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PAPER FOR THE NHA ANNUAL U.S. HYDROGEN CONFERENCE

HYDROGEN TECHNOLOGY DEVELOPMENT AND DEMONSTRATION AT THE SAVANNAH RIVER TECHNOLOGY CENTER

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1. Introduction

The Savannah River Technology Center (SRTC) is a U.S. Department of Energy research and development laboratory located at the Savannah River Site (SRS) near Aiken, South Carolina. SRTC has over 50 years of experience in developing and applying hydrogen technology, both through its national defense activities as well as through its recent activities with the DOE Hydrogen Programs. The hydrogen technical staff at SRTC comprises over 90 scientists, engineers and technologists, and it is believed to be the largest such staff in the U.S. SRTC has ongoing R&D initiatives in a variety of hydrogen storage areas, including metal hydrides, complex hydrides, chemical hydrides and carbon nanotubes. SRTC has over 25 years of experience in metal hydrides and solid-state hydrogen storage research, development and demonstration. As part of its defense mission at SRS, SRTC developed, designed, demonstrated and provides ongoing technical support for the largest hydrogen processing facility in the world based on the integrated use of metal hydrides for hydrogen storage, separation and compression.

The SRTC has been active in teaming with academic and industrial partners to advance hydrogen technology. A primary focus of SRTC's R&D has been hydrogen storage using metal and complex hydrides. SRTC and its Hydrogen Technology Laboratory (HyTech) have been very successful in leveraging their defense infrastructure, capabilities and investments to help solve this country's energy problems. Many of HyTech's programs support dual-use applications. HyTech has participated in projects to convert public transit and utility vehicles for operation on hydrogen fuel. Two major projects include the H2Fuel Bus and an Industrial Fuel Cell Vehicle (IFCV) also known as the GATOR™. Both of these projects were funded by DOE and cost shared by industry. These are discussed further in Section 3.0, Demonstration Projects.

In addition to metal hydrides technology, the HyTech group has done extensive R&D in other hydrogen technologies, including membrane filters for H2 separation, doped carbon nanotubes, storage vessel design and optimization**,** chemical hydrides, hydrogen compressors and hydrogen production using nuclear energy. Several of these are discussed further in Section 2, SRTC Hydrogen Research and Development.

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2. SRTC Hydrogen Research and Development

Hydrogen Storage

The SRTC Hydrogen Technology Laboratory (HyTech) has extensive expertise in a variety of hydrogen related technologies including hydrogen storage. An example of SRTC's hydrogen storage technology, metal hydrides absorb hydrogen when cold, store it below atmospheric pressure, and release it only when heated. This special group of metals provides a safer, more cost-effective method of storing, separating, pumping and compressing hydrogen. Potential applications exist in the transportation and energy industries, such as, hydrogen recovery from gas mixtures and hydrogen storage for alternative fuel vehicles.

HyTech continues to play a major role in the latest hydrogen research activities and developments. Besides the work on conventional low-pressure metal hydride materials for hydrogen storage, HyTech is also involved in research on new higher capacity materials such as complex hydrides (borohydrides and alanates), and carbon nanotube materials (Figures 1, 2 and 3). As research in the hydrogen storage field advances, there is a need to evaluate and analyze new, emerging technologies. With its many years of hydrogen experience, HyTech is in an excellent position to advise the DOE and other governmental and industrial entities on the merits of these high-potential hydrogen storage options. HyTech has a good working relationship with many of the leading researchers and research institutions in the area of hydrogen storage. Research is currently being conducted and SRTC is at the forefront to advance the characteristics of these materials to achieve the optimum performance in hydrogen storage capacity.

Hydrogen is the lightest element known. Several options exist for storing hydrogen; these include compressed gas, cryogenic liquid, or a solid matrix. Gravimetric and volumetric densities of storage systems have proven to be low as compared to fossil fuels. Further research into complex hydrides will most likely prove that they will exhibit higher storage capacities than that of metal hydrides. Complex hydrides, such as $NaAlH_4$ are fairly new to industry and have exhibited reversible hydrogen storage properties and promising storage capacities. Research on these materials have shown that the decomposition temperatures of these may be lowered by using special manufacturing techniques such as high energy ball milling and by doping the materials.

Figure 1
Alanate Material

Figure 2
Alanate Research Program

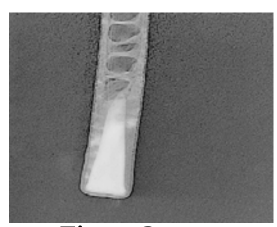


Figure 3
Doped Carbon Nanotube

The Savannah River Technology Center has submitted to DOE a proposal to become the lead laboratory in a Center of Excellence for hydrogen storage in the area of complex metal hydrides. SRTC has put together a world class team comprised of 7 universities, 5 other national and federal laboratories and 2 industrial partners to address what DOE has termed as the "Grand Challenge". The goal of the Grand Challenge is in the next 5 years to develop a hydrogen storage system that meets or exceeds the DOE 2010 goal for automotive applications [Report of the National Research Council, The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs, 2004]. These goals include system costs, refueling times, volumetric and gravimetric storage densities and energy efficiency. SRTC has the expertise and the capabilities to take on this challenge.

Hydrogen Separations

Ongoing defense work has led to SRTC's broad experience in the area of hydrogen separation. HyTech has developed a new patented technology for separating hydrogen from other gases particularly carbon monoxide and other hydrocarbon combustion products. The process makes use of a new class of composite materials referred to as "sol-gel metal hydrides". These materials have the ability to absorb hydrogen but also to restrict other gases such as carbon monoxide. Applications of this technology to commercial hydrogen production and separation systems are being investigated. A "thermal-swing" process utilizing this new composite material is believed to have significant advantages over traditional "pressure-swing" processes, especially on lower hydrogen containing feed streams [2003 Annual Merit Review and Peer Evaluation Report, Project #16, Encapsulated Metal Hydride for H2 Separations, Heung, Leung (SRTC)]. These lower hydrogen content feed streams are typically found in many biological hydrogen production processes. Hytech also has ongoing R&D on a new class of metallic and metallic oxide membranes that have the potential to overcome the limitation of many of today's current hydrogen membrane materials.

Hydrogen Production

In the area of hydrogen production, SRTC is currently involved in programs directed to achieve the goal of a hydrogen economy. In order for the United States to move toward a hydrogen economy, hydrogen will need to be produced from a variety of primary energy sources, including: renewables, fossil fuels (with carbon sequestration) and nuclear energy. Hydrogen production from nuclear energy can provide a significant portion of the future hydrogen demand. To meet the demand of a hydrogen economy, safe and cost-effective methods for producing and distributing large quantities of hydrogen to supply a major portion of the national energy and transportation needs will be required. SRTC is currently leading a team of industry, academia and consultants for a project funded by the U. S. Department of Energy, Nuclear Energy to perform a three year study of the production of hydrogen from nuclear energy with emphasis on hydrogen infrastructure issues.

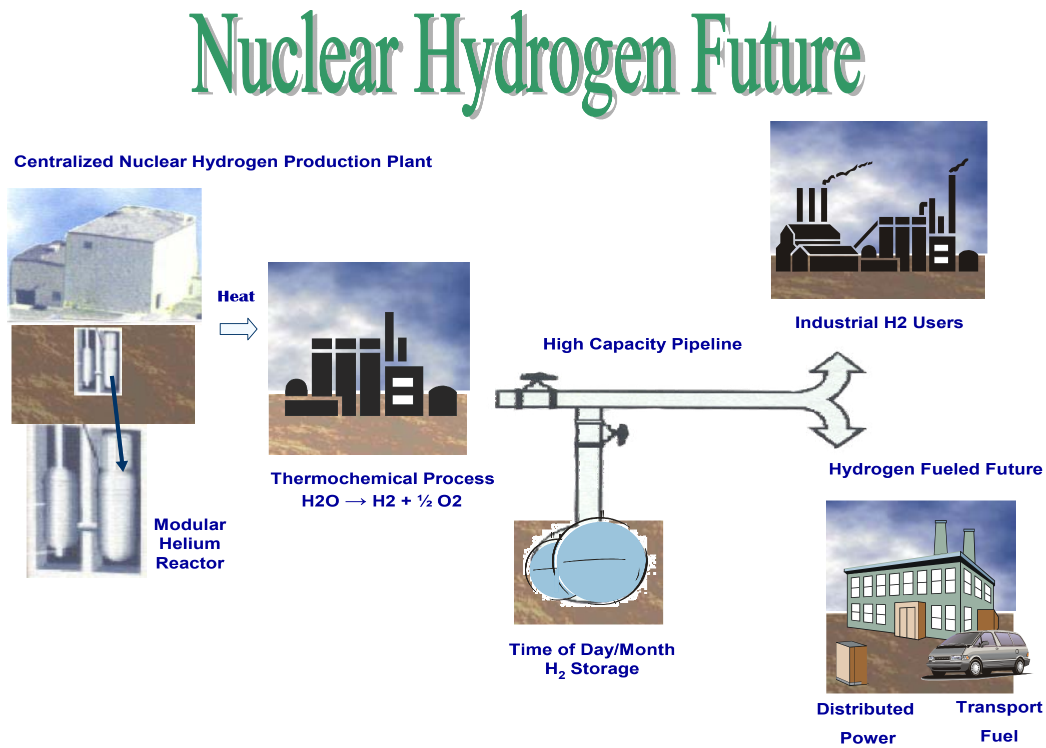


Figure 4

Figure 4 illustrates how a potential Hydrogen Future might appear. Heat would be generated by a next generation, fail-safe, nuclear power plant and directed to the thermochemical processing plant to produce hydrogen through a series of chemical reactions. Thermochemical processes have the potential to produce hydrogen from water at higher efficiencies than conventional and even high temperature electrolysis processes. The hydrogen could then be stored above or below ground or provided as needed directly to industrial hydrogen users or to supply a hydrogen fueled future for distributed power or for transport fuel. A hydrogen pipeline would be the means to carry the hydrogen to its destination.

Hydrogen Sensors

SRTC has done extensive research and development on hydrogen sensors. In addition to the mini-mass spectrometers and laser Ramon systems, SRTC has developed a world class expertise in sol-gel indicator technology.

Sol-Gel Indicators (SGI's) are a class of composite materials with unique and improved detection and measuring capabilities. SGI's have been developed at SRTC for use as sensor elements to monitor environmental conditions and species of interest. Organic indicators are embedded in a porous glass matrix and change colors in the presence of chemicals. The composite is produced without heat and can be coated onto fiber optic devices to produce probes for remote measurements.

3.0 Demonstration Projects

The H2Fuel Bus Project involved several academic and industrial partners whose goal was to modify an all electric transit bus to run as a hydrogen-electric hybrid vehicle. This bus would have double the range of the all electric vehicle and still have virtually zero emissions relative to a diesel bus. The H2Fuel Bus used an engine-generator set running on low-pressure hydrogen stored on metal hydride beds. The HyTech Team was tasked to develop the hydrogen storage system for the H2Fuel Project. To meet the vehicle's hydrogen delivery rate and rapid recharging requirements a new design for the metal hydride system had to be designed. HyTech scientists and engineers developed a new patented, high-heat-transfer vessel that allowed the hydrogen storage system to meet and even exceed its requirements. Several years later in one of the Site's defense applications, a similar need to improve the heat transfer in one of our separation units was identified. The prior work on the H2Fuel Bus storage system led the researchers to the solution. The HyTech solution led to a 50% reduction in the number of units required for the operation and a cost savings of over $20 million.

The H2Fuel Bus shown in Figure 5 uses a hybrid power system consisting of a hydrogen-fueled internal combustion engine in series connected to batteries and an electric motor. This project demonstrated the world's first hybrid hydrogen electric transit bus. It achieved double the range of the all electric vehicle and more than twice the energy efficiency of a diesel bus. The hydrogen IC engine had virtually zero emissions. The Blue Bird Body Company, a leading bus manufacturer, provided the transit bus incorporating an electric drive train supplied by Westinghouse Electric Corporation's Automotive Systems. The Savannah River Technology Center designed and in collaboration with Hydrogen Components Inc. (HCI), built the onboard hydrogen storage system based on advanced low temperature metal hydride technology developed as part of the Savannah River Site's national defense mission. The City of Augusta, Georgia operated the bus after successful testing and demonstration. The U.S. Department of Energy was the project sponsor.

The metal-hydride-based storage system contained had a capacity of 15 kg of hydrogen. The overall storage system weighed 2000 kg, making it one of the largest vehicle hydrogen storage systems ever built. It operated at 100 psig and used waste heat from an internal combustion engine at 80ºC. The bus operated successfully in transit service in Augusta, Georgia, and was later transferred to Las Vegas, Nevada as part of a DOE hydrogen demonstration program. Figure 6 shows one of two metal hydride hydrogen storage assemblies used in the bus.

Figure 5
World's first Hydrogen Hybrid Electric Bus (Augusta, GA)

Specifications

Length	33 ft.
Wheelbase	193 in.
Gross Vehicle Weight	33,000 lbs (15,000 kg)
Passenger capacity	27 seated
Electric Propulsion	230 HP AC (170 kW)
Range	120 miles
Fuel consumption	7.5 mpg equivalent
Braking	Regenerative
Emissions	CO near 0
	NO <1ppm

Mission

Convert a battery-powered transit bus to a hydrogen-powered hybrid bus, using metal hydrides to store hydrogen.

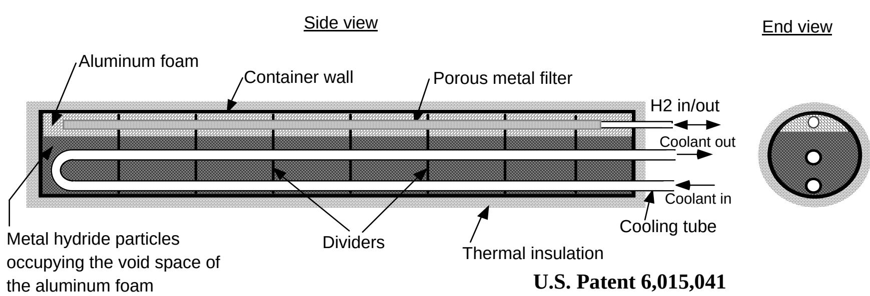
Project Team

U.S. Department of Energy
Savannah River Technology Center
Southeastern Technology Center
Georgia Tech Research Institute
Atlanta-Richmond County Public Transit
Hydrogen Components, Incorporated
Blue Bird Body Company

Figure 6
World's largest mobile metal hydride storage bed

Project Description

Road driving tests started April 1997
Hydrogen storage performed better than expected
Hybrid power train improved energy efficiency
Hydrogen doubled the operating range of batteries
Hydrogen engine demonstrated near-zero emission (No < 0.2ppm)



High performance tubular design permits compact storage and rapid refueling

Figure 7. Metal Hydride Bed

Figure 7 illustrates a cut away view of the metal hydride bed. This basic design was utilized in both the H2Fuel Bus and the IFCV " GATOR" project that is discussed in more detail below. The container is divided into sections that are fitted with metal foam and filled with metal hydride particles to occupy the void space within the metal foam. As shown, metal tubing is integrated into the assembly to provide heating and cooling as required.

The Industrial Fuel Cell Vehicle (IFCV) is shown in Figure 8.
Following the successful H2Fuel Bus Project, Hytech worked with several academic and industrial partners in developing an industrial fuel cell vehicle. The goal of this program was to develop and demonstrate two fuel cell vehicles running on direct hydrogen. The specific vehicles used were Deere and Co. GATOR vehicles with the fuel cell systems supplied by Energy Partners L.C. The project objective was to offer the small industrial vehicle sector an alternative to limited-range, battery-electric vehicles. To ensure the utmost safety for indoor applications, HyTech was asked to develop a low-pressure hydrogen storage system for these vehicles. The project team was able to develop and demonstrate two GATOR vehicles running on low-pressure hydrogen. The vehicles demonstrated a 50% improvement in fuel-to-wheel efficiency when compared to similar internal combustion engine vehicles and an 100% improvement in range when compared to battery-electric vehicles. During the course of the vehicle development the HyTech team was able to reduce the weight of the hydrogen storage system by 15% and lower its material costs by over 50%.

The goal of the Industrial Fuel Cell Vehicle project was to design, develop, validate, and demonstrate small industrial vehicles running on direct hydrogen by employing a fuel cell power system and onboard metal hydride hydrogen storage. Two fuel cell vehicles (John Deere GATOR’S) running on direct hydrogen stored in a metal hydride system were developed and demonstrated. A concurrent objective was to develop and validate a compatible hydrogen generator system that could ultimately be used to fuel fleets of IFCV’s. The project objective was to offer the small industrial vehicle sector an alternative to limited-range battery-electric vehicles.

Figure 8
Fuel Cell Vehicle w/MH Storage

<u>Mission</u>

Develop a fuel cell vehicle with onboard metal hydride storage for near-term niche markets such as airports, outdoor maintenance, warehouses, etc.

Project Team

U. S. Department of Energy
Savannah River Technology Center
Southeastern Technology Center
John Deere and Company
Teledyne Energy Systems
University of South Carolina
York Technical College

Project Description

Phase I – Feasibility Study, completed Jan. 1998
Phase II/III – Develop and Validate Technology, December 31, 2000

Benefits

Zero Emissions
Same Performance as Gasoline Vehicles
Out Performs Battery Vehicles

4.0 Summary and Path Forward

While SRTC has been successful in sharing its 50 years of hydrogen expertise with other government, industrial and academic entities over the past several years, the future for SRTC's HyTech organization and the hydrogen economy looks even brighter. SRTC is in the process of designing and constructing a new hydrogen laboratory, referred to as the Hydrogen Technology Research Laboratory (HTRL), see Figure 9. The new HTRL will be a 60,000 square foot facility dedicated to hydrogen research and development. One-half of the laboratory will be used by SRTC to continue its ongoing efforts in hydrogen storage, separation, sensors and production technology development. The other half of the facility will be available as a user-facility to encourage collaborative efforts between SRTC and other scientists from industry, academia or other government agencies. The hydrogen laboratory is schedule for completion and occupancy in the spring of 2005. Additional plans for the facility are underway to include a hydrogen refueling station, a small fleet of hydrogen vehicles and a stationary fuel cell for some of the facilities auxiliary or backup power requirements.

Figure 9

The Savannah River Site and Savannah River Technology Center have a long history of providing for our countries national security needs. With our increasing dependence on limited foreign oil reserves, SRTC has expanded its security role to include energy security. SRTC is seeking academic, industrial and other government agency partners to help meet our national and global energy needs.

References

Summers, W.A., T. Motyka, and E. Danko. Metal Hydride Technology – A Technology Transfer Success Story. Hydrogen storage paper for Department of Energy, Office of Industrial Technology, October 2001.

Motyka, T., Zidan, R., Summers, W.A., Hydrogen Storage: The Key Challenge Facing a Hydrogen Economy, paper for World Hydrogen Energy Conference, March 2004.

Danko, E., Summers, W. SRTC Research into Hydrogen Production from Nuclear Energy. *National Hydrogen Association Quarterly Newsletter* 9(2), Spring 2004

Ritter, J., Ebner, A.D., Wang, J., Zidan, R., Implementing a hydrogen economy, September 2003

2003 Annual Merit Review and Peer Evaluation Report, Project #16, Encapsulated Metal Hydride for H2 Separations, Heung, Leung (SRTC)

Heung, L. K.: On-Board Hydrogen Storage System Using Metal Hydrides, HYPOTHESIS II Conference, Grimstad, Norway, August 18-22, 1997, pp 251-256.

Westinghouse Savannah River Company Report WSRC-TR-98-00385, Final Report for the H2Fuel Bus, W.D. Jacobs, L.K. Heung, T. Motyka, W.A. Summers, J.M. Morrison, January 1999.

Fuchs M. et al.: Performance of 3rd Generation Fuel Cell Powered Vehicle #2 with Metal Hydride Fuel Storage, European PE Fuel Cell Forum, Luzern, Switzerland, July 2-6, 2001.

Danko, E. SRTC's Low-Pressure Metal Hydride Hydrogen Storage System: GATOR. *National Hydrogen Association Quarterly Newsletter* 7(3), Autumn 2002.

Curriculum Vitae

Mr. Danko has served with Westinghouse for over 26 years in variety of professional and management positions including manufacturing, marketing and administration, business development, and project management. He has fulfilled key roles at Westinghouse in marketing and administration of manufacturing operations for the manufacture of ASME components for Westinghouse power plant sites. He has also developed and instructed manufacturing technology related evening courses for the Community College of Allegheny County near Pittsburgh, PA.

Mr. Danko has assisted in developing partnering arrangements for hydrogen storage/fuel cell projects with the DOE, Office of Industrial Technologies, Industries of the Future Program. He has initiated Cooperative Research and Development Agreements with industry and university partners for hydrogen storage technology projects for industrial and utility vehicle projects.

At present, Mr. Danko is a project manager in the Hydrogen Technology Section at the Savannah River Technology Center that is leading a team of industry, academia and consultants to perform a study of hydrogen production from nuclear energy with emphasis on hydrogen infrastructure issues.

Mr. Danko has represented SRTC for more than seven years as an Executive Committee member of the DOE/OIT Laboratory Coordinating Council (LCC), a consortium of 16 laboratories within the DOE complex.