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Formic Acid Reformer

Enabling automotive and grid scale fuel cells

Background and problem statement

Fuel cells are considered one of the cleanest methods of converting fuel into electricity, with minimal to no global warming byproducts. Their potential to generate ultra clean electricity is driving increased adoption of automotive and grid scale fuel cells. Cars with fuel cells will enable the vision of true zero-emission vehicles, since all–electric vehicles merely move the source of greenhouse gas emissions to the point of electricity generation. Similarly grid scale fuel cells provide near zero greenhouse gas emission for electricity generation. One additional, key advantage of fuel cells are their "instantly rechargeable" nature, as opposed to traditional batteries. One of the main limiters with the adoption of automotive fuel cells and grid scale fuel cells is the use of hydrogen as a fuel. Compressed hydrogen as a fuel source, when used in automobiles, has associated safety issues, and there is only limited, and cost-prohibitive to expand, infrastructure in place to for the purchase and distribution of compressed hydrogen on a consumer basis. Similarly, grid scale storage typical fuel cell installations require an onsite hydrogen generation plant or a natural gas pipeline, both of which can add significant cost.

Neah's solution

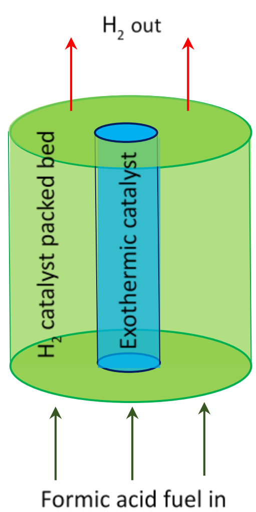
Neah Power Systems, through its recent asset acquisition from Clean Tech Investors (Nov 2013), has demonstrated a reformer that allows onsite (point of use) generation of hydrogen using formic acid (HCOOH). **This technology is covered by two pending patent applications.** Many portable energy sources have distinct differences in energy density, safety, cost and availability as shown in the table below. Formic acid, which is a liquid, is an attractive energy option without the associated safety and handling challenges of compressed hydrogen.

> *Neah's technology enables the use of a liquid, safe fuel (formic acid) for grid scale and automotive applications without the associated costs of a dedicated hydrogen generation plant or the safety and handling issues associated with the use of compressed hydrogen, especially for automotive applications. Furthermore, formic acid could leverage the existing gasoline distribution infrastructure for enabling zero emission transportation.*

Formic acid as a fuel

Power Source	Theoretical Energy Density (W-hr/kg)	Theoretical Energy Density (W-hr/L)
Lithium-ion[1]	125	440
Lead-acid[Error! Bookmark not defined.]	30-40	60-75
Formic Acid[2]	1,700	2,086
Hydrogen[3] (5,000psi compressed)	33,333	833

Formic acid is a safe, energy dense storage medium for hydrogen. It is a common preservative and antibacterial agent and is produced naturally in ants and bees. Formic acid is a commodity chemical, a raw material for a variety of products, and is available at low cost in bulk quantities from a variety of suppliers. Formic acid is also considered a carbon neutral, renewable energy source, and can also be obtained by aqueous catalytic partial oxidation of wet biomass (OxFA process[4,5]). When formic acid is heated it produces carbon dioxide and water, and upon exposure to catalysts formic acid decomposes to hydrogen and carbon monoxide. Although it must be handled safely, unlike more traditional fuels, such as gasoline, formic acid is not flammable in 85% concentration. The principal danger from formic acid is from skin or eye contact with concentrated liquid or vapors.



Neah system offerings

Neah presently offers four standard sizes of reformers for hydrogen fuel cells in **5W**, **10W**, **50W**, and **100W** configurations for demonstration purposes. The fuel tank is adjustable to the energy, or run-time required. Other power ranges and form factors can be made available in customized configurations as well.

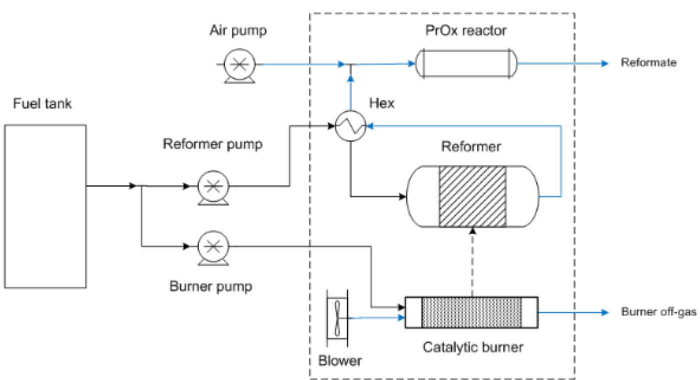
Formic acid is pumped from the cartridge with the use of two metering diaphragm pumps; one pump supplies the proper amount of formic acid for hydrogen (H_2) production as reformate, while the other supplies fuel to the catalytic burner to provide a continuous heat supply to the reformer, through a heat exchanger. After exiting the heat exchanger, the reformate is mixed with a small amount of air and passed through a preferential oxidation (PrOx) reactor to remove trace **carbon monoxide (CO) content to less than 1ppm**. The reformate is then passed to a fuel cell stack to produce electric power, with anode off-gases being vented to the atmosphere. The air supply for the catalytic burner is provided by a small blower. The hydrogen produced can then be used by a

[1] D. L. Anglin, D. R. Sadoway, "Battery", in AccessScience@McGraw-Hill, http://www.accessscience.com, DOI 10.1036/1097-8542.075200
[2]J. Yeom, R.S. Jayashree, C. Rastogi, M.A. Shannon, P.J.A. Kenis, "Passive direct formic acid microfabricated fuel cells", Journal of Power Sources 160 (2006) 1058–1064.
[3] National Research Council and National Academy of Engineering of the Engineering of the National Academies, The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs, The National Academies Press, Washington, D.C., 2004.
[4] R. Wölfel, N. Taccardi, A. Bösmann, P. Wasserscheid (2011). "Selective catalytic conversion of biobased carbohydrates to formic acid using molecular oxygen". Green Chem. (13): 2759.
[5] J. Albert, R. Wölfel, A. Bösmann, P. Wasserscheid (2012). "Selective oxidation of complex, water-insoluble biomass to formic acid using additives as reaction accelerators". *Energy Environ. Sci.* (5): 7956.

variety of fuel cell types – solid oxide fuel cells (SOFC), proton exchange membrane (PEM), etc. for either grid scale power or automotive power.

Fuel cell usage of H_2

The reformer system is designed to provide a sufficient amount of hydrogen to a fuel cell system that uses hydrogen gas as a fuel. For example, considering a 5W electrical power output, the consumption of hydrogen by a fuel cell is described as follows:



$$n_{H_2} = \frac{P}{V} \times \frac{60}{2 \times 96{,}485\mathrm{C/mol}}$$

where n_{H_2} is the hydrogen consumption in mol/min, P is fuel cell power, and V is fuel cell voltage. Assuming a 50% electrical efficiency for a PEM stack gives 0.6V, the hydrogen requirement is calculated to be 0.00259mol/min, or 58.1 sccm (standard cubic centimeters per minute - volumetric flow rate calculated at 1 atmosphere pressure and 0°C). It should be noted, however that this is the exact stoichiometric fuel requirement; that is, fuel utilization is 100 % in this calculation. Under more realistic conditions, a fuel stoichiometry of 1.1 or greater is typically used.

System design guidelines and initial product deployment

Neah is in preliminary discussions with other fuel cell companies to license the reformer technology for certain grid scale applications. Neah is also actively exploring partnerships with automobile manufacturers to implement this technology for point source of hydrogen generation for automotive fuel cells. In parallel, Neah is developing stand-alone systems for back-up power for a variety of applications as well as integrated solutions for a variety of remote monitoring systems. The table below demonstrates the capability of the reformer technology, and can be used as a guideline for design purposes.

Power (W)	Size of reformer unit (cc)	Fuel flow rate (mL/min)	Fuel Vol, 20hrs (L)	Energy Density* (Wh/L)	Energy Density* (Wh/kg)
5	5	0.16	0.19	508	417
10	10	0.32	0.38	508	417
50	50	1.61	1.93	505	415
100	120	3.2	3.84	505	415

*** Includes reformer size.**

For further information and product inquiry please contact Neah Power Systems, at info@neahpower.com or 425 424 3324 ext 108.