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A passive lithium hydride based hydrogen generator for low power fuel cells for long-duration sensor networks

D. Strawser, J. Thangavelautham*, S. Dubowsky

Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

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ABSTRACT

This paper focuses on developing an efficient fuel storage and release method for hydrogen using lithium hydride hydrolysis for use in PEM fuel cells for low power sensor network modules over long durations. Lithium hydride has high hydrogen storage density and achieves up to 95–100% yield. It is shown to extract water vapor freely from the air to generate hydrogen and has a theoretical fuel specific energy of up to 4900 Wh/kg. A critical challenge is how to package lithium hydride to achieve reaction completion. Experiments here show that thick layers of lithium hydride nearly chokes the reaction due to buildup of lithium hydroxide impeding water transport and preventing reaction completion. A model has been developed that describes this lithium hydride hydrolysis behavior. The model accurately predicts the performance of an experimental system than ran for 1400 h and consists of a passive lithium hydride hydrogen generator and PEM fuel cells. These results offer important design guidelines to enable reaction completion and build long-duration lithium hydride hydrogen generators for low power applications.
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Introduction

Long-life, low power sensor modules are a key component for many important sensor network applications. For example they could perform exploration and mapping of inaccessible environments, monitor disasters such as fires and earthquakes, monitor the environment including air quality in urban areas and soil conditions for agriculture (Fig. 1) [1]. In these applications several hundreds or thousands of modules might be deployed over large areas and wirelessly report their data to a base station. To be practical, once deployed, the modules need to operate unattended, ideally for years. A key to making these sensor systems feasible is requiring them to have long-duration power supplies. Today's conventional battery technologies are limited by their chemistries and will not meet the needs of many of these systems due to their relatively low energy densities [2,3]. The low total energy of batteries will not be able to provide power for the multiple years required of many applications. A better solution is required.

Fuel cells can produce power continuously and have been suggested for long-duration, low power sensors because they typically have high energy densities and their low power is not an important constraint for low power sensor modules. Polymer Electrolyte Fuel (PEM) cells in particular operate at

* *Corresponding author*. Current address: School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85283, USA.
E-mail address: jekan@asu.edu (J. Thangavelautham).
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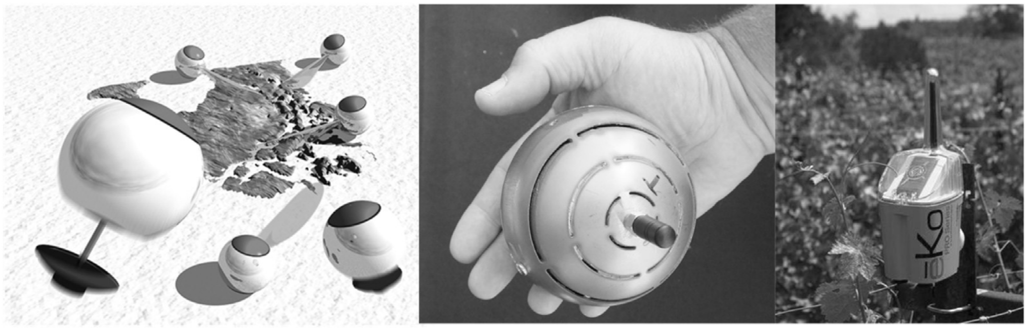

Fig. 1 – Low power mobile sensor network modules can be used in exploration and terrain mapping (left), for monitoring disasters using Intel's sensor grenade concept (center) and environmental monitoring and agriculture (right).

room temperature, with high conversion efficiencies ranging from 50 to 65%, and are clean and quiet [4]. In cases with higher peak power but with low duty cycles, hybrid fuel cell/battery power supplies [5] can be effectively used.

However PEM fuel cells face several challenges. Unlike batteries, they are relatively less robust to operating conditions [6–8]. Wrong operating conditions can drastically shorten the life of a PEM fuel cell to a few hours or days due to degradation of its components [6,8]. Important work has been carried out to identify, model and control degradation of PEM fuel cells [6,7,9]. It has been recently shown that properly controlling a fuel cell's operating conditions can avoid premature failures and, in theory, allow for long-lives of 3–5 years [8]. The second critical problem faced by PEM fuel cells is storing of the hydrogen fuel. Conventional storage and release of hydrogen can be prohibitively bulky and complex, making it unsuitable for small, low power applications like sensor networks. This includes storing hydrogen gas at high pressures, 300–700 bars [10]. Such technologies while proven for larger automobile sized applications face substantial challenges with miniaturization particularly low power sensor applications. A second approach is cryogenic storage of hydrogen in liquid form. This has been commonly demonstrated for applications in space exploration and is feasible for sensor network applications on the lunar surface [11]. However, for terrestrial applications, the systems can be complex, requiring substantial energy be expended to keeping the hydrogen at very low temperatures. This factor makes it inappropriate for low power, long-duration terrestrial sensor network module applications.

This paper addresses the fuel storage problem for the common Proton Exchange Membrane (PEM) fuel cell in a battery-hybrid power supply that would be appropriate for low power sensor modules with operational lives in the order of 3–5 years. The objective is to develop a fuel storage and release design that is pressure-controlled, small, light-weight, simple, compact, and is passive, not requiring active electronics, sensors, or actuators. Actively-controlled hydrogen generator concepts have been considered (see Fig. 5) [12] but is not the preferred option due to its increased complexity.

Feasibility studies of possible hydrogen storage mechanisms are performed and lithium hydride is selected as the storage medium because of its high weight density of hydrogen, its simple chemistry, achieving up to 95–100% reaction completion rates at room temperature [12,13], and its hydrogen release can be controlled simply as will be shown later by exposing it to water vapor. The key challenge with lithium hydride is how to package lithium hydride to achieve reaction completion. Experiments here show that thick layers of lithium hydride substantially slow the reaction nearly choking it due to buildup of lithium hydroxide impeding water transport. A semi-empirical model has been developed that describes this lithium hydride hydrolysis behavior. In Section A passive hydrogen generator, a prototype lithium hydride hydrogen generator is presented and experimentally tested with a PEM fuel cell power supply to validate the model. The lithium hydride model is shown to accurately predict the generator life and performance. The experimental fuel cell power supply consists of a lithium hydride generator that provides hydrogen and air breathing PEM fuel cells in a battery-hybrid system. In the hybrid system, fuel cell provide constant power trickle-charging a battery that meets the high and variable demands of the load. Based on the experimental results, guidelines to designing and operating long-duration lithium hydride hydrogen generators for low power applications are offered.

Background and literature review

Efficient hydrogen storage is a challenging problem and is one of the major factors preventing hydrogen from becoming a widespread energy source [14]. Here lithium hydride is explored for small, low power sensor network applications. Hydrogen stored as a liquid or compressed at very high pressures is not practical for this research because of the complexity and the difficulty integrating them into low power, long-life systems. Metal hydrides were then considered because of their high gravimetric hydrogen weight densities and the ease with which they could be stored on a low power system. Of the metal hydrides, lithium hydride was selected because of its high hydrogen weight density, its simple hydrolysis reaction, high yield, and the relative ease with which one can control the reaction. In this section, the first two advantages are reviewed, namely lithium hydride's high hydrogen content and its high yield.

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