

Status of Current Hydrogen R&D Program in Korea

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ABSTRACT: An increasing need for sustainable energy technology has become an issue of great concern throughout the world as well as an environmental solution for global warming. In spite that Korea is ranked the 10th energy consumed country in the world, about 97% of energy consumed in the country should be imported from foreign countries. In order to reduce the dependency on foreign resources and to solve environmental problem, the development of the hydrogen and fuel cell technology has been strongly supported by the government since 2003. Now, three R&D programs on hydrogen and fuel cell supported by government have been conducted and about 60 million US\$ was funded to those program in 2007. In this paper, the current status of research programs on hydrogen and fuel cell in Korea was reviewed and specific achievements in some projects were described briefly.

Keywords: hydrogen, fuel cell, national program, clean energy

1. INTRODUCTION

As efforts to reduce severe fossil fuel dependence derived by growing transportation, the researches on the efficient and clean fuel alternative have been recently intensified and the demand for the alternatives becomes more realized due to the recent soaring oil price and the global warming. Hydrogen is considered as one of promising alternative energy carriers due to its high specific energy density, pollution-free characteristics, and diversity of resources for its production. Fuel cell is one of effective device of hydrogen utilization, and has a wide range of applications: stationary and mobile applications.

It was in 1988 that hydrogen and fuel cell R&D program was started by our government for the first time, when the promotion act for the development of alternative energy was effectuated. But the

amount of research funds before the year 2000 was not so big and the research was concentrated on basic science.

In 21st century, the research funds were dramatically increased and the objective of R&D program has been shifted with the progress of technology development to demonstrate feasibilities of those technologies. The research field was broadened to cover hydrogen production and storage as well as fuel cell. Korea Government set up the scenario to the hydrogen economy in 2005. The long term vision of hydrogen economy is to achieve the economies of scale by mass production of hydrogen and fuel cell. Scenario by 2040 is divided by 4 phases and our plan is to replace 15% out of national energy demand by hydrogen energy and to replace 50% of automobile fuel with hydrogen energy by creating new industry on hydrogen and fuel cell. [1]

In the first phase, the technology of hydrogen and fuel cell will be introduced to the market through the demonstration program under the support of government grant. The dissemination target is so aggressive in view of current status.

2. HYDROGEN AND FUEL CELL PROGRAM IN KOREA

2.1 Hydrogen Energy R&D Center (HERC)

HERC (www.h2.re.kr), which is supported by MEST (Ministry of Education, Science and Technology), was established for fundamental technical development of clean and non-pollutant energy to the hydrogen economy in October 2003 and will last until March 2013.[2] The priority of R&D topics was set up for achieving sustainable growth of economy, after evaluation of the weight of contribution and the importance for achieving the ultimate goal. The impact factor of long term activities we selected is very high, but those activities need more time for realization of them because they are still in early stage of R&D. So weight of contribution of those technologies is very low at this time, but if the project is performed successfully the impact will be very high.

During the second stage from 2006 to 2009, securing core technologies developed in the first stage and demonstrations of viable technologies are going to carry out. The major emphasis of 3rd phase will be placed on fundamental issues and demonstration to promote innovation of the technology on hydrogen production and storage after reviewing the status of current technologies. Some selected project conducted in this program will be described later.

2.2 National RD&D Organization for hydrogen and fuel cell (H2FC)

The National RD&D Organization for Hydrogen and Fuel cell (H2FC) (www.h2fc.or.kr) was established to facilitate the research, development and demonstration of hydrogen and fuel cell

programs under the support of MKE (Ministry of Knowledge Economy) in the end of 2003. Its roll is to develop a national plan and road map to create a new energy industry, and finally to set up a detailed action plan to meet nation's dissemination target, as well as the coordination and management of the program.

The National RD&D Organization for Hydrogen & Fuel cells is currently composed of five subcommittees: 1) Hydrogen production/Storage/Distribution /Hydrogen Infrastructures, 2) Fuel cell for Industrial /Residential Generation, 3) Fuel cell for vehicle transportation, 4) Implementation, 5) Fuel cell for Portables.

Fuel cell vehicle monitoring project was started in August 2006, with the aim of launching the eco-friendly automobiles commercially by 2015. To achieve that goal, the government will invest \$22.7 million over 3 years. The Hyundai Motor and its subcontractors in charge of developing the experimental FCVs also plan to invest the same amount. This project is to learn experiences at point in time of replenishment for FCV from not only gaining various vehicle data but also constructing and operating the hydrogen charging station as FCVs and fuel cell bus would be driven on real road. Total 34 fuel cell vehicles will be rolled out to check the viability of the futuristic automobiles, which have an exponential potential until 2009. In Korea, three hydrogen stations are operating now and one station is under construction which will open this year. According to the national plan, minimum two more hydrogen stations will be constructed in Buan and Jeju to demonstrate fuel cell vehicle program.

The monitoring program of residential fuel cell system aims to make sure of the popularization of residential fuel cell system in the 1kW class by reducing the price and improving reliability of manufacturing technology. So far, there are a couple of fuel cells developed with capacity ranging from one to three kilowatts but their prices are too high for widespread use. In this

program, the government provided 40 standards fuel cells to see what needs improving. GS FuelCell (www.gsfuelcell.com) and FuelCellPower (www.fuelcellpower.co.kr) are participating in this program as supplier of fuel cell cogeneration system. In the year 2010, we expect that the price will be going down to one tenth of the current price, with high efficiency more than 40%. In addition they prove the reliability and long term stability of the system. In 2006, H2FC supported 29 projects with a total budget of about \$74 million including \$34 million from the private sector.

Korean Agency for Technology and Standards with Korea Specialty Chemical Industry Association is leading to develop codes and standards and participating in the activity of working groups in ISO/TC 197 and IEC/TC 105.

2.3 Nuclear hydrogen development and demonstration (NHDD)

Korea has set the goal of demonstrating nuclear hydrogen production in a five-phase development program (www.hydrogen.or.kr), which is also supported by MEST. KAERI (Korea Atomic Energy Research Institute) is leading this program and Doosan Heavy Industries & Construction Company is expected to join the program. In the first phase of this program from 2004 to 2005, 12 million US\$ was provided to this area. The aim of the 2nd phase program from 2006 to 2009 is to demonstrate reliability of 1m³/hr class IS (Iodine-Sulfur) H₂ production system and to develop conceptual design of nuclear reactor.[3] Pre-conceptual design work at KAERI is on going for pebble bed and block type high temperature reactor (HTR) cores. . When this work is finished, a decision will be made on the reactor type that will be built around the beginning of 2013 or 2014. Final target of this NHDD project will be to build 200MWth class VHTR and to produce 20 thousand tons of hydrogen annually, which could be used for fuel of 80 thousands fuel cell vehicles. The program has a cooperation with other

countries in both the generation of high-temperature process heat from gas-cooled nuclear reactors, and the IS technology for hydrogen production.

3. SOME SELECTED PROJECTS IN HERC AND THEIR RECENT ACHIEVEMENTS

Some representative projects which have been conducted in HERC were reviewed briefly and recent achievements were shown here.

3.1 Compact NG steam reforming system for H₂ fuelling Station

Hydrogen production from NG steam reforming is well known and mature technology. In an early phase of hydrogen economy, natural gas reforming technology should be contributed to supply hydrogen as is often in demonstration program. Still, commercialization has not been reached and challenges linked to lack of technology, incomplete systems solutions and difficult operability of fuelling stations requires research and development effort.



Figure 1. Hydrogen refuelling station at KIER, Daejeon

Main task in this work is to provide an engineering design basis for the unit through modularization and integration of both reformer and PSA unit for compactness with high efficiency. Technical target is to get the conversion efficiency of methane, more

than 85% and reformer thermal efficiency, 70 %.[4] In August 2006, hydrogen filling station (capacity 20 H₂ Nm³/hr) using this module was open and it has been operating with the fuel cell powered car project as shown in Figure 1.

3.2 Biological hydrogen production

Biological hydrogen production is one of long term projects. The production of hydrogen from wet biomass accomplishes two goals - reduction of pollutants and production of energy. The amount of hydrogen which can be produced from organic wastes is estimated to be about 650 million m³ annually, which is equivalent to 6% of hydrogen consumed in Korea.

This research topic focuses on the scale-up of fermentative H₂ production process using organic wastes and development of core-technology for bio-mimetic H₂ production system from water/organic substrates.[5],[6] For fermentation, hyperthermophilic strain screening and improvement, organic wastes pre-treatment, bioreactor design and development, process optimization, scale-up, long-term stability, and fuel cell application will be studied. For in vitro system, we will investigate the purification and characterization of photosynthesis and hydrogenase, biopolymer immobilization, system configuration and optimization, full genome annotation, proteome map, metabolic reconstruction, genetic engineering, and hydrogenase mass-production.



Figure 2. hydrogen production system from organic wastes (Lab.Scale)

The aim of the project in second phase is to obtain technical target with a specified level of productivity (fermentative H₂ productivity 15m³H₂/day/m³, H₂ productivity by bio-mimetic system 40 LH₂/kg Protein/hr). The research group are participating at the IEA-HIA task 21.

3.3 Photochemical hydrogen production

Water splitting using the photo-catalyst and solar energy will become one of the ultimate means to produce hydrogen. When light is introduced, the electron-hole pairs are produced in the photoactive material. The electron-hole pairs drive a chemical reduction and an oxidation reaction on the surface of the photoactive material, leading to hydrogen and oxygen evolution. In this situation, the photon energy is converted into chemical energy. But, the recombination of electron and hole causes to reduce quantum yield. So, the material and system design are important for the effective solar hydrogen production. The objective of this project in the second phase is to develop the system with 7% solar-to-hydrogen conversion efficiency. There are some R&D groups in the present R&D project in order to meet final target. Most of them are concentrated their efforts to search new high-performance material combinations and their application system.[7-13]

3.4 Hydrogen production by thermochemical water splitting

The thermochemical hydrogen production is processed at high temperature, as you can tell by its name. Hydrogen production by thermochemical water splitting using concentrated solar heat is competitive to other solar water splitting process in theoretical thermal efficiency. We are screening and evaluating the proposed thermochemical water splitting cycles for the concentrated solar energy utilization theoretically and experimentally. [14] Laboratory scale two-step

thermochemical water splitting by the solar simulator system will be demonstrated in the second phase.

3.5 Hydrogen production by low and high temperature water electrolysis

Renewable energy source such as photovoltaic and wind turbines are used to produce hydrogen via water electrolysis process. The present research aims at developing high efficient hydrogen production technology from water electrolysis, which is divided into two topics of PEME (Polymer Electrolyte Membrane Electrolysis) and HTSE (High Temperature Steam Electrolysis). For this purpose, the selection and fabrication of the electrode, electrolyte, and current collector materials have been carried out.[15] Then the electrode/electrolyte assembly as well as flow field design technology will be developed for optimum electrolysis cell design. Through the cell stacking and module design development, high efficient 3Nm³/h class PEME and 50l/h class HTSE hydrogen production system will be evaluated. Elchemtech (www.elchemtech.com) is leading PEME project, and has been conducting intensive researches on improving the system's efficiency and long-term stability, as shown in Figure 3.



Figure 3 PEME hydrogen production system (source:Elchemtec)

3.6 Hydrogen Storage Technologies

There is no material for hydrogen storage to satisfy DOE target. We are still trying to establish the innovative methods for design of hydrogen storage materials using molecular modelling.

New class of hydrogen storage materials such as organometallic nanoporous material and organic zeolites or non-covalent bonded molecular crystals has been searched.

(1) Metal hydride hydrogen storage materials and storage system for a FCV.

Metal hydride is well known and commercialized material for MH battery. This material has a potential to store hydrogen at low pressure but weight percent of hydrogen is still low because of its high density. So, light weight material with high hydrogen storage capacity at a moderate condition should be developed for on-board hydrogen storage of FCV. This project aims at developing metal hydride and storage system for FCV. Using the hydrogen storage materials which satisfy the specification (fuelling time, charge/discharge temperature) for FCV, small scale hydrogen storage system was manufactured and tested by the operation with fuel cell stack.[16] These results would be used to set up the development direction of hydrogen storage system for FCV.

(2) Nano-structured materials

Carbon materials due to their porous structures have been focused as one of promising materials for hydrogen storage. The surfaces of carbon have high energy density, so it is easy to modify for introducing some hydrogen-friendly functional groups. We are using various surface treatment techniques on several porous carbon materials. But the hydrogen capacity is still lower than the target and low temperature is needed for storing hydrogen. Also, we have searched some candidates for hydrogen storage materials based on molecular crystals and metal-dispersed materials by optimized materials design

using quantum simulations. The research group led by Dr.Jhi showed that hydrogen molecular binding in the CBGs is stronger than that on an isolated graphene with an increase of 20 to ~150% in binding energy, which is very promising for storage at ambient conditions[17]. Main focus should be to realize an experimental system, which synthesize and evaluate materials suggested by computational study.

(3) Chemical hydrides

The NaBH_4 dissolved in water in the presence of catalyst evolves hydrogen. This is very effective system, since we are getting hydrogen out of the water as well as NaBH_4 . This project aims at developing hydrogen generation system using NaBH_4 . [18] Successful implementation of NaBH_4 (sodium borohydride) hydrogen storage system needs more efficient regeneration process of the reaction product NaBO_2 (sodium metaborate)[19]. In addition to sodium borohydride which has been most studied to date, research is required for new materials exhibiting higher hydrogen storage capacity.

(4) Mg based storage materials

We have studied Mg based hydrogen storage materials with high capacity and application system by developing a microstructure consisting of nanocrystalline phases of Mg-Ni-X alloy with high capacity and kinetic. The capacity and kinetics of hydriding were strongly dependent on their microstructures [20].

(5) Measurement technologies for hydrogen storage and discharge materials

Measurement techniques of hydrogen storage capacity for new materials are also important. In order to support R&D team on hydrogen storage and to evaluate new developed materials, reliable volumetric and gravimetric measurement equipments are established. Measurement data on hydrogen storage amount have been collected and the

standardization of measurement methods will be established through this work.

3.7 Hydrogen Utilization Technologies

(1) Linear power/generation system using hydrogen combustion

The objective of this project in the second phase is to provide 5kW class hydrogen fuelled linear power/generation system. In the 1st stage, we already developed 1kW linear power/generation system successfully.[21],[22] Based on this experience, 5 kW class power converter, inverter, grid connection converter and hydrogen linear combustion engine will be designed and manufactured. If the linear power system is integrated with the linear generation system, it has the potential to be utilized in various applications including distributed generation, cogeneration systems, and power source for hybrid vehicles.

(2) Hydrogen detecting sensors

Hydrogen sensor is important to secure safety because most human senses won't help to detect a leak of hydrogen. The aim of this project is to develop catalytic combustion hydrogen sensor based on MEMS technology and optical sensor with high sensitivity and good reliability. [23],[24]



Figure 4. Optical sensor system (Prototype)

CONCLUSION

In 21st century, hydrogen and fuel cell program has been strongly supported by each government because of energy security and environmental problem. The International Partnership for Hydrogen Economy (IPHE) was launched to promote the hydrogen economy and Korea is participated at IPHE and IEA Hydrogen Implementation Agreement. Especially in Korea, to reduce the dependence on fossil fuels which most of them should be imported from foreign countries, hydrogen and fuel cell was selected as one of 10 economy growth engine for the next generation and was strongly supported by government. National program on hydrogen or fuel cell started with HERC (Hydrogen Energy R&D Center) in 2003. Now there are 3 national programs on hydrogen or fuel cell. The hydrogen production technology, which we are conducting now, covers 3 main basis, fossil fuel, renewable energy and nuclear energy.

There are still technical and economical barriers on the path to achieving the vision of the hydrogen economy. The hydrogen system must be cost-competitive, it must be safe and appealing to the consumer, and it would preferably offer advantages from the perspectives of energy security and global warming. Specifically for the transportation sector, dramatic progress in the development of fuel cells, storage devices, and distribution systems is especially critical. Through the national program on hydrogen and fuel cell, many scientists and industries are trying to develop and introduce cost-effective, durable, safe, and environmentally desirable fuel cell systems, and hydrogen production and storage systems.

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