Challenges and Opportunities for Hydrogen-Powered Portable Devices

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Abstract

The small/portable fuel cell industry is largely focused on market segments targeting individuals and organizations without easy access to cheap grid power sources. For this reason, the military is the major market today for smaller, portable fuel cell power generators. These fuel cells products are primarily made into recharging devices, although there has been much research into their integration into various consumer electronics. The market is dominated by fuel cells using methanol, and because of that fuel's relatively higher energy density, a hydrogen-based system must make improvements to achieve energy densities that are competitive with other technologies. A hydrogen fuel cell must also deal with perceived safety issues and a nascent fuel infrastructure.

Background and Objective

Fuel cells are electrochemical cells that produce electricity from chemical reactions between fuel and oxidant. They are similar to conventional batteries, but they do not use a stored reactant; they are continuous-flow devices taking in a variety of oxidants and fuels, the most common of which is hydrogen. Fuel cells are often hailed as a promising alternate energy source because of the ability to extract energy from hydrogen and produce only water as a waste product. Much research and development has been invested in the deployment of fuel cells, and there is much potential for their use in smaller portable applications.

The Ballard Mk 1030 hydrogen fuel cell stack

The Department of Energy is interested in is interested in the near-term widespread deployment of hydrogen fuel cells but sees that issues with hydrogen storage may be preventing this. The DoE has asked Sandia to find out why hydrogen storage is not being widely used in the portable electronics and man-portable power markets and what requirements would hydrogen storage devices need to meet to make this happen in the near-term future.

Methods and Scope of Study

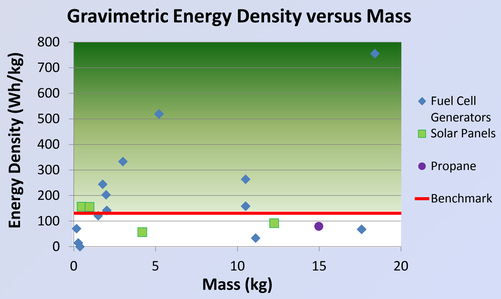
Our methodology consisted of the following:

1. Identify categories of common portable electronics
2. Compile a list of major brand names and companies who produce each product
3. Search for any active research, patents, news articles, and reports involving fuel cells
4. Talk to both fuel cell manufacturers and to consumer electronics companies to assess fuel cell potential
5. Select the categories with the most potential for near-term fuel cell deployment
6. Gather market research
7. Find technical specifications for sample products
8. Determine the requirements a hydrogen system would need to compete with currently available technology

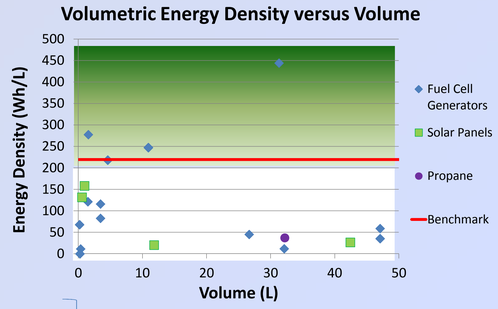
Broadband modems (mobile)	GPS (handheld)
Camcorders	Headsets (telecomm.)
Cellular phones	Laptop computers
Charging stations / power supplies	MP3 players
DVD Players (portable)	Radios (including 2-way)
Digital cameras	Tablet PCs / iPads / eReaders
External hard drives	Video game systems (handheld)

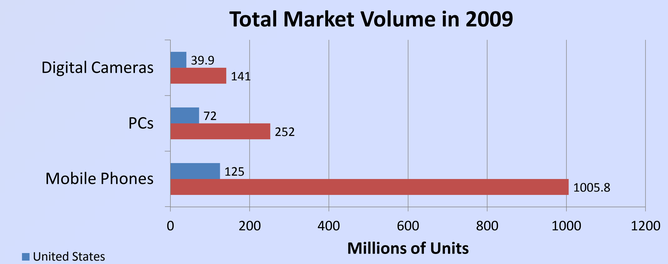
All Power America	Garmin	Novatel
Amazon	Generac	Olympus
Apple	Genport	Panasonic
Archos	Golla	Philips
Ardica	GoPro	Pioneer
ASUS	Hitachi	Plantronics
Barnes & Noble	Honeywell	PowerMate
Belkin	Horizon	Rayovac
Blackberry	HP	Samsung
Bose	HTC	SanDisk
Briggs & Stratton	Insignia	Sangean
Bushnell	Iomega	Sanyo
Canon	Jadoo	Seagate
Casio	Jawbone	SFC Energy
Colby	JVC	Sierra Wireless
Compaq	Kodak	Sirius
Creative	LaCie	Sonocaddie
CyberPower	LG	Sony
Dell	Magellan	Toshiba
Duracell	Maxwell	Trulite
Dynex	Midland	UltraCell
Eastern Tools	Motorola	Uniden
Energizer	mti micro	Verbatim
Flip Video	myFC	Western Digital
Fuji Electric	Nikon	Zune
Fujifilm	Nintendo	

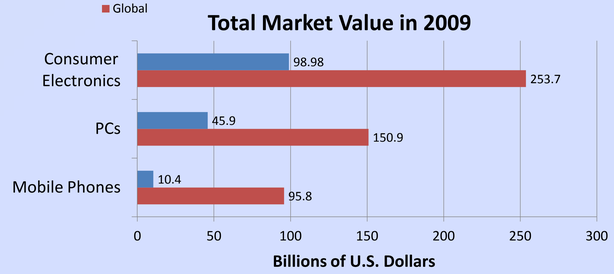
Industry Data and Feedback



▲▼ Graphs plotting the energy contents of various fuel cell systems against their device specifications. Note that while many fuel cells systems are competitive with the LI-145 battery gravimetrically, only 3 systems outmatch it on a volume basis. Energy densities above the red line (shown in green) are desirable for military applications.







Major Impediments

- **Pace of Development**: Integration into electronics is difficult because of the pace the electronics industry advances.
- **Limited Market**: The niche markets for portable power using fuel cells are too small to sustain a large company.
- **Fuel availability:** Consumers require convenience, and current fuels are not widely available.

Fuel and Fuel Source

- **Easiest fuels would be ethanol or propane** from a consumer perspective because of their availability
- **Methanol** is the most common fuel for currently available fuel cell devices.
- **Hydrogen gas is difficult to implement** because of safety concerns, stringent building codes, expensive electrolyzers, maintenance costs, and general fuel availability.

Military Use

- **Supply logistics challenge** with any new fuel needed on the battlefield.
- **LI-145 battery is the benchmark** for gravimetric and volumetric energy densities for fuel cell systems, as well as the desired form factor.
- **Compressed hydrogen gas is prohibited** on the battlefield for safety reasons.

Weight and Dimensions

- There are **exceptionally stringent requirements** on weight and volume for consumer electronics that fuel cell systems may never meet.

Competition with Other Energy Sources

- **Battery technology is rapidly advancing**, and consumer electronics research and development vastly outstrips fuel cell research.
- **Grid power is too cheap and convenient** to compete with in the developed world, limiting adoption of small fuel cell electronics to places where the grid is not established (see "Markets and Applications" below).
- **Consumers will prefer disposable fuel cartridges** unless the fuel is widely available. This effectively is a technological step backwards (from rechargeable batteries).

Markets and Applications

Only viable now in niche markets where access to grid power is limited:

1. **Soldiers and the military**
   - Product reliability required and very specific product specifications must be met.
   - Primary market today.
2. **Outdoorsmen and recreationalists**
   - For consumers away from the grid for extended periods of time.
3. **Remote Users**
   - Markets in the developing world, especially where consumer energy demand is inelastic or in places with no reliable or existing infrastructure.
   - Also includes doctors and other professionals working in remote locations.
4. **First responders and emergency medical technicians**
   - Possible application on medevacs, firefighters, etc.
5. **Highly mobile consumers with high demand for power (for example, travelling businessmen and women)**
   - According to industry research, as much as 10% to 20% of consumers have a high demand for energy and are willing to pay for it.
6. **Environmentally-aware consumers**
   - People that realize fuel cells can be less polluting than grid power.

◄ ▲ In terms of units per year globally, the volume of laptop computers sold, which accounts for 60.7% of total U.S. personal computer volume and 54.3% of total global volume, is much less than that of cellular phones. However, PCs cost more on a per unit basis, and thus its total market value is much more than that of mobile phones. The digital camera and consumer electronics statistics are shown to place the other two in context.

Selection and Specification

We identified four applications that may be amenable to hydrogen fuel cell use in the near-term:

1. Personal power supplies (25W range) for the military
2. Squad-level battery chargers (300W range) for the military
3. Consumer battery chargers (5W range)
4. Batteries for specialty laptops

Examples of each are shown below:

◄Benchmark
LI-145 by UltraLife
Lithium ion battery
15.2 V, 9.4 Ah (nominal)
143 Wh
1021 g
20.96 cm x 7.37 x 4.22

Military Personal Power►
JENNY 600S by SFC Energy
Direct Methanol
25 Watts
2.0 kg
25.2 cm x 18.4 x 7.44

M0.35 Regular cartridge
350 mL of 100% methanol
400 Wh
371 g
16.5 cm x 6.0 x 6.0

◄Consumer Recharger
PowerTrekk by myFC
PEM
5 Watts
270 g
6.6 cm x 12.8 x 4.2

PowerPukk fuel pack
4 L of hydrogen volume
4 Wh
30 g
5.2 cm dia. x 1.9

Squad-Level Power►
M300-CX by Protonex
Direct Methanol
300 W
17.5 kg
30 cm x 37 x 24

Methanol-Water cartridge
1200 Wh
1.58 kg
24.9 cm x 21.8 x 4.8

Specialty Laptop▲
Toughbook 31 (i5 CPU) by Panasonic
Lithium ion battery
10.65 V, 8550 mAh (typical)
91.1 Wh
475 g
16.5 cm x 8.2 x 2.1
~11 hours of runtime, Intel graphics

Analysis

The current state of the art in commercially available hydrogen storage is typified by DOE's 2010 targets for on-board hydrogen storage:

Volumetric: $28\ g_{H_2}/L$ (metal hydrides) — $360\ Wh/L$
Gravimetric: 4.5% (compressed gas, 300 bar) — $600\ Wh/kg$

assuming an efficiency of 40% and the lower heating value of H_2

Company	myFC	SFC Energy		UltraCell		Protonex	UltraLife	Panasonic
Fuel	PowerPukk	M0.35	M2.5	550 mL	XRT-75	M300-CX	LI-145	Toughbook 31 Battery
Volumetric (Wh/L)	99	673	682	375	580	457	219	320
Gravimetric (Wh/kg)	133	1078	1259	694	714	756	140	192

Methanol has a much higher density on a mass and volume basis. Although hydrogen is better than lithium ion batteries, storage technology must be able to compete with the already commercialized methanol systems in the market and provide a significant advantage over batteries to compensate for its lack of available fuel.

Conclusions

Methanol systems dominate the recharger market segment because of the fuel's relative high energy density. A viable hydrogen system must improve current stored energy density while minimizing safety hazards. Moreover, the issues facing the currently available technology will also affect a hydrogen system: problems with fuel availability and logistics, fuel safety, and sometimes stringent volumetric requirements may impede deployment.