A Review On Third Generation Future Fuel : Sodium Borohydride Fuel

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Abstract – **The current issues of the depletion of fossil fuels reserve and environmental changes have increased the concern for the hunt of sustainable renewable energy for the future generations. Biofuels emerged as a promising viable alternative to replace the existing fossil fuels. Among these, Sodium borohydride Fuel outstands due to its ability to substitute gasoline. Hydrogen is the most abundantly available element in the universe. It is environmentally friendly with its non-polluting nature. It has every reason to dominate the fuel market. Yet, it fails to fossil fuels, which is currently the driving force of our automobiles. Some have heralded hydrogen as the 'Energy of the Future', but sceptics say it will always be just that – A future fuel, which never makes it out of test cars. But this was until DaimlerChrysler came up with an innovative idea – SOAP to fuel the future automobiles. However, the major challenge in Sodium borohydride Fuel industry is the need to discover a suitable feedstock together with an environmentally friendly approach and an economically feasible process of production. The first generation and second generation Sodium borohydride Fuel appeared unsustainable due to its impact on food security as well as inflated production process. Therefore, the potential and prospects of the third generation Sodium borohydride Fuel feedstock are being highlighted in this review. This review can be crucial in providing ideas for the future studies that can be implemented in the commercialization of Sodium borohydride Fuelfrom the third generation feedstock.**

Keywords — **Liquefied Hydrogen, Compressed Hydrogen, Methanol, Gasoline Reformation, Metal Hydride, Natrium.**

I. INTRODUCTION

Today, millions of people depend on the automobile as their main source of transportation. Unfortunately, most of the automobiles use fossil fuels such as oil. The internal combustion engine consumes the hydrocarbon fuels to release carbon monoxide, nitrogen oxides, hydrogen carbons, and carbon dioxide. In addition to these disastrous effects to the environment, hydrocarbon fuels are a finite energy source. Therefore, another efficient and cheap energy source needs to be found quickly. Ideally, this energy source should be unlimited in its supply and friendly to the environment.

Many alternatives have been considered. For example, researchers have attempted to power cars by the use of batteries and solar power. However, since batteries operate on a stored amount of energy, they have a limited range typically around 100 miles. The batteries are also very large since it consumes over 17 times as much space and 45 times as much weight as gasoline tanks. Solar powered cars are limited to its use on sunny days. On cloudy days and at night, the car operates on batteries. Therefore, solar powered cars have a driving range of approximately 135 miles. For years, visionaries have proposed that the world switch from using hydrocarbons — fossil fuels such as diesel oil, gasoline and coal — to pure hydrogen. Hydrogen is one of the simplest, lightest and the most abundant element in the universe. It is made up of a single proton with one electron. It can be obtained from electrolysis of water by using a number of energy sources such as nuclear, solar and fossil fuels. Presently 95% of the hydrogen used today comes from reforming natural gas. When combusted, it produces only water and heat. Today with an emphasis on emission free fuel source and the desire to find an alternative fuel, hydrogen is been looked at and touted by many as the fuel of the future.

The use of hydrogen will decrease our dependence on the finite amount of fossil fuels. It will also spur economic growth.

II. LITERATURE SURVEY

The Chrysler Town & Country Natrium, DaimlerChrysler's fuel-cell concept vehicle running on clean, nonflammable, and recyclable sodium borohydride fuel, participated in a ride-and-drive display program at the Pentagon at the request of acting Secretary of the Navy, Honorable H.T. Johnson. The Natrium is the first fuel-cell powered vehicle built to operate on sodium borohydride, a fuel made from borax which is a mineral available in abundant supply.

In the Natrium minivan, this technology delivers the environmental benefits of a fuel-cell vehicle without the loss of cargo or passenger space, while providing a range of 300 miles, which is about 50% longer than any other fuel-cell vehicle ever produced. Never had a fuel cell vehicle been driven so far, in challenging real-world conditions, including high elevation and low temperatures. Also it's range is comparable to that of I.C. Engine powered vehicles.

III. FINDING THE RIGHT FUEL

Hydrogen-powered fuel cells, by themselves are completely emission-free in operation. No pollutants are emitted by the reaction of hydrogen with oxygen, which generates electrical energy, heat, and pure water vapour. The problem is that the fuel cell is considered as 'emission-free' only if is directly supplied with hydrogen – which may not be the most viable solution. There are various options for the delivery of hydrogen – and, essentially, the more environmentally friendly they are, the more costly they are to implement in terms of infrastructure. Hydrogen may be stored in the form of :

A. *Liquefied hydrogen*
B. *Compressed hydrogen*
C. *Methanol*
D. *Gasoline reformation*
E. *Metal hydride*

However, each of these methods are compounded with various drawbacks like- liquefied hydrogen is required to be stored on-board at -253 ^{0}C. Compressed hydrogen has to be stored at about 10,000 psi. Besides, there is a strong – but unwarranted – public perception that this form of storage of hydrogen is dangerous. Although metal hydrides offer very high storage capacity, the weight of the system increases to twice as much as compressed hydrogen for the same range.

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IV. STUDY OF CHEMICAL REACTIONS AND SPECIFICATIONS OF SOAP AS A FUEL

A. *The Sodium borohydride Fuel*

What's been holding back development of fuel-cell cars is the storage tanks that such vehicles require, which are so big, that there's hardly room for passengers, let alone cargo. The DaimlerChrysler 'Natrium' vehicle gets round this by storing the hydrogen as sodium borohydride, a non-toxic solution that can be pumped in and out of the vehicle safely and cleanly. The fuel is elusive hydrogen stored in a mixture of 75-percent water and 25-percent glorified soap powder. It is something like a soap factory under the hood. It involves simple borate - a chemical mined from the ground and used as laundry detergent. The fuel cell runs on hydrogen taken from sodium borohydride - a man-made chemical. What's left is borax soap in the tank. The only emission from the tailpipe is steam.

Sodium borohydride ($NaBH_4$) is the most benign fuel under consideration. It is a compound of sodium, boron, and hydrogen. It is used in a variety of chemical industries, including the paper and pulp industries (as a bleach), in wastewater processing and in pharmaceutical synthesis. Sodium borohydride is hydrogenated sodium borate ($NaBO_2$), chemically equivalent to borax - a substance used as a laundry detergent ingredient. The sodium borate ($NaBO_2$) is not consumed in the process, but merely acts as a carrier for the hydrogen. The system is completely safe since it produces the dangerous hydrogen gas only when needed. Once the flow of sodium borohydride over the catalyst stops, so does the production of hydrogen.

The hydrogen generation reaction is as shown below:

$$\underset{\text{Sodium borohydride}}{NaBH_4} + 2\,H_2O \xrightarrow{\text{catalyst}} \underset{\text{Hydrogen gas}}{4\,H_2} + \underset{\text{Sodium metaborate}}{NaBO_2}$$

The only other reaction product, sodium metaborate is water-soluble and environmentally benign. The reaction is exothermic - so there is no need to supply external heat to access the hydrogen. The heat generated is sufficient to vaporize some of the water present, and as a result the hydrogen is supplied at 100% relative humidity. This co-generated moisture in the H_2 stream is an added benefit both for fuel cells and for internal combustion engines.

The idea of using sodium borohydride as a fuel is not new – it has long been known that boron hydrides store more energy than similar hydrocarbons. Back in the 1960s, work on the fuel was abandoned because at that time the fuel was intended for combustion, which represented an insurmountable engineering challenge. The development of 'the catalyst' technology for controlled release of hydrogen have allowed engineers to take a fresh look at this possibility. Besides its infrastructure issues are less challenging that with other fuels proposed for fuel cell vehicles.

B. *Hydrogen on Demand Technical Specifications*

Gravimetric storage density	**% H_2 by Wt.**
Solid $NaBH_4$	10.6 %
$NaBH_4$-20 solution (20 wt% $NaBH_4$, 3 wt% NaOH, 77 wt% H_2O)	4.4 %
$NaBH_4$-25 solution (25 wt% $NaBH_4$, 3 wt% NaOH, 72 wt% H_2O)	5.5 %
$NaBH_4$-30 solution (30 wt% $NaBH_4$, 3 wt% NaOH, 67 wt% H_2O)	6.6 %
$NaBH_4$-35 solution (35 wt% $NaBH_4$, 3 wt% NaOH, 62 wt% H_2O)	7.7 %

Table 1

Volumetric storage density	**Mass of H2 gas stored**	**Standard Volume of H_2 Stored (70^{0}F, 1atm)**
1 Liter $NaBH_4$-20 sol.	44 grams	526 Std Liters
1 Liter $NaBH_4$-25 sol.	55 grams	658 Std Liters
1 Liter $NaBH_4$-30 sol.	66 grams	789 Std Liters
1 Liter $NaBH_4$-35 sol.	77 grams	921 Std Liters

Table 2

C. *Energy storage:*

a. 1 kg of hydrogen = 1000 g of hydrogen = 113,500 BTU energy = 33.26 kWh = 119600 kJ.
b. 1 kg of solid $NaBH_4$ reacted with 950 g of water yields 213.5 g of hydrogen gas, or 24230 BTU = 7.100 kWh = 25560 kJ.
c. 1 gallon of $NaBH_4$-30 = 1.16 kg solid $NaBH_4$ = 28100 BTU = 8.24 kWh = 29600 kJ.

d. 1 gallon of gasoline = 115,000 BTU energy = 33.70 kWh = 121300 kJ.
e. 1 kg of Hydrogen ~ 1 gallon of gasoline.

V. Integration to Fuel Cell Systems

Fig. 1 The 'Natrium' Minivan

The Natrium was unveiled at EVAA annual convention on December 12, 2001 in Sacramento, CA and at North American International Auto Show, Detroit, in January 2002. It was also presented to President Bush on February 25, 2002. A demonstration vehicle is available for drive and ride at the Innovation Symposium.

Natrium is the Latin word for sodium (i.e. Na), originating from it's fuel – sodium borohydride. One of the impressive things about the vehicle is its appearance: Unless you pop the hood or crawl underneath, the Natrium looks like a normal minivan. The tanks, catalyst, fuel cell and motor do not encroach in any way on the passenger or luggage space. The Natrium is a van weighing 4 tonnes and has a 53-gallon tank to achieve a range of 300 miles (500 km) — comparable to a gasoline-powered vehicle and roughly 50 percent further than typical fuel cell cars that use other fuels.

A. Chrysler Town & Country Natrium Preliminary Specifications

Vehicle : Chrysler Town & Country minivan
Powertrain : Front-wheel drive regenerative braking
Motor : 35 kW Siemens AC motor
Battery Pack : 40 kW SAFT Li-Ion
Fuel : Sodium boro-hydride, recyclable
Fuel Processor : Hydrogen on Demand system Millennium Cell, Inc.
Fuel Cell System : Ballard/XCELLSiS
Performance :
Fuel economy : 30 mpg gasoline equivalent
0-60 mph : 16 seconds (i.e. 0 – 100 km/h in 16 sec.)
Top speed : 80 mph (129 km/h)
Range : 300 miles
Emissions : Zero emissions

The Natrium's fuel cell system is produced by DaimlerChrysler's fuel cell partner, Ballard/XCELLSiS (Ballard Power Systems) of Vancouver, Canada. The hydrogen is produced using the "Hydrogen on Demand" system developed by Millennium Cell, Inc., of Eatontown, New Jersey.

B. The Natrium System

The successful integration of a fuel-cell system depends on implementation of several important sub-systems. This includes all fuel-cell mounting and packaging, fuel-cell cooling loop, air-handling components, humidification systems, etc. The 'Natrium' system is as shown in Fig. 4.2.

a. *The Electric Drive :* The electric drive is a 35 kW Siemens AC motor. It draws it's power from the fuel cell stack. A transformer in the engine siphons off the hydrogen to power a fuel cell. The Li-Ion battery pack powers the motor in event of failure of the fuel cell system.

b. *Li-Ion Battery Pack :* the battery pack is a 40kW SAFT Li-Ion Battery Pack that serves as a storage unit for electrical energy. The battery is recharged not only by the fuel cell unit but by the braking process as well i.e. the "Natrium" also uses the regeneration principle, whereby the energy that becomes available during braking is not simply transferred to the air as heat but instead used to generate electricity. Should the fuel cell system fail, the powerful battery alone is sufficient to drive the electric motor and move the vehicle. So, the "Natrium" minivan is not a pure fuel cell vehicle but rather a fuel cell hybrid.

c. *Fuel-Cell Stack :* The fuel cell module used in the Natrium is supplied by DaimlerChysler's Canadian fuel cell partner Ballard Power Systems. It is a P.E.M. fuel cell.

d. *Air-Compressor :* The air-compressor operates with a load following strategy. If the stack is under light load, the air-compressor provides minimum flow. At high loads, the air-compressor provides maximum flow. This allows the fuel cell to produce power at a more efficient rate and minimize losses. Monitoring the pressure of hydrogen flow into the fuel cell, the compressor regulates the air-pressure accordingly.

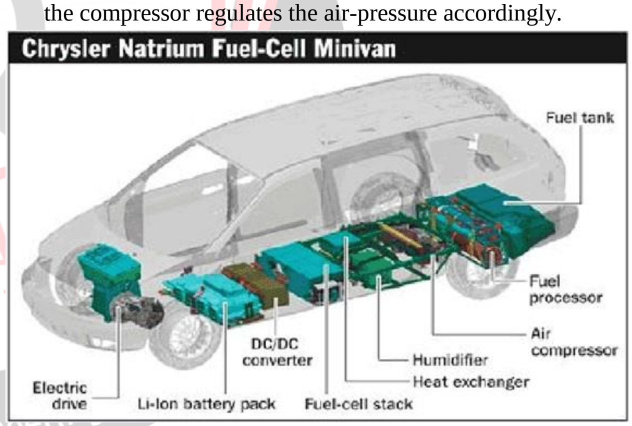

Fig. 2 The 'Natrium' System

e. *Humidifier :*The air is supplied to the system at 80% relative humidity. Humidification is accomplished through the use of a water injection system.

f. *Heat Exchanger :* The heat exchanger forms a part of the fuel cell cooling loop. The fuel cell cooling loop is a thermal system that removes excess heat from the fuel cell.

g. *Fuel Processor :* The fuel processor is the *'Hydrogen on Demand'* technology developed by Millennium Cell. It consists of the Fuel Pump and the catalyst chamber.

h. *Fuel Tank :* The fuel tank is a hand-laid fiberglass compartment with about a 53-gallon capacity that hangs off the posterior of the Natrium. The fuel tank receives the sodium borohydride from the fuelling station and supplies it to the catalyst chamber via the fuel pump when demanded. A bladder in the fuel tank separates spent borax from the fuel.

VI. 'HYDROGEN ON DEMAND' SYSTEM HIGHLIGHTS

A. Pure, humidified hydrogen source is obtainable.
B. High energy storage density.
C. Storable in plastic containers at room temperature and without pressurization.
D. Environmentally benign, non-flammable, non-explosive fuel and by-product.
E. Widely variable hydrogen output flow rate and delivery pressure.

VII. MERITS OF THE SYSTEM

A. There is no cabin intrusion at all, so the vehicle has a fully usable trunk.
B. The sodium boro hydride fuel can be recycled.
C. The borax used in the manufacture of sodium borohydride is available in abundance in natural reserves. A recently released study of global borate reserves by U.S. Borax Inc. indicates that even if all new cars were to adopt sodium borohydride as the energy carrier, there would be plenty of borax reserves. The study reports 600 million metric tons of borates in viable deposits worldwide. If 50 million new cars built each year were supplied with borates, this would require some 20 million metric tons – about 5 percent of known reserves. And very little additional borate would be required, as the spent 'fuel' is recycled.
D. The use of sodium borohydride as a fuel is not restricted to automobiles. The fuel is capable of producing 110- and 240-volt electricity.
E. This could enable a fuel-cell car to provide light and heat for houses when parked in the garage at night: The car's fuel cell could plug into the house to provide home electricity produced from hydrogen in the car's tank.
F. This unique technology could have great benefits for the military: in particular, it is nonflammable, greatly improving safety in battle zones.
G. It is useful for companies looking to buy safe, reliable generators for back-up power.
H. In consumer application the fuel cells could be used to energize laptop computers and mobile phones for weeks without recharging.
I. The weight-energy storage ratio of sodium borohydride is almost the equivalent to that of gasoline, meaning that sodium borohydride produces the same amount of energy per gallon of fuel as gasoline produces. Hence the range of 300 miles (500 km) achieved by Natrium is comparable to a gasoline-powered vehicle and roughly 50 percent further than typical fuel cell.
J. The system operates at a pressure of 150 psig (~10 bar) compatible with that required in the Fuel Cell. This low operation pressure for Hydrogen on demand is in contrast to the high pressures of 2200-5000 psig (~150-350 bar) that are present in typical compressed hydrogen tanks.
K. The main advantage offered is 'Zero dependency on oil for propulsion'.

VIII. DEMERITS OF SYSTEM

A. Millennium's 'Hydrogen on Demand' isn't a clear-cut winner that will change the world of transportation. There are a few kinks to work out before it becomes a widespread solution.

B. Another potentially expensive problem may be the sodium borohydride "fuel" itself. You have to have hydrogen production somewhere to convert borax into sodium borohydride. And producing pure hydrogen requires energy, which must be produced by some means and at some cost that is yet to be determined.

C. Building fuel-cell cars is one thing. But marketing them to the public with no corner hydrogen stations is another.

D. As the reaction is exothermic and spontaneous, it has to be controlled. Currently, sodium hydroxide is added to the fuel for stabilization, but this substance has the disadvantage of being highly alkaline. Researchers are testing possibilities for a more benign stabilizing agent.

E. Millennium's proprietary catalyst is composed in part of a very rare — and expensive — earth metal called ruthenium. Efforts are being made to redesign the system to use a high-temperature cobalt catalyst.

F. DaimlerChrysler and Ballard are developing fuel cell technology in leaps and bounds. One of the major challenges is the warm-up time. Currently, warm-up takes around two minutes. Anything longer than 20 seconds is unacceptable to the general public – and the goal is to make the warm-up time as short as around 2 seconds. However, in a hybrid electric powertrain like Natrium, the driver can drive away immediately on battery power while the fuel cell warms up.

IX. CONCLUSION

The Millennium Cell's technology is a promising alternative using environmentally friendly fuels. It helps to solve one of the biggest problems regarding the use and storage of the 'hydrogen' fuel. Sodium borohydride offers many advantages – such as low emissions, zero carbon, harnessing of renewable energy sources, high level of safety, and independence from oil imports. The technical challenges have largely been overcome. The key challenge will be economic viability – and that depends almost entirely on the price of gasoline. Without a tax concession, sodium borohydride will find it tough be a viable alternative while gasoline prices remains around US $1.25 per gallon. Increasing the $NaBH_4$ solution concentration to achieve the 300 mile range with about 35 gallons of mixture instead of 50 gallons would make the fuel more competitive. But without government standards on fuels, these clean cars from any continent will be sold only to commercial customers who can provide their own refueling infrastructure. Mass production of sodium borohydride has to take place. There is also a need to distribute the fuel through a network of service stations, just as gasoline is today. If the customers are unable to buy the fuel readily at their corner gas station, it will stunt the ability for the technology to be broadly used.

Besides, fuel cells are still expensive. A fuel cell powerful enough to run a car costs between $600,000 and $750,000. Right now, the fuel cell is not competitive. The price puts it out of the reach of consumers. Under such circumstances, one would not likely buy a fuel cell-powered car even if it worked perfectly. A customer would be willing to pay only about $1,000 more for a fuel cell vehicle because it is quieter and has zero emissions. The industry needs to work to develop fuel cell systems that can be mass-produced. The customer wants a high-performance car, the government wants an energy-efficient one, and a manufacturer wants to earn something from it. What is essential for a promising technology is - something that will fall in the yellow area common to these basic wants.

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