An Integrated PV – Electrolysis Metal Hydride Hydrogen Generation and Storage System

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Abstract

This project deals with the use of renewable electricity to generate hydrogen for large scale use in developing countries such as India. The hydrogen ICE scooter market in India was identified as a potential near-term application for hydrogen/metal hydride technology. India not only represents a large two wheeler market but also one that is growing the fastest. The hydrogen can come from the electrolysis of water using two sources of renewable, distributed electrical energy, PV and bagasse based cogenerated power. Bagasse is a byproduct of the sugar industry. We show how both of these scenarios are economically viable. Ovonic metal hydrides are used to store the hydrogen on-board and for transportation. Other uses of hydrogen/metal hydrides include distributed power generation to replace polluting kerosene or diesel generator sets and for portable power use. The renewable hydrogen thus produced can also be used as cooking fuel.

Introduction

The objective of the program is to introduce renewable hydrogen in the worldwide energy scene and pave way for the widespread use of metal hydride technology for storage. Before large scale use of hydrogen can be implemented, at least the following four issues need to be addressed:

1. Identification of the near-term market
2. Address the issues of storage, safety, distribution and refueling infrastructure
3. Cost and availability of hydrogen, and
4. Establishment of appropriate/strategic business alliances using a global approach

The market:

Two and three wheelers are a major consumer of petroleum and major source of air pollution in India. The global two wheeler fleet in year 2000 is estimated to be approximately 200 million units. Asia represents approximately 67% of global fleet and India being the largest market in Asia with an annual growth rate ~14%. We have identified the hydrogen –ICE two wheelers as an initial application for hydrogen because it permits transition to a clean alternative and will permit early large-scale use of hydrogen. The ICE manufacturing and maintenance infrastructure is available. This would minimize capital expenditure on the part of the OEM. When fuel cells become available, H_2 infrastructure will already be in place.

There are other promising markets for hydrogen/metal hydride technology and these include: distributed power generation to replace highly polluting kerosene and diesel generator sets, portable power, and use of hydrogen for cooking.

Storage:

Safety and compactness of the metal hydride storage system (MHSS) will ease transition to a hydrogen economy, especially when dealing with consumer applications.

ECD has extensive expertise in the science and technology of metal hydrides. Figure 1 shows the desorption PCT behaviour of a low temperature alloy with hydrogen absorption capacity ~2 wt% and a reversible desorption capacity of 1.5 wt%. This alloy is manufactured in large quantities. The plateau pressures of the alloy is suitable for use in storage systems for H-ICE and H-PEM Fuel Cell applications. The alloy exhibits excellent cycle life and resistance to CO poisoning.

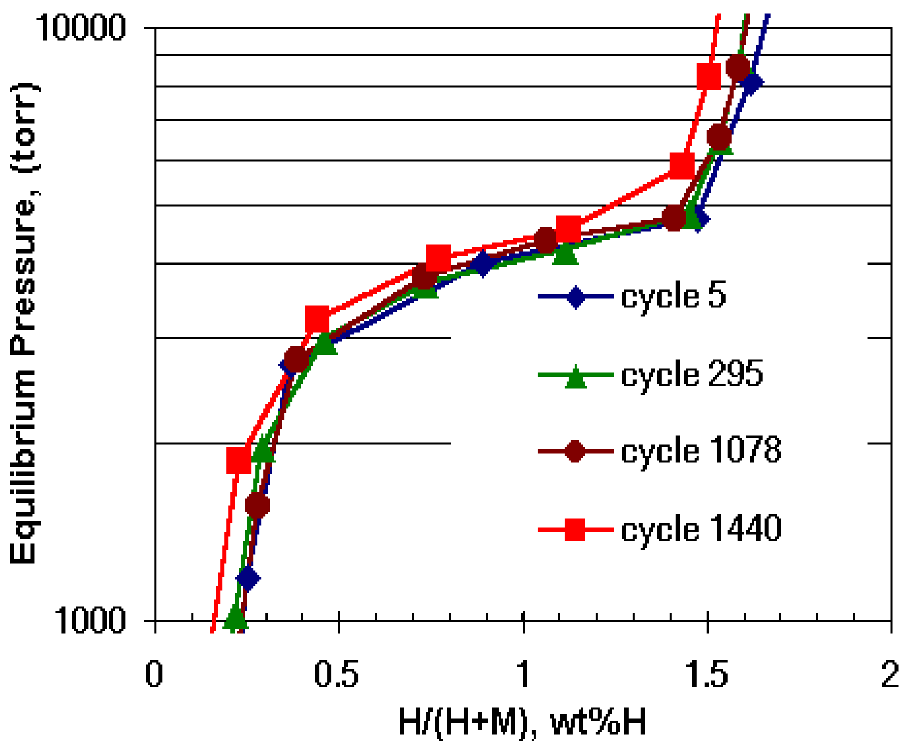


Figure 1. Desorption P-C Isotherms of TA-1b at 30°C. Cycles 1080-1429, H_2 / 0.1% CO

Figure 2 shows the desorption PC-isotherm of an alloy having a hydrogen absorption capacity of 3.5 wt%, and a desorption capacity of 2 wt% at 30 °C. Further work is required on this alloy to improve its plateau pressure, reversible capacity, cycle life, poison resistance and stability to moisture.

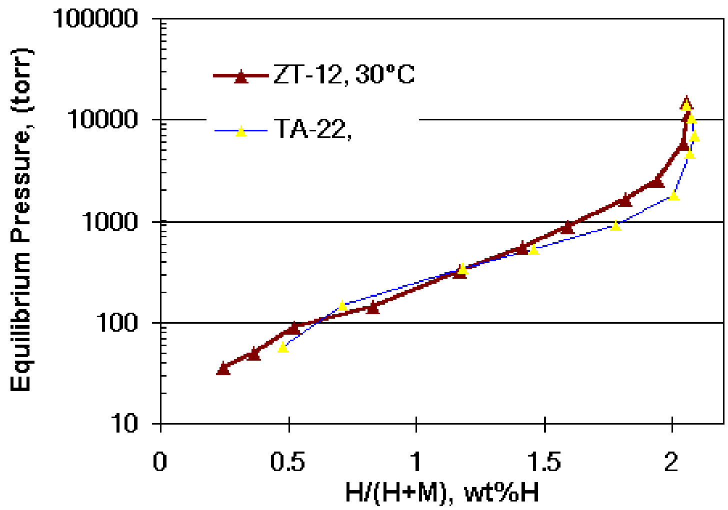
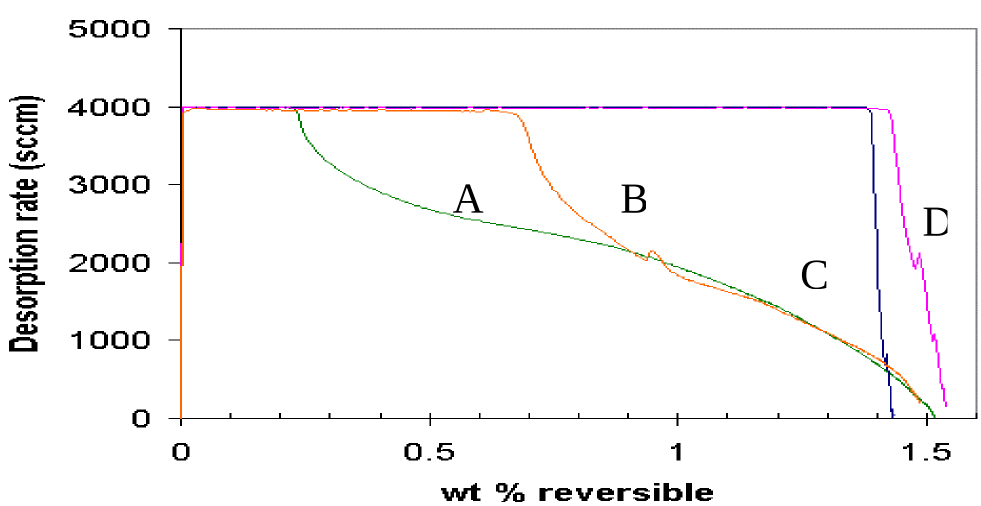


Figure 2. Desorption P-C Isotherms of TA-22 and ZT-12 at 30°C

The Storage System

While the metal hydride is the heart of a metal hydride storage system, the design and engineering of the complete system is critical for optimized performance. Figure 3 illustrates the effects of packaging on the hydrogen desorption characteristics of a metal hydride storage system. Four different canisters A, B, C, and D were packaged with alloy from the same production batch. The mass of the alloy and the desorption parameters (surrounding temperature, desorption pressure and desorption rate) were the same. The graph clearly shows the effect of heat and mass transfer on the hydrogen desorption characteristics. Storage systems C and D were able to sustain the desired discharge rate of 4000 sccm more effectively than systems A and B, which were packaged differently.

Figure 3. Effect of packaging on performance of a MHSS



MHSS for HICE Scooter for India

Fuel (H_2) use 5 gm/ km (assumed)
Avg. daily driving distance 20 km
Avg. driving speed 20 kmph
Onboard H_2 storage 100 gms
Mass of alloy (@ 1.5 w/o) 7 Kg

Figure 4 shows a prototype metal hydride storage module for H-ICE application. The module is designed to derive the heat of desorption from the hot exhaust of a H-ICE.

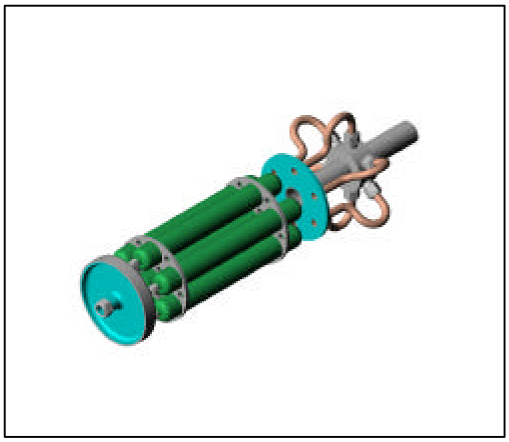
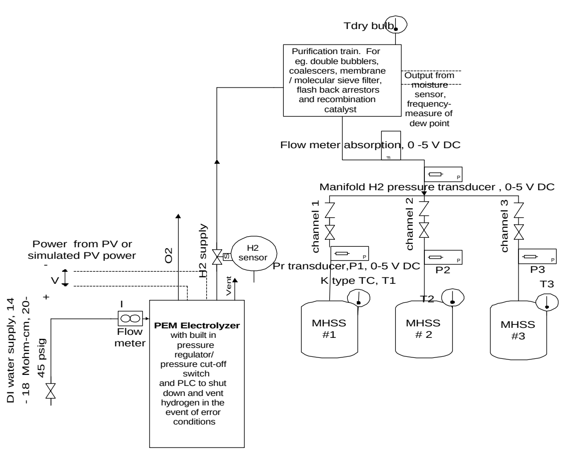


Figure 4. Prototype MHSS system for H-ICE scooter application

Fuel generation requirement is met with a USSC - 12 V, 1.66 kW_p a-Si PV array, 7.5 % panel. efficiency, 42 sq.m area, and a 1.25 kW water electrolyzer. On a typical July day in Detroit a PEM electrolyzer generated 134 grams of hydrogen, sufficient to run a scooter for one day. The metal hydride storage system was charged with hydrogen from the electrolyzer.

Figure 5: Schematic of a PV-Electrolysis Metal Hydride System



Preliminary test results

Heat of desorption from exhaust gas in a H-ICE scooter was determined by doing a mass balance to find exhaust gas volume ($V_{exhaust}$ in scfm**).** Using the hydrogen consumption at 20 kmph, the power at the rear wheel and the fuel -air ratio for a stoichiometric reaction a simple energy balance at the H-ICE determines the thermal energy lost to the exhaust ($Q_{exhaust}$ in Watts). It was assumed that about 30 % of the energy lost is in the form of thermal energy to the exhaust. The heat transfer medium used is air. The assumed range and hydrogen consumption data were used to determine the mass of the alloy required (total in the 7-tube bundle) to be 7 Kg.

In the absence of a HICE, we designed bench-top experiments simulating the exhaust heat. A simple exhaust gas – metal hydride storage system heat exchanger was designed and built. The hydrogen was desorbed at a fixed discharge rate and the hot air volumetric flow rate and the temperature were varied. It was found that about 80 % of the total reversible hydrogen could be released at the constant rate of 15 slm at 10 psig pressure. Figure 6 below shows the discharge characteristics and the temperature of the module surface as a function of time.

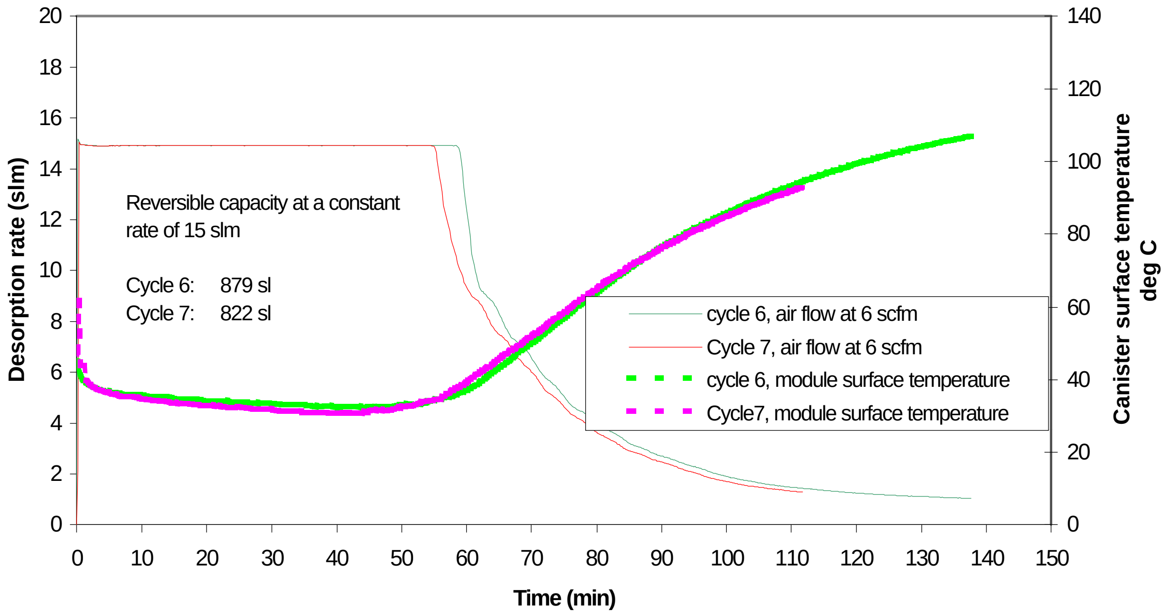


Figure 6. Hydrogen desorption from a tube bundle comprising of seven 140 sl modules. Desorption at 10 psig, 15-slm maximum, and airflow at 6 scfm

Renewable Hydrogen

a. PV/Electrolysis

India has a severe power shortage (greater than 11 GW), and a central power system that is highly unreliable and unable to meet the demand in remote areas. About 70% of the population lives in the villages. Decentralized renewable energy is the only option. India has approximately 39 MW installed PV capacity, the largest in Asia, and is the third largest in terms of installed Wind Power in the world. The country is receptive to renewable technologies, including hydrogen. India has established Independent Renewable Power Producers (IRPP's) organizations to accelerate the commercialization of decentralized power. PV can be placed anywhere and presently 50% subsidy is being offered on many PV products. We looked closely at the cost of hydrogen produced by PV –Electrolysis as a apart of our current year effort. A 2 kW PV-Electrolysis system represents a distributed, and renewable hydrogen generation system. It was demonstrated that a Ovonic metal hydride (TA-1) can be readily charged with electrolytic hydrogen from a PEM electrolyzer.

A preliminary cost analysis (Figure 7) was carried out for a PV- Electrolysis System producing hydrogen

The following assumptions were made

η electrolyzer 65%

Cost of electrolyzer not included

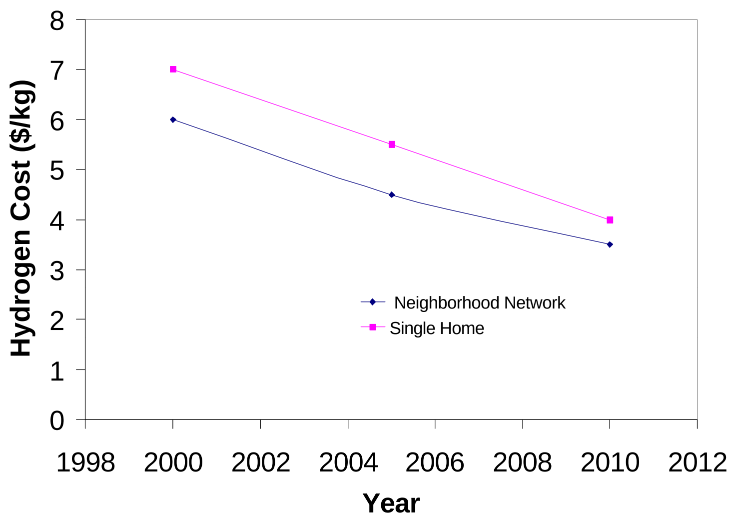


Figure 7. Cost of hydrogen from PV[1] – Electrolysis

Cost of PV – electrolytic hydrogen was calculated for both a-Si and crystalline Si PV panels in the kW range. Both the present cost and performance (efficiency) of the PV panels as well as the

[1] PV cost from report titled 'Overview of Photovoltaic technologies'

projected data were used to determine the cost. PV- Electrolyzer system can be tailored to meet the power and fuel requirement (hydrogen) in remote locations that are not grid connected and

India is the largest cane sugar producer in the world, producing about 13 million metric tons / year and bagasse is a by-product of this process with high density of thermal energy. The cogen power in India is 3,800 MW. Of this, 180 MW cogeneration is consumed internally for sugar manufacture and the rest is available for sale at a price of 2-4 cents/

Figure 8 shows a map of India with the number and location of existing sugar mills. mills are located next to the cane fields and are distributed all over the country. This minimizes the cost of transporting cane and will also reduce the cost of transporting the product hydrogen.

Cogen distribution in India

Shown below in Figure 9 is a concept of the proposed hydrogen production using bagasse based

The power available will be used to run the electrolyzers onsite. Hydrogen will be produced

tankers to ‘filling stations’. In addition, Ovonic metal hydrides would be charged at the hydrogen plants and distributed to the applications.

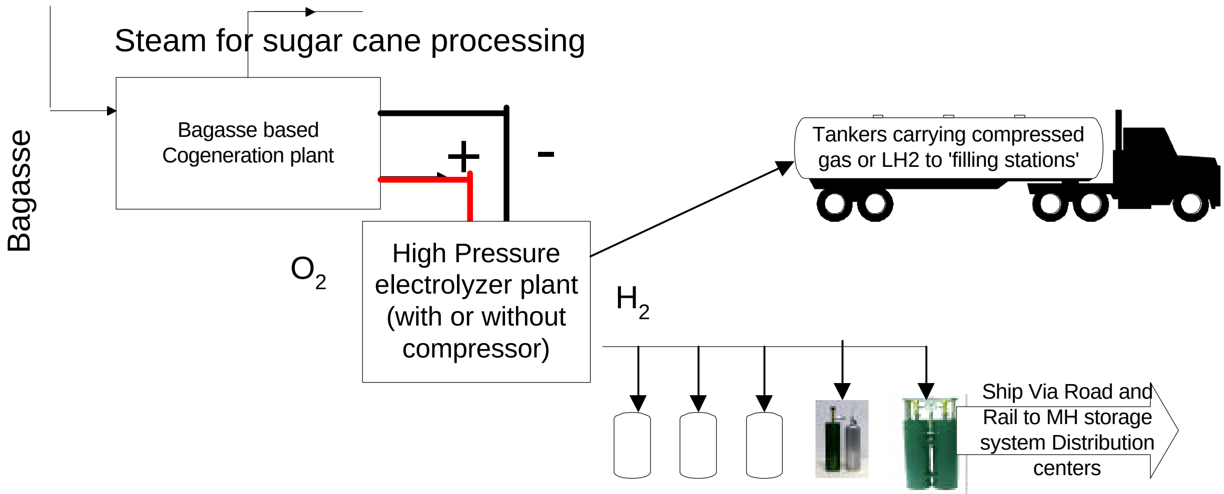


Figure 9 : Concept for bagasse based cogeneration electrolysis for hydrogen production and its distribution

Case study - three sugarcane processing mills in India [2]

Available low cost Power (GWh/yr)	**H_2 Energy (Gwh/ yr) (ηelectrolysis =0.5)**	**H_2 production (tonnes/year)**	**# Scooters fueled/year [!]**
295	147.5	4470	122457
166	83	2515	68908
89	44.5	1348	36945

! The fuelling capacity assumes 5 gm H2/Km and 100 gm / day per scooter and 365 driving days / year

Based on private discussions with Proton Energy Systems, the capital cost of an electrolyzer was included in the cost of cogeneration powered - electrolytic hydrogen. The plant is assumed to produce ~ 14.2 Tonnes H_2 / year assuming 300 days/ year and 19 hour operation per day.

Cost of power	**Cost of hydrogen**
2 cents / kWhr	US \$ 1.76/ Kg
4 cents / kWhr	US \$ 2.81 / Kg

We see that the low cost of cogeneration power reduces the cost of electrolytic hydrogen. Bulk hydrogen can be dispensed to the application directly at a ‘hydrogen filling station’ while the charged metal hydrides can be distributed to customer directly through retail outlets.

[2] USAID/NewDelhi and the Office of Energy and Infrastructure study (Report No. 93-02) titled ‘Advancing Cogeneration in the Indian Sugar Industry’