FC058: Research & Development for Off-Road Fuel Cell Applications

DOE Annual Merit Review & Peer Evaluation

June 7 – 11, 2010

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Presented by
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Overview

Timeline

Start date: Sept 2004
End date: Sept. 2011
Percent complete: 80%

Budget

Total project funding:
- DOE share $1,084,488
- Contractor share $464,780

Total funding received $843,261
Funding remaining for FY10/FY11 $241,227

Barriers

Durability
- Air-filtration for off-road applications
- Impact of shock & vibration (S&V) on system architecture

Partners

The Toro Company (Minneapolis, MN)
University of California – Davis
Donaldson (Minneapolis, MN)

End Users

Rivers Edge Golf Course (Bend, OR)
High Desert Museum and a Living History and Wildlife Exhibit (Bend, OR)

Objectives

Develop a PEM fuel cell system to operate in off-road applications and fully integrate it into commercially available off-road vehicles

Focus to Date

- Established comprehensive set of PEM fuel cell system requirements for turf and grounds maintenance vehicles
- Evaluate air-filtration technologies for off-road applications
- Shock and vibration testing in the lab and field
- Fully integrate prototype PEM fuel cell system in a Toro Workman® e2065 – series utility vehicle for field trials
- Fully integrate second generation PEM fuel cell system in a Toro MDE light duty maintenance truck
- Conduct field trials utilizing two vehicles at various venues

Approach

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- Fuel cell system integration
- Air filter testing with FCM
- Field S&V testing

TORO.

- Provide off-road vehicles
- Provide S&V data for off-road vehicle in typical operation

River's EDGE Golf Course

- Field trials

Develop a PEM fuel cell system to operate in off-road applications and fully integrate it into commercially available off-road vehicles

The HIGH DESERT MUSEUM
BEND, OREGON

- Field trials

Donaldson.
Filtration Solutions

- Air filter development

- S&V testing of fuel cell system
- Ex-situ air filter testing

Accomplishments

- Measured the shock and vibration spectrum for golf course maintenance vehicles
- Gathered information on the air contaminants that may have an effect on fuel cell operation and developed an air filter for fuel cell systems (Note – subsequently Donaldson has ceased production of air filter)
- Developed the Workman® Model e2065 light duty maintenance truck equipped to operate on DC voltages, and had accelerometers installed and evaluated shock and vibration
- Measured the power load profiles on two golf courses
- Designed and installed an IdaTech liquid fueled fuel cell system in a Toro Workman® model e2065 light duty maintenance truck
- Installed a 2nd generation IdaTech liquid fueled fuel cell system in a Toro Workman® model MDE light duty maintenance truck
- Completed field trials with two vehicles

Shock & Vibration Testing

Objective

Subject IdaTech Fuel Cell System to the Vibration and Shock Spectrum for Off-Road Vehicles

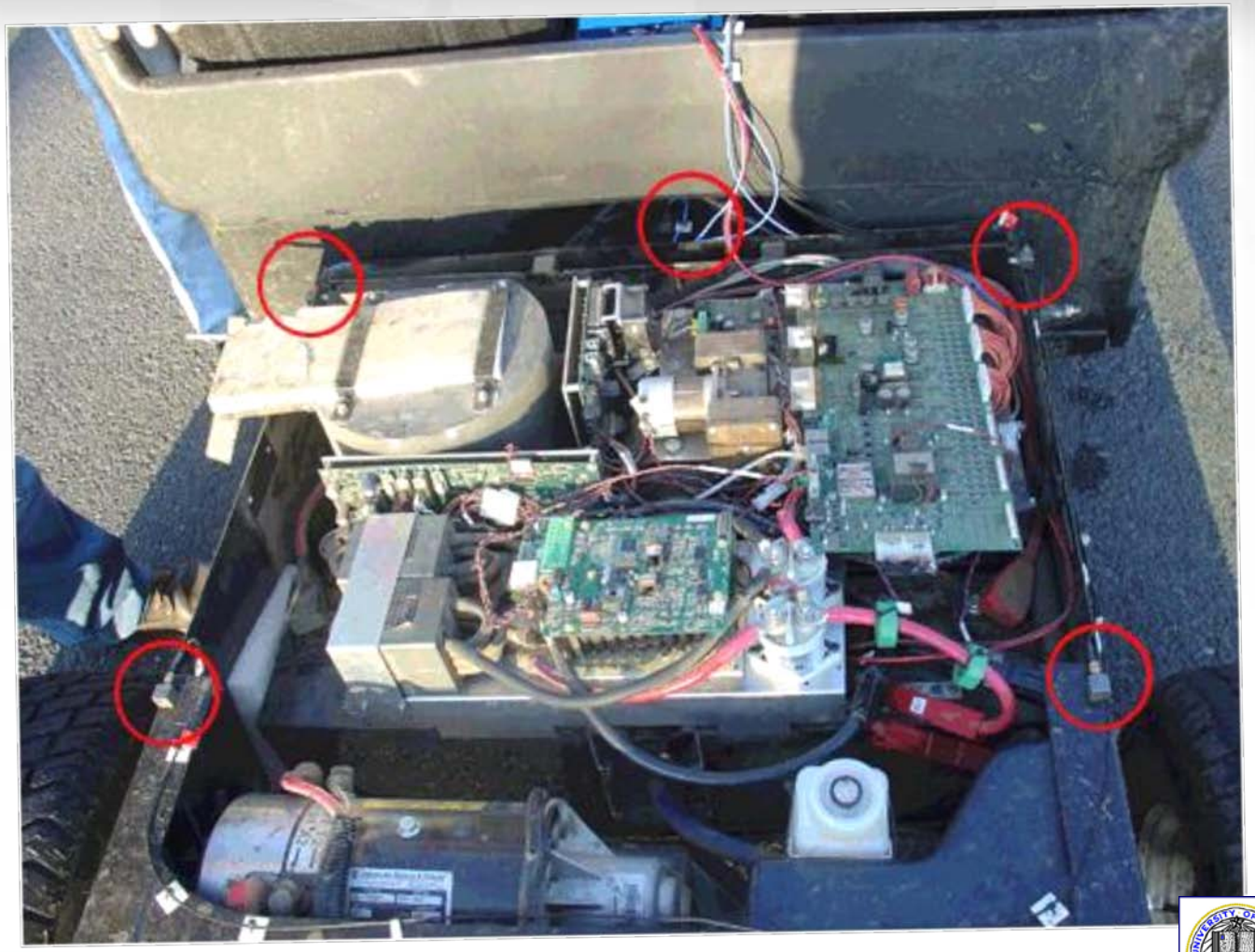
Status

The S&V field tests on the Toro Workman® vehicle with the IdaTech FCS 3000 Liquid Fueled Fuel Cell System were performed.

Set-up

Accelerometers attached to rear compartment where fuel cell system housed

S&V Accelerometer Layout



- **Photo of Accelerometers Layout**

Summary of S&V Testing

Shock

- The rear compartment of the vehicle sustained short time impacts of 117 g
- The back of the vehicle sustains higher g-force than the front

Vibration

- Terrain provided input vibrations in the range of 1 to 20 Hz at 2 to 3 g
- The vehicle does not sustain any vibration amplitudes > 1 g
- System components generate vibrations at high frequencies

Example of S&V Test Data

	Surface	Speed	Section	Acc. Location	X-direction (g) Min. A	B	C	D	E	Max. A	B	C	D	E	Peak Amplitude between 0-20Hz (Hz)	(g)	RMS Vibration Frequency (Hz)
Run 1	grass, pavement	var.	Top 9	See fig. 2	-56.93	-7.83	-0.40	-32.05	-7.73	87.09	1.31	0.17	117.20	1.09	ND	ND	ND
Run 2	grass, pavement, gravel	var.	Bottom 9	See fig. 2	-20.35	-5.21	-0.03	-30.10	-5.63	24.91	0.90	0.05	117.20	0.75	ND	ND	ND
Run 3	grass, pavement	var.	Bottom 9	See fig. 2	-37.42	-1.06	-0.09	-25.97	-7.18	103.40	0.75	0.09	117.20	0.90	ND	ND	ND
Run 4	grass, pavement	var.	Bottom 9	See fig. 2	-38.50	-6.22	-0.45	-59.08	-7.81	114.80	0.87	0.12	117.20	1.16	ND	ND	ND

	Surface	Speed	Section	Acc. Location	Y-direction (g) Min. A	B	C	D	E	Max. A	B	C	D	E	Peak Amplitude between 0-20Hz (Hz)	(g)	RMS Vibration Frequency (Hz)
Run 1	grass, pavement	var.	Top 9	See fig. 2	-42.02	-86.56	-17.46	-50.36	-98.39	89.53	76.66	12.93	113.90	72.73	ND	ND	ND
Run 2	grass, pavement, gravel	var.	Bottom 9	See fig. 2	-17.68	-36.24	-3.76	-18.55	-38.24	23.50	41.56	5.07	98.42	50.09	ND	ND	ND
Run 3	grass, pavement	var.	Bottom 9	See fig. 2	-24.81	-45.62	-10.14	-36.28	-55.06	116.00	49.48	8.24	113.90	96.94	ND	ND	ND
Run 4	grass, pavement	var.	Bottom 9	See fig. 2	-40.92	-46.72	-9.44	-56.80	-68.62	114.90	43.72	11.98	113.90	93.44	ND	ND	ND

	Surface	Speed	Section	Acc. Location	Z-direction (g) Min. A	B	C	D	E	Max. A	B	C	D	E	Peak Amplitude between 0-20Hz (Hz)	(g)	RMS Vibration Frequency (Hz)
Run 1	grass, pavement	var.	Top 9	See fig. 2	-53.83	-76.66	-21.86	-22.21	-91.34	112.40	86.57	22.84	116.50	68.05	3.20	0.01	0.02
Run 2	grass, pavement, gravel	var.	Bottom 9	See fig. 2	-19.18	-49.37	-6.66	-29.46	-93.84	38.07	49.37	7.51	116.50	60.27	3.20	0.03	0.03
Run 3	grass, pavement	var.	Bottom 9	See fig. 2	-49.97	-53.52	-12.71	-15.83	-110.50	113.80	76.29	15.22	116.50	79.97	3.20	0.04	0.07

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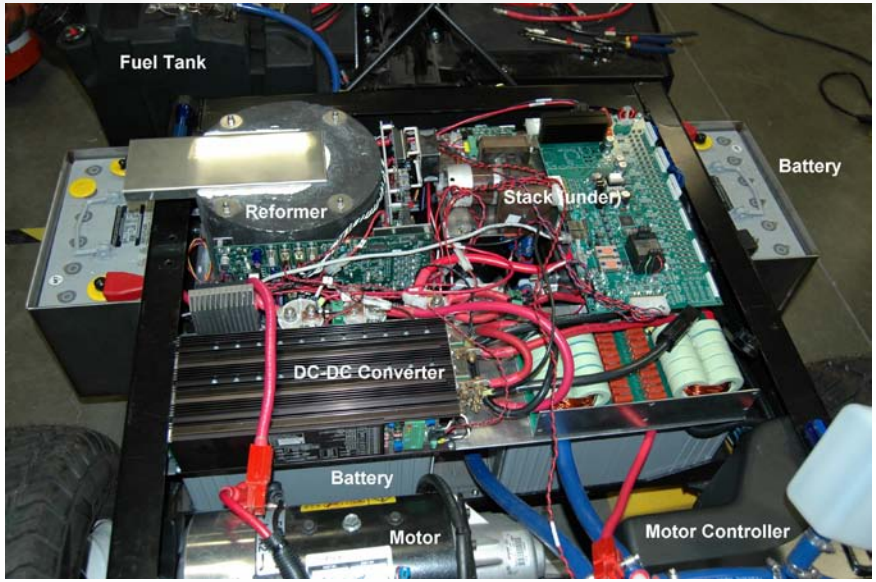
Hydrogen Production And Utilization Laboratory UCDAVIS

TV-1 Off-Road Vehicle

1st Generation fuel cell system

TV-1 Off-Road Vehicle

Original system integration



2nd generation system integration

2nd generation system configuration offers following improvements:

Hardware

- Improved H2 recirculation pump mounting
- Improved cabin fan
- Improved fuel line routing

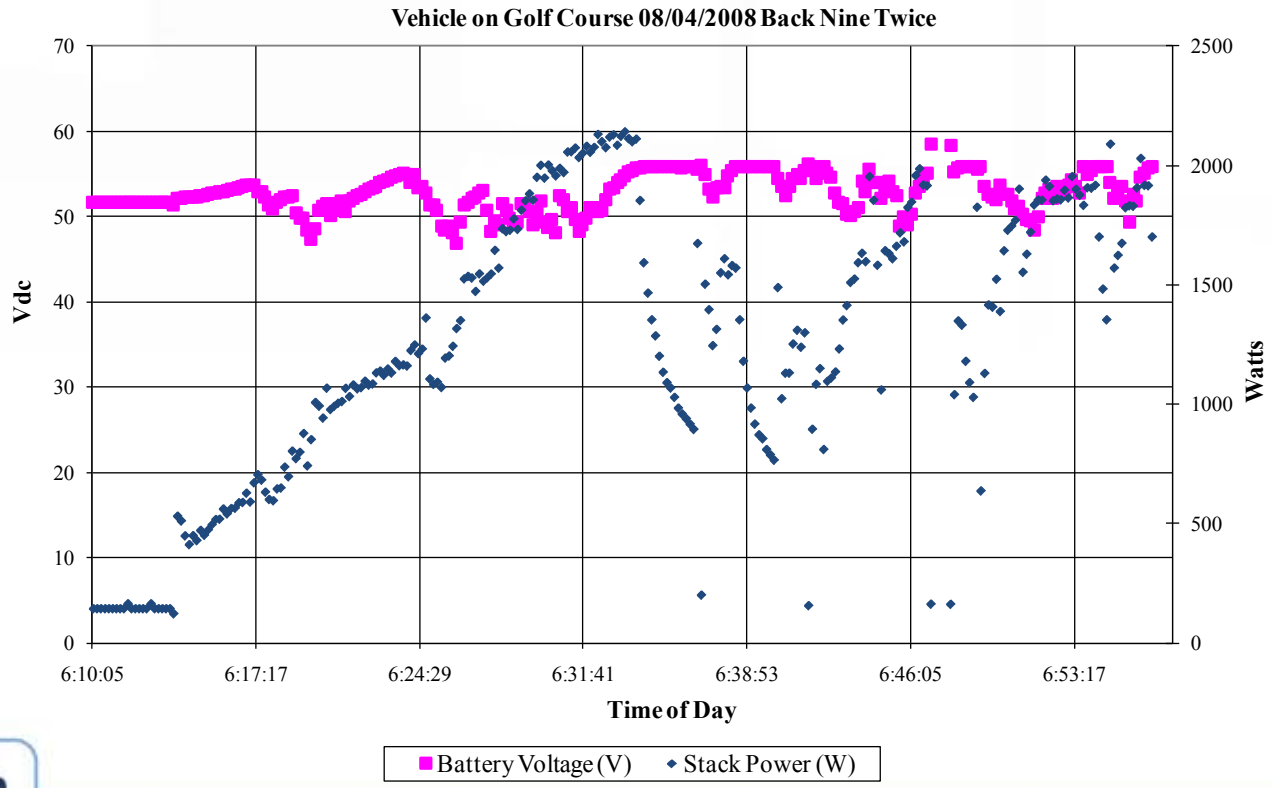
Controls and Electronics

- New firmware
- Onboard data acquisition
- Dash meter to monitor current to the battery
- Ramp rate increased
- New current sensor

TV-1 Field Trials – Golf Course

Two different applications

- Work Vehicle
- Drink Cart
  - Drink cart circuit more taxing than maintenance application



TV-1 Field Trials – Golf Course

TV-1 System accumulations:

- Total Run Time 318 hrs
- Consumed 474 Liter
- Produced 357 kW-hrs
- Experienced 172 thermal cycles
- kW-hrs/L = 0.75

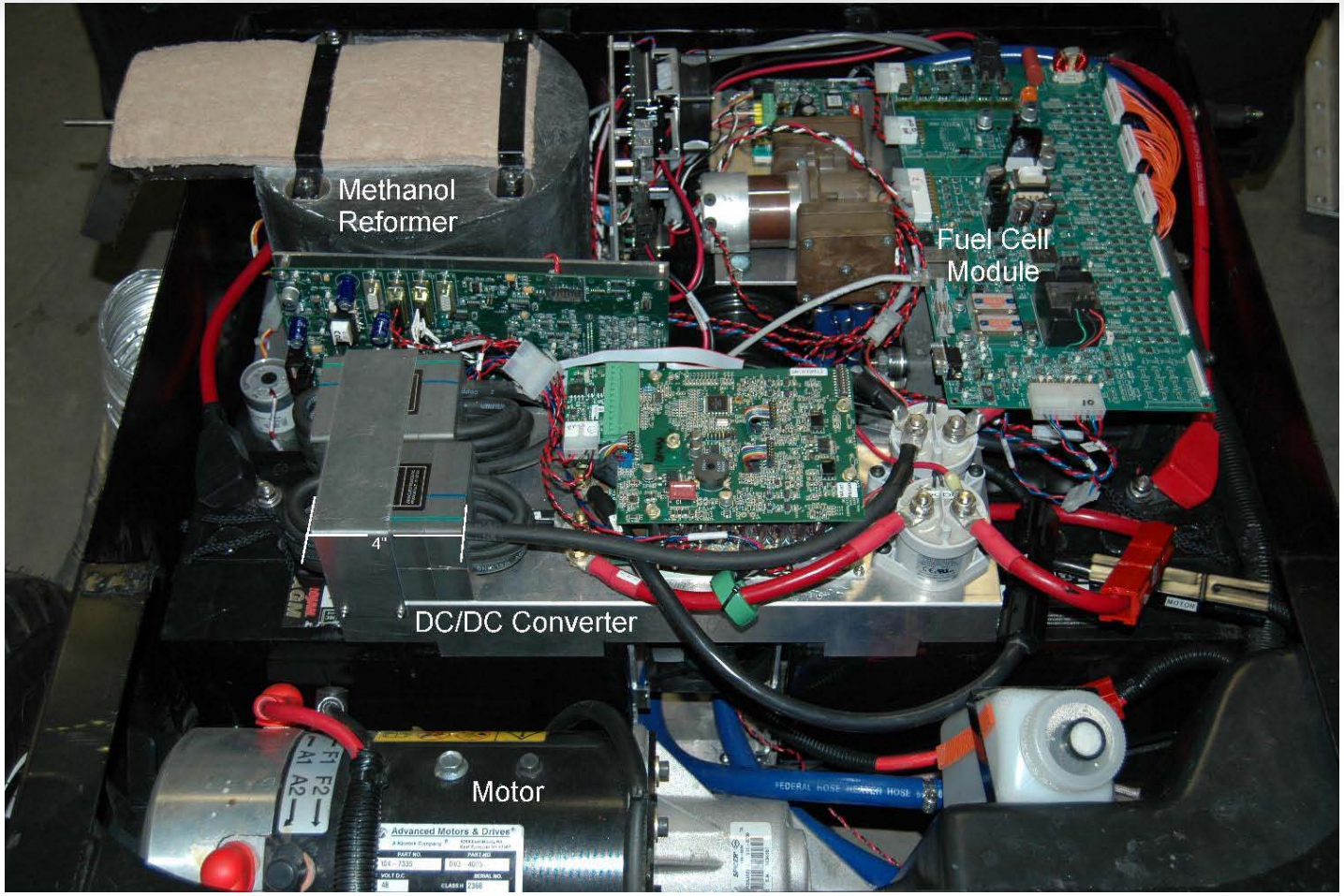
TV-1 Experienced:

- Rough and hilly terrain
- High temps
- Many types of air particles – dirt, dust, grass clippings, fertilizer and sand

TV-2 Off-Road Vehicle

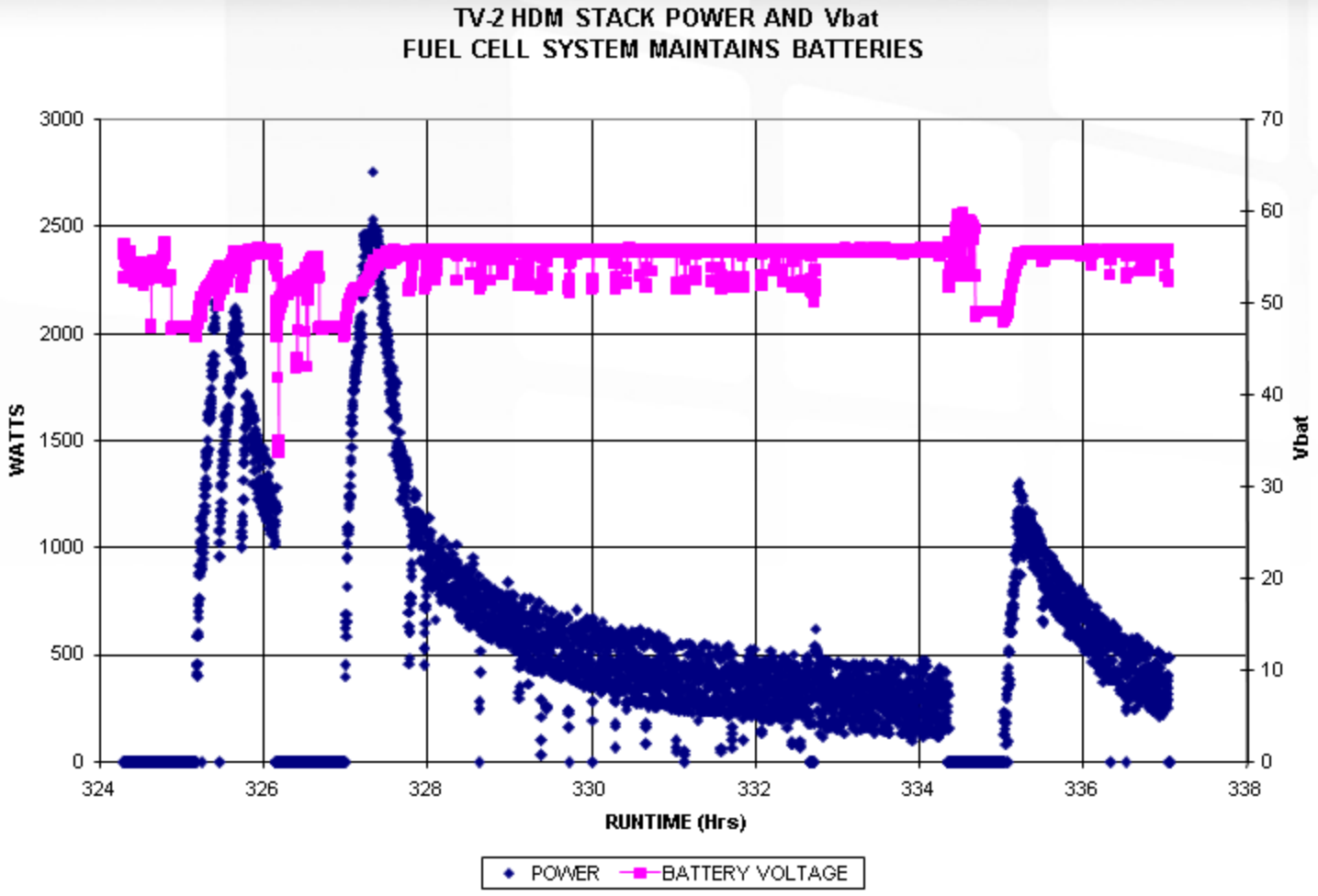
2nd Generation fuel cell system

TV-2 Off-Road Vehicle



Improved output to 3 kW in TV-2 (~2.2kW in TV-1)

TV-2 Field Trials – High Desert Museum



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The HIGH DESERT MUSEUM
BEND, OREGON

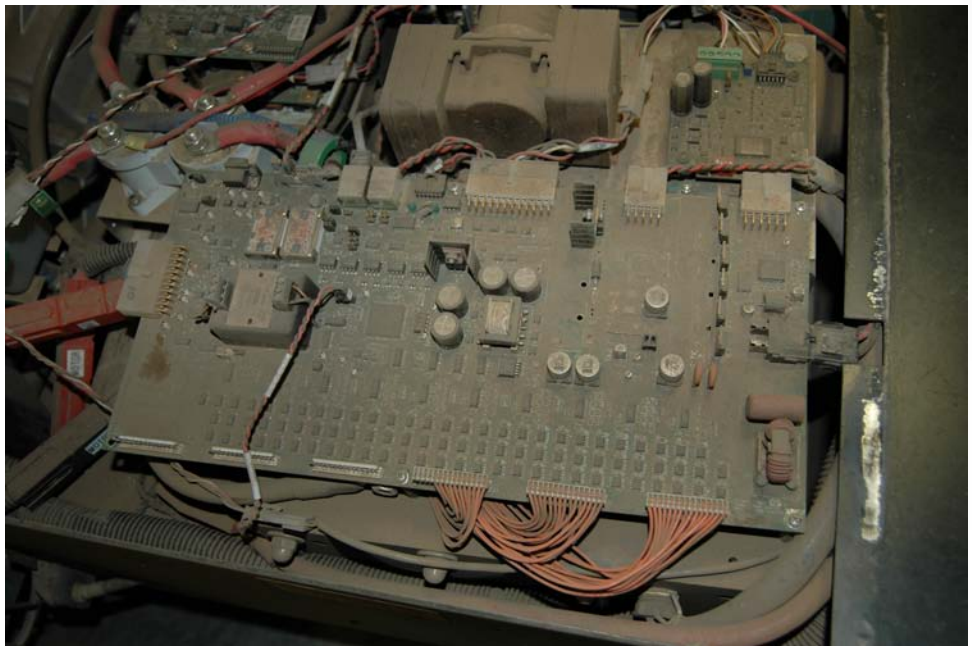
TV-2 Field Trials – High Desert Museum

TV-2 System accumulations:

- Total Run Time 368 hrs
- Consumed 315 Liter
- Produced 149 kW-hrs
- Experienced 63 thermal cycles
- kW-hrs/L = 0.47

TV-2 Experienced:

- Rough but flat terrain
- High temps
- Significant dirt and dust conditions



TV-2 Circuit Board after 57.2 hours at the High Desert Museum

Lessons Learned & Corrective Actions

- System over heated on very hot day – added cooling fan
- Thermocouple shorted – added restraint
- Wires fell off coolant switch – added restraint
- Fuel pump slowed down, dirt was cause – sealed pump gearbox opening
- Fuel line dry – removed tank dip tube and place exit at tank bottom
- Inverter not ramping up – installed improved inverter and improved firmware
- Troubleshooting faults takes too much time – added onboard data acquisition
- Multiple printed circuit boards with unused capability and extra connectors increase wiring breakage – consolidation of boards recommended

Bottom Line:

- It's dusty and dirty – need to protect sensitive equipment
- There's a lot of vibrations – need to restrain wires and consolidate circuit boards

Summary

- Established *comprehensive data base* of Fuel Cell System requirements for Off-Road Vehicles
- Developed two generations of advanced PEM Fuel Cell Systems, integrated these with commercial turf & grounds maintenance vehicles
- Maintenance operator experience at Golf Course and Living History Museum with demanding operating conditions
- Comprehensive laboratory & field testing *validated engineering data base*

Summary

System Integration, Shock & Vibration, Field Trials

- These activities were stopped in September 2009
- No further technical effort has been performed and none is planned
- The field trials have been completed
  - Both vehicles are going to Argonne National Labs to be used for grounds maintenance

Overall the prototype vehicle project was a great success making significant progress toward manufacturing of a Green Vehicle for golf course and parks and recreation maintenance vehicles with potential for liquid fuelled fuel cell powered vehicles in industrial settings

Future Work Activities

Task 3 – Air Quality: Re-visiting air filtration due to decision by Donaldson to cease fuel cell filter production and support

Objective - Evaluate air-filtration technologies for off-road applications

3.1 – Ex-Situ Air Filter Testing

- Measure capacitance (lifetime) of air filters
- Confirm capacitance under real world conditions
- Determine which variables impact filter performance

3.2 – FCM Air Filter Testing

- Validation of ex-situ filter testing by pairing it with FCM testing

Future Work Milestones

Task 3 – Air Quality

- Procure materials – June 2010
- Test set-up and validation – July 2010
- Commence short term, ex-situ air filtration studies – July 2010
- Commence long term, ex-situ air filtration studies – October 2010
- Commence in-situ FCM air filtration studies – March 2011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