IV.H.3 NaSi and Na-SG Powder Hydrogen Fuel Cells*

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- Trulite Inc., El Dorado Hills, CA
- University of Texas, CEM, Austin, TX

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*Congressionally directed project

Objectives

- Develop and demonstrate a controllable hydrogen generation system based on sodium silicide powder for portable fuel cell applications.
- Develop specific reaction control mechanisms which encompass water feeding, thermal management, and reaction site maximization.
- Verify operation of all core balance of plant and reaction control components in a laboratory setup.
- Design, fabricate, and assemble a prototype system packaged in a professional manner which generates controlled hydrogen with minimal user intervention.
- Demonstrate operation with a fuel cell system capable of 250 W.
- Conduct core research to evaluate the potential for ultra-high performance sodium silicide materials.
- Develop the appropriate manufacturing methods to readily scale production of sodium silicide in follow-on activities.

Technical Barriers

This project addresses the following technical barriers of the Storage section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) System Weight and Volume
(B) System Cost
(J) Thermal Management

Technical Targets

The developed sodium silicide technology is specifically focused on portable power applications such as back-up power, mobile workstations, and emergency responders. The target range includes applications from 50 to 500 W. The developed technology is expected to be scalable to at least 1 kW for applications such as lawn mowers that are known to be highly polluting.

The developed technology will likely not meet all DOE technical targets for automotive applications, but there is a significant focus on customer attributes such as fast starting, rapid restarting, low pressure, and ease of use. The specific technical targets are discussed below.

The primary focus of the current effort is to establish system technology using sodium silicide. SiGNa anticipates the development of advanced silicides with comparable system control architectures which will further increase performance metrics. The specific energy can reach up to 1,734 W-hr/kg (lower heating value) including all reaction water, power and packaging for the current commercial sodium silicide material. Further research is required to understand and optimize the over-stoichiometric water required in the silicide reaction. Advanced silicides, which are currently under development, will yield a specific energy of up to 2,125 W-hr/kg.

The cost will approach DOE targets even for small portable applications. The cost is expected to reach $4.47/kW-hr. Further cost reductions are possible which may be enabled by manufacturing scale up and the industrial usage demands of sodium silicate.

Accomplishments

Significant progress has been made in the development of a standalone hydrogen generation system for fuel cell applications. These accomplishments are summarized by the following:

- Completed laboratory system and demonstrated key performance attributes: >9 wt% hydrogen yield on a

powder basis, multiple re-starts with up to 1 week of off-time, and controlled generation (~3 slpm) at low pressures (~30 psi).
- Have successfully completed bench top testing and sustained operation of a 300 W fuel cell-powered electric bicycle.
- Developed a hydrogen purity filtration system and verified results with gas chromatography verifying 99.99% hydrogen purity.
- Completed design of stand alone hydrogen generation development unit.

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Introduction

SiGNa Chemistry, Inc. is developing a unique hydrogen storage mechanism utilizing SiGNa's air-stable sodium silicide powder derivatives (e.g. NaSi). SiGNa's stabilized powders have been shown to produce up to 9.8 wt% H_2. The primary goal is to develop a prototype system including all balance-of-plant components which generates hydrogen in a controlled manner based on usage requirements. SiGNa Chemistry will initially target a hydrogen generation system yielding approximately 3 slpm. This level of hydrogen generation can support a wide range of applications such as: supplemental hydrogen for diesel trucks for improved fuel efficiency and reduced emissions, primary power for small vehicles (i.e. scooters, mini-bikes), emergency responder stations, backup power, surveillance, and other off-grid applications. For reference, 3 slpm of H_2 will net approximately 250 W in fuel cell applications.

While numerous chemistries have been explored for hydrogen production for portable systems such as sodium borohydride or methanol reforming, hydrogen storage commercialization has been limited to high pressure tanks and metal hydrides both of which have significant usability issues. SiGNa's newly developed class of sodium silicides such as, NaSi, rapidly react with water to form hydrogen and a benign waste product, sodium silicate.

$$2NaSi(s) + 5H_2O(l) \rightarrow 5H_2(g) + Na_2Si_2O_5(aq)$$

SiGNa has developed systems implementation technology to facilitate this reaction in a manner that is highly controllable with high flow capability at low pressures with excellent re-start characteristics.

Approach

The overall approach is summarized in Figure 1. The basic architecture is straightforward; simply add water to powder. Water solutions, such as salt water, may also be employed for lower temperature operation or other reaction tuning parameters. In practice, a micro-spray water distribution system has been developed to increase the active reaction area. For a "single-start" reaction, this distribution system is not necessary as the bed will self-churn and fully react large quantities of powder. To rapidly start a cold, partially reacted solution, the micro-spray system serves to spray water streams on un-reacted powder throughout the chamber.

SiGNa first developed a series of clear reaction vessels to visualize the reaction and optimize the parameters. This series of breadboard test vehicles is used to test the various control components and demonstrate the core reaction characteristics. The results of these experiments are being incorporated to develop a standalone hydrogen generation system. This system will be tested in conjunction with a fuel cell/battery hybrid system against a range of operational scenarios.

The materials to date have only been manufactured on a lab scale. SiGNa is currently working with an established toll manufacturer with expertise in alkali metals to develop the next generation manufacturing process.

Results

Three different breadboard reactors have been fabricated and tested in a range of ~60 to ~1,200 ml. The primary areas of development and testing have been: water feeding and distribution, hydrogen separation, control system and balance-of-plant components, and the hydrogen purity system.

The water feed and distribution system primarily consists of the pump and micro-nozzle network. In practice, there are significant challenges in getting a far reaching spray at very low water flows (< 1 ml/min). The water distribution network is almost exclusively required for re-start conditions. The laboratory systems have shown the ability to rapidly restart after storage at room temperature for 7 days (Figure 2). In this test, the reactor was tested for a total of five starts with each run generating about 1/5 of the total available hydrogen. It is also required near the end of the reaction to ensure maximum powder reactivity. The water feed system was also modified to incorporate the spray nozzles directly over the separation membrane to minimize filter clogging.

A significant amount of work was done early in the project with the small reactors in the selection of separation membranes. For the small reaction chambers, significant foaming could readily cause filtration clogging. A filter spray system was developed to breakdown the foaming. This enabled significant improvements in the separation membrane pressure drop (Figure 3). The developed separation membrane

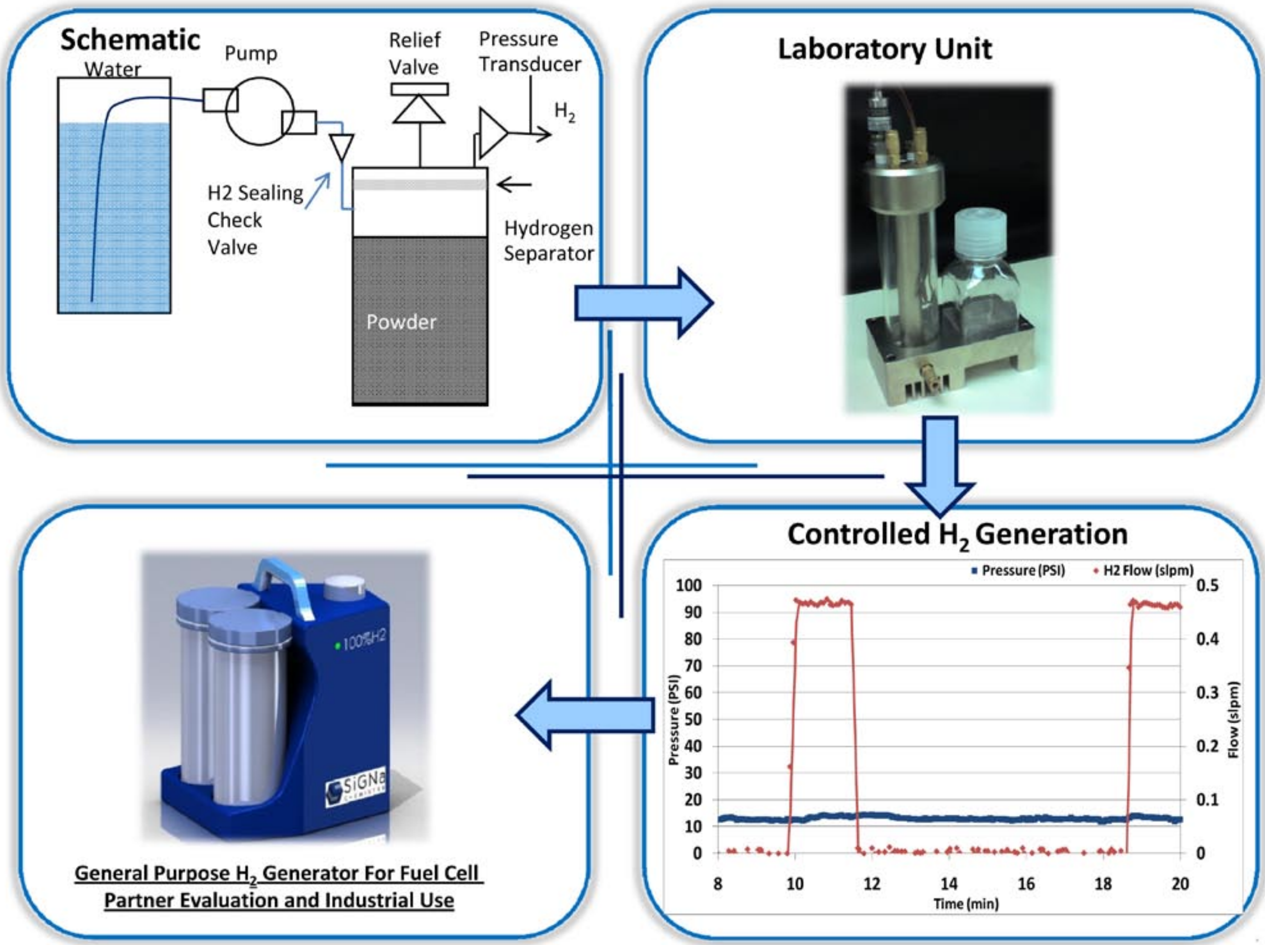

FIGURE 1. Development Approach Including Laboratory Test Systems and Controlled Hydrogen Generation

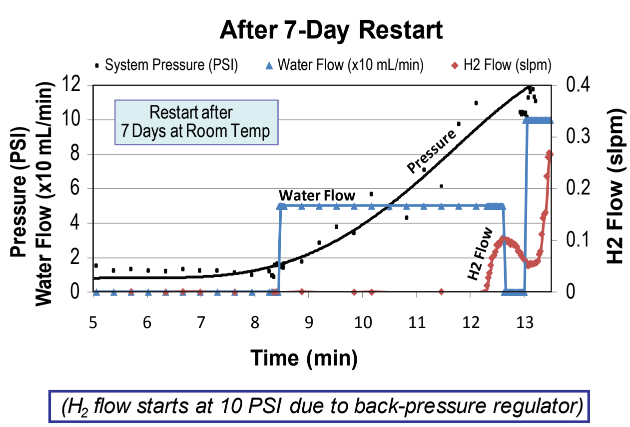

FIGURE 2. Restart Example After 7 Days at Room Temperature

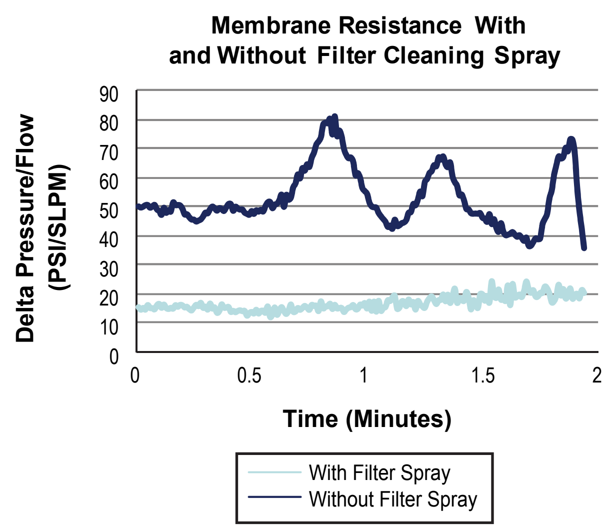

FIGURE 3. Impact of Filter Spray and Separation Membrane Resistance

included a sandwich of multiple layers. The much larger reactors have had very little foaming issues as the surface tension forces are typically insufficient to develop foam over the larger reactor area. However, the developed components are still utilized on the larger canisters for robustness and to ensure operation in non-typical operating scenarios such as vibration, upside down storage, etc.

The balance-of-plant components including check valves, on/off valves, sensors, and pumps have been selected and tested. In addition, a custom controller was developed with prediction control loops to handle the various start/stop and operational scenarios. While the basic start/stop and operational testing has been completed, additional work is required in this area.

SiGNa has also completed the design of the majority of the stand alone system components (Figure 4). SiGNa anticipates design completion and fabrication over the coming weeks.

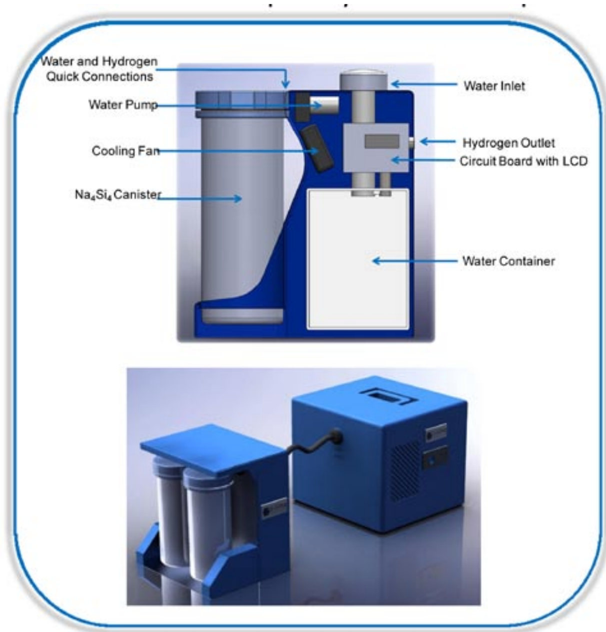

FIGURE 4. Stand-alone Hydrogen Generation and Fuel Cell Test System With Water Recirculation Capability Under Development

Conclusions and Future Directions

Sodium silicide has been shown to be capable of controlled hydrogen flow for a range of portable applications. A number of system implementation issues that have plagued other hydrolysis systems impacting restart capability have been resolved. All results continue to indicate that sodium silicide is capable of near term commercialization while providing a hydrogen source that is safe and easy to use. The balance of work in this project will be focused in the following areas:

- Design completion of the stand along hydrogen generation system.
- Completion of the fabrication, assembly, and testing of the standalone hydrogen generation system
- Continued testing on larger powder size runs to optimize control characteristics and minimize water usage. The largest run to date was ~150 grams of powder yielding ~15 grams of hydrogen. SiGNa anticipates the demonstration of at least 30 grams of hydrogen in a thin walled, low pressure hydrogen generation canister.
- Continued testing and verification of hydrogen purity over a range of particle size and operational scenarios.
- Demonstrated operability and usability in conjunction with a >250 W fuel cell.

Special Recognitions & Awards/Patents Issued

1. Andrew Wallace, John Melack, Michael Lefenfeld, Hydrogen Generation Systems Utilizing Sodium Silicide and Sodium Silica Gel Materials, Provisional Patent Application, March 30, 2009.

FY 2009 Publications/Presentations

1. DOE Annual Review, May 2009.