Jurnal Mekanikal
June 2010, No. 30, 17 - 23

A REVIEW ON THE HYDROGEN STORAGE SYSTEM FOR FUEL CELL VEHICLES IN JAPAN

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ABSTRACT

Due to global warming and depletion of crude oil in the world, exploring new energy sources and alternative fuels are essential. Hydrogen is the most abundant element on earth and expected to be one of the main future energies. However, it is not found freely in nature and must be extracted from other substances, such as water or natural gas. As a result, there are substantial technical hurdles to produce, store and distribute hydrogen. In this paper, hydrogen storage system for automotive application, particularly fuel cell vehicles (FCVs), planned in Japan will be reviewed mainly from a view point of materials. Social or political situations toward hydrogen society in Japan and a vision for hydrogen technology proposed by the Japanese government are firstly overviewed, and some challenges toward FCVs by Japanese automotive manufacturing companies are introduced. Finally, hydrogen storage materials, such as metal hydrides and chemical hydrides, extensively studied in Japan are also reviewed, and possible hydrogen storage system for automotive application in Japan will also be discussed.

Keywords: Hydrogen storage, hydrogen technology, fuel cell, automotive applications, storage materials.

1.0 INTRODUCTION

Although COP15 Climate Change Conference was held in Copenhagen to discuss the reduction of green house effect gas, mainly CO_2, it seems to be difficult to share the common consensus between each country. Furthermore, energy crisis is also looming in front of us. The oil reserves in the world are depleted, however, the global consumption is still increasing. Transportation is responsible for 60 % of world's oil consumption. The ways to save oil consumption or alternate energies are strongly needed. Some Japanese automobile manufacturing companies (Toyota and Honda) are developing hybrid vehicles, which utilize both internal combustion engine and electric motor, into the market. However, future type of hybrid vehicles should utilize fuel cell and motor (battery). For the advancement of hydrogen and fuel cell power technologies in transportation,

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stationary, and portable applications, hydrogen storage is an important technology. In this report, efforts or visions towards introduction of fuel cell vehicles (FCVs) in Japan are briefly overlooked, and the hydrogen storage technology and hydrogen storage materials to be used for FCVs in Japan are also reviewed.

2.0 SCENARIO FOR INTRODUCTION OF FUEL CELL VEHICLES

FCVs are extremely low emission vehicles and cut oil consumption but now at the stage of development. Therefore, Japanese automobile manufacturing companies start manufacturing so-called green (or eco) vehicles like hybrid, electric or green diesel ones. The government is now providing several kinds of tax reductions or grants to promote introduction of green vehicles or ones whose CO_2 emission level is lower than those in 2005. If the vehicles meet those criteria, no purchase and weight tax are subjected (plus a 50 % reduction of annual vehicle tax). Furthermore, if owners change vehicles (whose age is more than 13 years) into green vehicles by March 2010, they receive grants amounting about 2,600 USD (1USD=100yen). The government is now aiming that 50 % of the vehicles in Japan will be green vehicles by 2020. Besides vehicles, stationary fuel cells are now on market from May 2009 in Japan. A specification of the product (ENE-FARM) released from Tokyo Gas Co. Ltd. is shown in Table 1.

Table 1: Specification of stationary fuel cell released from Tokyo Gas Co. Ltd.

Power generation	1.0 kW
Heat generation	1.4 kW
FC system	Polymer Electrolyte FC (PEFC)
Reforming	Gas/steam
Efficiency	Power generation 33-37%+ Heat generation 47-52%+
Gas consumption	3 kW
Durability	40,000 hr operation or 4,000 times start
Cost	36,500 USD

This fuel cell, based on a polymerlectrolyte type, costs about 36,500 USD. The government now provides grants, whose maximum amount is approximately 14,700 USD to reduce burdens of the owners. The Ministry of Economy, Trade and Industry (METI) has divided the term of loading FCVs in Japan into four (at the time of introduction of the plan), which are present, technology demonstration stage (-2010), early dissemination stage (2010–2020) and full commercialization stage (2020–2030). 50 thousand FCVs and 500 hydrogen stations are expected in Japan by 2010, and 15 million FCVs and 8,500 hydrogen stations with 1.51 million tons of hydrogen demand are also expected at the stage of full commercialization. During the early dissemination stage, infrastructures for hydrogen are very limited to the large cities or industrial areas, FCVs are mostly for line buses or fleet vehicles, however, because of expansion of the infrastructures, FCVs should spread to all cities during the full commercialization stage. The target for travel mileage, hydrogen storage capacity and cost of storage system at the full commercialization stage are 700 km, 7 kg and about hundreds of thousand yen. In a scenario planned by European Union, 0.4 – 1.8 million FCVs (a few percent of the total number of vehicles) are expected in 2020 [1].

3.0 VISION AND STRATEGY FOR HYDROGEN TECHNOLOGY

Energy and Industrial Technology Development Organization (NEDO), which is a governmental organization affiliated with METI, leads to set some policies for hydrogen storage and funds for the research and development in Japan. NEDO has set roadmaps for the following six technological fields to facilitate the hydrogen technology [2].

i. Polymer electrolyte fuel cells technology (stationary fuel cell system)
ii. Polymer electrolyte fuel cell technology (fuel cell vehicle)
iii. Solid oxide fuel cell technology
iv. Hydrogen storage technology
v. On-site hydrogen station technology
vi. Off-site hydrogen station technology

Table 2 shows long term vision for hydrogen technology in Japan proposed by NEDO. Presently, hybrid vehicles with internal combustion engine and motor are being loaded. However, by 2050 vehicle should be hybrid with both fuel cell and battery (no internal combustion engine). Their fuel is changing from biomass to hydrogen. Hydrogen storage begins from compressing hydrogen gas at 35 MPa (70MPa), and hydrogen will be stored in liquid form or in hydrogen storage materials by 2100.

The United States Department of Energy (DOE) has also shown similar technical targets, particularly for on-board hydrogen storage systems, that are; to develop and verify hydrogen storage systems achieving 2kWh/kg (6wt.%), 1.5 kWh/L, and $4/kWh by 2010, and achieving 3kWh/kg (9wt %), 2.7kWh/L, and $2/kWh by 2015 [3].

Table 2: Long term vision for energy technology in Japan

Year	2000	2030	2050	2100
Efficiency (ManXkm, tonXkm)	1		X1.5	X2.1
Energy Saving	0%	30%	60%	80%
Vehicle Engine		Hybrid system (Engine/motor) →	Motor (FC/battery)	$0g\text{-}CO_2/km$
Liquid fuel (gasoline)		synthesized fuel (mixed) biomass fuel (mixed)		
Hydrogen storage	Compressed →		liquid/hydrogen storage materials	
Hydrogen supply	Batch transportation →		on-site production →	pipe line

4.0 CURRENT STATUS FOR HYDROGEN STORAGE MATERIALS

How to store hydrogen is one of the important issues for practical application of FCVs, because of the space for hydrogen storage system is very limited. The storage system weight directly affects the total performance and the energy efficiency, so that the system should be as light as possible. In case for storing 5 kg hydrogen (equivalent to about a travel mileage of 500 km), the weight of the storage system will be 100 – 125 kg, if one assumes the gravimetric hydrogen capacity (system base) is 4–5 mass %.

Hydrogen storage approaches currently being pursued in US are (i) on-board reversible hydrogen storage focused on materials-based technologies, with some effort on low cost and conformable tank as well as compressed gas/cryogenic hybrid tanks and (ii) off-board regenerable hydrogen storage, such as chemical hydrogen storage [3]. Japan also takes similar approaches.

There is a merit to store hydrogen in liquid form because the volume of hydrogen will be about 1/800 when liquefied so that the volume of 5 kg of liquefied hydrogen is about 70 L, similar to a conventional petroleum tank. A liquid hydrogen tank that stored 4.8wt% hydrogen (4.3 kg H_2) in a volume of 68 L (system weight 85 kg, more compact than high-pressure hydrogen tank) has been developed. However, the cost (USD532,600) and a boil-off are the crucial problems.

High-pressure hydrogen tank made of C-FRP with a plastic liner that stores 3 kg H_2 at 35MPa is now available, and the tank that will store 7 kg H_2 (9wt%H_2) in a volume of 170 L will appear by 2020. Codes or standards for the tank utilized at 35 MPa has already established. To increase the energy density, high pressure tank at 70 MPa (although the density is not doubled), is now under feasibility studies. Hydrogen and FCVs safety evaluation facility (Hy-SEF) at Japan Automobile Research Institute located in Ibaraki prefecture assisted to establish the codes and standards. However, cost down is needed for actual applications (USD10,000)/cylinder because of the price of C-FRP).

The other way to store hydrogen is in materials. As hydrogen storage materials, AB_5, AB_2 or AB (A, B: metal) type metals hydrides, BCC alloys (tetrahedral interstitial sites in the BCC structure are favorable sites for hydrogen atoms), Mg based alloys, chemical hydrides or chemical complex (alanate, amide, borohydride), carbon, metal organic framework (MOF) and organic hydride (cyclohexane-benzene) have been investigated worldwide.

For research and development of hydrogen storage materials, Japan Institute of Metals (JIM), which is an academic society which provide engineers and scientists in Japan some opportunities to present and exchange the information, is one of the large societies working for hydrogen storage in Japan. Table 3 summarizes topics presented at the Spring national meeting of JIM in 2009. Although the conventional or traditional metal hydrides are still being investigated, chemical hydrides like metal borohydrides, amide, or imide have mostly been focused. Figure 1 shows hydrogen storage densities for several hydrogen storage materials, in which a 2010 DOE target for the densities (volumetric and gravimetric) are also shown. Most of the storage materials that meet the target belong to chemical hydrides, and traditional metal hydrides formed from $LaNi_5$ and TiFe are out of the target. This is one of the reasons why the chemical hydrides are mostly being focused in Japan. Modifications of performance (kinetics, stability, cycling, etc.) of conventional metal hydrides (AB_5, AB_2, and AB type hydrides, BCC type and Mg-based hydrides), chemical hydrides and metal organic framework (MOF) have been presented and discussed at the meeting. Aluminum hydride, AlH_3, is comparatively new topic for hydrogen storage. Although researches on hydrogen storage materials have been actively performed worldwide, no hydrogen storage materials meet all the targets (besides hydrogen densities, there are also targets for kinetics, stability, reversibility, cycling etc.) at this moment so that the present hydrogen storage materials need further modifications, or may need completely novel ideas for hydrogen storage materials or system.

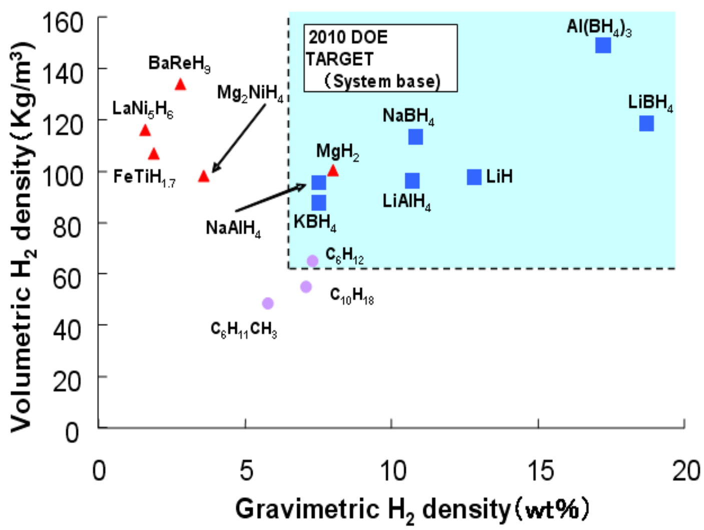

Figure 1: Hydrogen storage densities for several hydrogen storage materials.

Combining hydrogen storage materials with high-pressure tank, high-pressure hybrid tank and multi-cylinder hybrid tank system have been proposed by Toyota. Figure 2 shows the multi-cylinder hybrid tank [4]. This tank loads hydrogen storage materials in each cylinder and reduces system thickness that decrease the total cost for C-FRP.

Hydrogen storage for automotive application is mostly focused on on-board application. However, another possibility is off-board application. Sodium borohydride off-board application, in which spent fuel ($NaBO_2$) will be recovered at hydrogen stations and dehydrogenated at remote areas.

There are merits and demerits for each hydrogen storage systems, so that the hydrogen storage technology will be dependent on and different from kinds of scale of FCVs and the ways how to use FCVs, etc. (buses, fleet vehicles, personal vehicles etc.)

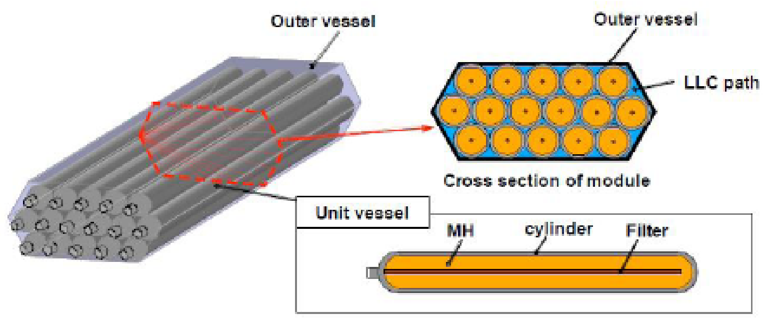

Figure 2: Multi-cylinder hybrid hydrogen tank proposed by Toyota [4].

Table 3: Research topics presented at JIM Spring meeting in 2009

Materials	No. of Presentations
Metal borohydrides ($LiBH_4$, $NaBH_4$…)	10
Li-N-H (amide, imide)	8
RNi_3 (R: La, Pr, Nd, Sm)	6
Mg based alloys	3
bcc alloys (Ti-Cr-V etc.)	3
RE2Ni7	2
Mg-C	2
$A1H_3$	2
MOF	2
$M(A1H_4)n$	2
Laves	2
LiH, NaH	1
TiFe	1
Pd-X(X: Ba, Y, La)	1
Li-TM(TM: Ti, V, Zr, Nb, Hf)	1
Mg-Co	1
Clathrate	1

5.0 CONCLUSIONS

i. High-pressure tank, which may be the key to hydrogen storage system at the beginning of the full commercialization stage, and hybrid hydrogen tank, in which metal hydrides are utilized, are now at the applicable stage.
ii. Some hydrogen storage technologies are still competing each other to achieve H_2 storage capacity of 5 – 7 kg.

iii. In future hydrogen society, only one hydrogen storage technology will survive. The storage technology will be dependent on and different from kinds of scale of FCVs and the ways how to use FCVs.

ACKNOWLEDGEMENTS

The author thanks Mr. Akinori Sugimoto, an undergraduate student of Shibaura Institute of Technology at that time, for his help. A part of this work was supported by the European Commission (project *Dev-BIOSOFC*, FP6-042436, MTKD-CT-2006-042436).

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