related to technology development, cost effectiveness and safety to facilitate the commercialization of FCV and hydrogen infrastructure. The results will be utilized for related NEDO projects.

Outline The Japan Hydrogen & Fuel Cell Demonstration Project (JHFC), a government/private sector joint research effort has been making steady progress towards the commercialization of FCV and hydrogen infrastructure. In order to ensure the commencement of commercialization in FY2015, as referenced above, in addition to existing efforts, new approaches for subsequent verification tests will be clarified through the reinforcement of activities related to safety verification and regulatory review as well as the examination of commercial infrastructure models from the perspective of energy suppliers.

2. Project features

FY2009-FY2010 project targets

1. Hydrogen infrastructure
   a) Analyze and suggest future commercial infrastructure model.
   b) Evaluate hydrogen infrastructure data collected under actual use conditions and clarify issues for practical application.
   c) Design specific programs for safety verification and review hydrogen infrastructure regulations with the aim of widespread commercialization in FY2015.

2. Fuel cell vehicles
   d) Evaluate fuel cell vehicle data collected under actual use conditions and clarify issues for the practical application.
   e) Verify energy-savings effect (improved mileage) and environmental load reduction effect.

3. Common targets for vehicles and infrastructure
   f) Analyze common requirements for vehicles and infrastructure and suggest coherent measures to address those requirements.
   g) Analyze common issues between vehicles and infrastructure, seek collaboration and suggest countermeasures.

4. Dissemination of research results, recognition improvement, internationalization and local demonstration
   h) Enhance cooperation with other hydrogen development-related projects.
   i) Publicize research results and promote improved recognition/understanding of fuel cell vehicles and hydrogen infrastructure among influential stakeholders.
   j) Share information with affiliated international authorities and conduct overseas verification tests; suggest and encourage international cooperation and global standardization.
   k) Analyze and organize rural demonstrations

5. Future verification testing
   l) On the basis of the above targets a to k, design a plan for subsequent verification testing.
Project overview

NEDO

Subsidization

Japan Petroleum Energy Center

Japan Automobile Research Institute

Engineering Advancement Association of Japan

The Japan Gas Association

Automobile manufacturers

Automobile manufacturers that submitted vehicle driving data were selected through a public solicitation.

Technology overview

Chubu Area
- Test drives for commercialization
- Fuel cell bus demonstration in cooperation with Ministry of Land, Infrastructure, Transport and Tourism
  Shuttle bus and ramp bus operations in/around the Chubu International Airport
- City gas reforming & off-site production hydrogen station
  Verification of large-scale hydrogen supply system and assessment of future prospects

Kansai Area
- Urban hydrogen station, simplified hydrogen supply equipment
- Verification of hydrogen supply for various uses
- Verification of emergency equipment
  Emergency equipment powered by fuel cells
- New hydrogen applications and verification of fuel cell systems

National Activities
- Public relations and educational activities
  Holding and participating in events
  Organizing tours to JHFC Park
  Educational activities for stakeholders
- Evaluation of domestic and international trends, promotion of international cooperation
  Survey on FCV and hydrogen infrastructure policies and technologies

Metropolitan Area
- Test drives for commercialization
- FCV demonstration in designated areas conducted by third parties
- Hydrogen stations using various feedstocks and production methods
  Verification of safety, reliability and performance
- Verification of 70MPa hydrogen supply system
  Test runs of 70MPa-compatible FCVs on public roads
Overview of 2008 Roadmaps for Fuel Cell and Hydrogen Technology

NEDO’s Fuel Cell and Hydrogen Technology Development Division has formulated roadmaps for six technological fields in order to efficiently and effectively promote research and development of these technologies.

● Objective

i) To clarify technical issues that must be tackled for the development of fuel cell and hydrogen technologies, to provide direction for technological development, and to serve as a point of reference that leads the way to efficient, precise research and development initiatives in this field at all industry and academic levels.

ii) To share technology development scenarios with stakeholders and ensure efficient, effective implementation in line with these scenarios.

iii) To promote further research and development and encourage new participation through broad dissemination of the roadmaps.

● Roadmaps for six technological fields

**Polymer Electrolyte Fuel Cell (PEFC) Technology Roadmap (stationary fuel cell systems)**
To contribute to CO₂ emissions reduction through early commercialization of the world’s most advanced high-efficiency household cogeneration systems

**Polymer Electrolyte Fuel Cell (PEFC) Technology Roadmap (fuel cell vehicles (FCV))**
To contribute to CO₂ emissions reduction through the future commercialization of next-generation clean energy vehicles (FCVs)

**Solid Oxide Fuel Cell (SOFC) Technology Roadmap**
To achieve high-efficiency power generation through the establishment of small-scale system technology and to scale this technology up for medium and large-scale systems

**Hydrogen Storage Technology Roadmap**
To develop light, compact, low-cost, safe hydrogen storage vessels for FCVs

**On-site Hydrogen Station Technology Roadmap**
To supply low cost hydrogen by producing hydrogen cost effectively on-site

**Off-site Hydrogen Station Technology Roadmap**
To supply low cost hydrogen through the establishment of safe delivery and efficient production systems, including by-product hydrogen supply systems

Overviews of the roadmaps are shown on the following pages. A full version of each roadmap was published in the NEDO 2008 Roadmap for Fuel Cell and Hydrogen Technology Development pamphlet and is available at the following website: URL: https://app3.infoc.nedo.go.jp/informations/koubo/events/FA/nedoeventpage.2008-06-18.141472325/
Polymer Electrolyte Fuel Cell (PEFC) Technology Roadmap
(Stationary fuel cell system)

To reduce CO₂ emissions through early commercialization of world's most advanced high-efficiency residential cogeneration systems

**Overview of 2008 Roadmaps for Fuel Cell and Hydrogen Technology**

**Present (end of FY2007)**
- Demonstration to early introduction
- **Electric efficiency**: 33% / 36%
- **Durability (start/stop operations)**: 20,000 hrs
- **Operating temperature**: 70°C
- System cost: 4.8 million yen (average for large-scale demonstration project)

**2008**
- **2008 Roadmap**
- **Electric efficiency**: 33% / 37%
- **Durability (start/stop operations)**: 40,000 hrs
- **Operating temperature**: 70°C
- **System cost**: 2 - 2.5 million yen (at early introduction in 2009)

**2010**
- **Electric efficiency**: 33% / 37%
- **Durability (start/stop operations)**: 40,000 hrs
- **Operating temperature**: 70°C
- **System cost**: 0.7 - 1.2 million yen (in ca. 2012)

**2015**
- **Electric efficiency**: 33% / 37%
- **Durability (start/stop operations)**: 40,000 - 90,000 hrs
- **Operating temperature**: 70 - 90°C
- **System cost**: 0.5 - 0.7 million yen (in ca. 2015)

**2020 - 2030**
- **Electric efficiency**: > 36% / 40%
- **Durability (start/stop operations)**: 90,000 hrs
- **Operating temperature**: 90°C
- **System cost**: <0.4 million yen

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**Footnotes**

1. Electric efficiency is expressed in HHV/LHV.
2. 40,000-hr durability by 2008 corresponds to 10-year daily start and stop (DSS) operation.
3. System costs correspond to shipments of 1 kW residential fuel cell systems by manufacturers. (Number of systems listed below system cost does not express market size.)
4. Assumed technology cost at a production level of 1,000 systems/company/year. Marketing strategies will also factor into the actual market price.

**Progress in stack and component cost reduction**
- Installation and operation of over 2,000 PEFC systems at private residences in Japan since 2005
- Progress in stack and component cost reduction
- Progress in reducing system costs through standardization of specifications for common BOP and vertical cooperation development
- Progress in factor analyses on degradation mechanisms through stronger cooperative efforts among industry-university-government
- Progress in various fundamental analysis and evaluation methods

**Next generation technologies for MEAs, cells, and stacks**
- MEAs and cells for high-temperature, low-RH operation (including electrolyte membranes and catalysts)

**Durability improvement stacks for high-temperature, low-RH operation**
- For 90°C operation (at <30%RH) and 40,000 - 90,000-hr durability

**Enhancement of long-term basic/fundamental technologies**
- Identification of reaction and material transfer mechanisms in/at catalysts, electrolyte membrane, and cell interfaces
- Non-humidification MEAs, non-Pt catalysts (e.g. carbon alloys, oxides, etc.), highly-active cathode catalysts, etc.
Polymer Electrolyte Fuel Cell (PEFC) Technology Roadmap
(Fuel cell vehicles (FCV))

To reduce CO₂ emissions by disseminating next-generation clean energy vehicles, FCVs, in the future

<table>
<thead>
<tr>
<th>Present (end of FY 2007)</th>
<th>2008</th>
<th>2010</th>
<th>Ca. 2015</th>
<th>2020 - 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle efficiency</strong> (10-15 mode)</td>
<td>50% (42%)</td>
<td>50% (42%)</td>
<td>&gt;60% (42%)</td>
<td>60% (51%)</td>
</tr>
<tr>
<td><strong>Durability</strong></td>
<td>1,000 hrs</td>
<td>2,000 hrs</td>
<td>3,000 hrs</td>
<td>5,000 hrs</td>
</tr>
<tr>
<td><strong>Operation temperature</strong> (including start-up temperature)</td>
<td>80°C</td>
<td>-30°C to 80°C</td>
<td>-30°C to 90°C</td>
<td>-30°C to 90-100°C</td>
</tr>
<tr>
<td><strong>Stack production cost</strong></td>
<td>Hundreds of thousands of yen/kW</td>
<td>50,000-60,000 yen/kW</td>
<td>10,000 yen/kW</td>
<td>&lt;4,000 yen/kW</td>
</tr>
</tbody>
</table>

**PEFC technology trends**

- Progress in improving stack performance (lighter, more compact, and more power, etc.)
- About 120 FCVs have been registered and participated in the JHFC project since 2002, logging about 600,000 km and accumulating data constantly.
- FCVs, efficiency measured by chassis dynamometers, has been increased from approx. 50% (in 2004) to approx. 60% (2007). Top runner values of JHFC demonstration project.
- Improved cold/start performance (start-up at -30°C is possible)
- Progress in factor analyses on degradation mechanisms through stronger cooperative efforts among industry-academia-government

**Technological challenges**

- Improving stack durability (e.g. for start/stop loads)
- Reducing cost of stacks and components
- High-temperature and low-RH operation (e.g. MEAs)
- Reducing noble metal loading
- Mass production (stacks and MEAs)

**Next-generation technologies for MEAs, cells, and stacks**

<table>
<thead>
<tr>
<th>MEAs and cells for high-temperature and low-RH operation</th>
<th>Durability improvement stacks for high-temperature and low-RH operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(including electrolyte membranes and catalysts)</td>
<td>For 90-100°C operation (at &lt;30% RH) and 3,000 hr durability</td>
</tr>
<tr>
<td>For 30-120°C operation (without a humidifier) and 5,000 hr durability</td>
<td></td>
</tr>
</tbody>
</table>

**Enhancement of long-term basic/fundamental technologies**

Identification of reaction and material transfer mechanisms (e.g. carbon alloys, oxides, etc.), highly-active cathode catalysts, etc.

**Footnotes**

*Values are expressed in LHV; HHVs are noted as reference.
**Durability includes tolerance of start/stop times at required operating conditions.
### Solid Oxide Fuel Cell (SOFC) Technology Roadmap

To attain high efficiency power generation through technological establishment of small-scale systems and extension of medium and large-scale systems.

<table>
<thead>
<tr>
<th>System Type</th>
<th>Present (end of FY2007)</th>
<th>2010</th>
<th>2015</th>
<th>2020 - 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Residential cogeneration system</strong></td>
<td>Development and demonstration¹ 40%/44% 3,000 hr operation verification Millions - tens of millions yen/kW</td>
<td>Early introduction 40%/44% 40,000 hr prospect (continuous operation) 1 million yen/kW (at several MW/yr)</td>
<td>Dissipation &gt;40%/44% 90,000 hr prospect (continuous operation) &lt; 0.4 million yen/kW</td>
<td></td>
</tr>
<tr>
<td><strong>Business-use cogeneration system</strong></td>
<td>System development 40%/44% 3,000 hr operation verification Millions - tens of millions yen/kW</td>
<td>Development and demonstration 40%/44% 10,000-20,000 hr prospect Millions of yen/kW</td>
<td>Early introduction 40%/44% 40,000 hr prospect 1 million yen/kW (at several MW/yr)</td>
<td></td>
</tr>
<tr>
<td><strong>Industrial cogeneration system</strong></td>
<td>Hybrid system development 48%/52% Millions - tens of millions yen/kW</td>
<td>Development and demonstration 50%/55% 10,000-20,000 hr prospect 3 million-yen millions yen/kW</td>
<td>Early introduction &gt;50%/55% 40,000 hr prospect Hundreds of thousands &lt; 1 million yen/kW</td>
<td></td>
</tr>
<tr>
<td><strong>Utility or private power generation</strong></td>
<td>Present (end of FY2007)</td>
<td>2010</td>
<td>2015</td>
<td>2020 - 2030</td>
</tr>
</tbody>
</table>

#### Technological challenges in development and demonstration

- Improving durability and reliability
- Reducing cost of cells and stack materials and components
- Improving operational feasibility and establishing start/stop technology
- Establishing technologies for high-pressure operation

#### Technological challenges in early introduction

- Introducing technologies to improve stack durability
- Reducing cost of stacks and modules
- Establishing flexible fuel technologies
- Optimizing system configurations and simplifying BOPs

#### Technological challenges in dissemination

- Reducing cost through mass production
- Improving performance and durability of next-generation stacks

### SOFC technology trends

- Progress in cell and stack technologies for 1 kW-class systems
- Launch of demonstrations with real load conditions
- 3,000 hr operations using tens of kW-class systems
- Identification of technical challenges, including durability
- Progress by industry-university-government sectors in USA in fundamental studies such as on identifying degradation mechanisms to enhance durability and reliability

### Footnotes

1. Research or business stage
2. Electric efficiency (HHV/LHV)
3. Durability (operating hours)
4. System cost

### Enhancement of fundamental technology

Identification of degradation mechanisms (e.g., thermodynamic, chemical, and mechanical challenges, three-phase interface analysis with multidisciplinary approaches)

- Accelerated durability test methods, durability improvement, and remaining life assessment methods
- Cost reduction, provisions for influence of impurities and fuel variations, etc.

### Notes

1. System costs represent the total cost of power generation components, excluding heat recycling parts. (However, cost of hot water storage tank is included for residential systems.) The value in parentheses for each system does not express market size in each FY, but is used for estimating system costs.
2. Hybrid systems refer to cogeneration systems, where SOFC and gas turbines are combined and exhaust heat is recovered. The combined power generation systems that are a combination of SOFC, gas turbines, etc., recycle exhaust heat only for power generation.
Hydrogen Storage Technology Roadmap

To develop light, compact, low-cost, safe hydrogen storage tanks for FCVs

Prospects for FCVs

<table>
<thead>
<tr>
<th>Present (end of FY2007)</th>
<th>2010</th>
<th>2015</th>
<th>2020-2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology validation</td>
<td>Technology demonstration to public demonstration</td>
<td>Early dissemination</td>
<td>Full commercialization</td>
</tr>
</tbody>
</table>

Vehicle range
- 300-500 km
- 500 km
- 500-700 km
- 700 km

Hydrogen storage
- 3-5 kg
- 5 kg
- 5-7 kg
- 7 kg

Cost of storage system*
- 3-5 million yen
- 3-5 million yen
- Drastic cost reduction (~hundreds of thousands yen)

Achievements and Challenges

- Verification of safety of high pressure tanks
- Development of more compact, lighter tanks
- Search for new storage materials

Hydrogen storage technology:

- 500 km prospect with high pressure tank technology
- Development of more compact, lighter tanks
- Search for new storage materials

High cost reduction through material development and manufacturing technology

Note: Numbers for tanks are indicated in the following order:
- Hydrogen storage (kg), Internal capacity (L), Tank weight (kg)

Hydrogen tanks
- High pressure tanks (-70 MPa)
- Hybrid tanks (containing MH)

Hydrogen storage materials
- Metal hydrides
- Inorganic materials
- Liquid hydrogen

Development of hydrogen storage materials with high capability of H₂ absorption/desorption

Breakthroughs based on fundamental research
(e.g. understanding of hydrogen storage mechanism)

Development of innovative hydrogen storage materials and systems

Hydrogen tanks
- 35 MPa tanks: Practical use phase
- 70 MPa tanks: Development phase (requires special approval for road use)

Hybrid tanks
- Development phase (e.g. 35 MPa: 9.2 kg, 150 L, 420 kg)
- Development of H₂ storage materials with 3 – 6 mass%
- Development of H₂ storage materials with 6 – 9 mass%

High pressure tanks
- Safety assurance (technology to detect deterioration and invisible damage)
- Materials with less H₂ embrittlement (e.g. Type 3; 70 MPa: 5 kg, 120 L, 75 kg)

Hybrid tanks
- Lighter tanks and heat-exchangers
- Improvement of safety/reliability

Optimized H₂ pressure in total system

Verification of safety of high pressure tanks

Higher performance hydrogen storage materials

Development of more compact, lighter tanks

Search for new storage materials

Development of innovative hydrogen storage materials and systems

Low cost, light weight, compact, durable, and safe hydrogen storage system

Notes:
- *total cost of all storage tanks/systems on-board.
### On-Site Hydrogen Production Station Technology Roadmap

**To supply low-cost hydrogen through cost-effective on-site hydrogen production**

<table>
<thead>
<tr>
<th>Year</th>
<th>Achievements and Challenges</th>
<th>H₂ Supply Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H₂ cost:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Station cost (H₂ supply capacity):</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present (end of FY2007)</td>
<td>Technology Validation</td>
<td></td>
</tr>
<tr>
<td><strong>80 yen/Nm³</strong></td>
<td><strong>40 – 80 yen/Nm³</strong></td>
<td><strong>40 yen/Nm³</strong></td>
</tr>
<tr>
<td><strong>300 million yen</strong></td>
<td><strong>150 million yen</strong></td>
<td><strong>&lt;150 million yen</strong></td>
</tr>
<tr>
<td><strong>(50 Nm³-H₂/h)</strong></td>
<td><strong>(300 Nm³-H₂/h)</strong></td>
<td><strong>(300 – 500 Nm³-H₂/h)</strong></td>
</tr>
</tbody>
</table>

**Prospects for FCVs**

<table>
<thead>
<tr>
<th>Year</th>
<th>Prospects for FCVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present (end of FY2007)</td>
<td>Technology Validation</td>
</tr>
<tr>
<td>2010</td>
<td>Technology demonstration to public demonstration</td>
</tr>
<tr>
<td>2015</td>
<td>Early dissemination</td>
</tr>
<tr>
<td>2020-2030</td>
<td>Full commercialization</td>
</tr>
</tbody>
</table>

**Clean H₂ production technology using renewables**

- (Long-term commitment toward innovative technologies)

**Fundamental research**

- (e.g. material science on H₂ environment)

---

*Hydrogen cost target should be reviewed with social external conditions such as oil price surge.*
Off-Site Hydrogen Production Station Technology Roadmap

To supply low-cost hydrogen by establishing an effective production and safe delivery system for by-product hydrogen

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2015</th>
<th>2020-2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ cost:</td>
<td>110-150 yen/Nm³</td>
<td>80 yen/Nm³</td>
<td>(40 - 80 yen/Nm³)</td>
</tr>
<tr>
<td>Delivery cost</td>
<td>20 yen/Nm³</td>
<td>10 yen/Nm³</td>
<td>(3-6 yen/Nm³)</td>
</tr>
<tr>
<td>Compressed liquid</td>
<td>6 yen/Nm³</td>
<td>3-6 yen/Nm³</td>
<td>3 yen/Nm³</td>
</tr>
</tbody>
</table>

**Off-site Hydrogen Production Station Technology**

- **Prospects for FCV**
  - Present (end of FY2007)
  - Technology Validation
  - Technology demonstration to public demonstration
  - Early dissemination
  - Full commercialization

**H₂ Delivery Technology**

- Compressed H₂ delivery
- Liquid H₂ delivery
- Other delivery

**Off-site H₂ Production Technology**

- Steam Reforming (large-scale)
  - Practical phase (Steel vessels)
  - Higher efficiency (higher pressure, larger volume)
  - Application of technologies for early dissemination
  - Development of low-cost delivery technology for large-volumes of H₂

**By-product H₂** (Steel plants, refinery plants, petrochemical plants, soda production plants)

- Low-cost, high-efficiency, and low-CO₂ emission off-site H₂ production technology
- Production of liquid hydrogen requires improvement of liquefaction efficiency

**Clean H₂ Production Technology using renewables**

- Long-term search for innovative technologies (e.g., solar, photocatalysts, bio-fermentation)

**Fundamental research** (e.g., material science on H₂ environment)

*H₂ cost target should be reviewed with social external conditions such as oil price surge.

*For purification of hydrogen, PSA or membrane separation processes is needed.
**Industry Results and Trends**

**Fuel cell vehicle commercialization scenario**

Spurred by the establishment of the Fuel Cell Commercialization Conference of Japan (FCCJ) in 2001, the private sector has become increasingly active in fuel cell and hydrogen technology development. FCCJ, whose members include private companies and associations, promotes fuel cell research and development and efforts to commercialize fuel cells. FCCJ developed a fuel cell vehicle and hydrogen station commercialization scenario, with a goal of commercialization starting in 2015.

**Scenario for Dissemination of FCV and Hydrogen Stations**

- **Phase 1**: Technological Demonstration (2010)
- **Phase 2**: Technological Demonstration & Public Demonstration (2011)
- **Phase 3**: Early Dissemination (2015)
- **Phase 4**: Full-scale Commercialization (2018)

**Practical use ahead of the world**

The Ministry of Economy, Trade and Industry’s Agency for National Resources and Energy is supporting the introduction of pioneering residential fuel cell cogeneration systems (“ENE FARM”).

After extensive research and development, residential fuel cell systems have now been commercialized. "ENE FARM," an abbreviation for "energy farm," was coined by FCCJ as a name to describe the residential fuel cell cogeneration system product category. In 2009, Japan became the first country to commercialize residential fuel cell systems. The Ministry of Economy, Trade and Industry (METI) is supporting the introduction of the systems as part of the broader scheme of the public and private sectors working together to realize a fuel cell · hydrogen energy economy.
Hydrogen basics

Hydrogen has the simplest structure and is the lightest of all elements. The number of hydrogen molecules is the highest in space. Hydrogen is found in water (H₂O) and fossil fuels in large amounts on the earth. Due to the fact that little toxic gas is produced when hydrogen is burnt and that it can be used as a fuel for fuel cells, which are more efficient than ordinary engines, hydrogen is expected to be the future energy source for automobiles, home appliances, and mobile devices. (See “Basics of fuel cells”.)

For example, fuel cell vehicles are driven by electric motors, with hydrogen used as the fuel and the electricity produced by means of a chemical reaction. Unlike ordinary automobiles driven by combustion engines, fuel cell vehicles are expected to be clean vehicles as they produce almost no exhaust gas while running.

NEDO is actively engaged in various research and development activities in order to realize a society that uses clean hydrogen energy, for example, in fuel cell vehicles. As the use of hydrogen energy becomes popular, it will offer a significant advantage in reducing air pollution and preventing global warming. However, there are a number of challenges to be overcome before hydrogen energy is popularly used; it is necessary to construct a comprehensive system infrastructure to cover the production, storage, transport, and use of hydrogen.

Characteristics
- No toxic gas is produced when burnt (only water is produced)
- Hydrogen can be produced from various materials including natural gas, water, and biomass (i.e. organic resources originating from plants and animals that may be reused as an energy source)
- It can contribute to the reduction of carbon dioxide (CO₂) emissions, which are considered to be the major cause of global warming

Challenges
- Reduction of production costs and enhancement of production capacity
- Finding a compact storage method
- Solving the problems inherent to hydrogen, such as hydrogen embrittlement (*)
- Sufficient safety assurance
- Establishment of a comprehensive system to cover production, storage, transport, and use

(*) This is the phenomenon through which the strength of metal is reduced as a result of the presence of hydrogen in metal.

Figure: Concept of fuel cell vehicles
How to produce hydrogen

Hydrogen hardly exists at all in the natural world in the form of gas (i.e. in a form that enables it to be used as it is to provide the fuel for fuel cells). As such, it is necessary to produce hydrogen from fossil fuels, water, or biomass using some sort of energy such as heat or electricity. Today, hydrogen is mostly produced from fossil fuels (i.e. mainly from natural gas). This is because it is easier and the production cost is lower than when using other materials. While we are unable to reduce the use of fossil fuels if hydrogen is to be produced from them, we can still reduce the emission of carbon dioxide (which causes global warming) as a whole, if the usage efficiency is improved by employing fuel cell-based cogeneration systems (i.e. a system involving the combined use of electricity and heat). Also, the use of hydrogen greatly assists in the prevention of air pollution. In the future, it will be necessary to increase the quantity of hydrogen produced from other sources, such as biomass or natural energy. Regarding the use of hydrogen for fuel cell vehicles, there are two methods of production: mass production at hydrogen manufacturing hubs for transport to each area where it will be used and individual production at each hydrogen stand. It is believed that a hydrogen supply environment will be constructed in the future with various combinations of these methods.

Realizing a society based on hydrogen energy

In order to ensure the popularization of fuel cell systems and fuel cell vehicles in the future, it will be necessary to develop a good supply system for the hydrogen that will be the fuel. As the number of hydrogen stands increase, fuel cell vehicles become more popular, together with the more common use of hydrogen in applications other than automobiles, such as home-use fuel cell systems. Then it can be reasonably expected that hydrogen may be produced increasingly from sources other than fossil fuels, such as biomass and natural energy, including wind and solar power. As a result, it will be possible to form a society based on earth-friendly hydrogen energy with a lower environmental load. In Japan, North America, and Europe, various research programs are actively ongoing in the hope of realizing a society based on hydrogen energy.
Basics of fuel cells

A fuel cell is a power generation system used to produce electricity using hydrogen. Thermal power stations produce electricity by burning some sort of fuel such as heavy oil, coal, or natural gas to produce heat energy that is converted to mechanical energy by way of turbines, for conversion to electrical energy. On the other hand, fuel cells use the chemical reaction of hydrogen and oxygen to directly produce electricity, as shown in Figure 1. Accordingly, fuel cells have the characteristics and problems described below.

Characteristics:
- In theory, the efficiency of power generation is high (about 83 %)
- They use hydrogen as fuel, so they generate electricity by means of a reaction that does not produce carbon dioxide (CO₂)
- Nitrogen oxides (NOₓ) and sulfur oxide (SOₓ), which are toxic materials, are not generated
- The overall efficiency is high. (As a cogeneration system, the heat energy produced in the power generation process of the fuel cells can be reused to significantly increase the overall efficiency of energy use.)
- The hydrogen used as the fuel can be produced from various sources (fossil fuels such as oil, coal, natural gas, and methanol, as well as through the electrolysis of water)
- Very little noise and vibration are generated

Challenges
- Improved power generation efficiency as a system
- Cost reduction
- Improved durability
- Sufficient understanding of the reaction mechanism

Types of fuel cells

Fuel cells can be broadly divided into four types, based on the type of electrolyte through which the ions are passed, as shown in Table 1.

<table>
<thead>
<tr>
<th>Stack</th>
<th>Polymer Electrolyte Fuel Cell (PEFC) or Proton Exchange Membrane Fuel Cell (PEMFC)</th>
<th>Phosphoric Acid Fuel Cell (PAFC)</th>
<th>Molten Carbonate Fuel Cell (MCFC)</th>
<th>Solid Oxide Fuel Cell (SOFC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyte</td>
<td>Polymer electrolyte membrane</td>
<td>Solution of phosphoric acid</td>
<td>Carbonate</td>
<td>Zirconia type</td>
</tr>
<tr>
<td>Yield temperature</td>
<td>70℃~ 90℃</td>
<td>200℃</td>
<td>650℃~ 700℃</td>
<td>700℃~ 1000℃</td>
</tr>
<tr>
<td>Diffusing species (ion)</td>
<td>Hydrogen ion H⁺</td>
<td>Hydrogen ion H⁺</td>
<td>Carbonate ion CO₃²⁻</td>
<td>Oxygen ion O₂⁻</td>
</tr>
<tr>
<td>System</td>
<td>Fuel</td>
<td>Hydrogen</td>
<td>Hydrogen</td>
<td>Hydrogen, carbon monoxide</td>
</tr>
<tr>
<td></td>
<td>Generating efficiency (HHV)</td>
<td>30%~ 40%</td>
<td>35%~ 42%</td>
<td>40%~ 60%</td>
</tr>
<tr>
<td></td>
<td>Characteristics</td>
<td>Low-temperature operation, compact, portable power supply for mobile use</td>
<td>Distributed power supply (practical application)</td>
<td>No precious metals required, high efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Can be combined with a gas turbine for high-efficiency power generation</td>
<td>No precious metals required, high efficiency</td>
</tr>
</tbody>
</table>

Table 1. Types and features of fuel cells
Basics of fuel cells

Structure of Polymer Electrolyte Fuel Cells (PEFC)

The fuel cells that are used in fuel cell vehicles, home-use power supplies, and mobile devices are polymer electrolyte fuel cells (PEFC). The basic configuration of PEFC and the resulting chemical reaction are shown in Figure 2.

PEFC is constructed so that two electrodes face each other with the polymer electrolyte membrane placed between them.

Here, a precious metal such as platinum is used with the electrode as a catalyst to promote electricity generation. One of the two electrodes is the fuel electrode (anode) at which the oxidation reaction takes place when the fuel hydrogen makes contact with the anode (the electron is separated and the hydrogen is ionized). The other electrode is the air electrode (cathode) at which the reductive reaction (oxygen bonded to hydrogen ions) takes place when it makes contact with air.

The fuel electrode (anode) is the negative electrode and the air electrode (cathode) is the positive electrode. In this configuration, the chemical reaction in which hydrogen ions are bonded to oxygen after passing through the electrolyte produces electricity.

The above combination of the electrolyte and two (positive and negative) electrodes is called the “unit cell”. In practice, as the voltage generated by a unit cell is not sufficient (i.e. up to about 1 V, which is barely enough to run a small lamp), a number of cells are stacked together.
Introduction to NEDO’s Web site

NEDO’s Web site allows visitors to access various publications, including press releases, public solicitations related to projects in a wide range of technology areas, achievement reports, technical descriptions, and event information.

URL: http://www.nedo.go.jp/english

You can also review NEDO’s fuel cell and hydrogen technology activities by visiting the Fuel Cell and Hydrogen Technology Development Department section (Japanese only).

URL: http://www.nedo.go.jp/nenryo/index.html

Contact information:
New Energy and Industrial Technology Development Organization (NEDO)
Fuel Cell and Hydrogen Technology Development Department

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