PROCEEDINGS OF THE WORKSHOP

FUEL CELLS FOR PORTABLE POWER

Sponsored by the

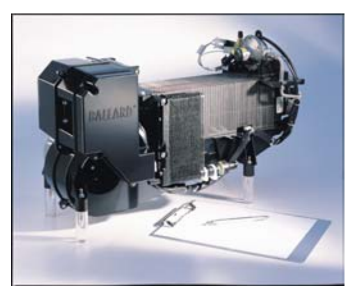
U.S. Department of Energy
Office of Hydrogen, Fuel Cells and Infrastructure Technologies

Hosted by

Motorola Laboratories

January 15-17, 2002

Phoenix, Arizona



ACKNOWLEDGMENTS

We would like to express our sincere appreciation to Motorola Laboratories for hosting this workshop and providing an excellent tour of their fuel cell and ceramics facilities. Special thanks to Dr. Jerry Hallmark of Motorola, who arranged the tour and reception, and served on the workshop organizing team. Special thanks are also to all of the plenary session presenters and the breakout group facilitators and scribes. We would like to especially recognize the important contributions made by the DoD representatives from DARPA, the Army Research Laboratory, Army Natick Soldier Center, Army CECOM and Naval Research Laboratory. We also thank Ms. Christine Weaver of the Los Alamos National Laboratory Protocol Office who coordinated all arrangements for the workshop. Finally, we thank all of the workshop participants from industry, academia, and government agencies/laboratories for their contributions. Your input will be invaluable as we move forward with our program plan.

EXECUTIVE SUMMARY

The Workshop on Fuel Cells for Portable Power was held January 15-17, 2002 in Phoenix, Arizona. Sponsored by the U.S. Department of Energy (DOE) Office of Hydrogen, Fuel Cells and Infrastructure Technologies (OHFCIT), and hosted by Motorola Laboratories, the workshop included fifty-five participants from industry, academia, national laboratories and government.

This workshop was based on the premise that portable power devices are likely to be the first fuel cell systems introduced into the commercial marketplace. Fuel cells for portable power, therefore, will create important manufacturing and customer bases for applications that require higher-power fuel cells, e.g. transportation and stationary applications. The findings of this workshop will contribute to developing a strategy to facilitate commercial introduction of automotive-scale PEM fuel cells.

A plenary session included presentations that summarized and reviewed requirements for portable power fuel cells from both an end-user and fuel cell developer perspective. Three concurrent breakout sessions – low-power consumer electronics (sub-watt to 50W), high-power portable systems (20W to 5kW), and fuels and fuels packaging – established performance targets, identified technical barriers to commercialization, and proposed R&D activities to address and resolve the barriers.

Performance targets were identified for applications at all power levels including sub-watt battery replacements, laptop and cell phone battery chargers and power supplies, power units for personal transportation devices, back-up/emergency systems, and auxiliary power units for recreational vehicles and long-haul trucks. A summary of the commercialization performance targets is presented in Table 1. Performance criteria were also developed by the Fuels and Fuels Packaging Breakout Group and may be found on Page 16.

R&D activities were proposed for both high- and low-power applications to achieve the target values within the 2005 to 2010 time frame. The top priority barriers to commercialization and the proposed R&D activities to resolve those barriers from each of the three breakout groups are summarized in Table 2.

The recommendation for the best demonstration project to be undertaken in the consumer electronics area was the stand-alone battery charger. For the higher power applications, an auxiliary power unit for a recreational vehicle and/or a large truck was chosen. The group also felt that an educational/academic demonstration project was very important. This project would involve all academic levels – primary, secondary and post-secondary.

There was strong agreement within the group that near-term portable power applications would lead the way to a smoother transition to the more complex, more demanding transportation applications. Finally, the group stressed that the two primary challenges for portable fuel cell power systems were cost and manufacturability – these are also primary issues for transportation.

Table 1. Summary of Commercialization Performance Targets for Portable Fuel Cell Power Systems.

	Low-Power [a] Consumer Electronics **Sub-watt to 20W**	**High-Power** [b,c] Laptop Computer ***20-50 W***	**High-Power** [b,c] Auxiliary Power Unit ***1 – 5 kW***
Specific Power	100 W/kg	**	200 W/kg
Power Density	100 W/l	**	200 W/l
Energy Density	1,000 Wh/l	**	**
Specific Energy	**	600 Wh/kg	**
Efficiency [d]	**	25% for commercial, 50% for military/industrial	30%
Cost	$3/W	$400 for a 20W unit, $1,000 for a 50W unit	$1/W for commercial use, $3/W for military/ industrial use
Lifetime/ Durability	5,000 hours	1,000 hours of full power use (1.5 hours/day for 2 years)	1,500-2,000 hours for commercial use, 5,000 hours for military/industrial use
Start-up Time	**	20 µsec	<1 minute for APUs, ~ 20 µsec for back-up power units

a. Long-term (2010) Commercialization Performance Targets
b. Targets to be met simultaneously in 2007
c. Operating temperature range: 10 – 50°C; survivability requirements: -10 – 70°C
d. Efficiency is defined as the ratio of the output electrical power to the total HHV of the fuel consumed
*** Value was not determined by Breakout Group*

Table 2. Summary of Barriers and Proposed R&D Areas from each Breakout Group.

Barrier	Proposed R&D Areas
Low Power System – sub-watt to 20 W	
Power Density/ Specific Power	• Improve electrocatalysts, electrode structures, & MEAs • Optimize stack design/engineering to reduce size and weight
Cost	• Develop low-cost materials and processing • Simplify system design and engineering
System and Component Miniaturization	• Incorporate low-power miniature electronics (e.g., converters) • Simplify design concept – eliminate components
Energy Density & Conversion Efficiency	• Improve membranes to eliminate methanol crossover while maintaining conductivity • Achieve higher voltage cell operation at a given power output
Consumer Safety & Effluents	• Eliminate noxious effluents (methanol, CO, etc.) • Ensure fuel/water containment
High Power Systems – 20 W to 5 kW	
Packaging	• Improve system engineering and component multi-functionality • Develop new materials and advanced manufacturing methods
Power Density **Specific Power** **Energy Density** **Cost (Precious Metal Loading)**	• Develop alternative catalyst with reduced precious metal loading • Develop sulfur tolerant catalyst and/or develop sulfur removal (from fuel) techniques
Balance of Plant Components	• Improve pump efficiency and reduce acoustics (noise)
Code & Standards Recommended Practices	• Develop and adopt centralized, focused codes, standards and recommended practices
Standardized Test Procedures	• Develop and implement standardized test procedures
Fuels & Fuels Packaging	
Candidate Fuel	**Proposed R&D Area**
Direct Methanol	• Optimize packaged energy/power density • Address toxicity issues
High Pressure Hydrogen	• Optimize packaged energy/power density • Ensure safety
Chemical Hydride Storage	• Optimize packaged energy/power density • Reduce storage system cost
Reformed Hydrocarbons	• Optimize packaged energy/power density • Reduce reformer volume & weight

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**** May be downloaded at the following website – http://www.eere.energy.gov/hydrogenandfuelcells/pubs.html***

INTRODUCTION

The Workshop on Fuel Cells for Portable Power was held January 15-17, 2002 in Phoenix, Arizona. Sponsored by the U.S. Department of Energy (DOE) Office of Hydrogen, Fuel Cells and Infrastructure Technologies (OHFCIT), and hosted by Motorola, the workshop included fifty-five participants from industry, academia, national laboratories and government. (See Appendix A for a list of participants.)

DoD representatives from DARPA, the Army and the Navy made significant contributions to the workshop. The military has extensive requirements for portable power sources, ranging from a few watts to several hundred watts. Today power requirements are met primarily by batteries, but there is strong interest within DoD to replace batteries with alternate power sources including fuel cell power systems. The Palm Power Program is a major DARPA effort to develop a "20 W power source in a ***hand-held package*** having 15 times the energy content of the best battery." A particularly challenging aspect of military requirements is operation on logistics fuels such as diesel or JP-8. Strong synergies exist between the DARPA Palm Power Program and the DOE Fuel Cell Portable Power Program and the programs are closely coordinated to avoid any duplication of effort.

This workshop was based on the premise that portable power devices are likely to be the first fuel cell systems introduced into the commercial marketplace. Fuel cells for portable power, therefore, will create important manufacturing and customer bases for applications to follow that require higher-power fuel cells, e.g. transportation and stationary applications. The objectives of the workshop were to:

- Establish technical performance targets for Proton Exchange Membrane (PEM) fuel cells for portable applications,
- Identify and prioritize the technical barriers to achieving those targets and commercializing portable power fuel cells,
- Propose research, development and demonstration activities to overcome those barriers,
- Develop a strategy to build on the progress of portable power fuel cell systems that would facilitate commercial introduction of automotive-scale PEM fuel cells.

WORKSHOP ORGANIZATION

The workshop began with a plenary session that included several presentations that summarized portable power fuel cells from several important perspectives. The plenary session was followed by three concurrent breakout sessions – low-power consumer electronics (sub-watt to 50W), high-power portable systems (20W to 5kW), and fuels and fuels packaging. A final summary session brought all workshop participants back together to collate and integrate the findings of the breakout groups. (See Appendix B for a detailed workshop agenda.)

Plenary Session

- Overview: Dr. JoAnn Milliken, DOE Technology Development Manager, opened the plenary session by describing the purpose and rationale of the workshop and the desired goals and objectives (See Appendix C.)

- Industry end-user perspective: Dr. Jerry Hallmark of Motorola Laboratories reviewed low-power consumer electronics requirements, from sub-watt power levels to 50 Watts. He pointed out that cell phones carry a 2-5 W-h battery (100 mW to1W power consumption); a fuel cell power system could function as a battery charger or replacement. He also discussed fuels issues, including energy density and transport of fuels as areas requiring attention. (See Appendix D.)

- Industry end-user perspective: Dr. Pavlo Rudakevych of iRobot Corporation discussed systems at higher power levels, above 50 Watts. He indicated iRobot is presently using NiCad batteries because they are robust and last ~2 hours in a robot operating "on the road". Technical issues for robots include thermal management and problems with radio frequency signals that control the robots but get blocked inside buildings**.** For DOD missions, fuel is an issue because DoD prefers diesel fuel for most operations. (SeeAppendix E.)

- Government end-user perspective: Dr. Karen Swider-Lyons of the Naval Research Laboratory reviewed power requirements for military applications. She described the DARPA Palm Power Program that started in 2001. The goal of this program is a 20-W power source in a hand-held package having 15 times the energy content of the best battery to meet future power requirements in 2010 and beyond. Specific energy goals are 1,000 Wh/kg for a 3-hour system, 2,000 Wh/kg for a 3-day system and 3,000 Wh/kg for a 10-day system. (See Appendix F.)

- Fuel cell developer perspective: Dr. Shimshon Gottesfeld of MTI MicroFuel Cells, Inc. described development of fuel cell systems for consumer electronic applications. He identified technical issues at the consumer electronics power level, including performing at near-ambient conditions, simplifying the system, operating under air-breathing conditions, developing a complete power system with required sensor and control systems, cost, and packaging (energy density). Technical barriers include: improving MEA performance and cell design for methanol and water management; achieving higher power at higher cell voltages; achieving required reliability and durability; lowering catalyst loading; using inexpensive cell hardware; and operating under a broad environmental window in terms of temperature, relative humidity, etc. (See Appendix G.)

- Fuel cell developer perspective: Mike Walkinshaw of Ballard Power Systems, Inc. covered the fuel cells for portable power systems above the 50 Watt range. He discussed portable power devices up to 3-4 kW, and informed the group that the next Ballard product would be a 1.2 kW, 500-hour Nexa-power module.

Issues at the higher power levels include fuel and fuel storage, infrastructure issues, and system weight and cost. For hydrocarbon reforming to produce hydrogen fuel, the issues include start-up, cost, volume, and emissions. For compressed hydrogen on-board storage, the barriers include fuel storage technologies, cost, cold start, and power density. (See Appendix H.)

- DOE Fuel Cell Report to Congress: Ms. Donna Ho, DOE Technology Development Manager, described plans for preparing a report that had been mandated by Congressional legislation. The findings and conclusions of this workshop will be included in this report.

Workshop information and presentations, including these Proceedings and Appendices may be found at the following website:
http:///www.eere.energy.gov/hydrogenandfuelcells/pubs.html.

Breakout Sessions

Breakout groups were formed in the following topical areas:
- Low-power (consumer) electronics (sub-Watt to 50W)
- High-power portable systems (20W to 5kW)
- Fuels and fuels packaging

Breakout Group 1: Low-Power Consumer Electronics (sub-Watt to 50W)
Facilitator: Ken Stroh, Los Alamos National Laboratory
Scribe: Rajat Sen, Sentech

This breakout group included fuel cell, component, power system, and product developers, laboratory researchers, technology managers from sponsoring agencies, and end-users. The approach adopted by the group was first to identify performance targets for fuel cell systems that would be required for the technology to achieve significant market penetration as a viable battery replacement in consumer electronics applications. Next, the technical barriers to achieving those targets were identified and, finally, R&D projects needed to overcome the barriers were proposed.

The timing for product development and market introduction was discussed by the group, however, a consensus was not reached. Some group members felt that the near term (2005) and long term (2010) dates for achieving performance targets were too far out in the future for fuel cells to ever be commercially competitive with existing technologies. Other members of the group felt that the technical problems were too challenging and the technology too immature to shorten the time frame for development significantly.

In identifying needed R&D, the group felt that many of the barriers identified for portable power fuel cells were consistent with those for transportation fuel cell systems. To avoid duplication of effort, therefore, the focus of the portable power activity should be on the barriers unique to fuel cells for portable power. However, the synergy between portable and transportation applications should be a strong consideration in developing and funding portable power fuel cell activities.

Technical Targets

Targets are for a complete power pack including packaging and balance-of-plant components. In this group cost was defined as the price to an OEM (manufacturing cost and supplier mark-up) and does not represent the retail price that the OEM would pass on to the consumer. Table 3 lists the current status (in 2002) with performance values based Li-ion battery technology that was considered to be the "competition" in this low power category. The group felt that it was important to identify target parameters and values that are technology and fuel neutral and are measurable. After much discussion, the values in Table 3 were derived as a compromise between market competition requirements and technological feasibility or reality.

Table 3. Performance Targets for Low-Power (Consumer) Electronics (sub-watt to 50W).

	Li-ion Battery 2002 Status	Fuel Cell Near-Term 2005	Fuel Cell Long-Term 2010
Sample Market		Cell Phone Charger	Cell Phone/Laptop
Specific Power	50 W/kg	30 W/kg	100 W/kg
Power Density	60 W/l	30 W/l	100 W/l
Energy Density	150 W-h/l	500 W-h/l	1,000 W-h/l
Cost	$3/W	$5/W	$3/W
Lifetime	300-500 cycles	1,000 hours	5,000 hours

Technical Barriers and R&D Areas

The most significant technical barriers to commercialization of low-power fuel cells are listed below in Table 4, in priority order as voted upon by the group. Also listed with each barrier are the R&D areas that should be pursued to overcome the barrier.

The following items were listed as "second tier" barriers with lower priority than those listed in Table 4 below:

- Reliability (mean time between failures)
- Manufacturability/mass production
- Consumer acceptance/perception (education)
- Codes & Standards
- Infrastructure requirements

These barriers should be addressed after substantial progress has been demonstrated on the primary barriers.

Table 4. Barriers to Commercialization for Low-Power (sub-watt to 50 W) Consumer Electronics Fuel Cell Power Systems.

Barrier	Proposed R&D Area
Power Density *2010 target - 100 W/l* **Specific Power** *2010 target - 100 W/kg* @ near ambient conditions,	• Electrocatalysts, electrode structures, & MEAs a. Improved catalyst utilization b. Advanced methanol oxidation catalyst c. Breakthrough cathode catalyst resistant to methanol d. Manufacturability e. Mechanistic and modeling studies* • Stack design/engineering to reduce size and weight a. Low-volume, low-pressure stack design b. Manufacturability c. Engineering models*
Cost *2010 target - $3/W*	• Low-cost materials and processing • System simplification • Low-cost balance of plant components • High-volume/low-cost manufacturing techniques • System optimization and DMFA (design for manufacturing and assembly) tools • Low fixed-cost over time (durability, O&M costs) • System models*
System and Component Miniaturization	• Low-power miniature electronics (e.g., converters) • Simplicity of design – eliminate components • Miniature fluid handling systems (including connections, valves, etc.) • Sensors and controls • Liquid/gas separation and handling (e.g., sump not viable on small scale, orientation to gravity not assured) • Efficient system and thermal integration (take heat and water from where not needed and deliver to where needed)
Energy Density & Conversion Efficiency @ near ambient conditions *2010 target – 1000W-h/l*	• Improved membranes to eliminate methanol crossover while maintaining conductivity • Higher voltage cell operation at a given power output • Low-power, highly efficient ancillaries (DC/DC converters, pumps, fans)
Consumer Safety & Effluents	• Eliminate noxious effluents (methanol, CO, etc.) • Fuel/water containment • Low-volume, high-efficiency thermal barriers
Balance of Plant (thermal management, water management, reactant management)	• TBD
Operating conditions	• TBD
Durability (degradation over time)	• TBD

** The group agreed that all R&D tasks should include mechanistic or engineering model development as appropriate. The modeling should serve as a knowledge transfer mechanism and the emphasis should be on system models suitable for trade-off studies facilitating total system simplification and optimization.*

Breakout Group 2: High-Power Portable Systems (20W to 5kW)

Facilitator: Nancy Garland, DOE
Scribe: Larry Blair, DOE Consultant

The high-power breakout group decided to begin their system consideration at the 20-watt power level. Two distinct power ranges were considered – 20 to 50W with a laptop computer as a typical application and 1 to 5kW range where an auxiliary power unit (APU) or backup power generator are typical applications. The APU for long haul, over-the-road trucks is of particular interest to DOE. Diesel truck engines typically idle 20 to 40% of the time, to provide power for refrigeration and cab hotel loads. Within the U. S., this idling requirement consumes between 840 million and 2 billion gallons of diesel fuel annually while emitting tons of EPA-criteria emissions.

Technical Targets

Technical performance targets for the 20-50 W power region, where a laptop computer is a reasonable near-term application goal, are listed in Table 5.

Table 5. Performance Targets for 20-50W (laptop computer) Applications.

	Performance Target[a,b]	Comments
Energy Density	600 W-hr/kg	This target value is defined as mid-way between the fuel cell present performance and the energy density of batteries. This value was consider appropriate to demonstrate reasonable technology improvement to for the 2007 time frame.
Efficiency[c]	25% for commercial applications 50% for military applications	It was noted that efficiency is not particularly meaningful because fuel must be carried along with the device and adds total system weight.
Durability	1000 hours of full power use (1.5 hours/day for 2 years)	Laptop battery packs are specified to recharge 300 times with 2 hours of operation per recharge for a total of 600 hours of use. This target is set to be 2/3 higher than the current status to gain consumer approval and acceptance.
Cost	\$400 for a 20W unit \$1000 for a 50W unit	This is the current market price for a laptop battery pack - NOT the OEM cost. The group felt that since the battery pack could be an after-market product, the actual market price is most appropriate.
Start-up Time	20 µsec	Start-up time for this power range was considered to be very important.

a. Targets to be met simultaneously in 2007.
b. An operating temperature range from 10-50°C was established with system survivability required between –10 and 70°C.
c. Efficiency is defined as the ratio of output electrical power to HHV of the input fuel.

Table 6 summarizes performance targets for applications in the 1-5kW range where an auxiliary power unit (APU) or a backup generator are typical applications. In this power range, the commercial competition would come from internal combustion engine (ICE) powered units.

Table 6. Performance Targets for 1-5kW (APU) Applications.

	Performance Target[a,b]	Comments
Power Density **Specific Power** **Efficiency**[c]	200 W/kg 200 W/l 30 %	Transportation fuel cell system targets were set by examining the specifications for internal combustion engines (ICE). Because these fuel cell systems will replace ICE backup power generators, target values were set 2/3 higher than the current ICE status as a reasonable, but significant, goal for the 2007 time frame.
Durability	1500-2000 hours for commercial use; 5000 hours for military/ industrial use	The demand for extended durability or lifetime for military and/or industrial applications is indicated in the enhanced performance target for these applications.
Cost	$1/W for commercial use; $3/W for military/industrial use	Based on the current commercial price of a 1kW backup generator; for military/industrial systems enhanced performance is valued over price.
Start-up Time	< 1 minute for APUs ~ 20 µsec for back-up power units	Rapid start-up is required for back-up power systems

a. *Targets to be met simultaneously in 2007.*
b. *An operating temperature range from 10-50°C was established with system survivability required between –10 and 70°C.*
c. *Efficiency is defined as the ratio of output electrical power to HHV of the input fuel.*

Tables 5 and 6 do not cover power levels between 50W and 1 kW, so the group discussed potential applications in this power range and decided that a powered wheelchair would be an appropriate medium power application at about 500W. The power source to be displaced is the nickel metal hydride battery. Other portable power applications in this power range included personal transportation devices such as a motorbike powered at about 400 W. An estimated cost for the fuel cell power system was $600/kW. It was noted that prototype fuel cell powered bikes exist today.

Technical Barriers and R&D Areas

Barriers to commercialization and R&D areas proposed to address the identified barriers for high power fuel cell portable systems are summarized in Table 7.

Table 7. Technical Barriers and R&D Activities for High Power Portable Systems.

Barrier	R&D Area
Packaging	• Improve system engineering and component multi-functionality • Develop new materials and advanced manufacturing methods • Engineer new structure interfaces
Power Density **Specific Power** **Energy Density** **Cost (Precious Metal Loading)**	• Develop alternative catalyst with reduced precious metal loading • Develop sulfur tolerant catalyst and/or develop sulfur removal (from fuel) techniques • Develop new membrane with MeOH permeability at higher temperatures • Improve wetability of electrode structures • Improve load following with enhanced kinetics and reduced thermal mass
Balance of Plant Components	• Improve pump efficiency and reduce acoustics (noise)
Code & Standards **Recommended Practices**	• Develop and adopt centralized, focused codes, standards and recommended practices
Standardized Test Procedures	• Develop and implement standardized test procedures

Technical Status

Brief presentations (5-10 minutes) were given by members of this group, which described their activities supporting fuel cells for portable power.

- Piotr Zelenay, LANL, described ~20 W units being developed with Ball Aerospace with DARPA funding. He mentioned methanol crossover and high temperature membranes as specific R&D areas. With DOE funding they are working on precious metal loading and bipolar plates.

- Jack Kosek, Giner Electrochemical, described DMFC units built for the Army under an SBIR program, and briefly mentioned work they are doing with GM.

- Owen Hopkins, Donaldson, talked about the filters they are making for fuel cells and for computers.

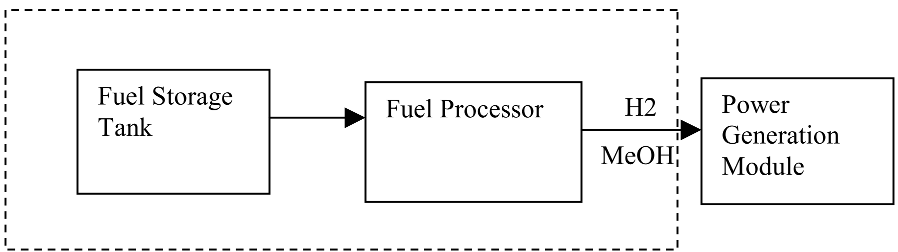
- Paul Osenar, Protonex, described the injection molding capabilities of his company for fabricating PEM components.

Breakout Group 3: Fuels and Fuels Packaging

Facilitator: Mike Krumpelt, Argonne National Laboratory
Scribe: Erin Cready, Sentech

This breakout group began with a discussion of the technical targets that would be needed for fuels and fuels packaging systems. Since targets would depend on what was identified as the fuel system, they agreed that this system needed to be defined. The following schematic was developed to identify the fuel system, which is contained within the dotted line. Potential primary fuels considered were direct methanol, hydrogen, hydrocarbons, chemical hydrides, and ammonia.

Figure 1. Definition of Fuels System



It was also agreed that fuel systems needed to be broken down into two distinct categories, according to application, before meaningful technical targets could be established. These categories, with typical applications, were:

1. Low Power (Consumer Electronics) Portable Systems (Sub-watt – 500 W)
    - Cell phones
    - Laptops
2. High Power Portable Systems (500 – 5,000 W)
    - Robots
    - Lawn Mowers
    - Life-support, emergency equipment

Technical Targets

The following performance characteristics were identified as critical to developing a successful fuel system:

1. Specific energy density
    a. Fuel processor
    b. Whole system
2. Cost
    a. $/kW
    b. $/kW-h
3. Lifetime
4. Safety Standards (UL recognized, FAA regulations, etc.)
5. Environmental Acceptability
    a. EPA Acceptability (Landfill requirements)

6. Operating Limitations
    b. Temperature
    c. Humidity
    d. Start-up
    e. Physical Durability

Technical targets were developed for specific energy density, cost, and lifetime requirements in both consumer and "power" application areas. Lithium-ion batteries were considered when determining technical targets so that fuel cells would meet or exceed their performance.

Table 8. Performance Targets for Portable Power Fuels Systems.

	Consumer Electronics [a] **Sub-watt – 500 W**	**"Power" Systems [a]** **500 – 5,000 W**
System Energy Density **System Specific Energy** **Fuel Processor**	500W-h/L 400W-h/kg 65%-75% of the system	
System Power Density **System Specific Power**		100 W/l 100 W/kg
Cost: **-Initial cost of FC system** **-Recurring fuel cost**	 $2/W-h $0.30/W-h	 $400/kW
Lifetime	2 years (2,000 hours)	5,000 hours

a. Targets are to be achieved in the 2007 timeframe.

<u>Technical Barriers and R&D Areas</u>

To identify technical barriers for fuel systems, Table 9 was developed to illustrate the potential issues associated with the use of various fuels. The group collectively graded each fuel by the technical challenge that each item presented to its use. A plus (+) represents great difficulty, a zero (0) represents a few issues, and a minus (-) represents no issues. Each fuel was graded individually on the potential barriers, without comparison to other fuels. The fuels considered by this breakout group, identified as the leading candidate fuels for portable fuel cell power systems, were direct methanol, hydrogen stored as a high pressure gas, hydrogen from reformed hydrocarbons including methanol, hydrogen stored in a chemical hydride, and hydrogen produced from the decomposition of ammonia.

Table 9. Barriers to Fuel Systems Commercialization.

	DMFC	**Hydrocarbon**	**H_2**	**Chemical Hydrides**	**Ammonia**
Toxicity	+	-	-	+	+
Flammability	0	0	++	+	-
Energy Density	++	+	+	0	0
Power Density	++	+	0	0	0
Cost	+	+	+	+	0
Safety	0	0	++	+	+
Corrosion	0	-	0	0	++

Reforming Start-up Temperature Catalyst Life By-Product	-	++	-	+	+
DOT Compliance	-	0	+	+	+
Emissions	0	0	-	-	-

+ great difficulty
0 few issues
- no issues

After identifying the technical barriers to the use of each fuel, the group voted on which of these areas R&D activities should concentrate. The R&D areas receiving the largest number of votes are listed in Table 10.

Table 10. Proposed R&D Activities for Candidate Fuels for High Power Portable Fuel Cell Systems.

Candidate Fuel	R&D Area
Direct Methanol	Package energy/power density Toxicity Flammability
High Pressure Hydrogen	Package energy/power density Safety Storage System Cost
Chemical Hydride Storage	Package energy/power density Storage System Cost
Reformed Hydrocarbons	Package energy/power density Reformer Volume & Weight

Summary Session

Following the Breakout Sessions, all of the participants met together in a summary session in which demonstration projects were proposed and timeframes for commercialization were discussed. A meaning educational demonstration was also proposed to promote public knowledge and acceptance. And finally, the group discussed the synergy between the proposed portable power activities and transportation applications.

Proposed Demonstration Projects

Sub-Watt to 50W Consumer Electronics

In the consumer electronics area, fuel cell power systems for cellular phones, laptop computers or battery chargers were consider as representative applications that could be accomplished in the near term. The stand-alone battery charger was chosen as the best demonstration project to be undertaken. A three-phase project was outlined:

Feasibility Demonstration (2003 – 2004 time frame)

- 25 units would be produced with technical focus on the output power

- test group users would be fuel cell developers and an external control group

Alpha Prototype Development (2005 – 2006 time frame)
- 500 units that would be fully functional but would not be fully packaged; the technical focus is on output power and lifetime
- test group users would be fuel cell developers and a government control group (perhaps DoD)

Beta Prototype Development (2007 – 2008 time frame)
- 5000 fully engineered units with technical focus on output power, lifetime, and cost feasibility
- test group users would include government and consumer control groups

50W to 5kW High-Power Portable System

For the higher power application, an auxiliary power unit for a recreational vehicle and/or a large truck was chosen. The APU would operate on multiple fuel feedstocks including propane, gasoline, hydrogen and, perhaps, diesel fuels. Again a three-phase demonstration project was proposed:

Feasibility Demonstration (2002 – 2003 time frame)
- 10 units would be produced
- test group users would include government control groups (Army)

Alpha Prototype Development (2004 – 2005 time frame)
- 100 units would be produced
- test group users would include truck OEMs, RV companies and tour boat operators

Beta Prototype Development (2006 – 2007 time frame)
- 1000 units would be produced with performance increasing from RV to truck APUs in terms of output power, duty cycle, life time and specific power
- test group users would include truck fleet operators in California and elsewhere

Educational Demonstration

The group also felt that an educational/academic demonstration project was very important. This demonstration would involve hands-on training, as well as experience in dealing with both fuel cell reactants and products. A three-phase project was proposed that would involve all academic levels – primary, secondary and post-secondary. In this project, it was suggested that DOE explore partnering with the National Science Foundation and the U.S. Department of Education.

- Phase 1, beginning as soon as possible, would involve 50 colleges working with hydrogen-powered fuel cells and would serve as a test case.
- Phase 2 would extend the program to 10,000 colleges and high schools again focusing on hydrogen-powered fuel cells.

- Phase 3 would involve 100,000 colleges, high schools and primary schools (K – 8th grade) and would include DMFCs.

It was suggested that a robot might be an interesting educational tool; for example, a robotic pet might appeal to primary grade level children. The pet would also involve programming/software development, sensors, mechanical and electrical engineering experiences.

Timeframes for Commercialization

The group discussed the time frame required for commercialization of fuel cell portable power system and identified specific applications that they felt could be deployed in the near-term (~2005); it was felt that other applications would require a longer time frame (~2010). And finally some applications were identified that the group could provide a near-to-long timeframe transition (~2007). The time frames for commercialization along with the proposed applications are summarized below:

Near-Term ~2005
Battery Charger for Laptop Computers
Wheelchairs (~200 W)
Robots
Air Monitoring/Remote Sensing
Battery Extender for Golf Carts (5-10 kW)
Sensor Power

Near-to-Long Transition ~2007
APUs for Recreational Vehicles
Telecommunications Back-up Power
Emergency Response Power Supply
FEMA Back-up Power

Long-Term ~2010
Commercial Personal Portable Power
APUs for Trucks
Industrial Vehicles, e.g. forklifts (20 kW minimum)
Aviation Ground Support
Cell Phone Battery Replacement
Life Support

Synergy with Transportation
There was strong agreement within the group that near-term portable power applications would lead the way for a smooth transition to more complex, more demanding transportation applications. Clearly the development of the manufacturing base required for meaningful deployment of portable power systems, both at the system and component levels, would begin to achieve the economy of scale needed to impact costs in a significant manner. Successful development of fuel cells for portable power requires important advancement in the quality of materials used in the system, such as the electro-

catalyst, membrane electrode assembly and bipolar plates. These material advancements would directly benefit fuel cell power systems for the transportation sector. Codes and standards development was identified as an important activity for portable power and it is equally important for transportation power systems. Having basic codes and standards in place early would relieve the pressure of developing them at the same time as transportation applications are underway.

As discussed above, public education and awareness would be advanced by portable power system introduction; early public exposure to fuel cell systems would prepare the way for market release of hydrogen fuel cell vehicles. Portable power system will require a supporting fuel infrastructure; while not as extensive or complex as the fueling infrastructure needed for transportation, this portable power would initiate infrastructure development and would begin to reduce costs associated with infrastructure development. Finally, the group stressed that the two primary challenges for portable power were cost and manufacturability – these are also primary issues for transportation.

Appendix J: Acronyms

APU	Auxiliary Power Unit
BOP	Balance of Plant
CECOM	US Army Communications-Electronics Command
DARPA	Defense Advanced Research Projects Agency
DMFC	Direct Methanol Fuel Cell
DoD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
H2	Hydrogen
HHV	Higher Heating Value
ICE	Internal Combustion Engine
JP-8	DoD Logistic (Aviation) Fuel
K	Kindergarten
LANL	Los Alamos National Laboratory
MEA	Membrane Electrode Assembly
MeOH	Methanol
OEM	Original Equipment Manufacturer
OHFCIT	DOE Office of Hydrogen, Fuel Cells and Infrastructure Technologies
PEM	Polymer Electrolyte Membrane
PEMFC	Polymer Electrolyte Membrane Fuel Cell
R&D	Research and Development
RV	Recreational Vehicle
TBD	To Be Determined
UL	Underwriters Laboratory
U.S.	United States