Silicide-Based Hydrogen Generation for Back-Up Power and Portable Fuel Cells

On-demand hydrogen generation systems for high-performance, low-cost and portable fuel cells

Hydrogen fuel cells have great promise as a sustainable energy source, but hydrogen generation and storage issues continue to prevent their widespread acceptance. Many portable hydrogen fuel cell systems use hydrogen supply systems, such as high-pressure tanks, metal hydrides, and chemical hydrides, to store needed quantities of hydrogen. These systems have not gained market acceptance, however, due to significant safety risks, difficulties in hydrogen control management and, in most cases, the logistical difficulty of refilling high-pressure tanks.

SiGNa Chemistry has taken a different approach to the hydrogen generation and storage issues. SiGNa's solution uses sodium silicide to produce clean hydrogen gas *in real time, as needed by the fuel cell and at pressures less than those found in a common soda can*. SiGNa's hydrogen-generation process is safe, clean and scalable; this revolutionary approach has enabled cost-effective back-up power and portable fuel cell systems that are perfectly suited for the military, medical, transportation, and electronics industries.

Sodium Silicide

Sodium silicide (NaSi) and its hybrids are non-flammable, air-stable powders that instantly react with water (or water solutions) to produce pure hydrogen. Sodium silicide yields significantly more hydrogen per weight than pure sodium, but unlike sodium it is a non-pyrophoric, non-flammable material. It differs from other hydrogen-generation materials in that no hydrogen is actually stored in the sodium silicide. As a result, this hydrogen-generation process is safe, has fast reaction times, and an infinite shelf-life. *Importantly, this generation process generates no greenhouse gases and leaves no environmentally-unfriendly waste.*

Fuel Cell System Benefits

Energy Density Energy density exceeds 1,000 W-Hrs/kg

Power Density Very fast, load following reactivity enables high power output without thermal run away.

Control Hydrogen generation is based on the amount of water pumped into the NaSi, enabling rapid starts/restarts (>30 sec.) at room temperature.

Stability Material is stable over all practical temperature ranges (-55 to 300°C) with an unlimited storage lifetime.

Pressure is determined by system design, not material characteristics (<30 psi).

Safety Fuel does not ignite or oxidize in air, even when exposed to air (i.e., in an opened canister).

Low Cost Low manufacturing costs due to the low cost of the starting materials.

Sodium silicide, which was originally developed as a reducing agent for the industrial chemicals industry, is formed by combining sodium metal with silicon powder to create a fine-grained powder. Sodium silicide can be easily and cost-effectively manufactured. *The primary inputs, sodium and silicon, are abundant materials that are derived from renewable resources whose prices are not influenced by the cost of oil*. There is NO waste in the sodium silicide manufacturing process—everything that goes into the reactor is used in the final product. The synthesis of sodium silicide is exothermic (i.e., heat/energy is released in its formation); this translates into very low energy requirements in manufacturing.

Winner of the Presidential Green Chemistry Challenge Award

Silicide materials retain a high level of reactivity with any water solution, even sea water or urine, and provide a stable source of pure hydrogen gas. NaSi's reaction with water produces 2.5 moles of hydrogen (H_2) per mole of NaSi according to a reaction such as

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

The final powders are composed of only the sodium metal and silicon starting materials. *This hydrogen-generation approach eliminates all of the most common fuel cell containments such as carbon monoxide (CO) or sulfur (S).*

Performance Results

Sodium silicide has been shown to readily and controllably react with water, liberating pure hydrogen. Figure 1 depicts the results from a low-pressure, controllable hydrogen generation test demonstrating the on/off capability of the sodium silicide hydrogen cartridge.

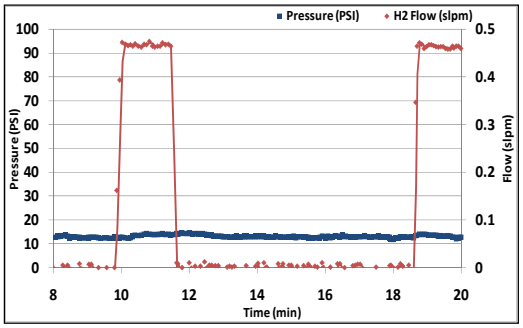

Figure 1. Low-pressure hydrogen for smartphone recharging and portable GPS applications.

Silicide/Borohydride Hybrid

To increase hydrogen density above 9.9 wt%, ***SiGNa has also developed an anhydrous NaSi hybrid with 15.6 wt% hydrogen.*** The derivative, a blend of NaSi and sodium borohydride ($NaBH_4$), combines the characteristics of both materials for high energy dense storage and fast and self-sufficient hydrogen generation.

An energy density comparison is shown in Table 1.

Table 1. Energy density comparison.

	$NaBH_4$ (Fixed bed)	$NaBH_4$ (Acid Hydrolysis)	Aluminum	NaSi	NaSi Hybrid
Mass of Dry Reagents (g)	105	100	248	100	100
Mass of Hydrogen (g)	21.1	3.2	21.1	9.8	15.6
Mass of Water (g)	400	190	319	144	168
H_2 Wt.% (Dry)	20.1%	3.2%	8.5%	9.8%	15.6%
H_2 Wt.% (w/ Water)	4.2%	1.1%	3.7%	4.0%	5.8%
Energy Density (W-hr/kg)	1,391	367	1,238	1,336	1,936
Energy Density (W-hr/L)	1,338	352	1,191	1,256	1,859

Portable NaSi Fuel Cell System

Sodium silicide and its hybrids have unique attributes that enable simple, high-performance fuel cell systems with significant advantages compared to other hydrogen storage technologies. The advantages of a silicide fuel cartridge include:

- Light-weight packaging
- Fast start/stop capability
- High/low temperature stability
- High power density
- Low water absorption by waste product
- Low-temperature and pressure operation
- Long-term fuel storage
- Very low cost

SiGNa's business focus is the development and sale of hydrogen fuel cartridges, however, SiGNa has also developed power system technology to support the demonstration and initial use of the sodium silicide canisters. SiGNa's power system architecture (Figure 2) centers on a power manager that communicates with multiple devices in order to produce, store, and output power. Energy, in the form of sodium silicide, is stored in a lightweight, low-cost fuel canister; this canister is also where the hydrogen is generated. Water from a small reservoir, either internal or external to the fuel canister, is supplied to the powder. Hydrogen generated from the reaction is fed to the fuel cell via a hydrogen control module. The fuel cell then provides energy to the power manager, where it can be used immediately by the electronic device or stored for future use in a battery.

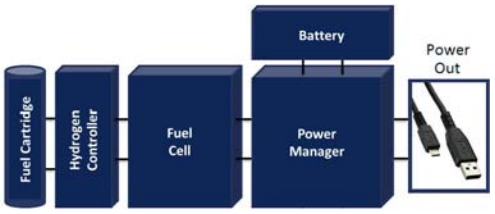

Figure 2. Portable power system architecture.

It is important to note that silicide-based fuel cell systems can use any type of water solution including potable water, polluted water, sea water, or even urine. For weight

sensitive applications, the fuel cell waste water can also be recycled to reduce the overall amount of water required by the system. Typically, 50% of the generated fuel cell water can be recaptured, reducing carry water requirements.

While SiGNa has developed its own fuel cell systems for demonstration purposes, SiGNa's development activities focus primarily on the sodium silicide cartridges, *which are designed to be integrated with any fuel cell system*. The fuel cell systems that SiGNa currently has under development target a maximum pressure of less than 30 psi.

Hydrogen Fuel Cartridges

Sodium silicide and its hybrids are stored in disposable or reusable cartridges (example shown in Figure 3) that are hot swappable, allowing users to easily replace empty canisters with no loss of power supply. The fuel cartridge design facilitates easy to use, low-cost, and low-complexity power systems compared to other high-density hydrogen-generation materials. Because sodium silicide is solid and non-flammable, these cartridges are inherently safer than other storage alternatives. For instance, a comparable compressed hydrogen system stores flammable gas at >4,000 psi (276 bar) or greater.

Figure 3. SiGNa H_2 cartridge.

Fuel cartridges have been designed to yield up to 600 standard liters of hydrogen in a size of 3.5" diameter by 9" (~1.4 liters). The exact dimensions and requirements for each fuel cartridge are customized based on the final application/system need. The specifications for several of SiGNa's cartridge designs are shown in Table 2. These hydrogen storage materials are governed under existing regulatory guidelines, which allow for cartridge distribution and shipment to end users as a consumer commodity (i.e., ORM-D).

Table 2. NaSi canister options.

	PowerPukk Canister	H-40 Canister	H-800 Canister
Power	0 to 5 W	6 to 50 W	50 to 500 W
Capacity	10 Hrs	> 40 W-Hrs	800 W-Hrs/Canister
Volume	22 c	1.6" X 3.5"	3.5" X 9" / Canister
Pressure	3 psi for regulator-free fuel cell	~15 psi	~30 psi
Design Features / Architecture	-Passive -Water Self-Contained -Orientation Independent -Start/Stop Capable	-Passive -Water Self-Contained -Orientation Independent -Start/Stop Capable	-Pump-driven -Water Fill Port -Start/Stop Capable
			

Emissions and Byproducts

A silicide-based fuel cell outputs pure hydrogen and water vapor. Once the sodium silicide in a cartridge is spent, the fuel cell is left with a non-toxic by-product (sodium silicate, $Na_2Si_2O_5$) that is wholly contained within the cartridge. In addition, no contaminants reside in the resulting hydrogen stream. The sodium silicate by-product also simplifies the system implementation when compared to other technologies, such as sodium borohydride. The by-product of a sodium borohydride reaction forms sodium metaborate crystals that are six times less soluble in water than sodium silicate. This sodium metaborate characteristic can make a sodium borohydride reaction significantly more difficult to re-start than a sodium silicide reaction.

Sodium silicate, the by-product of the sodium silicide reaction, is a common industrial material often called "water-glass". This material can be used as an industrial feedstock in many industries, such as concrete production, glass, toothpaste, etc. Sodium silicate is classified as a non-hazardous solid waste under the Resource Conservation and Recovery Act (RCRA) and can be readily disposed of in municipal waste.

Portable Power Systems

Silicide hybrids have been proven as a high-performance, scalable hydrogen-generation technology with a low carbon footprint and a beneficial life cycle relative to other chemical hydrides used for fuel cells (Figure 4). These materials are inexpensive, easily transportable, safe for indoor and outdoor operation, and create no pollution. These features make silicide based fuel cells a perfect fit for any application that needs a portable power source.

SiGNa's portable power platform can be used for any standalone application that requires from 1 W to 3 kW of power. Applications needing higher power include forklifts, lawn mowers, bicycles, and golf carts. Lower power applications include refrigerators, generators, power tools, water pumps and consumer electronics. For low cost, commercial applications, sodium silicide is primarily used. For applications requiring ultra-high-density energy storage, SiGNa silicide hybrid is used to deliver ultra-high energy density.

Transportation and Personal Mobility Applications

SiGNa's NaSi technology can be integrated in many industrial and personal mobility applications ranging from forklifts and golf carts to electric bicycles and scooters. One such application is SiGNa's fuel cell extender for electric bicycles. This silicide-based fuel cell extender creates up to 200 W of continuous power and stores excess energy in a lithium battery for more energy-intensive conditions. SiGNa's range extender, shown on a Pedego™

Figure 5. NaSi range extender powers a Pedego™ electric bike.

electric bicycle (Figure 5), is also directly compatible with most other electric bicycle models.

For an electric bicycle rider, the benefits include tripling the range of the e-bike with only minimal additional weight. Existing e-bikes have a range of up to 20 miles without pedaling; SiGNa's system reaches up to 60 miles without pedaling for each carried fuel cartridge. Speed is regulated by the user, using a throttle, and reaches speeds up to 20 miles per hour (32 kph).

Emergency and Natural Disasters Preparedness

Figure 7. DPS300 fuel cell generator.

During emergencies and natural disasters, when electric grids unavailable or unreliable, silicide-based fuel cells will prevent service disruptions for critical emergency response equipment. Generators, radios, cell phones, satellite phones, computers, telecommunications repeater stations, and temporary medical equipment can safely be powered with silicide cartridges. These fuel cells offer high power density, continuous runtime, and the ability to operate in harsh environments—all in a safe, lightweight form factor. These fuel cartridges also have a long shelf life and can be stockpiled for future use. Where clean water is not available, any water solution, regardless of its quality, can be used.

Military Applications

For military applications, this innovative technology translates into a more durable energy source to power communication, sensory and navigation devices—reliably, safely and without interruption. SiGNa's lightweight, yet robust, power systems can fully replace legacy battery technologies and do not require new refueling infrastructures or battery recharging. NaSi power systems are also fully safe for indoor and outdoor use, including onboard use and in confined spaces.

Consumer Electronics

Figure 6. Fuel cartridges for consumer electronics include the PowerTrekk.

Silicide-based fuel cells offer great value for the computing and consumer electronics market. These fuel cells have higher energy density than batteries and delivery a significant increase in power availability and lifetime for portable electronics. SiGNa has developed a various cartridge forms for consumer applications (Figure 6). The FlatPack is capable of generating hydrogen on demand to support a 30 W fuel cell. With dimensions of ~6" X ~6" X 1" and a capacity of >500 W-Hr (LHV), the Flatpack will allow NaSi fuel cells to provide power to a variety of consumer electronics

products.

A silicide power system is ten times less expensive than alkaline batteries and six times less expensive than lithium batteries, including the amortized fuel cell cost (Table 3). Sodium silicide is also significantly less expensive than other high-density hydrogen storage materials like sodium borohydride ($NaBH_4$) or ammonia borane (BH_3NH_3), where the material itself stores a significant amount of hydrogen and makes them more difficult to control and restart.

Table 3. NaSi cost compared to battery power solutions.

	One Time Cost ($)	Price / Package	Energy / Package 2W Load (W-Hr)	$ / W-Hr	Total Cost for 100 Uses (800 W-Hr)
Disposable Battery, Alkaline (4-pack, AA)	$10	$5.98	5	$1.2	$967
Disposable Battery, Lithium (4-pack, AA)	$10	$8.79	14	$0.63	$512
Fuel Cell/SiGNa (4-pack NaSi)	$18	$3.56	40	$0.89	$89

Cost Sources 1. Amazon.com, Energizer, E91BP, 4-Pack AA, Alkaline
2. Amazon.com, Energizer, 191BP, 4-Pack AA, Lithium
3. Fuel cell cost = $2.96/W, $9 for 3W (US Fuel Cell Council; SiGNa NaSi cartridge = $0.32 each)

About SiGNa

SiGNa Chemistry, Inc. is the creator of a suite of "green" chemistry materials based on the company's core technology for transforming reactive alkali metals into safe, free-flowing powders. SiGNa's groundbreaking technology portfolio eliminates the hazards traditionally associated with reactive materials and introduces a new class of materials that prevent waste, increase the safety and energy efficiency of chemical processing, and enable the cost-effective production of hydrogen energy.

SiGNa's Hydrogen Energy Division is an industry leader in the portable hydrogen energy industry. SiGNa develops and manufactures portable H_2 cartridges for fuel cell integrators and product developers in the industrial, data/communications, emergency and military and consumer markets.

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