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Policy and Action Programs in Japan – Hydrogen Technology as Eco Technology

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Summary

This paper reports an overview of policy and action programs for hydrogen technologies of Japan. Comprehensive and diverse action programs have been implemented by the NEDO (New Energy and Industrial Technology Development Organization). Various approaches to realize sustainable low carbon societies are being made also in local governmental levels. Saijo City, Ehime Prefecture, have been applying hydrogen storage technology to food production “Hydrogen Strawberry” and on-land fish breeding, and which has been found effective in CO₂ reduction and energy saving. Fukuoka Prefecture has reported effective CO₂ reduction and energy saving using the residential fuel cell system “ENE FARM” in a large scale. This paper concludes that hydrogen technology is human environment conscious technology - Eco Technology - which contributes to realize a sustainable low carbon society.

1 Japan’s Policy and Action Programs for FC and Hydrogen Technologies

1.1 Background

In 1999, the Japanese Government launched a strategic policy for fuel cell (FC) and hydrogen technologies. Since that time the government has boot up several strategic programs for energy innovation to realize sustainable development of Japan. By effective collaborations among governmental, academic and industrial sectors, the research and development (R&D) of FC and hydrogen technologies has yielded fruitful results in the development, introduction and diffusion of innovative clean energy technologies of FC and hydrogen.

Recent Japan’s energy self-sufficiency rate is 4% without nuclear power, or 20% with nuclear power. About 96% of energy demand of Japan is dependent mainly upon imported oil and uranium from foreign nations. The volatile oil price in the Middle East is violently threatening Japan’s fragile energy supply structure. The reinforcement of energy security is one of the prime issues for Japan. The R&D of clean energy and energy saving technologies are vital for Japan’s energy security.

As well known, our global environment is facing many serious issues such as global warming, climate change, desertification, acid rain, decreasing forest land, pollution of air, water, soil and sea, diffusion of chemical pollutants over countries etc. The CO₂ concentration in the atmosphere is said to be increasing at a rate of 600 to 900 tons-CO₂/sec, and other greenhouse gases emitted from our activity are assumed to contribute to global warming. Although other incredulous opinions are argued, we should avoid any possible dangerous factors which may threaten our global environment and our life. Japan will contribute to decrease of CO₂ emissions as the Japanese Prime Minister, Mr. Yukio

Hatoyama, addressed to the United Nations Summit on Climate Change that for the mid-term goal Japan will aim to reduce CO₂ emission by 25% by 2020 compared to the 1990 level [1]. If or not this would be possible, his words express Japan's strong intention and leadership in the fight and challenge on climate change and curbing CO₂ emissions. In Japan, 90% of the emitted greenhouse gas is CO₂. Therefore, the R&D of new energy technologies which contribute to energy saving and decrease CO₂ are the vital issue for Japan's energy policy. For the reduction of CO₂, the development of innovative new energy technologies such as FC and hydrogen technologies is needed. The Japanese Government has incorporated these new technologies into Japan's policy of energy security. The Japanese Government is implementing comprehensive R&D for FC and hydrogen technologies from fundamental to practical levels. In this paper, Japan's current action programs and activities in the R&D of FC and hydrogen technologies is summarized.

1.2 Action programs for clean energy technologies and low carbon society

In March 2008, a program for innovative energy technology - the Cool Earth - started. This program aims at efficiency improvement and low carbonization in the fields of energy supply side, energy demand side, and in the cross sectional field of the energy supply and demand sides as shown in Fig.1 [2]. The 21 key innovative energy technologies are selected with high priority. For these systematic R&D of clean energy technologies, the development of a new concept of the Japanese Smart Grid is included in the combination of solar, FC and battery technologies.

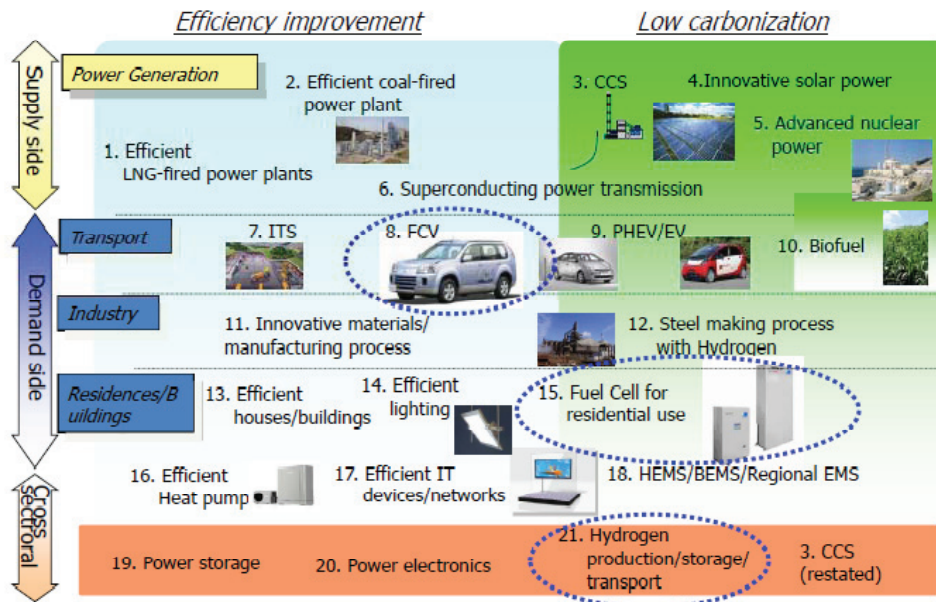


Figure 1: The 21 key technologies in the Cool Earth Program [2].

The Ministry of Economy, Trade and Industry (METI) is providing funding to NEDO which is acting as the center of operation and management of actual R&D projects among universities, companies and national research institutes. For these systematic R&D of clean energy technologies, the development of a new concept of the Japanese Smart Grid is included in the combination of solar, FC and battery technologies. Fig.2 shows comprehensive action programs of the R&D of FC and hydrogen technologies at NEDO until 2014.

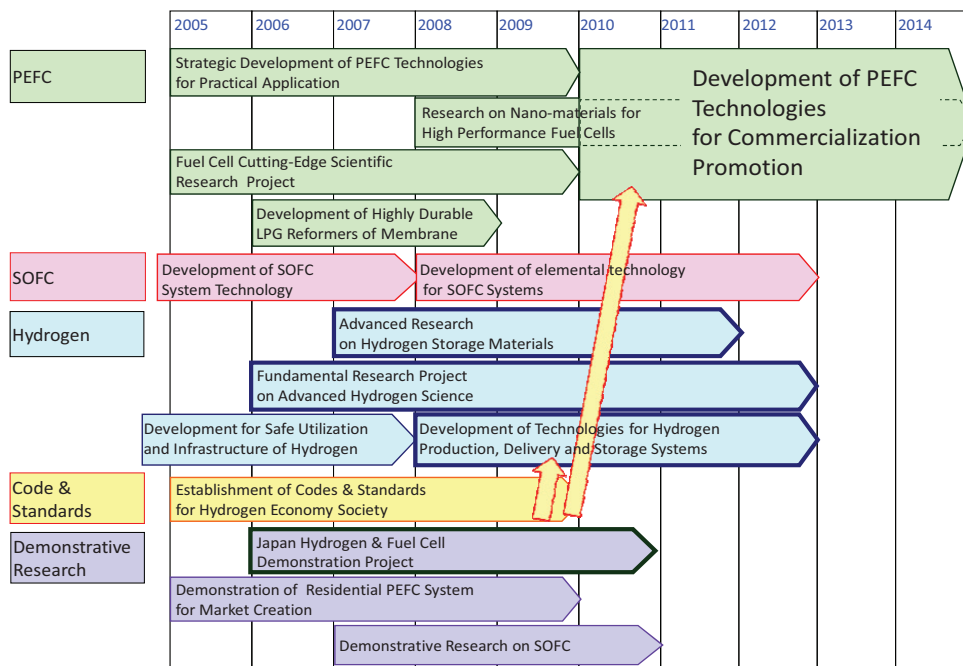


Figure 2: R&D on fuel cell and hydrogen technologies at NEDO [3].

Each project is being implemented with development of clean energy technologies as follows; **<PEFC>** Strategic development of PEFC technologies with basic research on materials for high performance practical applications / Development of standards for advanced application of FC / Demonstration of residential PEFC systems for market creation **<SOFC>** Development of system and elemental technology, and demonstrative research on SOFC including residential use; **<Hydrogen>** Fundamental research on advanced hydrogen science - high pressure H₂, liquid H₂, H₂ tribology, H₂ embrittlement etc / Advanced research on hydrogen storage materials / Development of technologies for hydrogen production, delivery, and storage systems / Establishment of codes & standards for hydrogen society; **<Battery>** Development of high performance rechargeable battery for the next-generation vehicles such as hybrid electric vehicle, plug-in hybrid electric vehicle and electric vehicle.

1.3 Residential FC test and demonstration in a large scale

The demonstrative research of residential FC systems is exhibiting highly successful results. The demonstrative test of residential PEFC systems started in 2005, and more than 3,300 PEFC system units were tested at houses until 2008. In 2009, a residential model “ENE-FARM” producing electricity and hot water entered into market with an output from 0.7 kW to 1 kW, an electric generation efficiency of 35 % to 37 %, and a heat recovery efficiency of 45 % to 52 % at 337 K using liquid petroleum gas (LPG) or town gas. Each system unit is found to reduce 1.5 tons-CO₂/y. The price of this model ranges from 3.2 million yen to 3.46 million yen. Since 2009, 1.4 million yen per unit has been subsidized. Typical ENE-FARM system units by three manufacturers (ENEOS, TOSHIBA, Panasonic) are shown in Fig.3. Until the end of March 2010, around 5,000 units of ENE-FARM have been installed to houses. Very stable operational performance was confirmed through an operation of 2.159×10^7 h at the end of March 2009. The number of ENE FARM is predicted to expand from 750,000 in 2015 to 2,500,000 in 2030. A residential SOFC model with a higher electric efficiency of around 50 % and a higher operation temperature than 973 K is being tested as larger FC systems. Fig.4 shows a scenario for a market creation and commercialization of residential FC systems [4].



Figure 3: Typical residential FC system unit “ENE-FARM” [4].

Fukuoka Prefecture has demonstrated a successful “Hy-Life Project” in Fukuoka Hydrogen Town in which 150 residential FC systems have been tested at each house. Effects of 31 tons-CO₂/y reduction and 130,000 MJ/y primary energy saving were reported on March 2010.

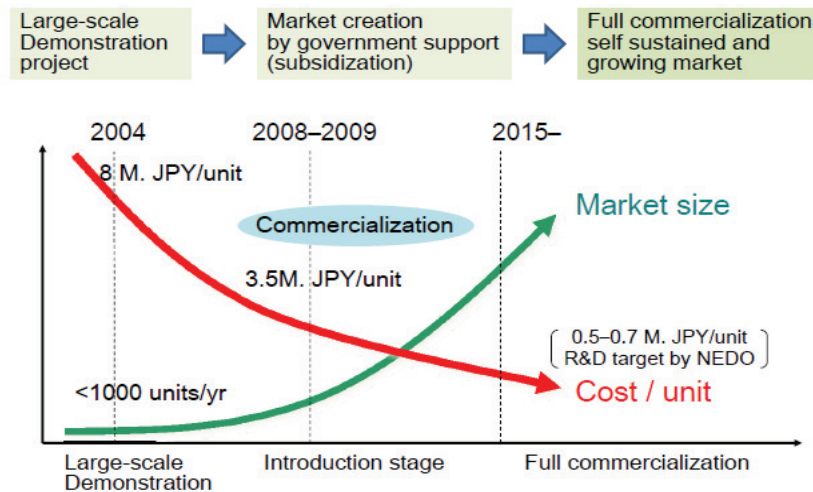


Figure 4: A scenario of development of residential FC system [4].

A hybrid residential FC system with a solar voltaic generation was commercialized in 2008, and a more marked effect of CO₂ reduction is anticipated together with conventional energy saving technologies.

1.4 Next-generation vehicles

The Japan's scenario of the commercialization of FCV is shown in Fig.5 [5]. This scenario was drawn by the Fuel Cell Commercialization Conference (FCCJ) under the agreement of the major Japanese companies involved in the R&D of FC and FCV. FCV will be commercialized in 2015 at the early stage, and 2050 in full commercialization.

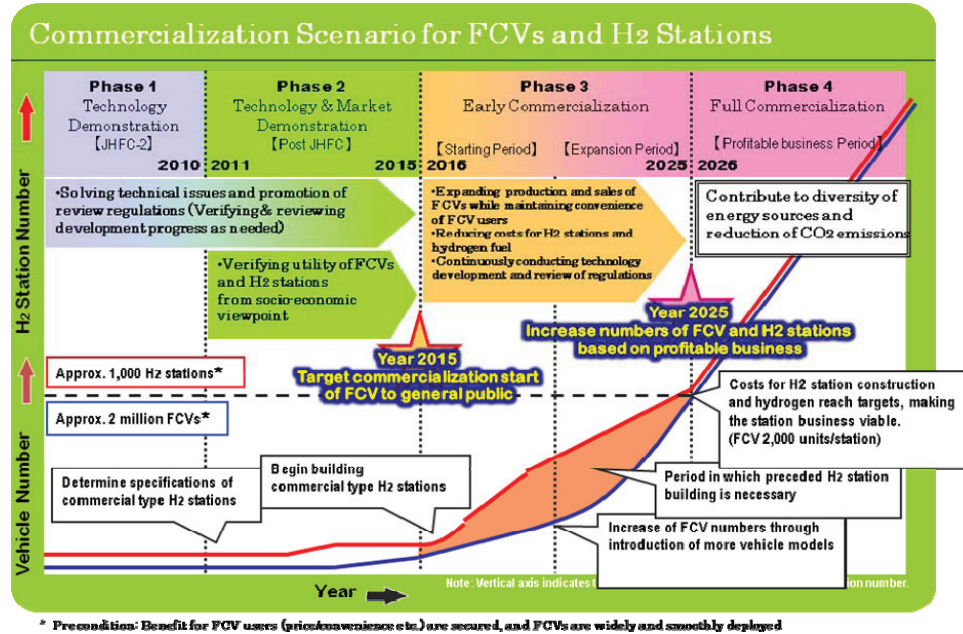


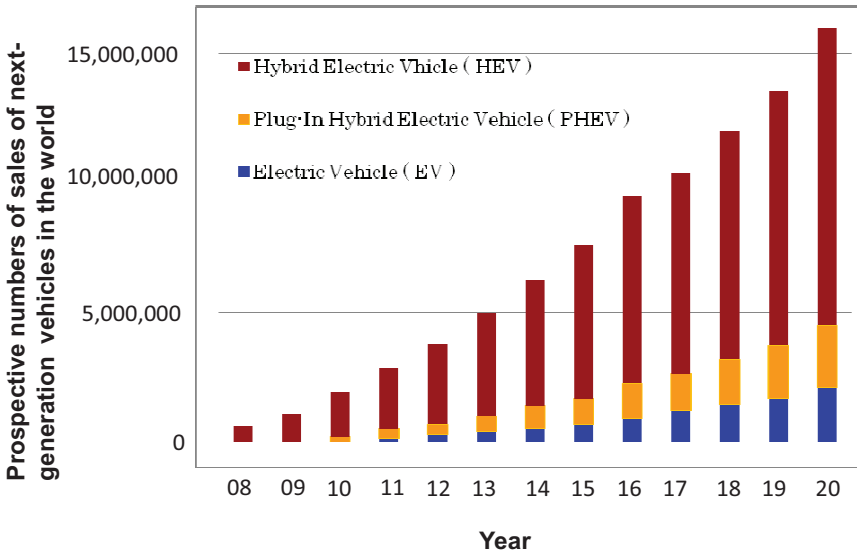
Figure 5: A scenario of commercialization of FCV in Japan [5].

This scenario becomes realized if preconditions such as cost reduction, improvement of reliability and durability for FC would be fulfilled, and hydrogen infrastructure such as the construction of enough numbers of H₂ fuel station and safety securement for FCV would be well developed.

Typical FC stacks for compact FCV have a weight less than 100 kg, and can start at 243 K and be operated at 373 K, 30 %RH. Strategic tasks to be solved for FC stacks are increasing durability longer than 5,000 h by improving membrane electrode assembly (MEA), and cost reduction by decreasing amount of platinum by 90 %. In this respect, basic research for used materials is vital for further development. As an example of a typical FCV, HONDA Clarity with its FC is shown in Fig.6. This FCV runs by a 100 kW PEMFC, and a high pressure H₂ tank (35 MPa H₂) with a volume of 171 Litter. The maximum speed is 160 km/h, the driving range is 380 km to 620 km, depending upon driving modes. The lease price is \$600 per month for three years [6].



Figure 6: HONDA FCX CLARITY [6].



Reference data from Nikkei Business , 1st February 2010

Figure 7: Prospective numbers of sales of next-generation vehicles in the world [7].

The R&D of the next-generation vehicles such as hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV) and electric vehicle (EV) are advancing. Fig.7 shows prospective numbers of sales of the next-generation vehicles in the world from 2008 to 2020 [7]. A rapid

growth of the number of these vehicles is predicted in the next 10 years. About 20 % of the total number of vehicles will be dominated by the next-generation vehicles in 2020 [7]. Further development of new rechargeable battery like Li air battery is needed for the next-generation vehicles.

Vehicles with a hydrogen rotary engine are successfully developed. Fig.8 shows MAZDA RX-8 Hydrogen RE with a dual fuel system driven by either the H_2 gas (35 MPa) or gasoline [8]. The maximum output power is 80 kW and driving range is 100 km by hydrogen, and 154 kW and 549 km by gasoline, respectively. This vehicle has been contributing to HyNor Project, Norway, since 2007 [9].



Figure 8: MAZDA RX-8 Hydrogen RE vehicle and the H_2 rotary engine [8].

1.5 Fundamental research on materials for innovative technologies

As these comprehensive R&D projects have been advancing, it is found that more precise and exact information on the behaviour of hydrogen and relevant elements on/ in materials under various conditions is needed in order to develop innovative, practical, durable and reliable systems. In Japan, a special fundamental research project “Advanced Fundamental Research on Hydrogen Storage Materials: HYDRO-STAR” was launched in 2007. In this project, basic research for hydrogen storage materials is actively being conducted. Under the motto “Back to the basic”, several basic research programs for FC and hydrogen technologies are advancing: Research Centre for Hydrogen Industrial Use and Storage (FY2006-2012), Basic Materials Research for High Performance Fuel Cell (FY2008-2014).

2 Hydrogen Technology

Hydrogen technology can be divided into two types. The first one is hydrogen consuming technology such as FC systems, and internal hydrogen combustion engines. In these systems, hydrogen reacts with oxygen to produce water, and in which chemical energy is converted to electric or mechanical energy. In this technology, the price of H_2 production is essential and predicted as 80 yen/ Nm^3 (2010), 80-40 yen/ Nm^3 (2015) and below 40 yen/ Nm^3 (2020) [10].

2.1 Hydrogen storage

In the second type, hydrogen is not consumed, but acts as a media of energy conversion or carrier in such systems as heat pump, nickel-metal hydride (MH) rechargeable battery, and mechanical actuator where hydrogen storage materials play crucial roles [11,12]. The fundamental reactions of hydrogen absorption and desorption of a hydrogen storage alloy are shown below,



where M is hydrogen storage alloy, H_2 is hydrogen gas, H^+ is hydrogen ion, MH is metal hydride, and Q is reaction heat. These simple reactions can be applied to practical hydrogen technologies. A hydrogen storage alloy absorbs and stores hydrogen atoms in a higher density in the metal lattice than in the liquid state of H_2 . This feature is applied to hydrogen storage tanks. Based on the NEDO's road map of hydrogen storage technology for FCV and H_2 station, various metallic, carbon and organic materials have been examined. The recent R&D on the storage materials are being implemented in the HYDRO-STAR project [13]. New materials should have a higher H_2 storage density than 6 to 9 mass% below 423 K, a storage capacity over 90 % of a maximum capacity after 1,000 cycles, and a cost less than 1,000 yen/kg. A hybrid use of H_2 gas and hydrogen storage materials in a H_2 container is anticipated to H_2 station and transport.

The hydrogen storage alloys are used for negative electrode of Ni-MH batteries which have been used for hybrid vehicles like TOYOTA PRIUS. Compared with conventional Ni-MH batteries, new Ni-MH rechargeable batteries like SANYO ENELOOP and Panasonic EVOLTA exhibit markedly low self-discharge rates. Almost 80 % of the full charge capacity remains after one year. Charge and discharge of these batteries can be made over 1000 to 1200 cycles. The successful commercialization of these batteries were realized as a result of fundamental research on electrode materials such as alloy lattice modifications (super lattice hydrogen storage alloys) or alloy microstructure modifications.

2.2 Heat reactions of hydrogen storage alloys

A hydrogen storage alloy releases heat Q in the hydride MH formation by H_2 absorption, and absorbs heat Q from the surrounding by H_2 desorption in the hydride MH decomposition. By combining two different hydrogen storage alloys, M_a and M_b , connected with a closed pipeline. By applying high temperature waste heat from factories or incinerators to a hydride M_aH , H_2 is desorbed from M_aH . The released H_2 gas moves to M_b and forms a hydride M_bH . When M_bH desorbs H_2 , which is moving back to M_a , M_b absorbs heat from surroundings. Using a heat exchanger, this heat absorption reaction of M_b can be applied to decrease the ground water temperature at a level of 293 K to 273 K by repeated H_2 absorption and desorption reactions. The temperature can be decreased to as low as 243 K in the use of a refrigerant instead of water [14]. The MH freezer can be driven by the combination of waste heats with high (>433 K) and low (300 K) temperatures. This is an effective use of waste heat when

the fact is taken into account that about 60 % to 70 % of the primary energy is generated as waste heat to surroundings. This MH freezer system has been applied to produce cold water for food production and on-land fish breeding in a large scale in a local city, Saijo, Japan.

2.3 Application of MH freezer to food production

The policy of clean energy by the Japanese Government has been extending to local areas in Japan. Saijo City, Ehime Prefecture, Japan, set up a MH (Ti-Zr based alloys) freezer system (2.5 USRT) in 2001 by the support of the METI, Advanced Industrial Science and technology (AIST), and Japan Steel Works, Ltd [12]. Using this MH freezer, the temperature of two rooms was cooled down to 243 K and 273 K, respectively. Compared with conventional CFC freezers, the MH freezer reduces the energy consumption and the CO₂ emission by 70 %. The city initiated a project "Saijo Cool Earth Project" in 2009, and introduced additional four MH freezer systems (1.2 to 1.5 USRT) for cold water production with temperatures from 273 K to 278 K. The cold water has been used to the cultivations of strawberry ("Hydrogen Strawberry") and the on-land fish breeding. This application has demonstrated that strawberry can be cultivated all the year round, resulting in increase twice in production amount and income compared with usual cultivation way without the MH freezer. The MH freezer has been applied to control of temperature of on-land fish breeding in Saijo City. Compared with conventional electric chillers, the MH freezer system reduces 25.6 tons-CO₂/y for a field of 1000 m² strawberry cultivation, and 38.5 tons-CO₂/y for fish breeding tanks with 20 tons of water. Furthermore, CO₂ produced from an oil refining factory was spread into the strawberry house to facilitate photosynthesis of the cultivation. This resulted in a reduction of 3.6 tons-CO₂/y. In addition, a solar photovoltaic system, which supplies electricity to control electric valves and motors of the house and breeding tanks, reduces 6.3 tons-CO₂/y. As the overall effect in the application of the MH freezer systems, 74 tons-CO₂/y reduction and about 90 % of electricity consumption were confirmed. Saijo City will expand the MH freezer technology to other agricultural and fishery fields, and connect to employment action, and the realization of a sustainable low carbon society

3 Hydrogen Technology as Eco Technology [14,15]

Environment means not only natural surroundings like water or air, but more. We should recognize that our sense of values and ethics vary and are strongly influenced by his/her environment, i.e., family, community, country, tradition, culture, religion, economic and political system, and so on. In this respect, we should use the expression "Human Environment" with great diversity of sense of values, instead of "Environment". Sustainability may be carried out from generation to generation only if people can feel comfortable or any merit. Traditional science and technology have served the kingdom of universality, objectivity and rationality. However, this has not been comfortable for us because we are living in the diversity of the natural environment, locality, and human environment surrounding us. At present, various renewable energy systems are developed and applied in each local area. This seems quite natural in accordance with our diverse human environment. Hydrogen may be applied not only to FC but to various purposes like agriculture and fishery. The high diversity of hydrogen technologies may serve our diverse requirement and environment.

From this point of view, hydrogen technology may be considered as “Human Environment Conscious (=Eco) Technology”.

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