



Hydrogen and Fuel Cell Activities in Korea

Tae-Hwan Lee

*Team Leader of National RD&D Organization for Hydrogen and Fuel Cells
(MKE, or Ministry of Knowledge Economy; KIST, or Korea Institute of Science and Technology)*

hwant@gmail.com

Abstract

Since 1988, the Republic of Korea (South Korea) has been aggressively pursuing research, development, validation, demonstration, and commercialization of hydrogen and fuel cells in order to cope with her urgent energy and environmental challenges. This paper summarizes the overall hydrogen and fuel cell activities in Korea, focusing on the overview of our nation's research and development (R&D) program and technical status.

1. Energy Situation in Korea

Currently, Korea is 97% dependent on foreign imports for her energy and ranks 10th in the world in terms of energy consumption. Korea's energy intensive economy has been vulnerable to world energy markets because, as of 2006, Korea is the fifth largest oil importer and the second largest importer of liquefied natural gas. Also, per capita energy consumption in Korea (181 MBtu) already surpassed that of Japan (175.6 MBtu) and Germany (172.7 MBtu) as of 2003. (See *Figures 1* and *2*.)

Figure 1: South Korean Oil Consumption

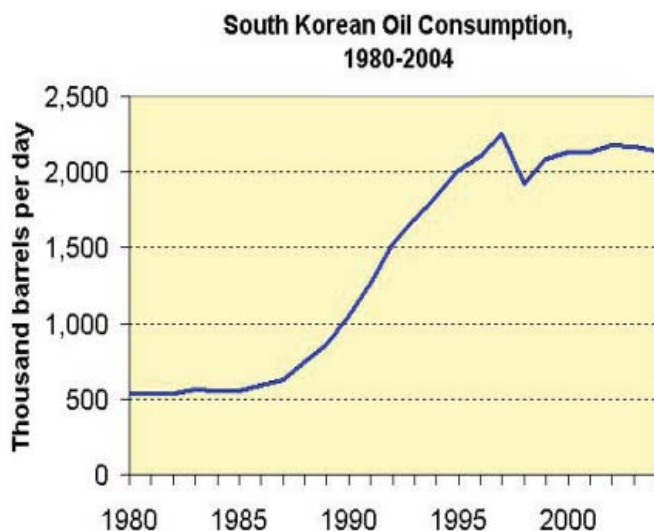
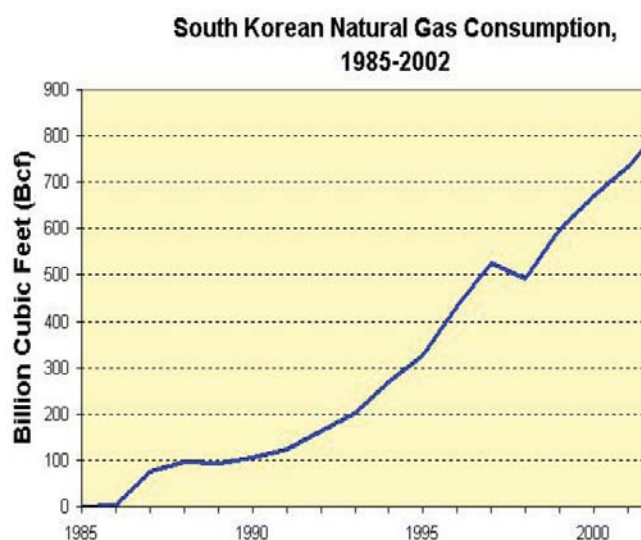


Figure 2: South Korean Natural Gas Consumption



Source: EIA (2005), <http://www.eia.doe.gov>.

Therefore, Korea has been keenly interested in reducing her dependence on foreign oil and gas by developing technologies needed for commercially viable hydrogen and fuel cells, in addition to her increasing energy mix of nuclear and renewable energy form such as solar and wind power.

2. Environment in Korea

Korea's rapid economic growth has resulted in significant environmental side effects because industrial emissions from factories have caused serious acid rain problems. Moreover, increased car ownership (15,000,000 vehicles total, 0.86 vehicles per household as of 2005) has led to a corresponding rise in carbon emissions from the country's transportation sector, contributing to Korea's air pollution problems.

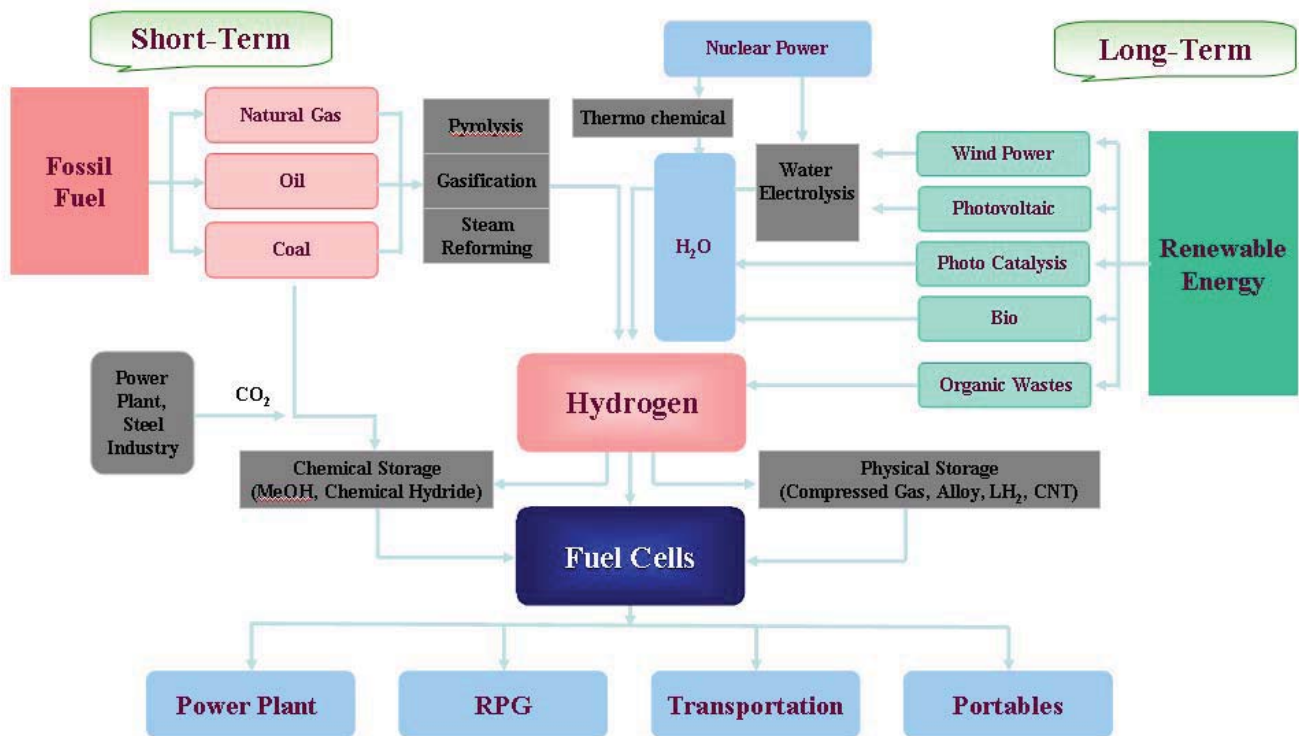
Hence, during the past 10 years, Korea has emphasized the development of more clean energy sources to reduce growth in carbon emissions. As a result of continuous commitment of solving environmental issues, Korea ratified the Kyoto Protocol on greenhouse gas emissions in 2003. Along with the Alternative Energy Promotion Act, the National Vision for Environmental Policies in the 21st Century is also promoting green development schemes such as increased usage of solar and wind power and of hydrogen and fuel cells.

Therefore, Korea has committed to commercialize hydrogen and fuel cells, considering that the future environmental outlook depends on its ability to shift its energy supply mix to cleaner-burning fuels and to de-link the increase in carbon emissions from economic growth.

3. National Vision

On July 2005, the Korean government announced the long-term vision of Korea's transition to a hydrogen economy, including a national plan, road maps, and detailed action plans to commercialize hydrogen and fuel cells. The long-term vision of Korea's hydrogen economy is to generate massive electricity through renewable energy sources such as solar, wind, biological, and organic wastes and then to use the surplus electricity for water electrolysis so Korea can produce hydrogen from water, as well as produce hydrogen from water through thermo-chemical process from generation IV nuclear reactors (VHTRs, or very high temperature reactors). With the hydrogen produced from renewable and nuclear energy, Koreans would use electricity from fuel cell generators, would drive fuel cell cars, and would enjoy fuel cell-powered portables after 2040 (see *Figure 3*).

Figure 3: Structure System of Hydrogen Energy and Fuel Cell Energy



Source: National RD&D Organization for Hydrogen and Fuel Cells (2003).

However, substantial benefits of a hydrogen economy are that Korea not only can achieve national energy efficiency, energy independence, and clean environment but also can develop new hydrogen and fuel cell industries. For example, the current efficiency of fuel cell vehicles, which use hydrogen from natural gas reforming, is above 36% whereas the efficiency of internal combustion engines is about 16%. Hence, fuel cell vehicle commercialization would create a reduction of more than 50% of energy consumption and contribute to a sound environment because fuel cell vehicles would replace oil with hydrogen.

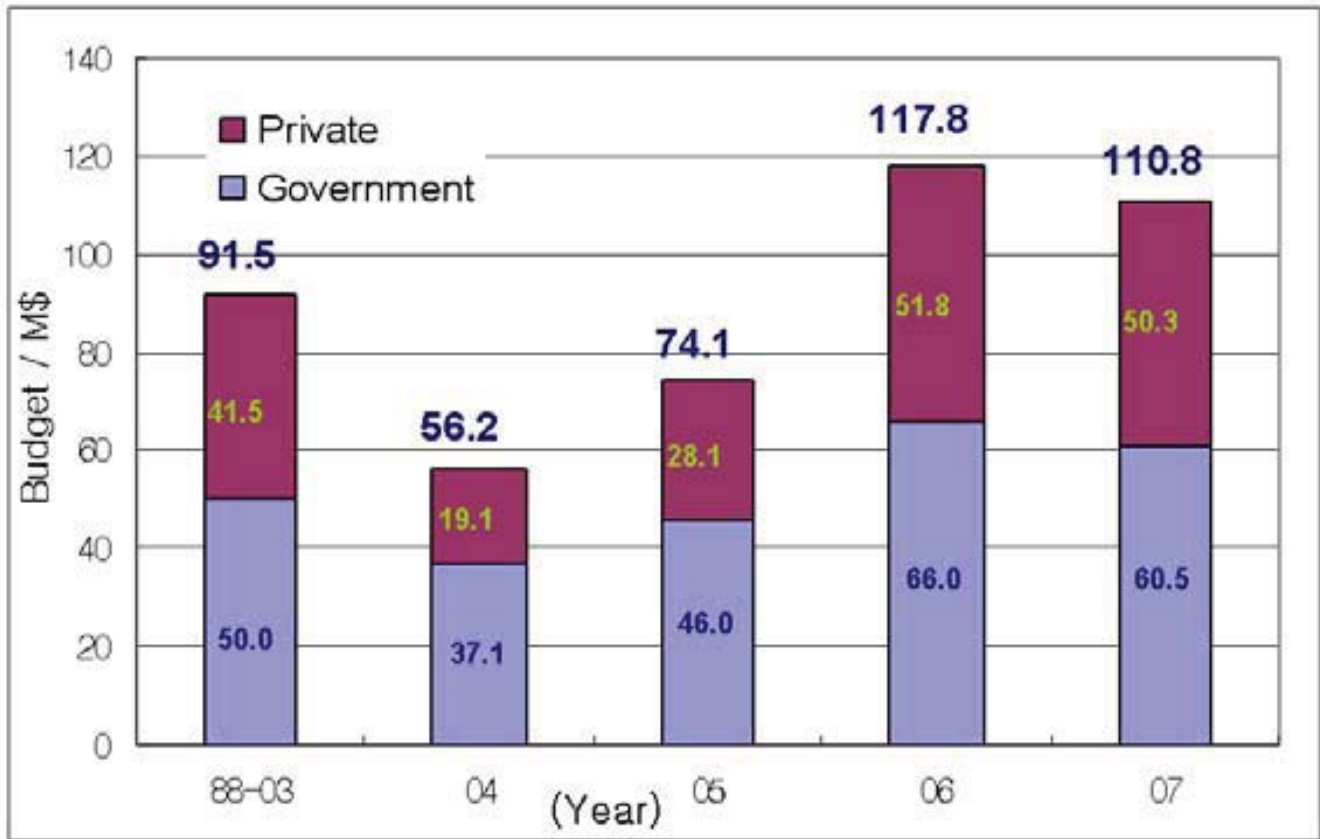
For the time being, the short-term vision is to produce hydrogen from cheaper fossil fuels (oil and natural gas) rather than from expensive renewable energy and to establish hydrogen economy infrastructures by diverse applications of fuel cell technology and the facilities of hydrogen production, storage, and delivery.

Then, as the cost of hydrogen from renewable energy sources decreases to an economically feasible level (US\$ 3~4/kg), Korea can achieve the ultimate long-term vision of a hydrogen economy mentioned earlier.

4. Budget History

In 1988, Korea initiated the Hydrogen and Fuel Cell R&D Program for the first time, following the enactment of the Alternative Energy Promotion Act. From 1988 to 2003, Korea invested a total of US\$ 91.5 million (which included contributions from both the government and the private sector), and the amount has been increasing since 2004: US\$ 56.2 million in 2004, US\$ 74.1 million in 2005, US\$ 117.8 million in 2006, US\$ 110.8 million in 2007, and more than US\$ 150 million expected to be invested in 2008 (see *Figure 4*).

Figure 4: Budget of Government R&D Program



Source: National RD&D Organization for Hydrogen and Fuel Cells (2008).

With the progress that has been made in hydrogen and fuel cell technology, the major objective of R&D programs has shifted from fundamental technology to scaling up and to system engineering. Current R&D objectives are moving toward monitoring (validation and demonstration) and dissemination because the key issues for fuel cell commercialization lie in the reliability, cost, and duration of fuel cells.

5. Government Policy

The Korean government announced a very ambitious plan to replace 5% of national energy consumption with new and renewable energy sources by 2012. Currently, new and renewable energy sources account for less than 2% of national consumption. As one of the action plans to achieve the target, the government selected hydrogen and fuel cells as 1 of 10 economy growth engines for the next decade and has subsidized

half of the project budget to facilitate the market introduction of hydrogen and fuel cells. These projects include R&D and monitoring projects of fuel cell vehicles; portable devices; and industrial, commercial, and residential fuel cell generators. Codes and standards, safety, education, policies, and laws related to hydrogen and fuel cells will be established in the near future.

6. Key Players

The two main Korean government agencies involved in both hydrogen and fuel cells are the Ministry of Education, Science, and Technology (MEST) and the Ministry of Knowledge Economy (MKE). MEST is oriented more toward the development of fundamental, basic technologies from the long-term perspective, whereas MKE is more engaged in applicable or commercial technologies in the short term. Between them, the Korean government formed the National RD&D Organization for Hydrogen and Fuel Cells (see <http://www.h2fc.or.kr>) in January 2004 to promote overall R&D, validation, demonstration, and commercialization of hydrogen and fuel cell technologies. Also in 2003, under the 21st Century Frontier Program, MEST launched the Hydrogen Energy R&D Center (see <http://www.h2.re.kr>), which focuses on facilitating the development of hydrogen production and storage technologies.

In 2006, MEST contributed US\$ 10 million for R&D of hydrogen production and storage, whereas MKE and the major Korean companies together (50:50 ratio) invested US\$ 80 million in the same year for R&D and validation and demonstration of hydrogen refueling stations and fuel cells (stationary, transportation, portable devices, etc.). These expenditures may expedite the commercialization of hydrogen and fuel cell technologies described in *Table 1*.

7. Action Plan Goals by 2012

The National RD&D Organization for Hydrogen and Fuel Cells was established by MKE to expedite the commercialization of hydrogen and fuel cells. It is not only developing a national plan and strategies, but also coordinating 30 national projects by directly controlling US\$ 40 million in government funds. With the support of substantial budget increases since 2004, the National RD&D Organization for Hydrogen and Fuel Cells has been carrying out the ambitious 2012 action plan as it moves toward the technological readiness of hydrogen and fuel cells (see *Table 2*).

According to this plan, by 2012, MKE will have constructed and be operating 50 hydrogen refueling stations. Also, MKE expects to demonstrate and disseminate 300 industrial fuel cell (FC) prototype distributed power generators, 2,000 commercial FC generators, and 10,000 residential FC generators, all of which will provide a combination of heat and power. Two hundred FC buses and 3,200 FC passenger cars are expected to operate on roads, using the infrastructure of hydrogen production and the supply system. In addition, in portable devices, such as notebooks, PDAs, mobile phones, and digital media broadcasting (DMB) devices, FCs may replace the current lithium ion-based batteries.

In 2006, MKE launched two aggressive monitoring projects for FC vehicles and residential FC generators in order to validate and demonstrate FC performance before full-scale dissemination begins. The FC Vehicle Monitoring Project is expected to promote the hydrogen infrastructure in Korea by validating and demonstrating both FC vehicles and hydrogen refueling stations simultaneously. Furthermore, the Residential FC Monitoring Project will accelerate the commercialization of FC technology for household customers because Korea's well-organized natural gas pipeline grid across the nation can be reformed to use hydrogen; therefore, residential FC generators can provide heat and power for most Korean households.

Table 1: Current Project of Hydrogen and Fuel Cells

Related Party	2006 Budget	Field	Status
MEST (Hydrogen Energy R&D Center)	US\$ 10 million	Hydrogen Production	<ul style="list-style-type: none"> • Natural Gas Steam Reforming H2 Production • Biological H2 Production Using Anaerobic or Photosynthetic Microorganism • Photochemical H2 Production from Water Splitting • Thermochemical H2 Production from Water Splitting • Electrolysis
		Hydrogen Storage	<ul style="list-style-type: none"> • High-Pressure H2 Storage System for FC Vehicles • Metal Hydrides H2 Storage System • Carbon-Based Nano Materials H2 Storage System • Noncarbonic Nano Materials H2 Storage System • Chemical Hydrides H2 Storage System • Organometallic Nanoporous Material H2
MKE & Companies (National RD&D Organization for Hydrogen and Fuel Cells)	US\$ 80 million	Hydrogen Refueling Station	Open 3 H2 Stations (SK, GS-Caltex, KOGAS) Using LNG, LPG, Naphtha
		MCFC	<ul style="list-style-type: none"> • 100 kW System Development (KEPCO) • 250 kW System Development (KEPCO) • 250 kW Demonstration (POSCO)
		Portable PEMFC	50 W System Development (Samsung SDI)
		Robot PEMFC	1 kW System Development (KIST)

(continued next page)

		Residential PEMFC	<ul style="list-style-type: none"> • 1 kW Validation (FCP) • 2 kW Validation (TaeGu City Gas) • 1/1.5/3 kW Validation (GS Fuel Cell) • 1~3 kW Monitoring (GS Fuel Cell, FCP, KOGAS)
		Transportation PEMFC	<ul style="list-style-type: none"> • 80 kW Vehicle System Development (Hyunda-Kia Motors) • 200 kW Bus System Development (Hyunda-Kia Motors) • 80 kW Vehicle Monitoring (Hyunda-Kia Motors) • 200 kW Vehicle Monitoring (Hyunda-Kia Motors)
		DMB DMFC	5 W System Development(Samsung SEM)
		Portable DMFC	50 W System Development(LG Chem)
		Robot DMFC	1 kW System Development(KIST)
		SOFC	<ul style="list-style-type: none"> • 1 kW System Development (KEPRI) • 1 kW APU System Development (KIER)

Source: National RD&D Organization for Hydrogen and Fuel Cells (2008).

Note: APU = auxiliary power unit; DMB = digital media broadcasting device; DMFC = direct methanol fuel cell; FC = fuel cell; KEPRI = Korea Electric Power Research Unit; KIER = Korea Institute of Energy Research; KIST = Korea Institute of Science and Technology; LNG = liquefied natural gas; LPG = liquefied petroleum gas; MCFC = molten carbonate fuel cell; MKE = Ministry of Knowledge Economy; PEMFC = proton exchange membrane fuel cell; POSCO = PoscoPower; R&D = research and development; RD&D = research, development, and demonstration; SOFC = solid oxide fuel cell.

Table 2: Dissemination of Target by 2012

Fuel Cell Classification	Fuel Cell Type	Capacity	Phase I (03 ~ 05)	Phase II (06 ~ 08)	Phase III (09 ~ 12)
			R & D	Validation Demonstration	Dissemination
Hydrogen Fueling Station	-	-	1	10	50
Industrial Power Generation	MCFC	250~1,000 kW	Cumulative 300 units		
Vehicle Transportation	PEMFC	200 kW	Bus: -	Bus: 10	Bus: 200
		80 kW	Passenger Car: 10	Passenger Car: 300	Passenger Car: 3,200
Commercial Power Generation	PEMFC/SOFC	5~50 kW	Cumulative 2,000 units		
Residential Power Generation	PEMFC/SOFC	less than 3 KW	Cumulative 10,000 units		
Portables	DMFC/PEMFC	2W,50W, 100W	R & D	Commercialization	

Source: National RD&D Organization for Hydrogen and Fuel Cells (2008).

Note: DMFC = direct methanol fuel cell; MCFC = molten carbonate fuel cell; PEMFC = proton exchange membrane fuel cell; R&D = research and development; SOFC = solid oxide fuel cell.

8. Hydrogen Refueling Stations

To facilitate the infrastructures for hydrogen FC vehicles across the nation, MKE plans to install eight hydrogen refueling stations in 2008. In 2006, MKE opened four hydrogen refueling stations in Inchon (KOGAS), Seoul (GS-Caltex), Taejon (SK), and Buan in partnership with the FC Vehicle Monitoring Program, in addition to one station in Yongin (Hyundai-Kia motors). The stations near Seoul and in the western province are expected to provide hydrogen fuels made from liquefied natural gas (LNG), liquefied petroleum gas (LPG), and naphtha.

In 2007, MKE opened two more hydrogen refueling stations on Cheju Island, which produce hydrogen by water electrolysis, using wind power. In 2008, MKE plans to open two hydrogen refueling stations in the southern province, which may provide hydrogen by truck-in methods, which would then deliver the by-produced hydrogen from a nearby petrochemical refinery complex.

9. Transportation

Since 2004, MKE has launched several aggressive R&D and monitoring projects to accelerate the commercialization of FC vehicles. These R&D projects are involved in breakthrough proton exchange membrane fuel cell (PEMFC) technology, and the monitoring projects are to validate and demonstrate the overall feasibility of PEMFC vehicles along with hydrogen refueling stations before full-scale dissemination begins. Two R&D projects are the 80 kW PEMFC Vehicle Program, with US\$ 33.4 million budgeted from 2004 to 2008, and the 200 kW PEMFC Bus Program, with US\$ 49 million budgeted from 2005 to 2009. Also, the FC Vehicle Monitoring Program covers the operation of 30 FC cars, 4 FC buses, and 10 hydrogen refueling stations, with US\$ 48 million budgeted from 2006 to 2008.

Hyundai-Kia Motors has been cooperating with MKE as the main contractor for three of the projects, investing in half of the project budget. Along with domestic programs, Hyundai-Kia Motors has been a participant in global efforts such as the California Fuel Cell Partnership to develop and commercialize FC vehicles since 1997, working with diverse partners including UTC (United Technology Co., Ltd.) in the United States. Even though Hyundai-Kia Motors is operating several FC vehicles on roads in California and Korea, many technical and economical barriers must be overcome for the commercialization of FC vehicles to become a reality.

Under the leadership of MKE and Hyundai-Kia Motors, Korea would disseminate 200 FC buses and 3,200 FC cars by 2012. After that, the cost of the PEMFC system should go down from the current US\$ 10,000/kW to US\$ 100/kW by 2015, which would reduce the overall price of FC vehicles. Also, the durability of PEMFC system should increase from the current 750 hours to 5,000 hours (10 years of operation), and the driving distance should increase from the current 200 km to 500 km by 2015.

10. Residential Power Generation

MKE is planning to commercialize both PEMFC and solid oxide fuel cell (SOFC) technologies for residential power generation (RPG). Currently, two Korean companies (GS Fuel Cell and FCP) have domestically developed their respective PEMFC systems for RPG. These companies, which are the main contractors of the government program, are leading R&D and validation projects to decide on a commercial model suited to the Korean lifestyle, to solve the inherent problems in reforming the current city gas grid connection, and to overcome technological and economic barriers for RPG. From 2006, the national LNG wholesale monopoly KOGAS, which is the second largest LNG importer in the world, has participated in the RPG

monitoring project along with GS Fuel Cell and FCP. KOGAS is also participating in a FC vehicle monitoring project by establishing a new type of LNG hydrogen refueling station in Incheon.

From 2006, MKE has planned to purchase RPG units from manufacturers with the target price. However, the current price (US\$ 100,000/kW) is much more expensive than our ultimate target price (US\$ 10,000/kW). Hence, our plan is to promote the dissemination by purchasing the RPG units with a government subsidy and to reduce the target price year by year until the ultimate target price is achieved.

Under the leadership of MKE, KOGAS, GS Fuel Cell, and FCP, Korea is expected to disseminate 2,000 commercial FC generators and 10,000 residential FC generators at the price of US\$ 10,000/kW by 2012.

11. Industrial Power Generation

MKE is planning to demonstrate a type of molten carbonate fuel cell-based (MCFC-based) distributed power generator for industrial power generation. From 2001 to 2005, with a budget of US\$ 18 million, the national electricity monopoly KEPCO developed a 100 kW MCFC stack and system that is currently operating at Boryung Power Plant. That system is based on the operational experience of the 25 kW MCFC system in 1999. Following this 100 kW MCFC system, KEPCO plans to develop a 250 kW MCFC system from 2005 to 2009, with a budget of US\$ 43.7 million. Ultimately, it will develop, demonstrate, and disseminate the MW class MCFC system after 2010. Meanwhile, to speed up the technology development and to achieve the dissemination target of 300 prototype units by 2012, the Korean government is seriously searching for international partnerships with foreign companies.

From 2005, as a type of validation project, the steel giant PoscoPower installed three 250 kW MCFC systems made by Fuel Cell Energy (FCE) in the United States in order to accumulate prerequisite data and experiences, which are essential for demonstration and full-scale dissemination. These 250 kW MCFC systems would be operated to supply power for steel mills and sewage treatment facilities, using the coke oven gas from steel mills and the biogas from sewage as fuel feedstock. PoscoPower, which signed a technology transfer contract with FCE, will lead the project in association with domestic subcontractors in Korea.

12. Portable Applications

MKE also supports the development of both PEMFC and direct methanol fuel cell (DMFC) technology for portable appliances such as notebooks, mobile phones, and DMB devices. Using world-class information technology in the industry infrastructures, Korea has the real potential to commercialize a portable FC that can replace the lithium ion battery with higher efficiency and longer duration.

From 2004 to 2006, Samsung SDI developed a 50 W PEMFC system for notebooks with a budget of US\$ 5.5 million, and LG Chem developed a 50 W DMFC system for notebooks with a budget of US\$ 8.9 million. From 2005 to 2008, Samsung SEM plans to develop a 5 W DMFC system for DMB technology with a budget of US\$ 7.5 million. Hence, under the leadership of MKE and major Korean portable manufacturers such as Samsung SDI, Samsung SEM, and LG Chem, Korea is expected to realize portable FC systems by 2008.

Korea Economic Institute

1201 F Street NW Suite 910
Washington, DC 20004
202-464-1982; Fax: 202-464-1987
www.keia.org

As of August 9, 2008, our address will be:

1800 K Street NW Suite 1010
Washington, DC 20006

KEI Editorial Board

Editor-in-Chief: James M. Lister
Contract Editor: Barbara Hart
Assistant Editors: James H. Alvis
Greg Scarlatoiu
Arthur N. Taylor

The Korea Economic Institute is registered under the Foreign Agents Registration Act as an agent of the Korea Institute for International Economic Policy, a public corporation established by the Government of the Republic of Korea. This material is filed with the Department of Justice, where the required registration statement is available for public inspection. Registration does not indicate U.S. Government approval of the contents of this document.

KEI is not engaged in the practice of law, does not render legal services, and is not a lobbying organization.

The views expressed in this publication are those of the author. While this publication is part of the overall program of the Korea Economic Institute, as endorsed by its Board of Directors and Advisory Council, its contents do not necessarily reflect the views of individual members of the Board or the Advisory Council.

Copyright © 2008 by the Korea Economic Institute of America.
Printed in the United States of America.
All Rights Reserved.