Ground Support Equipment Demonstration

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MT011

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OVERVIEW

Timeline

- Project start – January 2013
- Project end – December 2015
- Kickoff meeting – 3/27/13

Barriers

- Barriers addressed:
  - Power upsizing for BTT app
  - Outdoor operation
  - Run time

Budget

- Total project funding - $5.0M
  - DOE - $2.5M
  - Partners - $2.5M
  - Status: 19.5% Complete

Partners

- Plug Power
- FedEx Express
- Charlatte
- Memphis-Shelby County International Airport

RELEVANCE

- **DOE Fuel Cell Technologies Objectives Over Project Life**
  - To create a hydrogen fuel cell-based solution as a cost-competitive and more energy-efficient baggage tow tractors (airport vehicle) compared to the incumbent internal combustion engine-powered vehicles.
  - To enable airport end users to accomplish their daily tasks with a hydrogen fuel cell solution while reducing consumption of gasoline and diesel fuels, reducing U.S. demand for petroleum.
  - To demonstrate lower carbon emissions with the fuel cell solution
  - To demonstrate a value proposition that shows decreased energy expenditures when compared to diesel-powered airport vehicles

- **Specific Project Objectives During 2013/2014**
  - Plug Power develops the 80V fuel cell product for baggage tow tractor
  - Testing with Charlatte CT5E baggage tow tractor
  - Factory Acceptance Test to demo equivalent operation as battery / ICE
  - Hydrogen installation at Memphis-Shelby Country Airport

RELEVANCE

- **Specific Project Objectives and Expectations**

DOE Project Objectives	Plug Power-FedEx Project Expectations
Reduce petroleum consumption	Each BTT uses ~2 gal/hr. Total BTT run time of 15 BTT's over 2 years will be upwards of **175,200 gallons of diesel fuel reduced.**
Reduce emissions at airports	AT 9.8 kg CO2 per gal of diesel, there will be upwards of **1717 metric tonnes of CO2 eliminated at airports.**
Operate 10 hrs/day & 5,000+ hours	BTT operation occurs during two shifts: day (11 AM-3 PM) and night (10 PM-2 AM). The total clock day is 11AM-2PM (15 hours). **Actual BTT activity is 8 hours per day. Total run time of 15 BTT's over 2 years will be upwards of 87,600 fleet hours.**
Towing capability of 3,000 to 6,000 lbs.	The BTT will be able to tow 4 FedEx containers each weighing 40,000 lbs. The corresponding **drawbar capacity of the fuel cell-powered BTT is 5,000 lbs.**
Accelerated development of FC-powered GSE	**Fleet of 15 80V fuel cell systems in real world application in 2013 gaining significant field experience while allowing a premier BTT end user to evaluate for larger deployments.**

APPROACH

- **Deployment of 15 FC-powered Units for Two Years at National Airport**
  - 15 BTTs at Memphis, TN (fleet of 1383 BTTs to manage 270 flights / day)
  - Site represents the single largest business opportunity for this market
  - Site allows the end user to demonstrate the fuel cells in one of the harshest environments
    - Heavy duty cycle
    - High temperature
    - Humidity

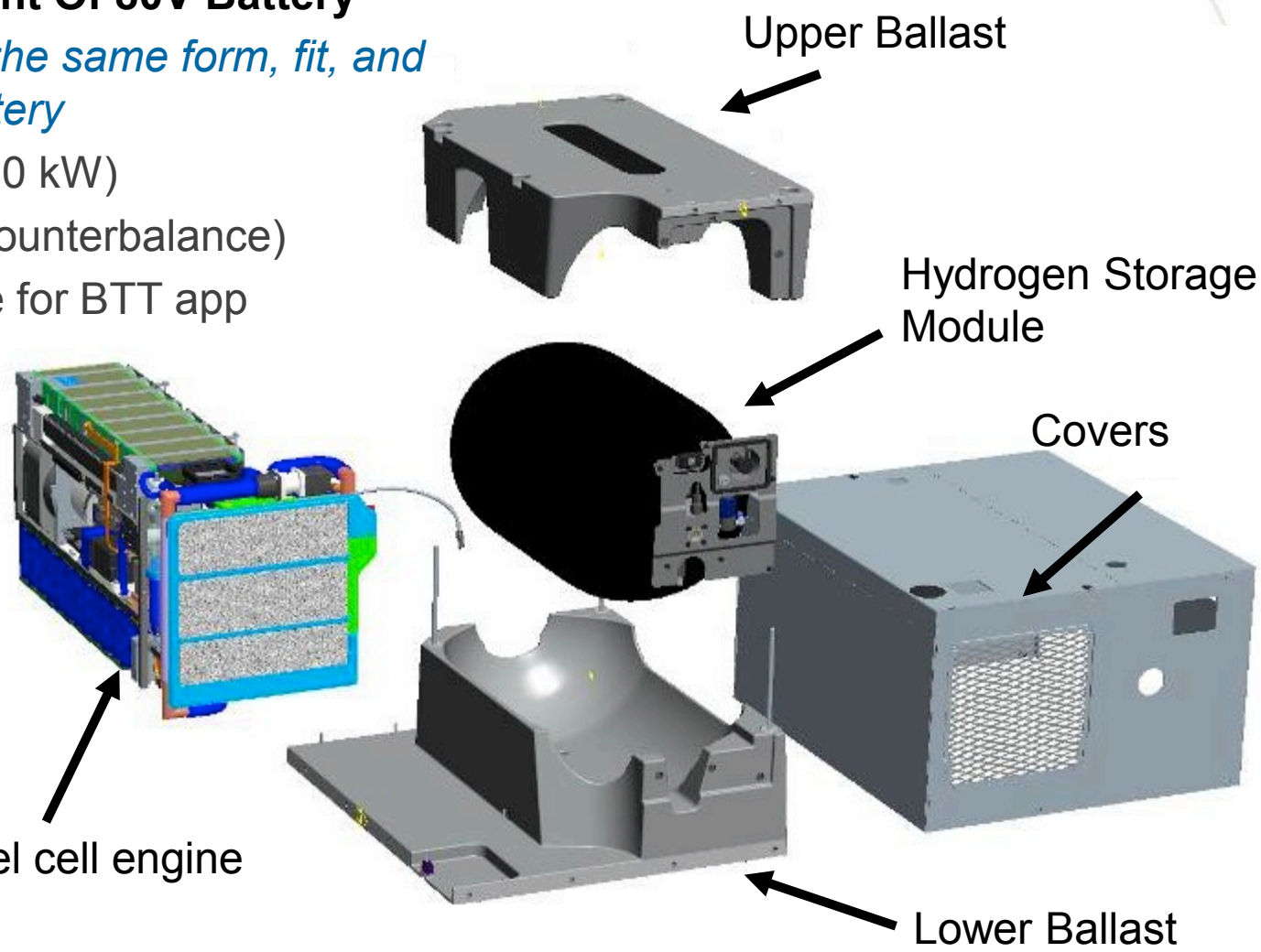
- **Project Phases:**
  - Phase 1: development phase where Plug Power develops, builds and tests the 80V (~20 kW) fuel cell system for the BTT application
  - Phase 2: two-year demo where a fleet of BTTs are integrated into electric tow tractors and deployed at the location under real world conditions
  - The fuel cell fleet will be fueled by liquid hydrogen supply and CSD (compression, storage, and dispensing) solution at each site

APPROACH: 80V Fuel Cells

Direct Replacement Of 80V Battery

Designed to meet the same form, fit, and function as the battery

- Stack – power (~20 kW)
- Ballast - weight (counterbalance)
- H2 Tank - run time for BTT app



APPROACH: Hydrogen

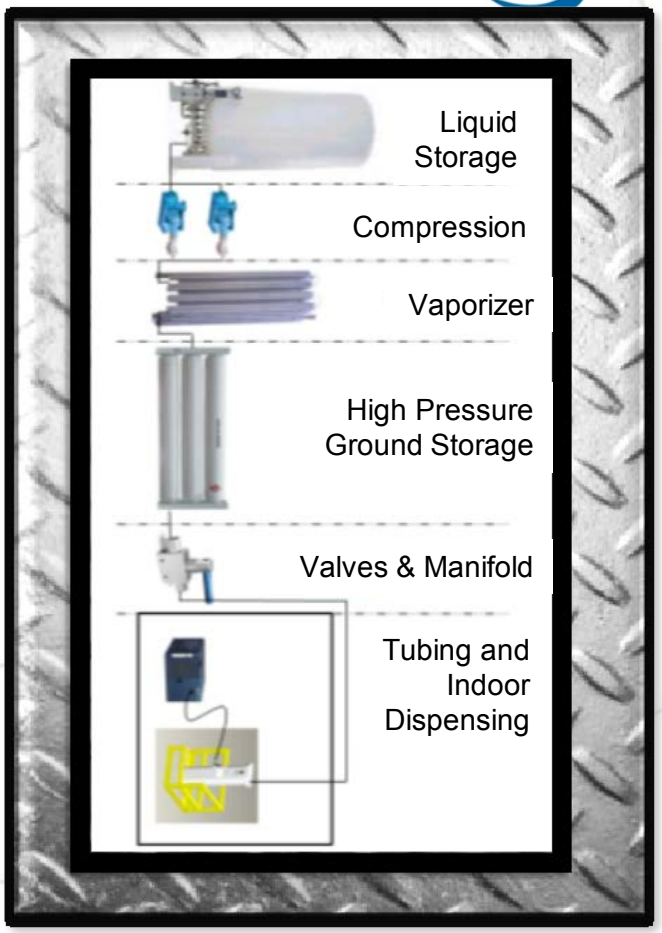
Transitioned from onsite production to liquid hydrogen infrastructure

- Fueling Pressure: 350 bar
- Refueling time: 1 kg/min
- H2 Capacity: 9000 gallons
- Refueling nozzle is proven, simple and safe – breakaway hose includes hydrogen safety shutoff valve

Reason for Change:

- Installation prep (natural gas, water, electricity lines) were 10x the expectations at the beginning
- For that kind of investment, the hydrogen solution needed to be scalable to allow for further conversion to fuel cells

GenKey
Power • Fuel • Serve



APPROACH: Integration in Baggage Tow Tractor

Charlatte CTE5 BTT

- Plug visited Charlatte to discuss integration, specifically for FedEx app
- 80V GenDrive meets the battery requirements of CT5E (developed for FedEx's application)

Plug Power GenDrive® 80V Fuel Cell

- Stack sized for necessary power
- Ballast sized for weight (traction)
- H2 Tank sized for long run time

Electric Baggage Tow Tractor					
OEM	Model	Drawbar (lbs)	Power	hp (comp.)	Voltage
Charlatte	CT5E	5000	22.1	30	80
TUG	MZ	4500	17.7	24	80
Toyota	2TE18	4000	16.4	22.3	80
Eagle	MTT	5000	18.4	25	80
Harlan	Charger HLE	5000	30.9	42	80

OEM	L	W	H	GVW	Batt Wgt
Charlatte	45"	27.5"	31.25"	4,824	4,000
TUG	36	26.125"	Open	3,550	3,500
Toyota				4,960	2,535
Eagle				5,600	3,400
Harlan	47.5"	31"	28"	4,200	

APPROACH

Partners $2.5 M pays for:

- Fed Ex: Operator Labor
- Plug Power: Engineering
- Plug Power: Program Mgmt
- Plug Power: Service Personnel

DOE's $2.5 M pays for:

- Liquid Hydrogen Infrastructure
- Fuel Cell Systems
- Plug Power: Engineering
- Plug Power: Program Mgmt
- Plug Power: Service Personnel

Outside Budget:

- Fed Ex: 15 Charlatte BTTs ($32k * 15 = $480k)
- Fed Ex: Utilities to produce hydrogen (~$2.50/kg) – *cheaper than diesel*

APPROACH: Scope of Work

Budget Period 1

- Task 1: Definition of Requirements
- Task 2: Alpha Prototype (milestone: Detailed Design Review)
- Task 3: BTT Beta Builds (milestone: Build of 15 units)
- Task 4: BTT Testing and Certification (milestone: go/no go decision)

Go/No Go Decision (Testing of Alpha prototype fuel cell system)

- Criteria: Does the Beta system fuel cell meet the same form, fit, and function as the 80V battery?
  - Voltage output: 72-80V continuous output
  - Maximum dimensions: 45” L x 27.5" W x 31.25” H
  - Weight (traction): > 3,800 lbs. (per Charlatte)
  - Drawbar capacity: 5,000 lbs.
  - Speed rating: 10 mph unloaded

Desired Result: Achieve OEM certification

APPROACH: Scope of Work

Budget Period 2

- Task 5: Site Preparation (milestone: H2 installation, receipt of units)
- Task 6: Commissioning (milestone: commissioning of units)
- Task 7A: Demonstration During Budget Period 2
- Task 8: Assessment after Year 1 (milestone: see below)

Go/No Go Decision (Performance Assessment)

- Criteria: Does the fuel cell meet customer requirements
  - Power: Capable of 5,000 lbs. drawbar capacity
  - Availability: > 80%
  - Run time: > 1 shift
  - Reliability (MTBF – Mean Time Between Failures): > 100 hours
  - Speed rating: 10 mph
  - Outdoor operation: no non-recoverable issues
  - Hydrogen Fills: 350 bar

Desired Result: Continued operation for 2nd year

APPROACH: Scope of Work

Budget Period 3

- Task 7B: Demonstration during Budget Period 3

- Task 9: Assessment after Year 2

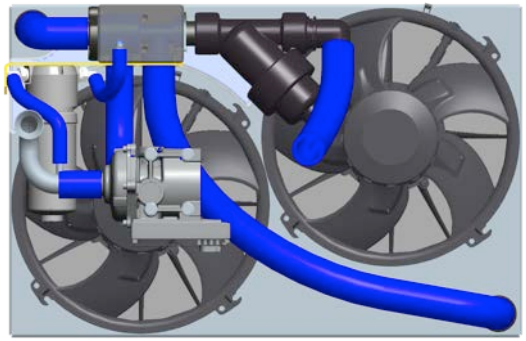
  Final Milestone:
  - Financial & Technical Assessments, Lessons Learned
  - Decision to continue in commercial application or decommission

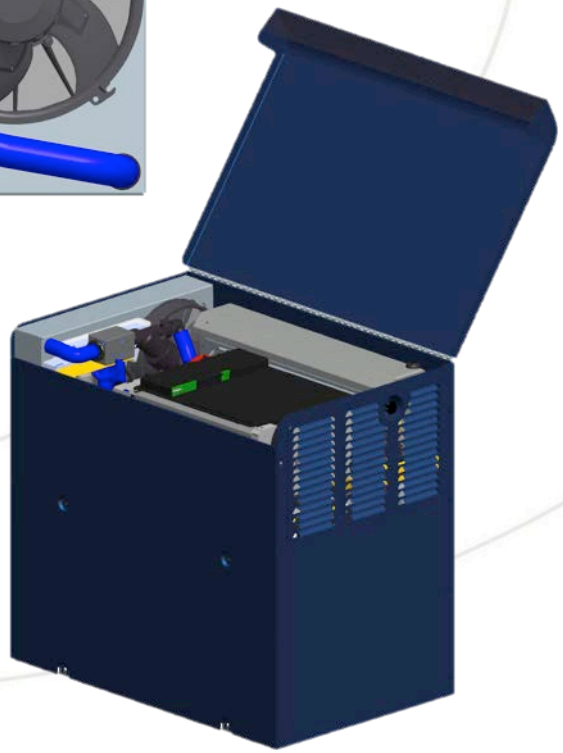
ACCOMPLISHMENTS

- **Systems Engineering - Collection of Requirements**
  - Data logging of CT5E in FedEx Express application (Ontario, CA)
  - Sharing of information with BTT OEM
- **Component Requirements and Supply Chain Discussions**
  - Identification of stack characterization and requirements for larger power (ex. pressure drop, polarization curve)
  - Identification of products with current component model lines
- **System Modeling → Module / Component Input-Output Charts**
- **Coordination with FedEx Express Site for Hydrogen Prep / Permits**
- **Kickoff meeting with DOE and Partners in Latham on 3/27/13**
- **Receipt of Charlatte CT5E at Plug Power for weatherproofing and interconnect design**

ACCOMPLISHMENTS

- **Advanced Packaging Design**
  - Easy top serviceability of all major components
  - 150 liter H2 tank
  - Driver-side fueling
  - Extended Li-Ion battery capacity
  - Vibration dampening frame
  - Weatherproofing

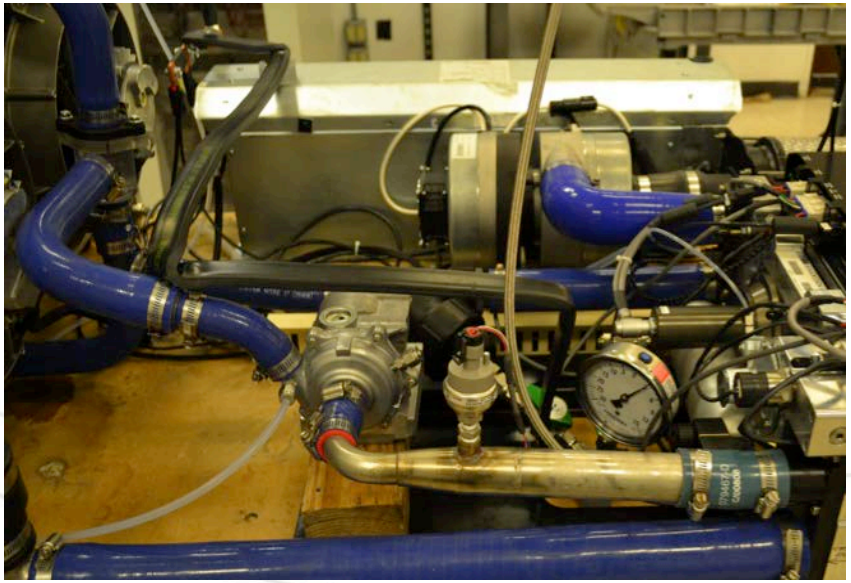


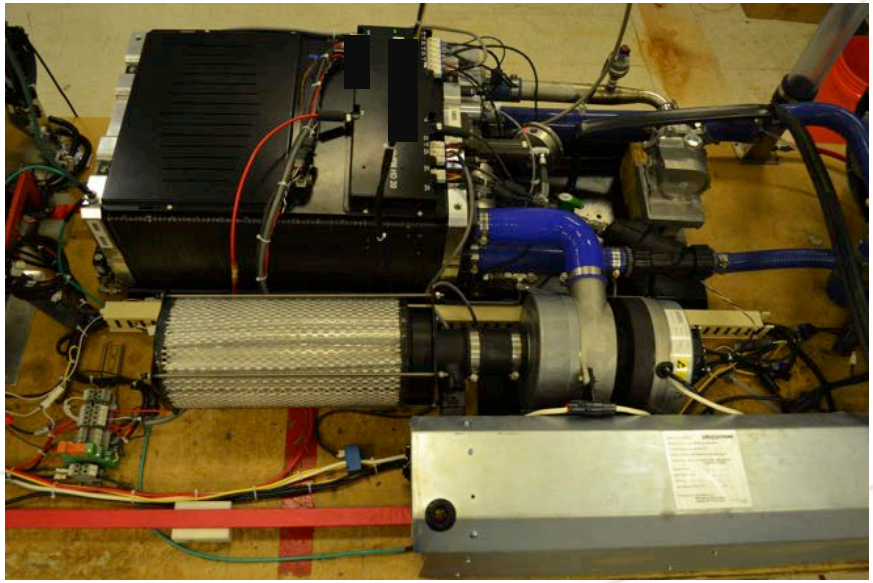


ACCOMPLISHMENTS

Alpha Prototype

- **Balance of Plant Design:** Integration of power generation module, energy storage module, air delivery, hydrogen regulation, thermal management, and system control

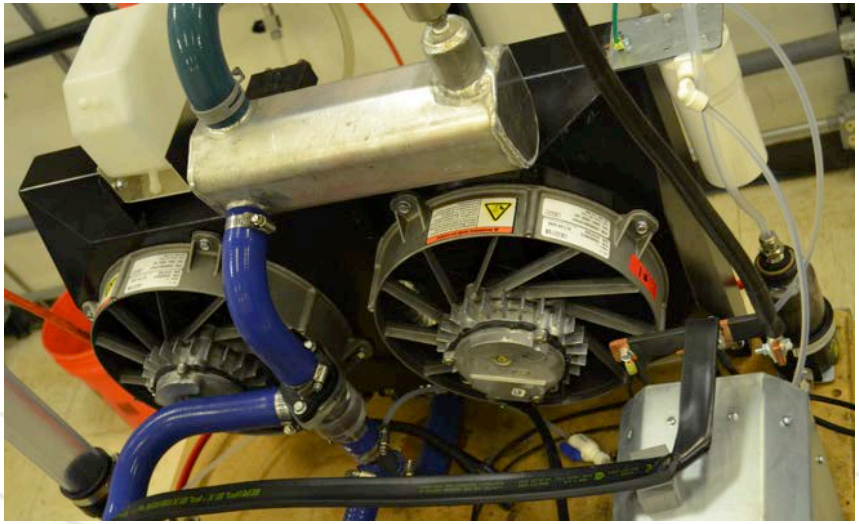


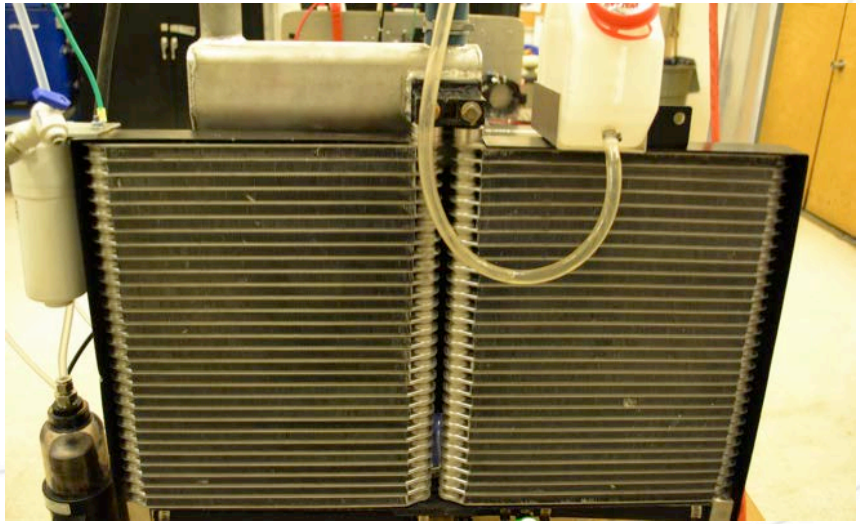


ACCOMPLISHMENTS

Alpha Prototype

- **Thermal Management Design:** intended to reject over 30 kW of heat in the confined space available in the tug vehicle

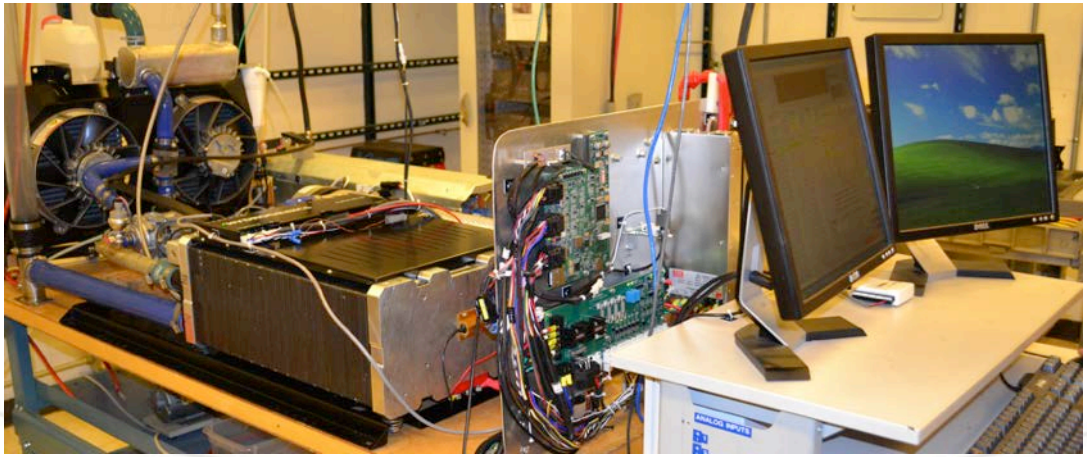


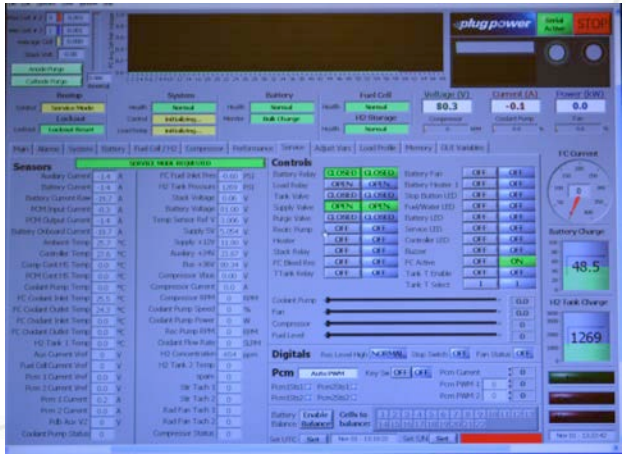


ACCOMPLISHMENTS

Alpha Prototype

- **Bench Testing:** Automated testing with onboard system hardware, graphic interface, liquid-cooled load banks, computer-controlled load profile management, and safety sensors/E-stops.

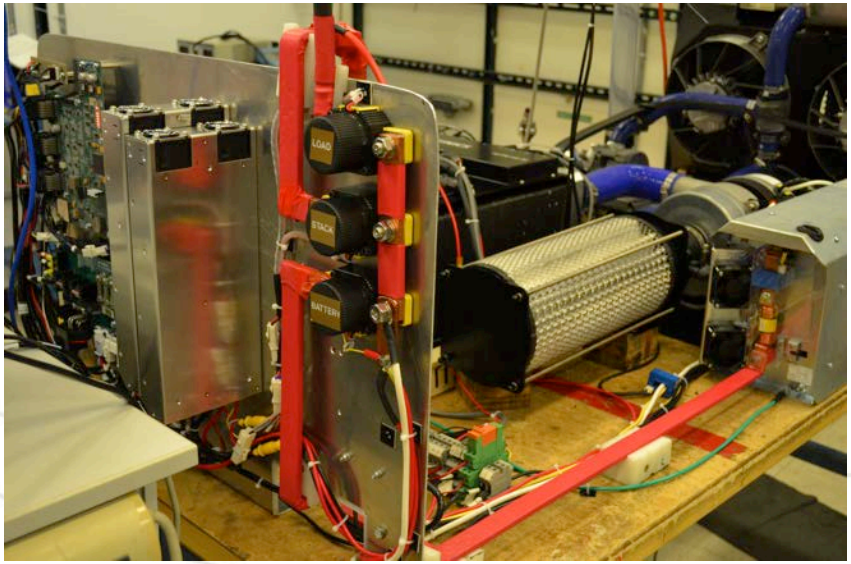


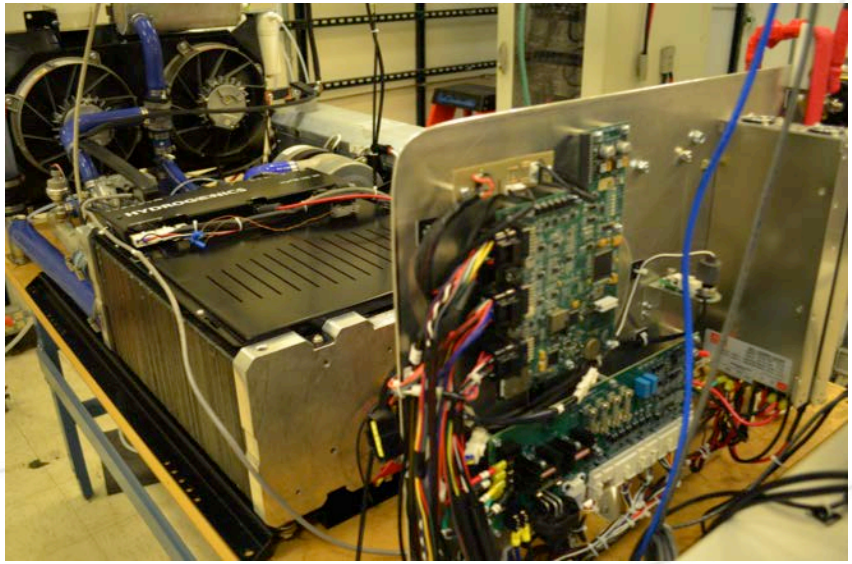


ACCOMPLISHMENTS

Alpha Prototype

- **Electrical System Design:** Leveraging the GenDrive® architecture, the system is controlled through main controllers, power distribution, component control boards, contactors and relays.

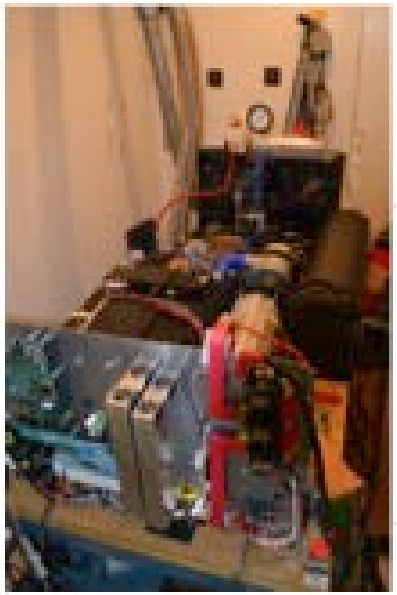




ACCOMPLISHMENTS

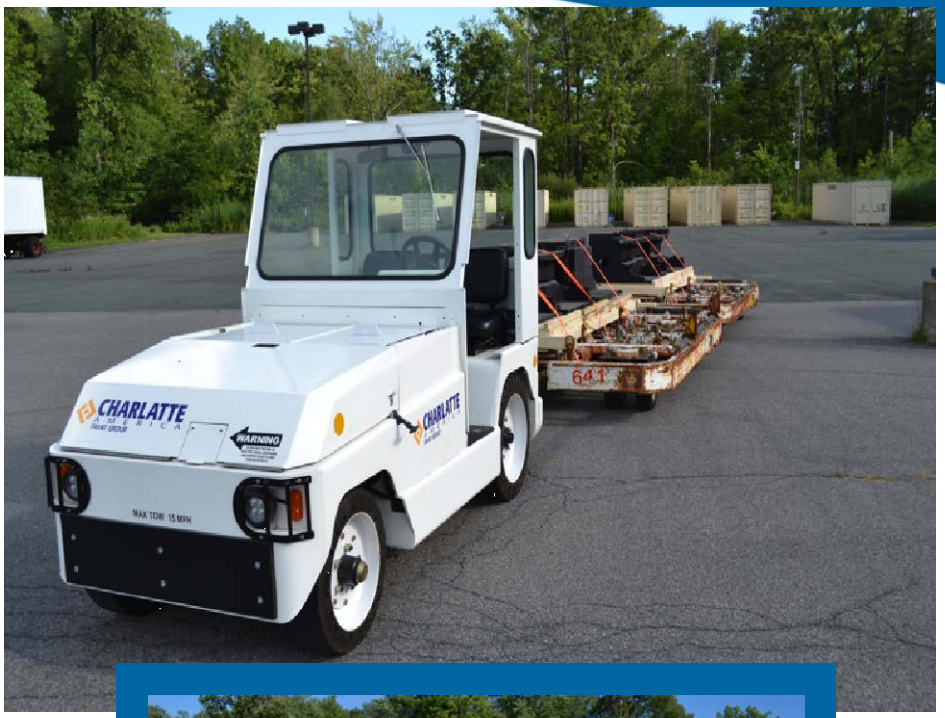
Testing at Extremes

- GSE application is much different than MHE (material handling equipment) because the tugs are exposed to the elements
- Designed, tested, stack and battery freeze protection down to -20 degrees F
- Tested heat rejection capabilities up to 108 degrees F at nominal stack temp set point (have margin to let stack temp drift)



Environmental Chamber Testing

ACCOMPLISHMENTS



Requirements

- BEV tug testing at Plug Power Latham
- Charlatte CT5E tug
- FedEx Express dollies
- Simulated weights

Findings

- Power requirements for different loads from 0 to 40,000 lbs. in increments of 10,000 lbs.
- Transient loads for starting from a stopped position.

Sunita even tried out the tug.

COLLABORATIONS

Project Team

Program Management

Fuel Cell System Integrator

BTT OEM

Airport BTT End User

H2 Supply

Airport Authority

FUTURE WORK

2014 focus will be a "go" decision followed by H2 install and FC commissioning

Budget Period 1

- Task 1: Definition of Requirements – continued collection (ex. other sites)
- Task 2: Alpha Prototype – Continued testing / design improvements
- Task 3: BTT Beta Builds – starting in June
- Task 4: BTT Testing and Certification – commissioned by September

Budget Period 2

- Task 5: Site Preparation – FedEx architecture & engineering subcontractor
- Task 6: Commissioning – expected mid-September
- Task 7A: Demonstration During Budget Period 2
- Task 8: Assessment after Year 1

Budget Period 3

- Task 7B: Demonstration during Budget Period 3
- Task 9: Assessment after Year 2

SUMMARY

Objectives

- FC development
  - Cost-competitive
  - More energy-efficient
  - Reduce consumption of diesel
  - Lower carbon emissions
  - Decreased energy expenditures
  - Validate value proposition

Major Contributions by Partners

- PP: Develop 80V FC product for BTT
- Charlatte: Testing with CT5E tug
- PP: Liquid hydrogen installation
- FedEx Express: end user evaluation

Fuel Cell Development

- Alpha prototype fully tested
- Beta prototype testing through Q2 2014
- Demo builds and certification in BTT by end of June 2014

H2 Infrastructure

- Site planning through Q3 2014
- Installation in Q3 2014

Start of Demo – Sept 2014

- FedEx Express – 15 units in Memphis, TN