SiGNa CHEMISTRY

improving our world...
one discovery at a time

NaSi and Na-SG Powder Hydrogen Fuel Cells

Andrew Wallace and Michael Lefenfeld

SiGNa Chemistry

June 7-11, 2010

www.signachem.com

apwallace@signachem.com

ST055

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Program Overview

Timeline

- Start date: 08/01/2008
- End date: 01/31/2011
- Percent complete: 66%

Barriers

- Enabling Technology for Near-Term High-Volume Fuel Cell Commercialization for Portable and Back-up Power Applications

Budget

- FY08 Funding: $1,476,000
- FY09 Funding: $951,500

Partners

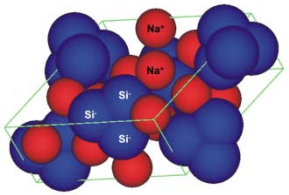
- University of Texas Austin - CEM
  - Reactor Mechanism Research
  - Richard Thompson and Michael Lewis
- Trulite Inc.
  - 250W Fuel Cell Demonstration System
  - John Patton

Technology Overview

- Sodium Silicide rapidly liberates hydrogen from water (or water solutions) leaving a benign common industrial chemical (sodium silicate)

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

(No Catalyst, Room Temperature)



Sodium Silicide (Na_4Si_4) Molecule

- Significant System Benefits for Portable Power Applications (1 W to 3 kW)
  - **Safety:** Does not ignite or oxidize in air at standard conditions even when fully exposed to air (i.e. opened storage canister).
  - **Thermal Stability:** Material is stable over all practical temperature ranges (-55 to 300°C)
  - **Storage:** The material has been demonstrated to have a shelf-life of over two years but is capable for being stored for significantly longer
  - **Pressure:** The maximum developed pressure is determined by the system design not the material characteristics. The maximum pressure is expected to be a nominal 30 psi (material capable of 1000's)
  - **Ease of Use:** No catalyst required to produce hydrogen gas
  - **By-products:** Generates a non-toxic aqueous waste, sodium silicate.
  - **Low-Weight:** NaSi yields 1715 W-Hr/kg (assume fuel cell conversion of 17.5 W-Hr / gm-H2)

Program Objectives

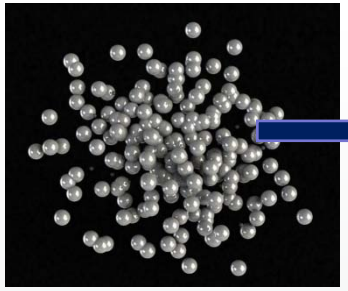
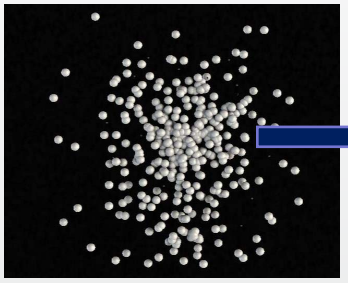
- Demonstrate enabling hydrogen storage technology suitable for early fuel cell market applications with high volume potential
- Demonstrate the benefits of sodium silicide technology in a push-to-start hydrogen generator system
- Develop a demonstration system capable of ~250 W for applications such as battery re-chargers, remote telecommunications, emergency responders, backup power, and personal mobility (i.e. scooter, bicycle, etc.)
- Improve hydrogen yield and maximize water utilization for sodium silicide based hydrogen release

NaSi Fueled Bicycle

300 W Electric Generator Replacement

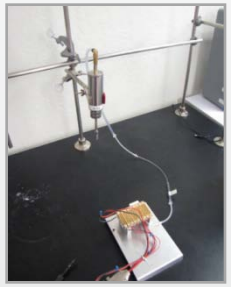
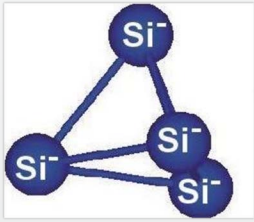
NaSi Based H_2 Fuel Cells

$$2NaSi_{(s)} + 5H_2O_{(\ell)} \rightarrow 5H_{2(g)} + Na_2Si_2O_{5(aq)}$$

Cheap Raw Materials with 100% Utilization	Patented Material and Production Processes	Rapid, Controllable, Safe Hydrogen Release	Lightweight, Low Cost Power for Portable Electronics	Cradle-to-Cradle Life Cycle Process and/or Low Cost Disposal
Sodium  **Silicon** 	**Sodium Silicide** 	**Hydrogen**  **Sodium Silicate**	Consumer Electronics Small, Low-Pollution Engines Backup Power Personal Mobility 	Food preservation Timber treatment Passive fire protection Refractory use Water treatment Detergent Auxiliaries

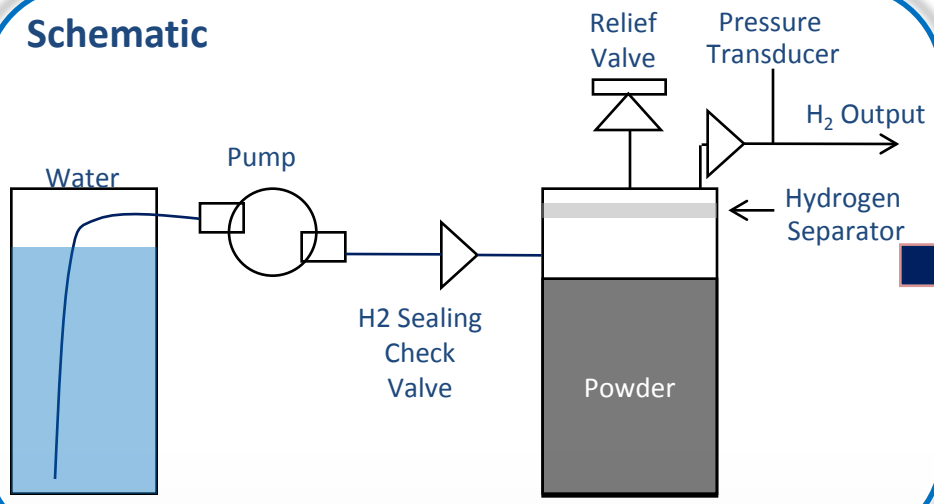
Technical Approach

Only Phase II Tasks (7-11) Are Shown

Task 7.0 Operational/ Env Testing	Task 8.0 2nd Gen Concept Testing & Dev	Task 9.0 2nd Gen Hardware Design & Dev	Task 10.0 2nd Gen Hardware Testing & Verification	Task 11.0 Materials Production & Adv. Research
Basic operation verified. Additional tests planned. • Multiple max capacity runs • Re-start / load variability testing • Low temperature start-up with water additives (hydrogen purity verified under room temp conditions)	**Multiple performance and reliability improvement activities** • Mechanical methods for better reaction temperature control • Continued development on water distribution mechanisms • Continued research on passive (i.e. pump-less) water feeding	**2nd Generation Hardware Improvements** • Improved canister connect / disconnect mechanism • Multiple operational and reliability improvements • Higher energy density cartridges	**2nd Generation Hardware Testing & Continued Fuel Cell System Operability** •100's of hours demonstrated. 1000's to be demonstrated.	**Continued energy density improvements and production process development** • Continued evaluation of high performance materials and mixtures • Continued evaluation of water control additives • Continued development of materials production processes
			 	

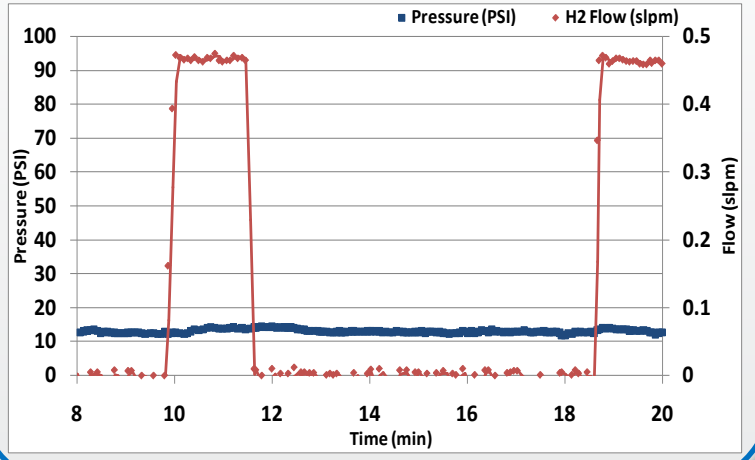
Previously Funded Results

Schematic



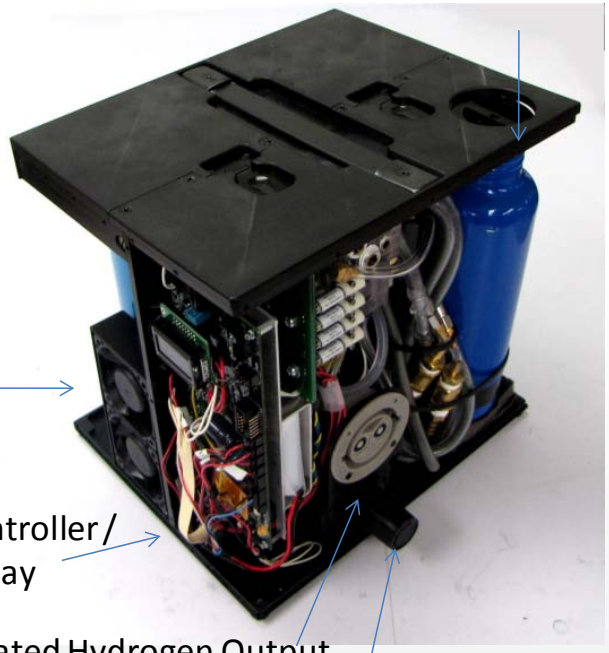
Laboratory Unit

Controlled H_2 Release



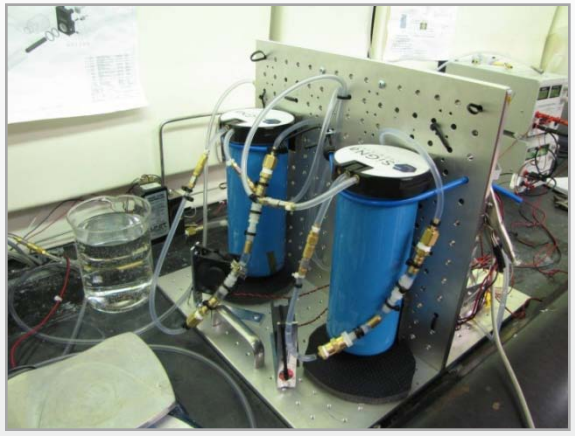
"Current Work" Includes Advancement of Laboratory Hardware to Prototypes

Hydrogen Generator Prototype

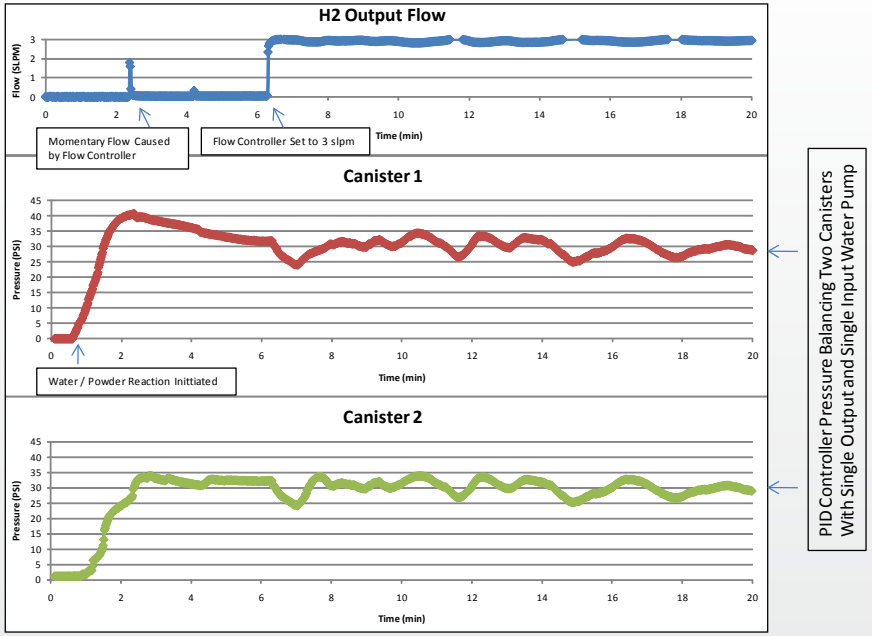


Dual Canister Control Progress

- Developed methods to maintain near constant pressure without measuring fuel cell current (i.e. Hydrogen Flow)
- Predictive PID controller variables include:
  - % Used
  - Temperature
  - Water Pump History
  - Pressure Changes



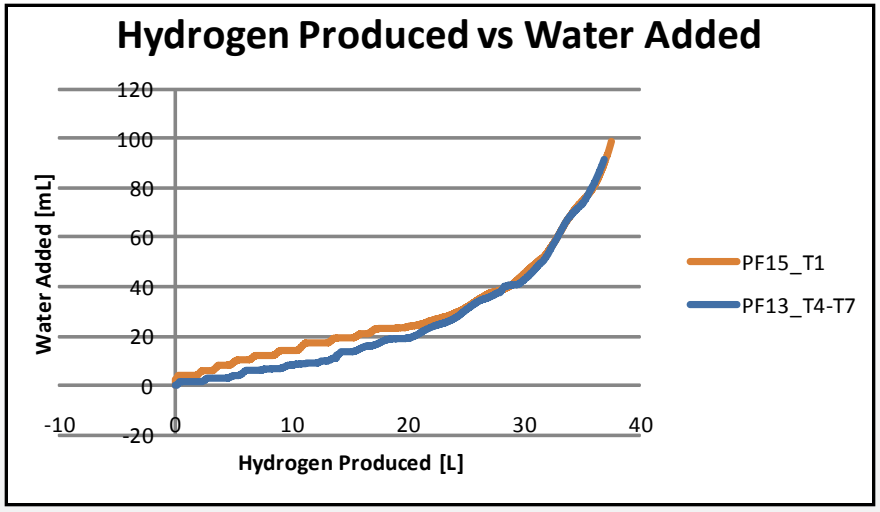
Laboratory Setup for Controller Development

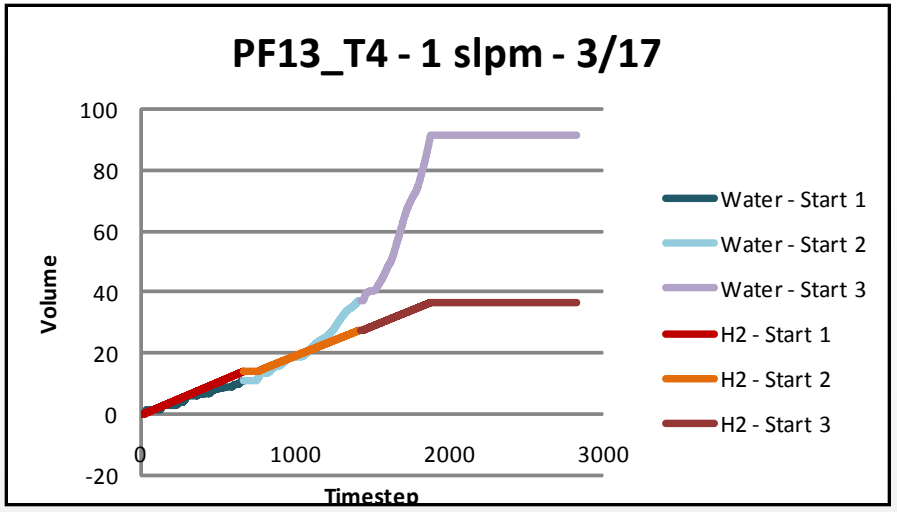


Multi-Canister Control Example

Start/Stop Operation

- "Water Flow vs. Hydrogen Delivery" is Nearly Constant for Steady-State or Start-Stop Operation
- Higher water flows at the end of the reaction are driven by internal temperature reductions. The reaction rate of sodium silicide is near constant until > 95% of reaction completion





PF15_T1: Constant Operation at 0.5 slpm H_2

PF13_T4-T7: Constant Operation at 1 slpm H_2. Cartridge utilized over 3 runs in equal duration. 24 hour off-time between runs.

NaSi Hydrogen Cartridge

Hot Swappable | **Integrated Capacity Meter** | **Start-Stop Capable** | **"Paint Can" Packaging**

Specifications	Value
Energy/Weight, Powder (W-Hr/kg)	1715
Powder Cost ($/W-Hr)	$0.01
Energy/Weight, Powder + Package (W-Hr/kg)	1300
Package + Powder Cost ($/W-Hr)	$0.02
Energy/Weight, Powder + Package + Water (W-Hr/kg)	> 650
Energy per Cartridge (W-Hr)	800
Flow Rate (slpm)	< 2
Powder Weight (kgs)	< 0.5
Nominal Pressure (psi)	30
Non-Hazardous Shipment	Yes*
Air Passenger Carry-on	Possible**

* Non-hazardous air-shipment up to 500 grams /cartridge

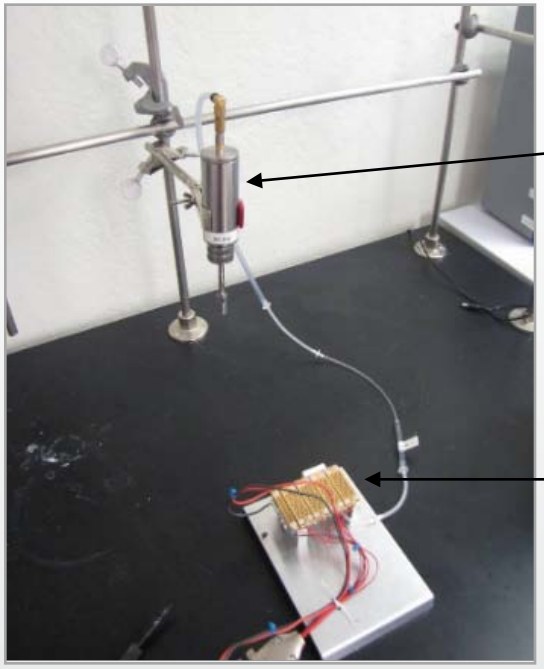
** Air Passenger carry-on limited to 200 grams /cartridge

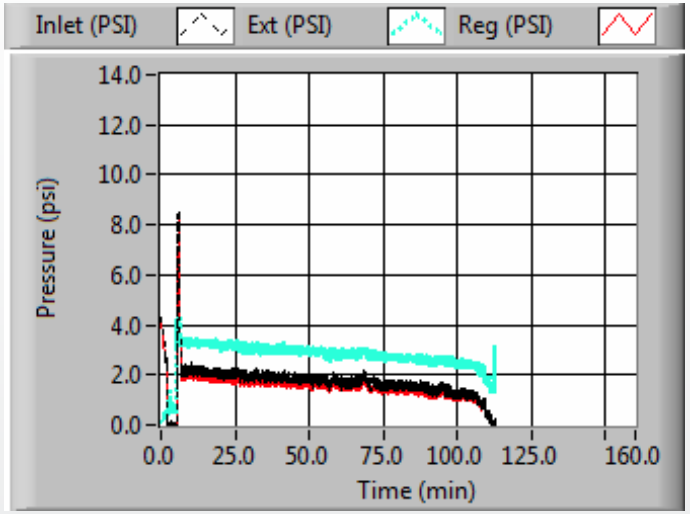
Next Generation Cartridges

NaSi Volume-Exchanging Lab Unit

- All balance of plant included → powder + water
- Orientation independent
- Passive volume exchanging
- Start-stop capable
- Regulator-free fuel cell operation

Volume-Exchanging Test Setup



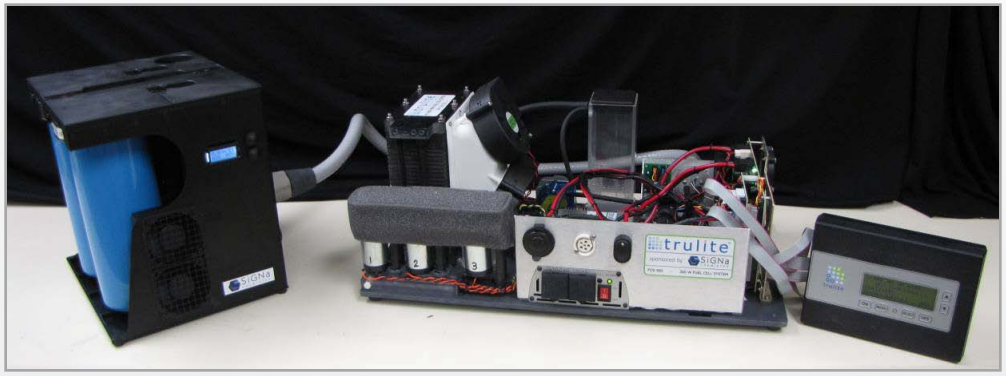


300W Fuel Cell System

Core System Features Developed Under Sub-contract to Trulite

- 300 W Continuous DC Output, 250 W AC
- Lithium-ion Battery Hybrid
- Fuel cell generated water capture and return
- Single hydrogen release – fuel cell connection: includes hydrogen, water return, balance-of-plant power, and data communications
- Stackable systems with lay-flat handles
- Two systems developed: one laboratory and one packaged

trulite®
Clean, reliable power – anywhere.



Sodium Silicide Based 300 W Hybrid Fuel Cell Based Test Stand

300 W Quiet, Pollution-Free Generator Replacement

Increasing Energy Density Plan

- Improve Hydrogen Yield: Standard NaSi generates 9.8% hydrogen. Ultra high density silicide mixtures have yielded over 13%. Research in this area is on-going.

- Reduce Over-Stoich Water (Chemical): Chemical methods to tailor waste product water absorption are under development. Preliminary results (not included in shown results) indicate an over 30% reduction in water.

- Reduce Over-Stoich Water (Thermal): Less over-stoich water is required at higher reaction temperatures. *Table below does not include other possible benefits of advanced material formulation or other chemical alterations of sodium silicide.*

Impact of Local Reaction Temperature on Over-Stoich Water for NaSi

Over-Stoich Water (%)	Internal/Local Reaction Temperature (deg C)	Specific Energy, LHV (W-Hrs/kg)	Net Usable Specific Energy Using Typical PEM Fuel Cell, W-Hrs/kg
210	85	992	491
90	150	1445	753
34	215	1877	959

Collaborations

Subcontract to Trulite Inc.

- **Program:** Development of a 250W fuel cell system with water recirculation
- **Status:** Subcontract awarded. 250W system delivered with testing on-going
- **Principal Investigator:** John Patton

trulite®
Clean, reliable power – anywhere.

Subcontract to the University of Texas Austin, CEM

- **Program:** Alternative reaction mechanism development and control
- **Status:** Subcontract awarded. Incorporating results into 2nd generation design
- **Principal Investigators:** Richard Thompson and Michael Lewis

The University of Texas at Austin • Center for Electromechanics
CEM 30 years of innovation for Texas and the nation

Proposed Future Work

- Deliver systems for hydrogen generator beta testing
- Improve hydrogen release system performance and robustness
- Work with development partners for end-system integration
- Develop scalable, high-volume manufacturing process for sodium silicide
- Continued research on ultra-high density silicide materials
- Minimize waste product water absorption

Program Summary

- Sodium silicide enables real-time hydrogen release for portable applications that require low weight and cost
  - ***Low Weight***: > 750 W-Hrs/kg demonstrated including water & powder
  - ***Controllable***: low-pressure, load-following H_2 release demonstrated for flows under 4 slpm H_2
  - ***High Purity***: H_2 purity verified to 99.99% (Limited by Equipment)
- Operated two ~300 W Fuel Cell Systems for 100's of Hours
  - Fuel Cell Generator and Electric Bicycle
- Continued research on ultra-high density silicides will enable packaged fuel to approach 2 kW-Hr/kg and $4/kW-Hr for mobile power solutions

NaSi Fueled Bicycle

300 W Generator Replacement