Poster Presentation FCP6

Cost and Performance Enhancements for a PEM Fuel Cell Turbocompressor

2008 DOE Hydrogen Program

United States Department of Energy

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Crystal Gateway Marriott
Arlington, Virginia

FCP6

Honeywell

This presentation contains no proprietary information

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Agenda

Overview

Objectives

Milestones

Approach

Technical Accomplishments/Progress/Results

Future Work

Summary

Overview

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Timeline

- September 2002
- September 2008
- 95% complete

Barriers

- Barriers addressed
  - Packaging
  - Cost
  - Performance

Budget

- Total project funding
  - $2,290K
  - $763K
- Funding received in FY07
  - $211K
- Funding for FY08
  - $0

Partners

- U.S. Department of Energy
- FreedomCAR Tech Team

Fuel Cell Turbocompressor Objectives

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DOE/FreedomCAR/Hydrogen Technical Barriers in 2005

4.4.4.2 Technical Barriers

- Although many issues are discussed below, it should be noted that cost and efficiency present two of the more significant technical barriers to the achievement of clean, reliable, cost-effective systems.

Transportation Systems Technical Barriers

- A. **Compressors/Expanders**. Automotive-type compressors/expanders that minimize parasitic power consumption and meet packaging and cost requirements are not available. To validate functionality in laboratory testing, current systems often use off-the-shelf compressors that are not specifically designed for fuel cell applications resulting in systems that are heavy, costly, and inefficient. Automotive-type compressors/expanders that meet the FreedomCAR program technical guidelines need to be engineered and integrated with the fuel cell and fuel processor so that the overall system meets packaging, cost, and performance requirements.

Program objectives are towards solving the barriers

Fuel Cell Turbocompressor Objectives

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DOE/FreedomCAR/Hydrogen Technical Challenges in 2007

3.4.4 Technical Challenges

- Cost and durability are the major challenges to fuel cell commercialization. Size and weight are approaching targets but further reductions are neeed to meet packaging requirements for commercial systems. . . For transportation applications, fuel cell technologies face more stringent cost and durability requirements. . .

Transportation Systems Technical Barriers

- **F. Air Management.** Automotive-type compressors/expanders that minimize parasitic power consumption and meet packaging and cost requirements are not available. Automotive-type compressors/expanders that meet the FreedomCAR and Fuel Partnership technical guidelines need to be engineered and integrated with the fuel cell stack so that the overall system meets packaging, cost, and performance requirements.

Program objectives are towards solving the barriers

Fuel Cell Turbocompressor Objectives

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Table 3.4.10. Technical Targets: Compressor/Expanders (C/E) for Transportation Fuel Cell Systems				
Characteristic	**Units**	**2005**	**2010**	**2015**
Input Power[a] a at Full Load, 40°C Ambient Air (with Expander / without Expander)	kW_e	6.3/13.7	5.4/12.8	5.4/12.8
Overall Motor/Motor Controller Conversion Efficiency, DC Input	%	85	85	85
Input Power[b] at Part Load, 20°C Ambient Air (with Expander / without Expander)	kW_e	5.2/12.4	4.4/11.6	4.4/11.6
Compressor/Expander Efficiency at Full Flow (C/E Only)[c]	**%**	75/80	80/80	80/80
Compressor/Expander Efficiency at 20-25% of Full Flow (C/E Only) /Compressor at 1.3 PR/Expander at 1.2 PR	%	55/45	60/50	60/50
System Volume[e]	Liters	15	15	15
System Weight[e]	Kg	15	15	15
System Cost[f]	$	600	400	200
Turndown Ratio		10:1	10:1	10:1
Noise at Maximum Flow (excluding air flow noise at air inlet and exhaust)	dB(A) at 1 meter	65	65	65
Transient Time for 10-90% of Maximum Airflow	Sec	1	1	1

[a] Input power to the shaft to power a compressor/expander, or compressor only system, including motor/motor controller with an overall efficiency of 85%. 80kWe compressor/expander unit for hydrogen/air flow – 90 g/sec (dry maximum flow for compressor, compressor outlet pressure is specified to be 2.5 atm. Expander (if used) inlet flow conditions are assume to be 93 g/sec (at full flow), 80oC and 2.2 atm.

[b] Projected

[c] The pressure ratio is allowed to float as a function of load. Inlet temperature and pressure used for efficiency calculations are 20-40oC and 2.5 atm.

[d] Measure blade efficiency.

[e] Weight and volume include the motor and motor controller.

[f] Cost targets based on a manufacturing volume of 100,000 units per year, includes cost of motor and motor controller.

[g] Input power includes leakages, bearing losses, additional flow to cool the motor rotor and bearings, motor and motor controller losses. Testing will have to be completed to determine if the additional flow can be recovered in the turbine inlet to reduce the input power at the 40^{o}C and 20^{o}C ambient air conditions to 8.6/15.7kW_e and 7.3/14.3 kW_e respectively.

[h] The estimate is in 2005 dollars. The estimate is for hardware only and does not include labor, testing, nonrecurring engineering or capital equipment costs. The turbomachinery, motor and motor controller costs are estimated at approximately 90%, 5.5% and 4.5% respectively of the total costs noted.

Program objectives are towards solving the barriers

Project Milestones and Timeline

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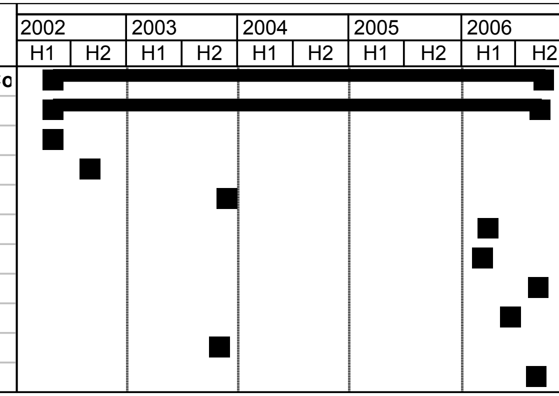
2005 Milestones

ID	WBS	Task Name
1	1	**Revised Program Plan (entire program) DOE Cooperative Agreement DE-FC04-02AL67624 Co**
2		**Milestone Targets**
3		DOE KICKOFF
4	1.1	Honeywell IPDS LAUNCH
5	2.0	Technical Objective #1: Trade Study
6	3.0	Technical Objective #2: Enhanced Turbocompressor
7	4.0	Technical Objective #3: Enhanced Motor and Motor Controller
8	5.0	Technical Objective #4: Integrated Enhanced Turbocompressor/Motor Controller Testing
9	6.0	Delivery to Fuel Cell Developer
10	7.0	System Developer Support
11	8.0	Phase 3 Testing

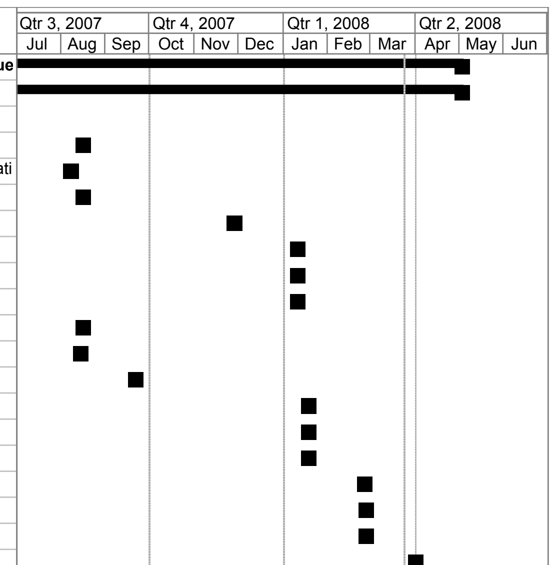


2007 Milestones after Program restart

ID	Task Name
1	**Cost and Performance Enhancements for a PEM Fue**
2	**Milestones**
3	Development Testing: Test Procedure
4	Development Testing: Test setup
5	Development Testing: Motor Controller Integrati
6	Development Testing: Mapping: Compressor
7	Development Testing: Mapping: Turbine
8	Development Testing: Mapping: Power
9	Development Testing: Acceleration
10	Analysis: Aerodynamic
11	Analysis: Rotordynamic
12	Analysis: Motor controls
13	Analysis: Motor
14	Assembly demonstration units: Unit 1
15	Assembly demonstration units: Unit 2
16	Assembly demonstration units: Unit 3
17	Test demonstration units: Unit 1
18	Test demonstration units: Unit 2
19	Test demonstration units: Unit 3
20	System developer test support

Technical Objective #4 (IDs 3–13)

Technical Objective #2 and #3 (IDs 14–19)



Milestone details shown in Project Approach

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Project Approach

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- Technical Objective 1: Perform a turbocompressor systems PEM fuel cell trade study to determine the enhanced turbocompressor approach
  - Utilize experience from phases 1-3
  - Compressor configuration
  - Turbine configuration
  - Trade performance improvements versus complexity, cost, weight, and volume
- Technical Objective 2: Using the results from Technical Objective 1, an enhanced turbocompressor, including a low cost turbomachinery core, will be fabricated.
  - Low cost and improved performance bearings
  - Improved shaft seals
  - Fabricate three (3) Demonstrator units
- Technical Objective 3: Using the results from Technical Objective 1, design a cost and performance enhanced compact motor and motor controller.
  - Trade between motor types
    - Two pole toothed vs toothless configuration
  - 55% and 30% reduction in motor controller volume and weight respecitvely from Phase 3 design
  - Low cost design
  - Fabricate three (3) Demonstrator units
- Technical Objective 4: Turbocompressor/motor controller development testing.
  - Test modified turbocompressor with new controller
  - Complete compressor, turbine, and power mapping
  - Acceptance test the three (3) Demonstrator units

Program approach working towards solving barriers

Technical Accomplishments

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- Technical Objective #1: Trade Study – Complete
  - Mixed flow compressor
  - Radial inflow variable nozzle turbine (VNT™)
    - Use of the VNT™ from GEBS turbocharger
  - Air bearings
    - Honeywell developed for turbocompressor application
      - Increased performance over existing designs
      - Lower cost than existing designs
  - Motor
    - New two-pole toothed design
  - Motor controller
    - New design
  - Liquid cooled motor and motor controller
  - Scalability
    - Modular design
    - Performance margin to handle future specifications

Trade Study determined go-forward design/concept

Technical Accomplishments

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- Technical Objective #2: Turbocompressor
  - Design and analysis complete
  - Hardware fabricated and assembled
  - Demonstrators assembled
- Technical Objective #3: Motor and Motor Controller
  - Motor
    - Design and analysis complete
    - Hardware fabricated and assembled
    - Demonstrators assembled
  - Motor Controller
    - Design and analysis complete
    - Hardware fabricated and assembled
    - Demonstrators assembled

Design complete and hardware assembled

Technical Accomplishments

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- Technical Objective #4: Integration Testing
  - Operational testing
    - Speed - completed
    - Power – completed
    - Performance – pressure ratio and flows met
    - Cooling – completed
  - Mapping
    - Compressor – completed
      - Wide operating range demonstrated
    - Turbine – completed
      - Wide operating range demonstrated with variable nozzle
    - Power – completed
      - Low idle power
    - Acceleration – completed
      - Moderate acceleration demonstrated
  - 3 Demonstrator units tested

Testing analysis underway

Technical Accomplishments

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Table 3.4.10. Technical Targets: Compressor/Expanders (C/E) for Transportation Fuel Cell Systems					
Characteristic	**Units**	**2005 Status[a]**	**2010**	**2015**	**2007 Honeywell Estimates**
Input Power[b,h] a at Full Load, 40°C Ambient Air (with Expander / without Expander)	kW_e	6.3/13.7[c]	5.4/12.8	5.4/12.8	11.0/15.7[h]
Overall Motor/Motor Controller Conversion Efficiency, DC Input	%	85	85	85	88
Input Power[h] at Part Load, 20°C Ambient Air (with Expander / without Expander)	kW_e	5.2/12.4[c]	4.4/11.6	4.4/11.6	1.3/14.3[h]
Compressor/Expander Efficiency at Full Flow (C/E Only)[d]	%	75/80[e]	80/80	80/80	70/77
Compressor/Expander Efficiency at 20-25% of Full Flow (C/E Only) /Compressor at 1.3 PR/Expander at 1.2 PR	%	45/30[e]	60/50	60/50	65/65
System Volume[f]	Liters	22[c]	15	15	15
System Weight[f]	Kg	22[c]	15	15	22
System Cost[g]	$	1,500[c]	400	200	1,500[i]
Turndown Ratio		10:1	10:1	10:1	10:1
Noise at Maximum Flow (excluding air flow noise at air inlet and exhaust)	dB(A) at 1 meter	65	65	65	TBD
Transient Time for 10-90% of Maximum Airflow	Sec	1	1	1	2-3

[a] First year for which status was available
[b] Input power to the shaft to power a compressor/expander, or compressor only system, including motor/motor controller with an overall efficiency of 85%. 80kWe compressor/expander unit for hydrogen/air flow – 90 g/sec (dry maximum flow for compressor, compressor outlet pressure is specified to be 2.5 atm. Expander (if used) inlet flow conditions are assume to be 93 g/sec (at full flow), 80°C and 2.2 atm.
[c] Projected
[d] The pressure ratio is allowed to float as a function of load. Inlet temperature and pressure used for efficiency calculations are 20-40°C and 2.5 atm.
[e] Measure blade efficiency.
[f] Weight and volume include the motor and motor controller.
[g] Cost targets based on a manufacturing volume of 100,000 units per year, includes cost of motor and motor controller.
[h] Input power includes leakages, bearing losses, additional flow to cool the motor rotor and bearings, motor and motor controller losses. Testing will have to be completed to determine if the additional flow can be recovered in the turbine inlet to reduce the input power at the 40°C and 20°C ambient air conditions to 8.6/15.7kW_e and 7.3/14.3 kW_e respectively.
[i] The estimate is in 2005 dollars. The estimate is for hardware only and does not include labor, testing, nonrecurring engineering or capital equipment costs. The turbomachinery, motor and motor controller costs are estimated at approximately 90%, 5.5% and 4.5% respectively of the total costs noted.

Design demonstrates feasibility

Turbomachinery Hardware

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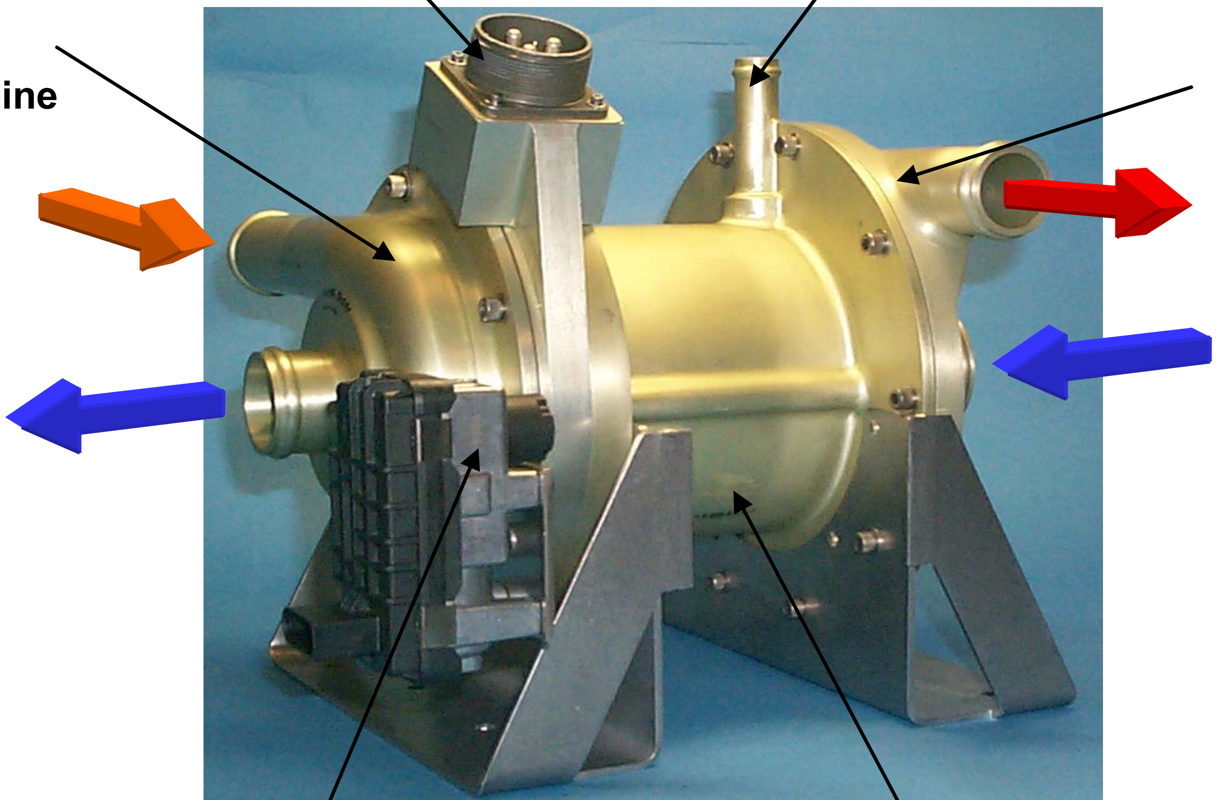

Motor Controller Hardware

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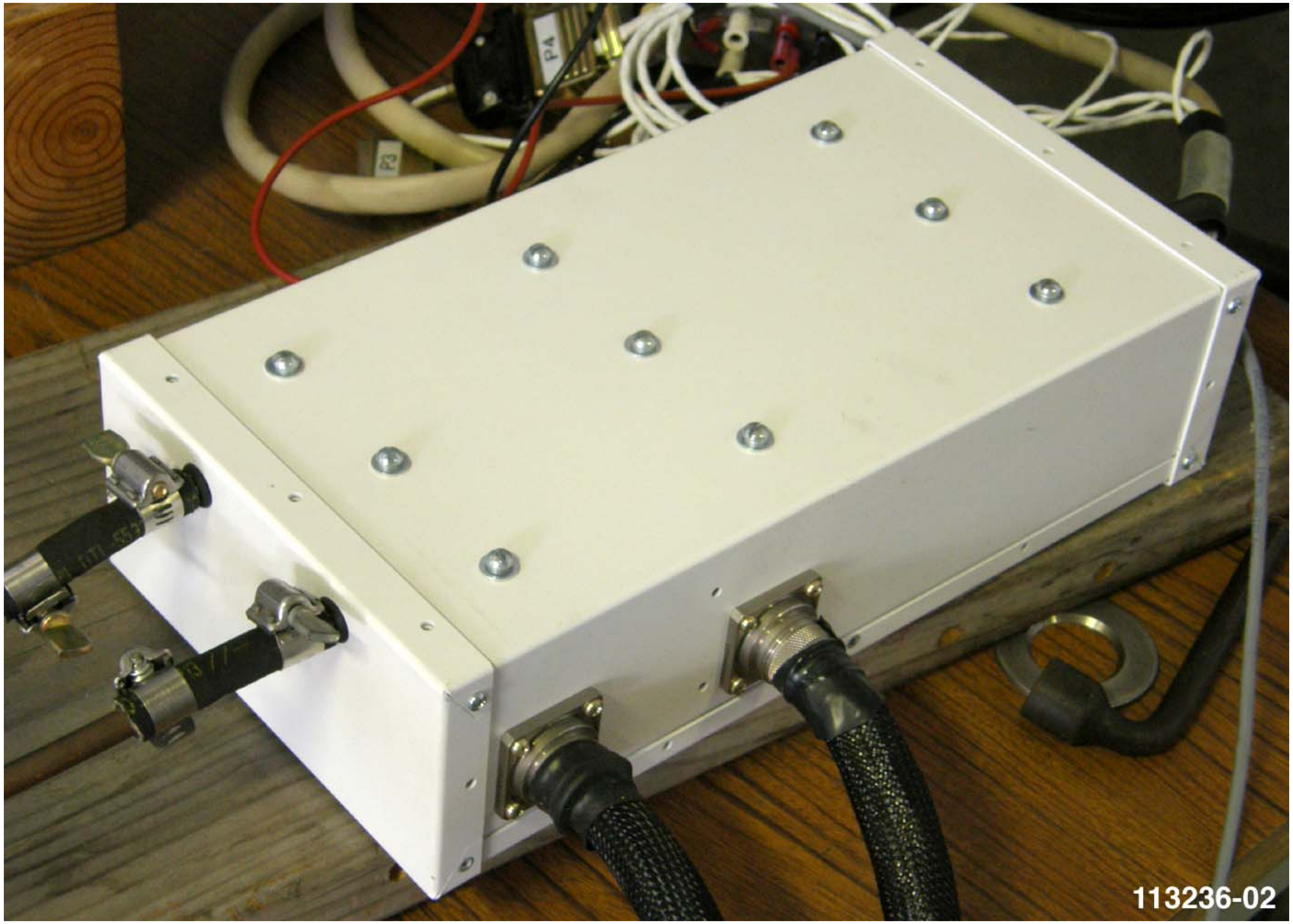

Future Work

- Complete analysis of testing
- Go/No-go on additional testing
- Final report

To complete testing analysis, additional testing if requested and final report

Summary

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- Trade study completed
- Analysis, design and fabrication completed
  - Turbomachinery
  - Motor controller
- Testing completed
  - Compressor, turbine, and preliminary power mapping
    - Pressure ratio and flow at full and part load met
  - Acceleration
  - Preliminary cooling
- Three (3) demonstrator units fabricated, assembled and tested
  - Units ready for delivery
- Potential additional testing to be performed at DOE request
- Areas to be further investigated
  - Weight
  - Power consumption
  - Cost

Program demonstrated wide operating range in a compact package