Presented at INTELEC 2006, Providence, RI, September 10-14, 2006

Metal Hydride Fuel Cells, A New and Practical Approach for Backup and Emergency Power Applications

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Abstract – **The tremendous growth of telecom services has resulted in an increased demand for backup power. Businesses and consumers are demanding continuous uptime and telecom companies must provide extended run time backup power on the order of hours and days. In addition, there is a growing need for power protection to cope with natural disasters and acts of terrorism. Conventional approaches using batteries have issues with life, footprint, maintenance, and weight. Similarly, diesel gensets have issues with startup, maintenance, noise, and emissions. As the backup power needs of telecom companies and their customers have grown, it has become evident that new backup power solutions need to be developed. Metal hydride fuel cells offer a fundamentally new approach to fuel cells that results in a practical, low cost technology with unique performance advantages, including intrinsic energy storage, instant start capability, good low temperature performance, and fuel "hot swap" capabilities. Metal hydride fuel cells use non-noble metal catalysts and can be manufactured using conventional processes similar to those used for manufacturing commercial batteries.**

This paper provides an overview of the current status and capabilities of metal hydride fuel cell technology, including performance, life, energy storage, and prototype hardware. The benefits of metal hydride fuel cells for Uninterruptible Power Supply (UPS) and emergency power applications will also be detailed.

I. INTRODUCTION

The tremendous growth of telecom services has resulted in an increased demand for backup power. Businesses and consumers are demanding continuous uptime and telecom companies must provide extended run time backup power on the order of hours and days. In addition, there is a growing need for power protection to cope with natural disasters and acts of terrorism. Conventional approaches using batteries have issues with life, footprint, maintenance, and weight. Similarly, diesel gensets have issues with startup, maintenance, noise, and emissions. Hydrogen fuel cells offer a very promising solution for extended run time backup power, but conventional approaches using Polymer Electrolyte Membrane Fuel Cells (PEMFC) tend to be expensive and have issues related to low temperature performance and life.

As the backup power needs of telecom companies and their customers have grown, it has become evident that new backup power solutions need to be developed. Ovonic Fuel Cell Company (OFCC), a subsidiary of Energy Conversion Devices, Inc. (ECD), is developing the innovative metal hydride fuel cell for UPS/emergency power applications. Metal hydride fuel cells offer a fundamentally new approach to fuel cells that results in a practical, low cost technology with unique performance advantages, including intrinsic energy storage, instant start capability, good low temperature performance, and fuel "hot swap" capabilities.

Metal hydride fuel cells use non-noble metal catalysts and can be manufactured using conventional processes similar to those used for manufacturing commercial batteries.

This paper provides an overview of the current status and capabilities of metal hydride fuel cell technology, including performance, life, energy storage, and prototype hardware. The benefits of metal hydride fuel cells for Uninterruptible Power Supply (UPS) and emergency power applications will also be detailed.

II. METAL HYDRIDE FUEL CELL BACKGROUND

A. Introduction to Metal Hydride Materials

The technological basis for metal hydride fuel cells is the metal hydride material developed for batteries and other applications. Metal hydrides work like a sponge by bonding hydrogen atoms to a metal alloy, forming a safe, compact, low-pressure storage medium. Novel concepts of compositional and structural disorder developed by S.R. Ovshinsky at our parent company Energy Conversion Devices, Inc. were fundamental to the development of metal hydride materials [1] and their subsequent commercialization into Nickel Metal-Hydride (NiMH) batteries [2] and solid state hydrogen storage devices [3]. NiMH consumer batteries are now a billion dollar a year business with billions of cells manufactured and sold annually under ECD licenses. For the emerging electric and hybrid vehicle industries, the chosen technology is NiMH batteries provided by ECD licensees and joint ventures. Our recent fuel cell advances also have origins in a corporate vision and commitment to the evolving hydrogen economy dating back to the formation of ECD in 1960.

B. Metal Hydride Fuel Cells

The Ovonic Metal Hydride Fuel Cell is a patented technology [4-8] that incorporates metal hydrides into the fuel cell hydrogen electrode, where it serves both as an anodic catalyst for the oxidation of hydrogen and as a hydrogen storage medium. The metal hydride imparts a charge storage or battery functionality to the hydrogen fuel cell electrode providing this fuel cell with a unique intrinsic energy storage capability.

The metal hydride fuel cell (MHFC) is simple in design as shown in Figure 1. The anode contains metal hydride as the anodic catalyst together with carbon and PTFE materials with a nickel screen current collector. The cathode contains metal oxides as the cathodic catalysts with carbon and graphite materials again with a nickel screen current collector. The electrolyte is potassium hydroxide with a composition similar to that of alkaline rechargeable batteries. The separator is an inexpensive polypropylene screen. The simple design and inexpensive materials provide for a manufacturable and cost-effective product.

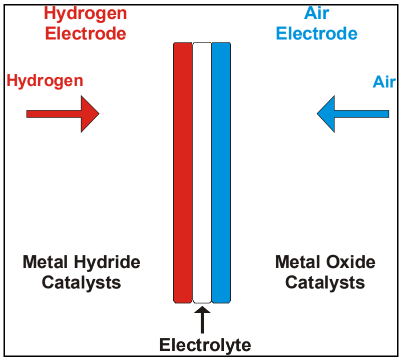

Figure 1: Schematic diagram of metal hydride fuel cell

C. Metal Hydride Fuel Cell Operational Modes

The unique energy storage capabilities of the MHFC catalysts enable the MHFC to provide additional modes of operation that conventional fuel cells do not have, including chemical charge, battery charge, and battery discharge. These additional modes of operation, shown in Table 1, provide the MHFC with unique performance advantages, such as intrinsic energy storage, instant start capabilities, and good low temperature performance.

TABLE 1: OVONIC METAL HYDRIDE FUEL CELL OPERATING MODES

Mode	**Hydrogen Electrode**	**Air Electrode**
Fuel Cell	$2\ H_2 + 4\ OH^- \rightarrow$ $4\ H_2O + 4\ e^-$	$O_2 + 2\ H_2O + 4\ e^- \rightarrow$ $4\ OH^-$
Chemical Charge*	$H_2 + 2\ M \rightarrow$ $2\ MH$	$O_2 + 2\ MO \rightarrow$ $2\ MO_2$
Battery Charge*	$M + H_2O + e^- \rightarrow$ $MH + OH^-$	$MO + 2\ OH^- \rightarrow$ $MO_2 + H_2O + 2\ e^-$
Battery Discharge*	$MH + OH^- \rightarrow$ $M + H_2O + e^-$	$MO_2 + H_2O + 2\ e^- \rightarrow$ $MO + 2\ OH^-$

* Not available with conventional fuel cells.

D. Intrinsic Energy Storage

The MHFC has a unique energy storage capability within the fuel cell stack. This fuel cell can be charged and discharged like a battery. Pulse charge-discharge capability in an early prototype is illustrated in Figure 2. During a ten second charge pulse, the voltage increases from 0.9 V on open circuit to around 1.15 V. Electrolysis does not occur since the voltage is below the theoretical electrolysis voltage of 1.23 V. During the subsequent ten second discharge, power is delivered at about 0.8 V. The energy storage or battery functionality of this fuel cell also provides other unique and useful features especially useful for UPS and emergency power applications such as instant start and excellent low temperature performance.

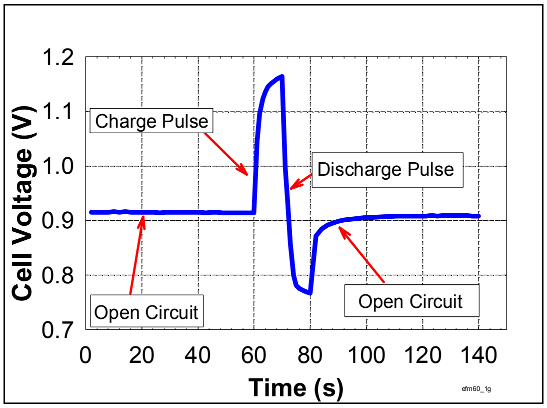

Figure 2: Intrinsic energy storage of metal hydride fuel cell

E. Instant Start

Conventional fuel cells require lengthy start-up times. High temperature fuel cell systems require many minutes or even up to several hours to start up. Ambient temperature systems such as conventional PEM fuel cells require seconds or minutes to reach temperatures needed to achieve rated power performance. At least a few seconds may be required for hydrogen to reach the fuel cell stack once the hydrogen is turned on. For UPS and emergency power applications, fast start-up times on the order of microseconds are required, something conventional fuel cells cannot provide. A solution for this problem is supplemental batteries or supercapacitors paralleled at the systems level. While providing for instant start, batteries add cost, weight, and complexity and additionally, the traditional battery maintenance and reliability issues. Supercapacitors are even more costly and provide less energy per unit weight and volume.

By contrast, metal hydride fuel cells with inherent battery functionality provide instant start in the fuel cell stack itself on the order of microseconds. This is illustrated in Figure 3 showing power generation in a few microseconds. Instant power generation is provided even at low temperatures down to -20°C.

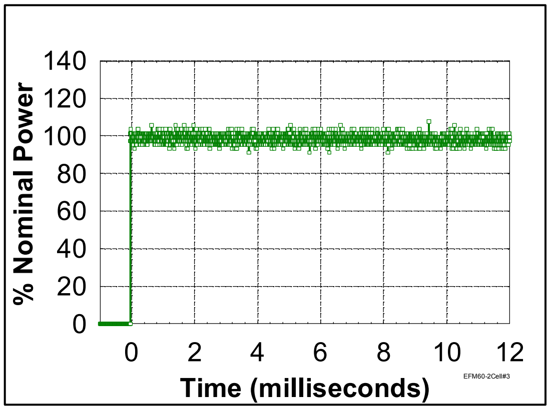

Figure 3: Instant start operation

The instant start feature illustrated in Figure 3 has a robust failsafe nature in that power can be provided even in the absence of hydrogen fuel flowing to the fuel cell. The hydrogen stored in the metal hydride anodes can provide power for several minutes at peak power levels, even if the fuel cell is not supplied with hydrogen gas fuel. This unique feature is illustrated in Figure 4. The intrinsic energy storage capability is thus significant, on the order of 10 Wh/kg with current prototype designs. The 10 Wh/kg intrinsic energy storage density is comparable to that of supercapacitor energy storage devices and can be substantially increased by designs with higher metal hydride contents.

The intrinsic energy storage of the MHFC provides a "hot swap" or buffer capability in which the MHFC system can continue to run even during a fuel tank changeover. This feature provides added versatility to the backup power system and the system can continue running even during fuel tank changes.

The total system energy density utilizing the fuel cell in combination with hydrogen sources is typically much higher than the intrinsic energy storage density. Total system energy densities on the order of 200-1000 Wh/kg or more are possible.

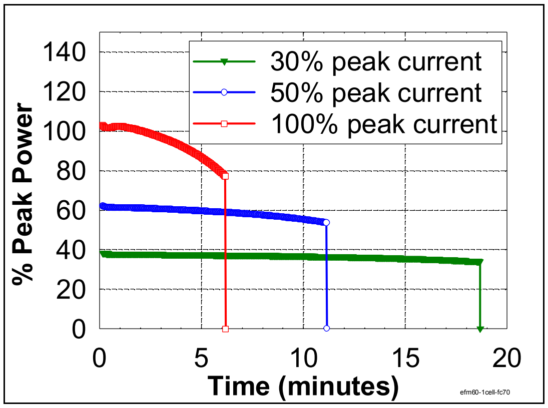

Figure 4: Instant start operation without hydrogen gas input

F. *Low Temperature Performance*

A significant advantage to this new technology is the operational and storage temperature range. The storage temperature extends to about -40°C, below which the electrolyte freezes. The operational temperature ranges from -20°C to 80°C. The dependence of power on temperature is less than that of conventional fuel cells leading to superior power performance at low temperatures as shown in Fig. 5. Over 75% of the peak rated power is available at room temperature and about 50% is available at 0°C.

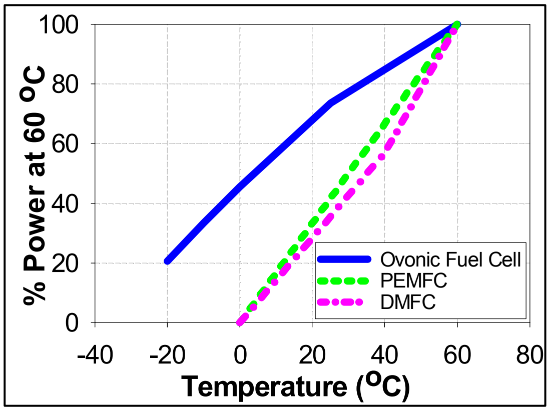

Figure 5: Effect of temperature on power performance

III. METAL HYDRIDE FUEL CELL PERFORMANCE

A. *Power Performance*

Prototype MHFC systems have been demonstrated at the 50 W level and have been scaled up to the 500 W level. MHFC stacks are modular and can be assembled together to provide sufficient power for UPS/emergency power applications ranging from 1 to 100 kW. Recently, 16-cell MHFC stacks were scaled up 400% from 60 cm^2 active area to 250 cm^2 active area. Figure 6 shows the very promising performance of the newly scaled up stack.

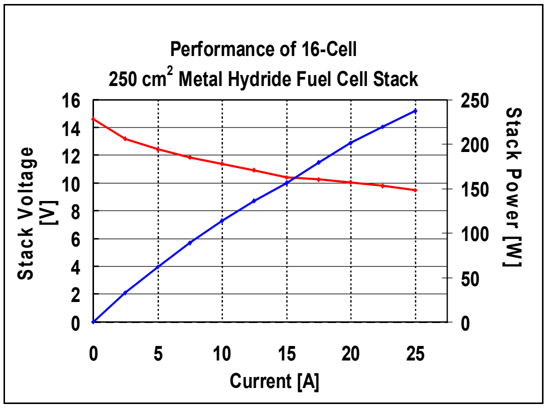

Figure 6: Performance of 250 cm^2 MHFC stack

B. *Life*

As shown in Figure 7, multicell 60 cm^2 MHFC prototype stacks have been demonstrated to last over 2,500 hours. Additional life testing of MHFC stacks is ongoing and the newly scaled up stacks will undergo life tests in the near future. Test data for these prototype stacks is very promising and MHFC systems will be able to meet the life requirements for UPS/emergency power.

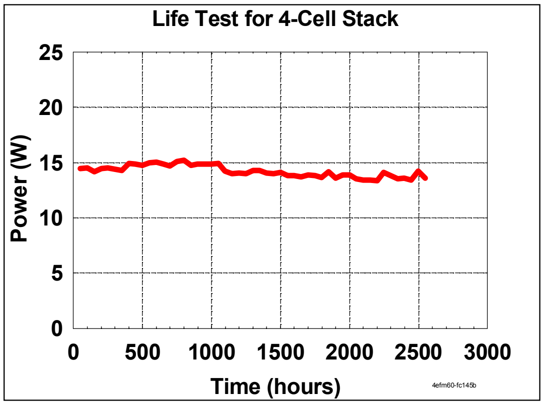

Figure 7: Life test of multicell MHFC stack

IV. LOW COST POTENTIAL

A. *Low Cost Materials*

PEM fuel cells require expensive noble metal catalysts, such as platinum. In addition, PEM fuel cells use specialty membranes that can cost even more than the platinum catalysts. Furthermore, PEM fuel cells require bipolar conductive plates that are constructed of special materials that require special fabrication techniques.

Unlike PEM fuel cells, metal hydride fuel cells do not require expensive components such as noble metal catalysts, specialty membranes, or bipolar plates. In fact, the MHFC uses relatively inexpensive materials. The anode active material includes metal hydrides that are composed of common transition metals. The cathode active materials are composed of non-noble metal oxides. The other electrode components for the anode and cathode include carbon and graphite powders, PTFE materials, nickel tabs, and nickel screens. The stack components include plastic frames, plastic meshes, and plastic endplates.

B. *Manufacturability*

The fabrication of PEM fuel cells typically requires carefully controlled environmental conditions due to the sensitivity of the special membranes. This type of rigorous environmental control requires expensive customized processing equipment.

The MHFC is designed with manufacturability in mind to complement the low cost materials approach. The MHFC can be manufactured using electrode fabrication processes similar to those used to manufacture commercial batteries. A manufacturing plan has been developed and includes a bill of materials, assembly process flowcharts, process time studies, direct labor estimates, and capital cost estimates. An analysis of the manufacturing plan shows that the MHFC can be fabricated using conventional processes and equipment, enabling the MHFC to be manufactured in high volumes.

C. *Bill of Materials and Systems Analysis*

OFCC has completed a bill of materials and systems analysis as part of its business planning and product development process. The analysis includes not only the bill of materials described above, but also systems and product aspects, such as thermal management, water management, packaging, and power conditioning. The analysis demonstrates the low cost potential of MHFC systems even in relatively low volumes of hundreds and/or thousands of units.

V. BENEFITS OF MHFC FOR UPS APPLICATONS

The attributes and unique performance advantages of the MHFC, coupled with its low cost and manufacturable nature, make it an ideal candidate for UPS/emergency power systems. The MHFC can provide robust operation over a wide range of temperatures and the intrinsic energy storage enables failsafe startup capabilities. The MHFC provides a practical approach for UPS/emergency power applications.

VI. MICHIGAN PUBLIC SERVICE COMMISSION (MPSC) PROGRAM

A. *MPSC Program Background*

OFCC has a program with the MPSC for developing prototype 500 W UPS/emergency power systems. As part of the Michigan Department of Labor and Economic Growth, the mission of the MPSC is to: 1) Grow Michigan's economy and 2) Enhance the quality of life of its communities by assuring safe and reliable energy, telecommunications, and transportation services at reasonable prices. OFCC was awarded one of 11 MPSC Energy Efficiency Grants which are aimed at benefiting Michigan residents, businesses, institutions, and/or governmental agencies by saving energy while invigorating Michigan's economy through the development and marketing of advanced energy efficient technologies. OFCC competed with over 140 other organizations in the two-stage grant competition.

B. MPSC Project Scope

The scope of Ovonic Fuel Cell Company's project for the MPSC included developing prototype 500 W systems aimed at the UPS/emergency power application. The key tasks for the project included: 1) System Specification, 2) Cell and Stack Development, 3) Systems Integration, and 4) Stack and Systems Testing. The project scope was designed to help accelerate product development of the MHFC for rapid commercialization.

C. Stack Development

One of the key aspects of stack development was to design the MHFC stacks for manufacturability. Based on fabrication and testing of earlier prototype stacks, new stack hardware was designed in order to improve fit, alignment, and reproducibility. The new design also enabled stacks to be made 300-400% faster than before. OFCC also began working closely with local plastics molders not only to accelerate parts fabrication for the project, but to also develop partnerships to accelerate commercialization. The new MHFC hardware is shown below in Figure 8.

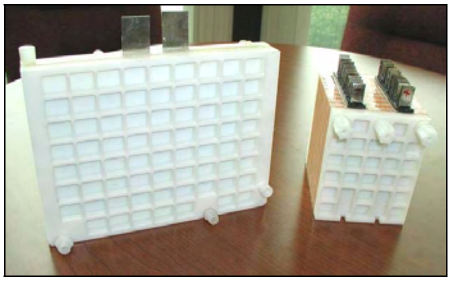

Figure 8: 250 cm^2 single cell (left) and 60 cm^2 stack (right)

D. Improvements in Performance and Life with Modeling

OFCC implemented fluid flow modeling capabilities using standard FloWorks software in order to characterize and quantify the behavior of fluid flows within the fuel cell to improve performance and life. A comparison of different air flow channels is shown in Figure 9. The rapid modeling simulations have enabled improvements in both performance and life. OFCC plans to partner with a local university for more in-depth analysis using Fluent software.

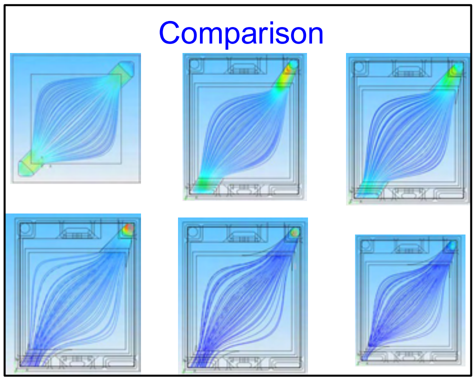

Figure 9: Comparison of air flow modeling

E. 50 W Demonstration System

One of the project deliverables included a 50 W demonstration system, shown in Figure 10. The main purpose of the 50 W system was to integrate and package a fuel cell stack, balance of plant, and control system into an enclosure. The 50 W system provides 12 V output via a standard automobile cigarette lighter outlet. The fuel supply was located outside of the enclosure, mainly for demonstration purposes, as explained below.

Figure 10: 50 W MHFC demonstration system

The MHFC is capable of operating for several minutes even without hydrogen fuel and placing the fuel supply outside of the enclosure allowed easy demonstration of this unique performance capability.

Figure 11: Metal hydride canister mounted outside of the system for demonstration of "hot swap" capabilities

F. Fuel Cell Hardware Scale Up

A key part of this project involved scaling up the MHFC fuel cell hardware from 60 cm^2 to 250 cm^2 active area. The need for scale up became very evident while preparing one of the deliverables, a mock up of the 500 W system. Using fuel cell stacks with 60 cm^2 active area resulted in a system that had 10 fuel cell stacks with a high number of components and somewhat complex plumbing. It was evident that for UPS/emergency power, hardware scale up was essential. Subsequently, 250 cm^2 active area fuel cell hardware was designed. Only two fuel cell stacks were required to provide the 500 W required for the deliverables.

G. 500 W System

The first 500 W system was fabricated and integrated into a standard 23" rack-mounted enclosure, as shown in Figure 12. This first system used the existing 60 cm^2 fuel cell stacks. Subsequent 500 W systems will incorporate the scaled up 250 cm^2 stacks, which will reduce part count and complexity as well as enable the use of a smaller and more compact 19" rack-mounted enclosure.

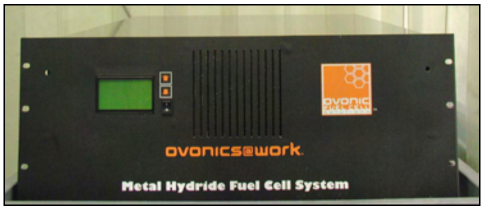

Figure 12: 500 W MHFC prototype system

The first 500 W system was tested and it provided 534 W, exceeding the 500 W design target as shown in Figure 13.

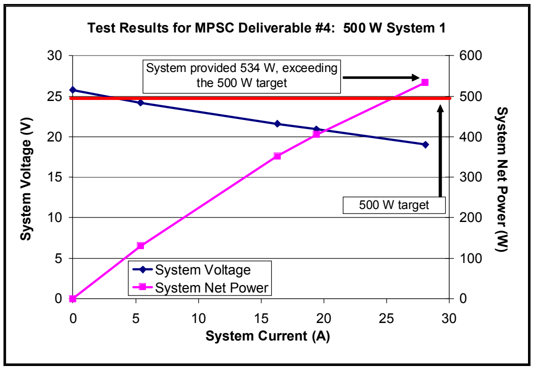

Figure 13: Performance plot for 500 W system

VII. SUMMARY

The metal hydride fuel cell is a fundamentally new approach to fuel cells that provides unique performance advantages, including instant start, intrinsic energy storage, and good low temperature performance. The metal hydride fuel cell has excellent low cost potential due to its highly manufacturable nature, as well as the use of non-noble metal catalysts and low cost components. This innovative approach to fuel cells has attributes well-suited for UPS/emergency power applications.

VIII. ACKNOWLEDGEMENTS

The author gratefully acknowledges the contributions of Dr. Dennis Corrigan, Dr. Srinivasan Venkatesan, Dr. Peter Kalal, Dr. Hong Wang, Mr. Frank Martin, Mr. Nathan English, and Ms. Lisa Abajian.

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