2006 DOE Hydrogen Program Review

DMFC Prototype Demonstration for Consumer Electronic Applications

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FCP-35

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This presentation does not contain any proprietary or confidential information

Overview

Timeline

- Project start – Aug ’04
- Funding gap - FY06
- Anticipated completion – FY08
- Percent complete – 40

Barriers

- Energy/power density
- Cost
- Codes and regulations

Budget

- Total project funding
  - DOE share - $3.0M
  - Contractor - $3.2M
- Received FY05 - $1.2M
- Funding suspended Jan ’06 – to be resumed in FY07

Partners

Tessy Plastics

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Cabot

Dupont

Gillette/Duracell

Donaldson

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Program Objectives

"This program will lead to the demonstration and real-world validation of a complete, integrated portable DMFC system for consumer electronics"

1. Overall energy density equal to or better than 800 Wh/liter
2. Demonstrate prototypes
3. Develop power density for the fuel cell array of 100-200 mW per cm^3
4. Design and manufacturing pathway to $5 per unit [in high volume applications]
5. Demonstrate continual operation of up to 1,000 hours
6. Accelerate codes and standards activities leading to appropriate regulations that allow shipping and airline passenger cabin usage

Micro DMFC is an early pathway for the large scale, public introduction to fuel cell benefits

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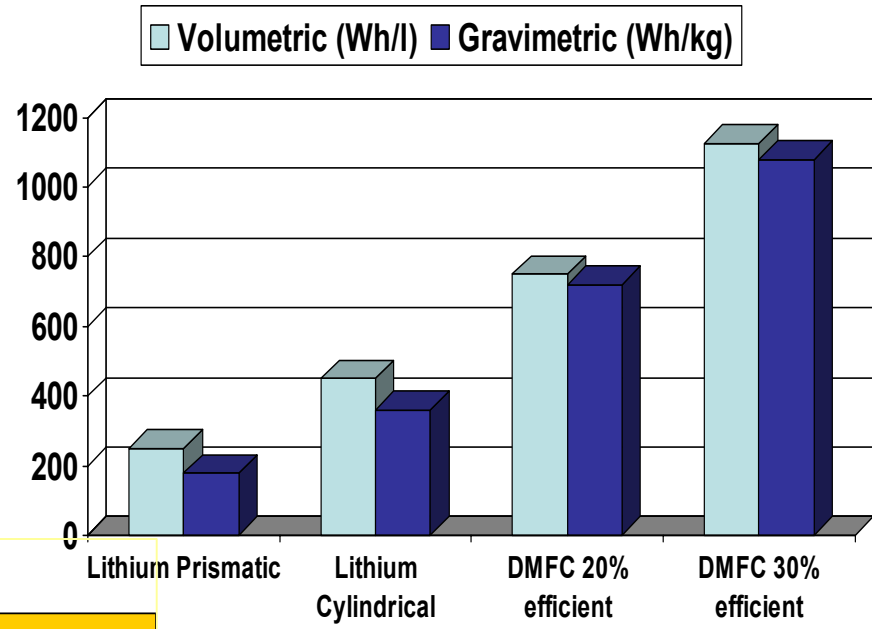
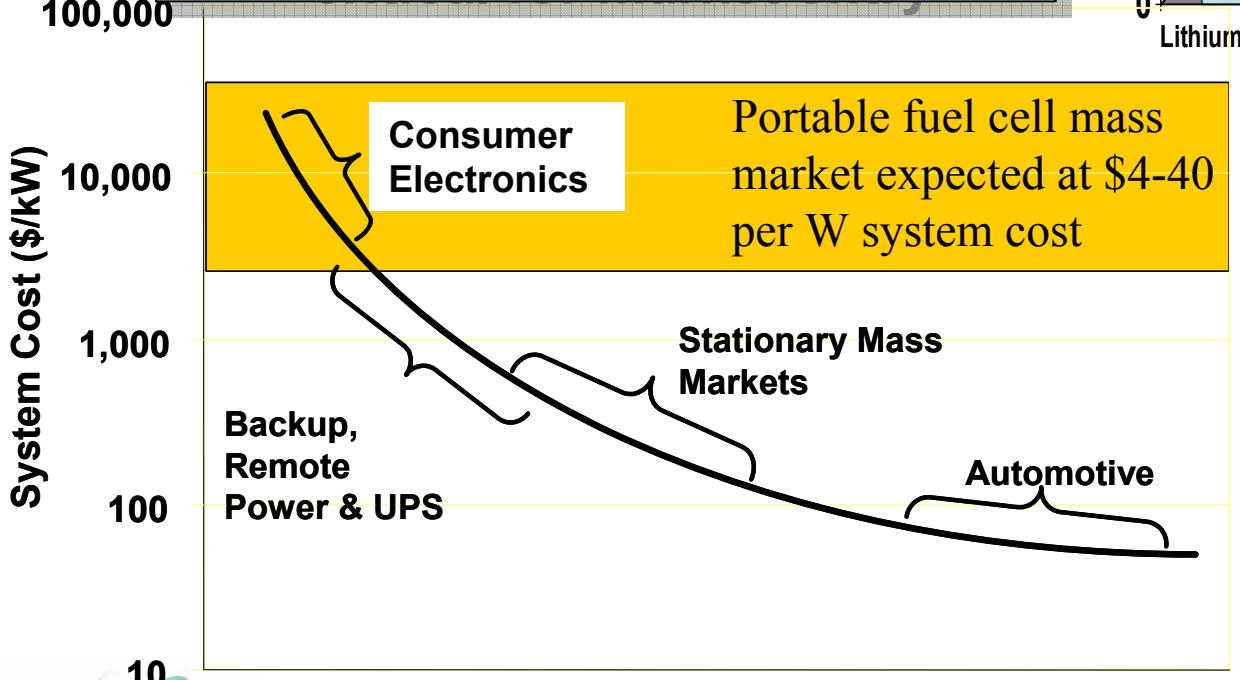
Merits of the DMFC Track

Value Proposition for Handhelds Provides an Early Track to Market

Growing Momentum for DMFC Product Platforms from a Number of US, Japan and European Organizations

Product capability and low cost, high volume manufacturing is critical for market entry





DMFC Advantages

- Energy density beats batteries
- Fuel logistics
  - High energy density
  - Simple fueling systems
- Regulatory acceptance

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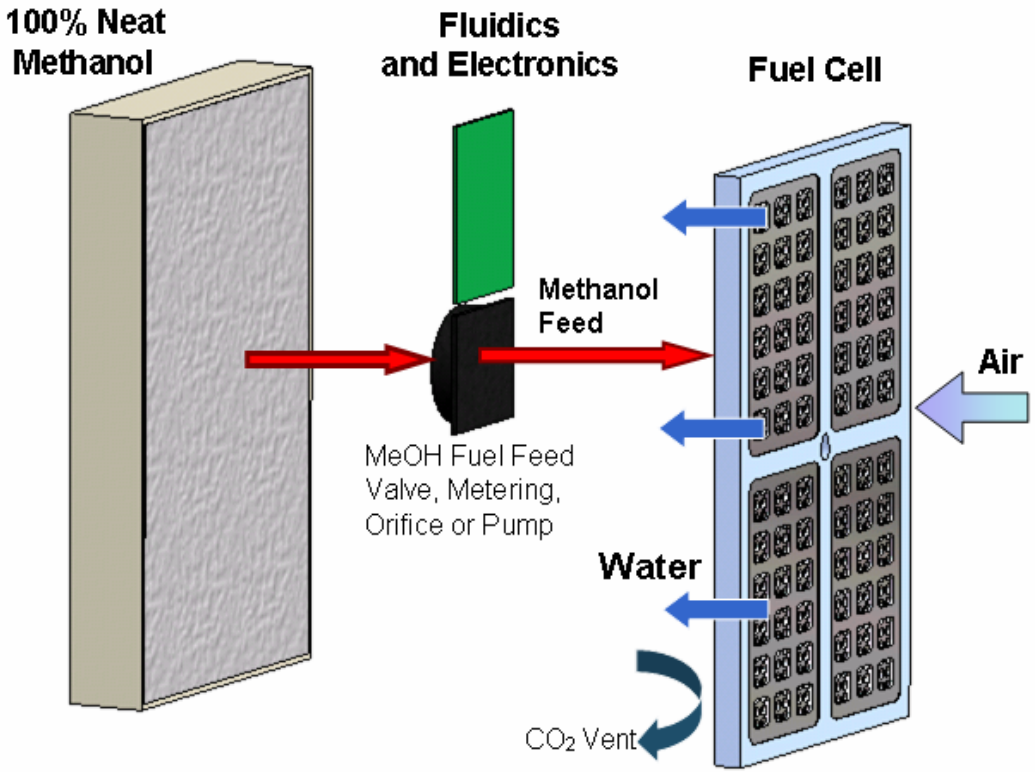
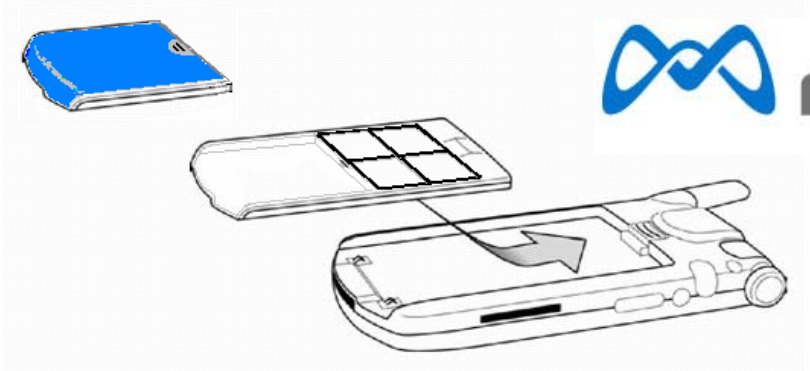
Approach

- Develop system designs that reduces complexity, size and number of components
- Use non-dilute methanol fuel
- Apply high volume manufacturing technology
- Work with OEM's to develop product introduction strategy
- Pursue early product codes and standard
- Develop supply chain





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DOE Sub-Watt System Targets

Sub-watt targets are driven by hand-held electronics product requirements (divergent from the 50 W targets)

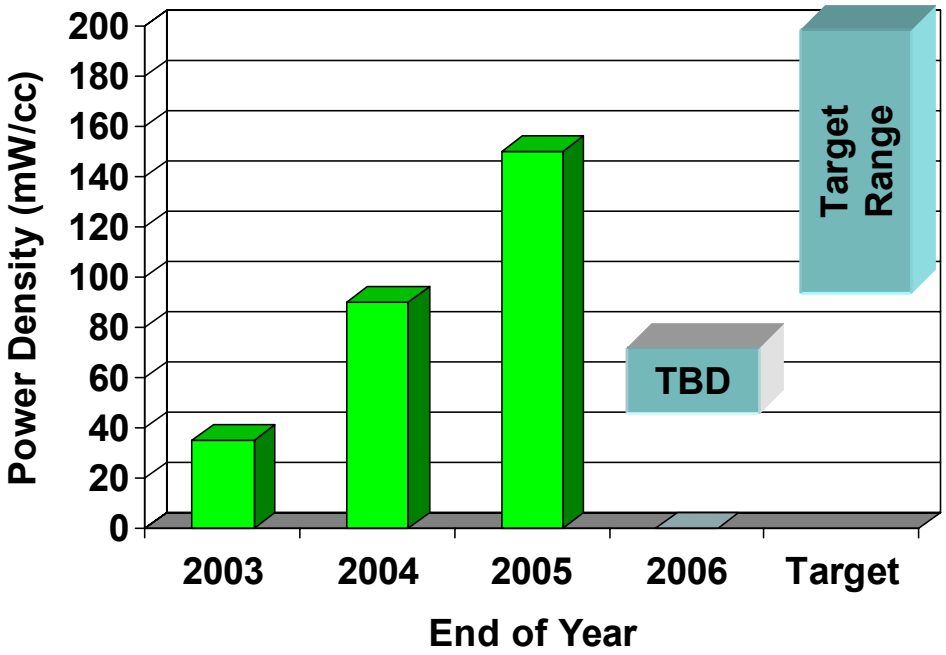
- Specific power and power density targets are 10 – 30 W/kg and 10 – 30 W/L, respectively
- Energy density must be at least 1 - 2 times competing batteries
- Handheld electronics market opens up well above the $5/W target

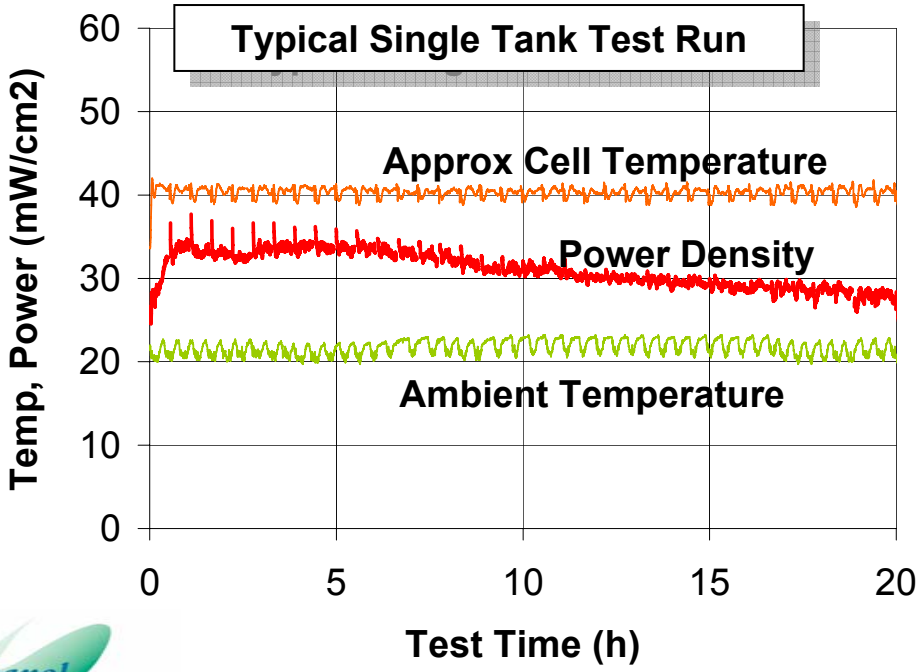
Parameter	Units	DOE Target for Sub-Watt to 50 W		Actual 2005 for Sub-Watt
		2006	2010	
Specific Power	W/kg	30 (10)	100 (30)	3
Power Density	W/L	30 (10)	100 (30)	3
Energy Density	Wh/L	500	1000 (800)	200
Cost	$/W	5	3	NA
Lifetime	Hours	1000	5000	500

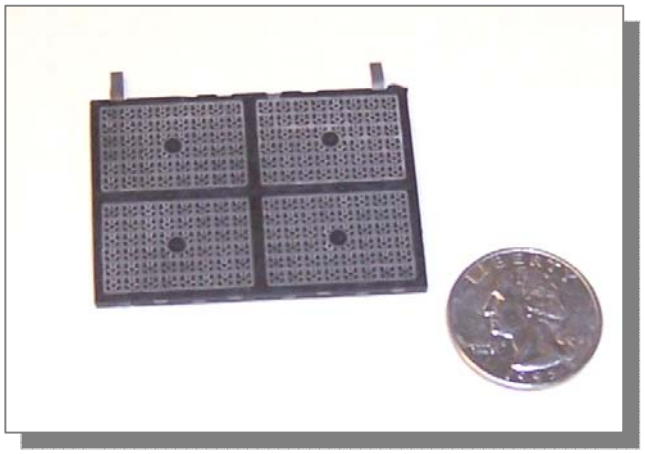
( ) – Recommended Sub-Watt Metric

Array Power Density

- Measured power density in 2005 within target range
- Advances in 2006 delayed by funding gap
- Arrays were at 30 mW/cm^2 in 2005 – expect higher power density as funding is resumed







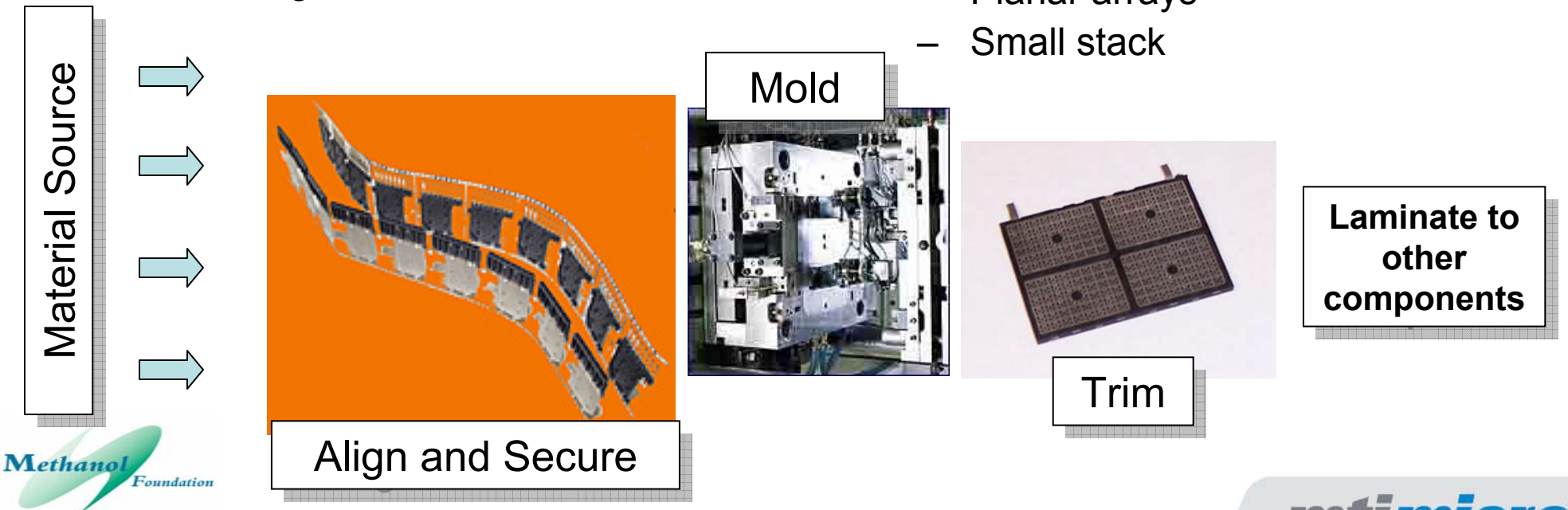
Manufacturing Development

Program Activities

- Current collector lead frame fabrication
- MEA production development
  - Work with multiple manufacturers
- Molding process development
  - With no MEA damage
- High volume process evaluation
  - Lead frames
  - molding

Impact to Industry

- Current collector lead frame capabilities will enhanced planar PEM array manufacturing
- MEA component production process will support PEM
- Molding development can support a number of micro PEM options
  - Planar arrays
  - Small stack



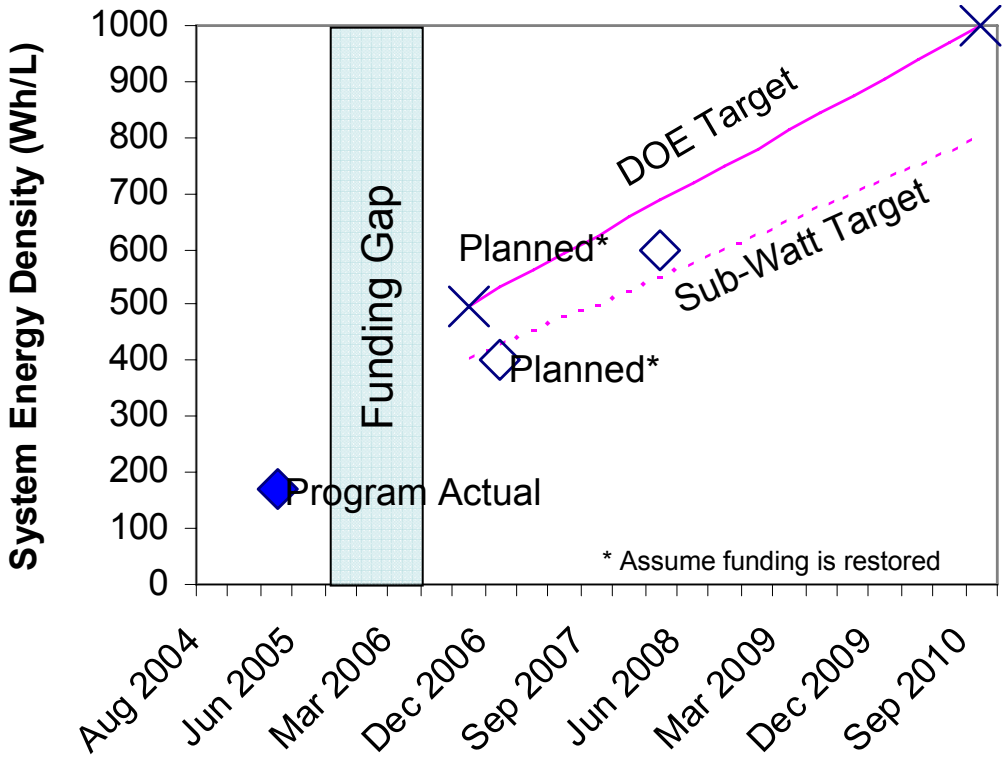
Component Miniaturization

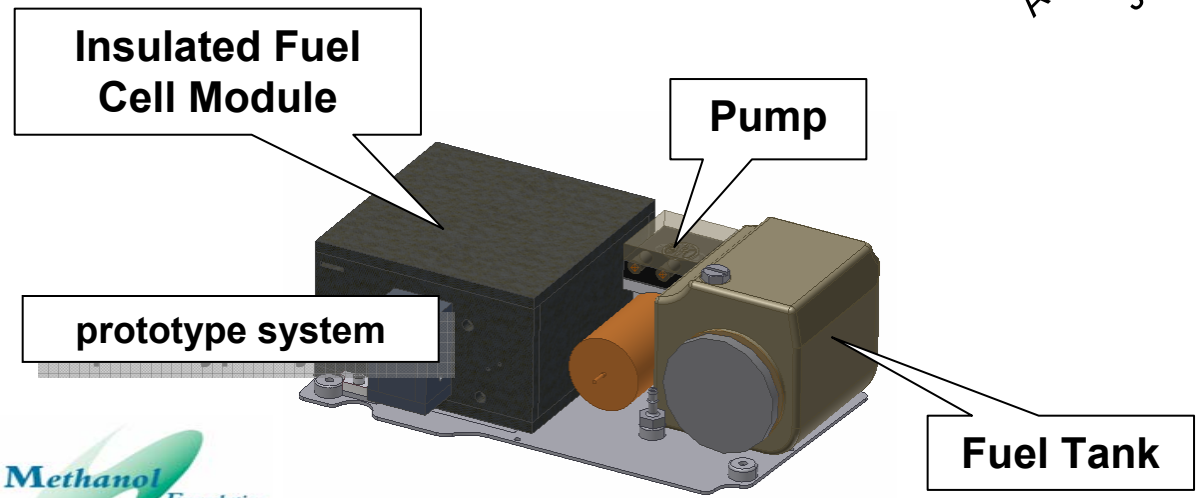
- Advanced insulation packages have produced impressive thermal isolation
- Fuel pumps are now less than 1 cc
- Fuel feed is tightly integrated to arrays
- Water management system is less than 10 cc
- Power processing and control electronics are small and highly integrated
- Thermal management components are tightly integrated and serving dual functions

Some portions of this effort funded by MTI IR&D

Prototype Performance Targets

- Substantial platform upgrades since 2005 brassboard
  - Changes in fuel and air feed
  - Changes in fuel cell packaging
- Full system prototype assembled for one market segment
- Test and evaluation beginning
- Funding gap (assumed 9 months) has delayed planned milestones – road map will be updated as funding resumes





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Codes and Standards Milestones

- Developed UL/CSA 2265A standard for shipping methanol cartridges under existing UN1230 for methanol
- Established new Shipping & Packaging ID #3473 for “Fuel Cell Cartridges with Flammable Liquid”-December ’04
  - Provides methanol cartridge shipping requirements
- International Electrotechnical Commission (IEC) has now approved a publicly available specification (PAS) 62282-6-1 for a number of fuel cell technologies include DMFC and PEM micro fuel
  - Provides product and qualification testing requirements
- International Civil Aviation Organization (ICAO) has adopted methanol, butane and formic acid for use in airline passenger cabin starting in 2007

Clear regulatory pathway to fuel cartridges available in every store and accepted in every airline passenger cabin

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Codes and Standard Roadmap

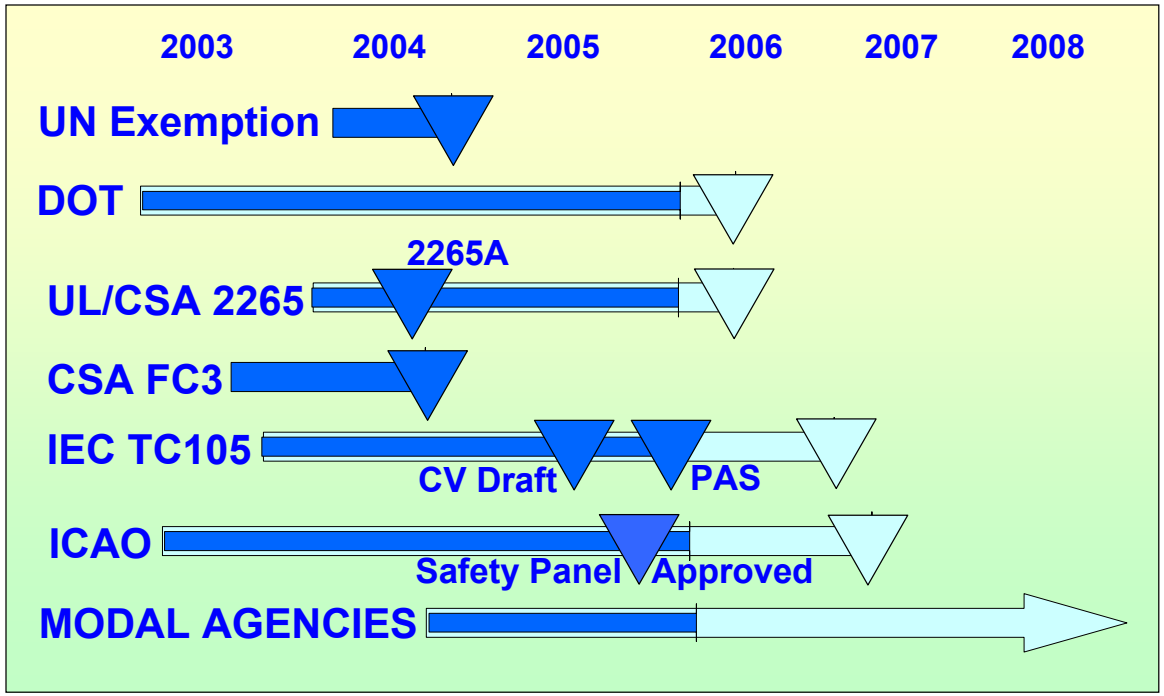
- IEC will continue to improve and finalize standard 62282-6-1
- IEC will work on a common interface standard between fuel cell and cartridge
- ICAO will finalize and publish passenger exemption language
- DOT will develop US regulations around UN and ICAO model regulations

<u>Milestones for 2006</u>

- US DOT airline passenger exemption and fuel transport regulations
- UL/CSA 2265 likely
- Issue next round of IEC Standard 62282-6-1
- ICAO published model regulations

<u>Milestones for 2007</u>

- Passenger exemption in place for methanol fuel cells



Micro PEM fuel cells will likely follow two years later

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Micro-DMFC Technology Supports US Fuel Cell Programs

- Provides early public exposure and acceptance of fuel cells
  - Numerous early applications in handheld consumer electronics
  - DMFC/methanol has minimal technical barriers
- Prepares regulatory environment for other fuel cell technologies
  - A number of technologies benefit from methanol's early entry
- Maintains important US leadership in portable power
  - Formidable foreign DMFC competition
    - Japan\Korea taking DMFC fast-track
  - US leadership benefits US economy and military

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Micro-DMFC Technology Supports US Fuel Cell Programs

- Component suppliers are looking for near term markets to justify technology development
  - MTI's platform targeted at near term markets
- Suppliers in all the following areas have expressed interest in DMFC as a path to the hydrogen market
  - Catalyst
  - Membranes
  - GDL
  - MEA
  - CC Plates
  - Molded frames
  - Filters
  - BOP
    - Pumps
    - Water management
    - Heat rejection

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Status Against Objectives

- Energy density greater than 800 Wh/cc
  - On path to 600 Wh/cc, which is sufficient to meet sub-Watt market requirements
  - Brassboard testing reached about 200 Wh/cc, and will continue to progress on the targeted path
- Fuel cell array power density 100 – 200 W/cc
  - Achieved 150 W/cc as targeted
- Demonstrate prototypes
  - First brassdboard benchmarked last year, with a follow up prototype in 2006
  - Two more rounds of prototypes as funding resumes
- Accelerate codes and standards
  - All past milestones to methanol fuel cartridge and system approval have been completed as planned AND expect continued success
  - Methanol progress providing pathway and vehicles for other fuel cells
- Demonstrate continual operation to 1000 hours
  - Candidate materials for long life still in selection – some candidates have reached 1000 hours in test cells (results are under evaluation)
  - Expect progress next year as funding is resumed
- Design and manufacturing pathway to $5
  - Studies show that large fuel cell markets for handhelds can be entered at costs significantly above this target – need to modify target for sub-Watt systems
  - Costs studies from first year of program will be updated as design matures

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Conclusions

- Substantial progress made thanks to DOE funding and over-sight
- Loss of funding has had a significant impact
  - Slowed technical progress
    - Reduced system integration work
    - Reduced advanced component development
  - Put most DFM and high volume manufacturing process development activities on hold
  - Significantly reduced brassboard and prototype fabrication and evaluation
  - Codes and standards work continues on residual funding – at reduced level of effort
- Timing is critical to maintain supplier interest in DMFC as a stepping stone to the hydrogen economy

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Summary

Relevance: This program continues to develop supplier and manufacturing capabilities applicable to hydrogen fuel cell AND opening the door to broad public exposure to fuel cells.

Approach: Develop and miniaturize DMFC technology, while finding pathways for low cost manufacturing and demonstrating early prototype capabilities. This “DMFC path” is validated by the growing international participation in DMFC product and regulatory development.

Technical Accomplishments: Reached target array power density and on pathway to meet prototype energy density targets. Excellent success on regulatory road map.

Technology Transfer: Continue to develop a broad range of MEA, flow field, current collector and BOP component vendors. DMFC related activities at key MEA companies, for example, are providing important leverage for hydrogen technology.

Propose Future Research: Given funding is resumed next fiscal year, performance and component miniaturization will continue with increased effort on high volume manufacturing cost reductions and performance durability.

Publication and Presentation List

- "DMFCs Power Up for Portable Devices", The Fuel Cell Review, 1(2), 25, 2004.
- "Direct Methanol Fuel Cell Technology and Product for Fuel Cell Applications", ECS, Fall, 2004.
- JA Paterson, “Methanol Fuel Cell Fact Sheet,” MTI MicroFuel Cell, December, 2004, http://www.usfcc.com/usfcc/methanol/Methanol_Micro_FC_Fact_Sheet_2004.pdf
- "First DMFC Power Source Integrated into a Hand Held Electronic Device", Proceeding of the 22nd International Battery Seminar, Fort Lauderdale, Florida, March, 2005.
- "First DMFC Power Source Integrated into a Hand Held Electronic Device", Proceedings of Small Fuel Cells 2005, Washington, DC, April, 2005.
- "Fuel Cell/Battery Hybrid Systems for Portable Power Applications" , Proceeding of 22nd International Seminar on Polymer Batteries and Fuel Cells, Las Vegas, June 2005.

Response to Reviewer Comments

- Relevance: What DMFC technologies translate into hydrogen technologies?
  - This was discussed in earlier slides
- Relevance: Quantities are too small to make a difference to hydrogen.
  - While bulk material quantities for a handheld fuel cell are small, the technology created for the industrial base and the wide public exposure to FC benefits are very important
- Approach: Need more performance data
  - Detail has be withheld in the public forum due to proprietary concerns
- Accomplishments: Cost vs volume not well defined
  - The program cost evaluation is a later stage task that has not been fully addressed, especially with the funding gap