MT011 Ground Support Equipment Demonstration

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June 2015

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OVERVIEW: Program

Cargo Tractor Demonstration Program

- $2.5 million from the Department of Energy
- 15 fuel cell cargo tractors in airport application in Memphis, TN for 2 years
- H2 infrastructure located on airport ramp
- 100% outdoor operation

Market Drivers

- Fuel savings | Clean | Less noise
- Operational flexibility - no regeneration
- Cost of compliance - EPA/CARB standards

OVERVIEW

Demonstrating fuel cells as a viable solution for airport ground support equipment

TIMELINE

- Project start – January 2013
- Kickoff meeting – 3/27/13
- Project end – April 2017

BARRIERS

- Outdoor operation
- Airport Emissions
- Energy requirement for cargo operations
- Run time

BUDGET

- Total project funding - $5.0M
  - DOE - $2.5M
  - Partners - $2.5M
  - Status: 73.6% Complete

PARTNERS

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

RELEVANCE

DOE Fuel Cell Technologies Objectives

- Create a H_2 fuel cell solution as cost-competitive and more energy-efficient cargo tractors compared to internal combustion
- Reduce consumption of diesel fuels (reducing U.S. demand for petroleum)
- Demonstrate lower carbon emissions
- Demonstrate a value proposition that shows decreased energy expenditures

Specific Project Objective

- Develop the 80V (~20 kW) fuel cell product for cargo tractor
- Testing with Charlatte CT5E cargo tractor | Design Improvements
- Factory Acceptance Test to demo performance parity with battery / ICE
- Build 15 cargo tractors for deployment
- Hydrogen installation at Memphis-Shelby Country Airport
- Permitting with Memphis Fire Services Bureau
- 2 years of demonstration in airport operations
- Use learning to make improvements

RELEVANCE

Specific Project Objectives and Expectations

DOE Project Objectives	Plug Power-FedEx Project Expectations
Reduce petroleum consumption	Each tractor uses ~2 gal/hr. Total tractor run time of 15 tractors 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	Tractor operation occurs during two shifts: day (10 AM-2 PM) and night (10 PM-2 AM). The total clock day is 10AM-2PM (16 hours). **Actual tractor activity is 8 hours per day. Total run time of 15 tractors over 2 years will be upwards of 87,600 fleet hours.**
Towing capability of 3,000 to 6,000 lbs.	The tractor will be able to tow 4 FedEx containers each weighing 40,000 lbs. The corresponding **drawbar capacity of the fuel cell-powered tractor is 5,000 lbs.**
Accelerated development of FC-powered GSE	**Fleet of 15 80V fuel cell systems in real world application gaining significant field experience while allowing a premier tractor end user to evaluate for larger deployments.**

APPROACH: Project Phases

- **Project Phases**

Phase 1: Development	Phase 2: Demonstration
Plug Power develops, builds and tests the 80V fuel cell system for the cargo tractor application	Fleet of fuel cells deployed in electric cargo tractors at FedEx Express Memphis under real world conditions
1 system in simulated conditions	15 systems in airport operations

- **Deployment of 15 FC-powered Units for Two Years**
  - 15 cargo tractors at Memphis, TN (fleet of 1400 to manage 270 flights / day)
  - Site represents the single largest business opportunity for this market
  - Site allows for demonstrating in one of the harshest environments
    - Most aggressive duty cycle
    - Large airport ramp – long runs
    - High temperature
    - High Humidity

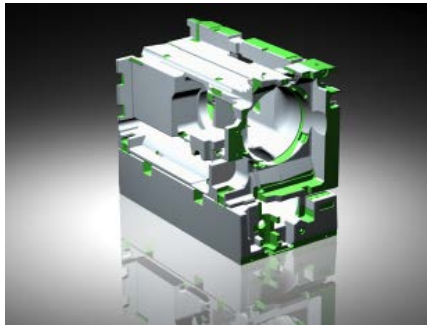
APPROACH: Fuel Cell Design

Drop-in-Place Replacement For 80V Battery

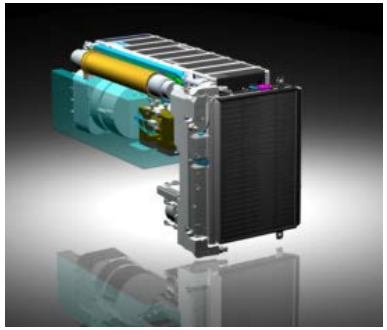
Designed to meet the same form, fit, and function as the battery

- Stack: power (~22 kW, 30 hp)
- Battery: handle transients
- Ballast: weight (traction)
- H2 Tank: run time for application

Storage Module



Ballast



Fuel Cell

GenDrive

Solution for All OEMs

- Electric version for all OEMs
- Same architecture
- Repackaging for battery box and required weight

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

APPROACH: Hydrogen Infrastructure

Liquid Hydrogen infrastructure at FedEx Airport Ramp

Best scalable, economic solution | Delivered liquid hydrogen

Specifications

- H2 Capacity: 15,000 gallons
- Liquid temp: -253 deg C
- Liquid Pressure: 5 PSI
- Gaseous Storage: 60 kg
- Gaseous Fueling Pressure: 350 bar
- Dispensing Time: 1 kg/min

Liquid Storage

Liquid Pumps

Vaporizer

High Pressure Storage

Dispensers

APPROACH: Dispenser Refueling

- Turn handle on hose until arrow is pointing away from vehicle
- Place hose on fuel cell fueling receptacle
- Turn handle 180 deg. clockwise until arrow is pointing at the vehicle
- Fueling hose locks and automatically starts flow to the tank

APPROACH: Integration

Charlatte Model CTE5 Cargo Tractor

- Why Charlatte? OEM designed tractor as a cab back design
- Hitch tractor to dollies from seat
  - Productivity - saves time
  - Health - Less stress on bodies

Solution for Other OEMs

- All of the major cargo tractor OEMs offer an electric version
- Architecture will be same
- Repackaging for battery box and required weight

Electric Baggage Tow Tractor					
OEM	Model	Drawbar (lbs)	Power	hp (comp.)	Voltage
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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: Financials

PARTNERS $2.5 MILLION

- FedEx: Operator Labor
- FedEx: ½ of Fuel Cell Systems
- Plug Power: Engineering
- Plug Power: Program Mgmt
- Plug Power: Service Personnel
- Plug Power: Service Materials
- FedEx: Service

DOE' S $2.5 MILLION

- Liquid Hydrogen Infra Lease
- ½ of Fuel Cell Systems
- Plug Power: Engineering
- Plug Power: Program Mgmt
- Plug Power: Service Personnel
- Plug Power: Service Materials

Outside Budget

The program partners are investing more in this project than DOE funding

- FedEx: 15 Charlatte BTTs (~ $500k)
- FedEx: Liquid hydrogen fuel (~ $150k)
- FedEx: Hydrogen Site – engineering, pad, utilities, lighting, installation (> $500k)
- FedEx: Project Management
- Plug Power: Additional support in Budget Periods 2 and 3

APPROACH: Scope of Work

Budget Period 1

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

✓ **Go/No Go Decision:**

- Testing of Alpha Prototype Fuel Cell System

  Criteria: Does Beta unit meet the same form, fit, and function as the 80V battery?

  Voltage output: 72-90V 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

Result: Achieved OEM certification on June 26th, 2014

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
  - Continuous Assessment | Weekly performance updates to FedEx Express
  - Quarterly data transmission to NREL
- Task 8: Assessment after Year 1 (milestone: see below)

Go/No Go Decision (Performance Assessment)

- Power: 5,000 lbs. drawbar
- Availability: > 80%
- Run time: > 1 shift
- Reliability (MTBF): >100 hrs
- Speed rating: 10 mph
- Hydrogen Fills: 350 bar
- No non-recoverable issues with outdoor operation

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: Requirements

Vehicle Testing

- Battery-powered tractor testing in Latham
- Charlatte CT5E tug
- FedEx Express dollies

Sunita was a volunteer operator

Findings

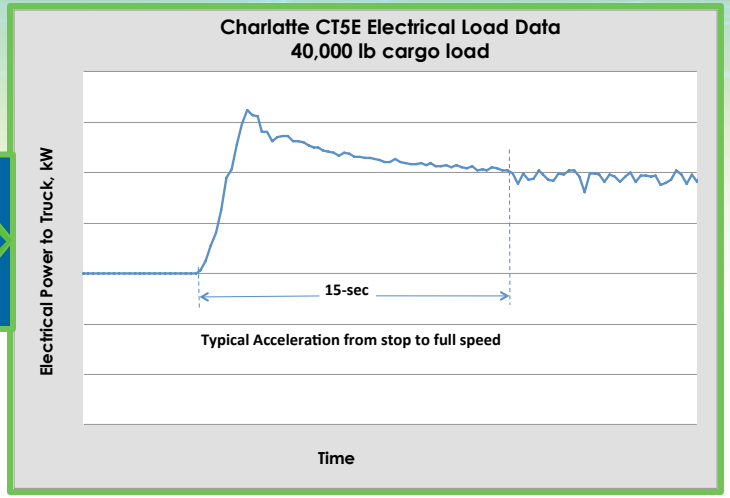
- Power requirements for different loads from 0 to 40,000 lbs. in increments of 10,000 lbs.
- Transient loads for starting from a stopped position

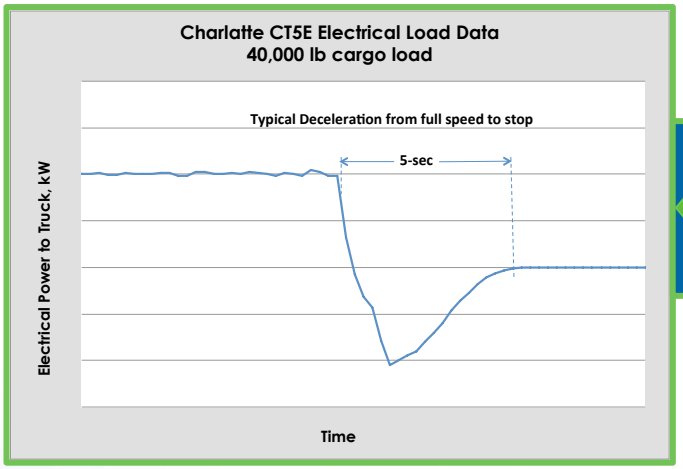
Shock Testing

- Captured G forces in 6 directions on 6 tractors in application

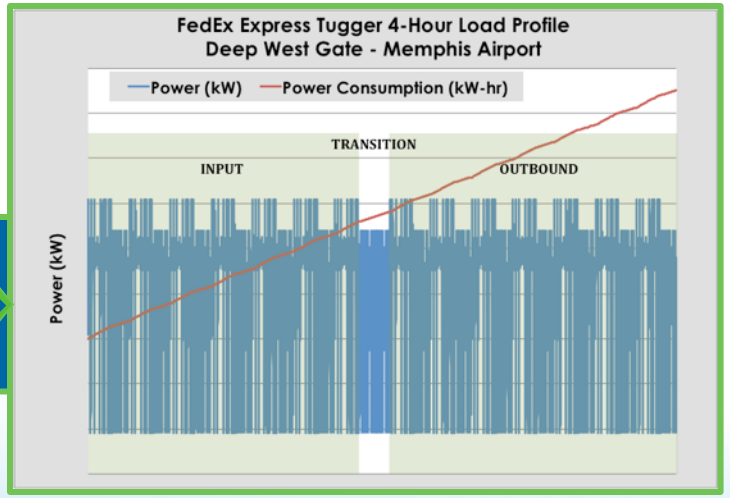
ACCOMPLISHMENTS: Requirements

Acceleration: Drives Battery Sizing
- Maximum Power Draw
- Time to Constant Velocity





Deceleration: Drives State-of-Charge Controls
- Maximum Regeneration (Energy Recovered)
- Frequency of Start / Stops



Load Profile: Drives Stack Size and H_2 Storage
- Average Power | Total Energy Consumed
- Length of Shift (Inability to Stop for Fueling)

ACCOMPLISHMENTS: Modeling/Testing

Systems Modeling

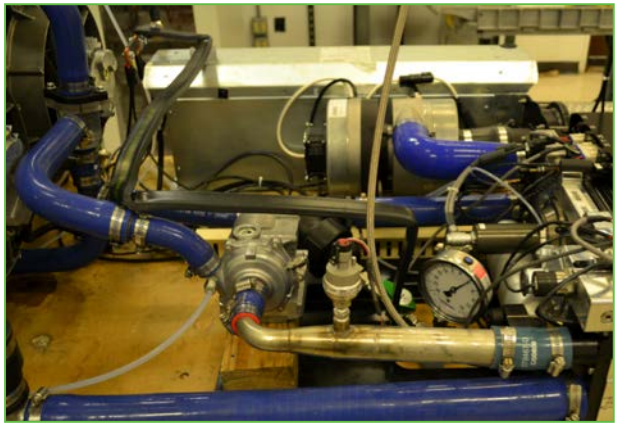
- Stack Sizing
- Battery Sizing
- Balance of Plant design

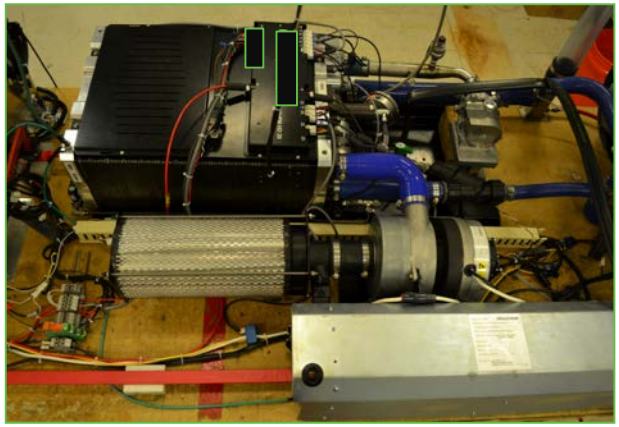
Alpha Breadboard

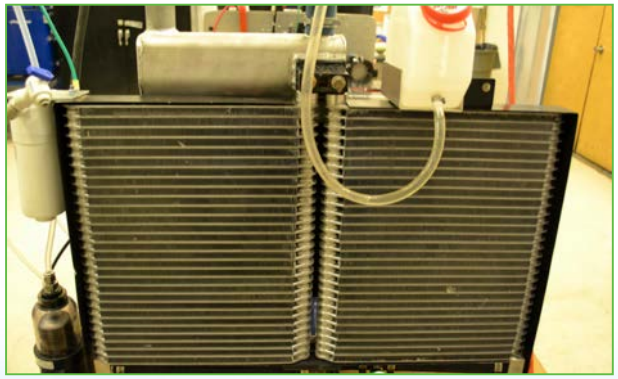
- Bench testing

Testing Achievements

- Automated testing
- Graphic interface
- Liquid-cooled load banks
- Safety sensors/E-stops
- Computer-controlled load profile management



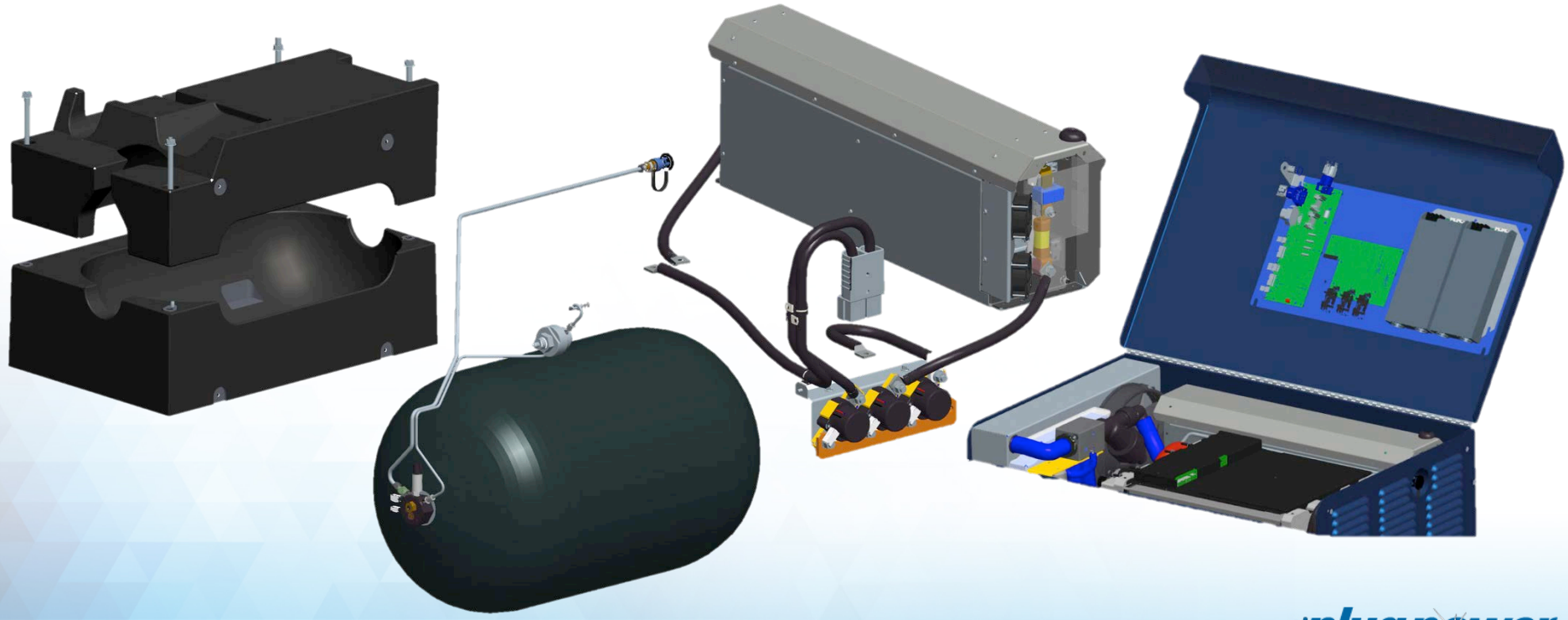




ACCOMPLISHMENTS: Alpha Prototype

Alpha Prototype

- Advanced packaging design
- Easy top serviceability of all major components
- 150 liter (3.6 kg) H2 tank
- Driver-side fueling
- Extended Li-Ion battery capacity
- Vibration dampening frame
- Weatherproofing



ACCOMPLISHMENTS: Alpha Prototype

- Charlatte CT5E tug, FedEx Express dollies, and 40,000 lbs. of weight
- Endurance testing
- Software/diagnostics testing

ACCOMPLISHMENTS: Stress Testing

Airport application is 24/7 outdoors

Tractors are exposed to the elements

Testing at Extremes

Environmental Chamber Testing

- Designed, tested, stack and battery freeze protection down to -20 deg F
- Tested heat rejection up to 108 degrees F at nominal stack temp

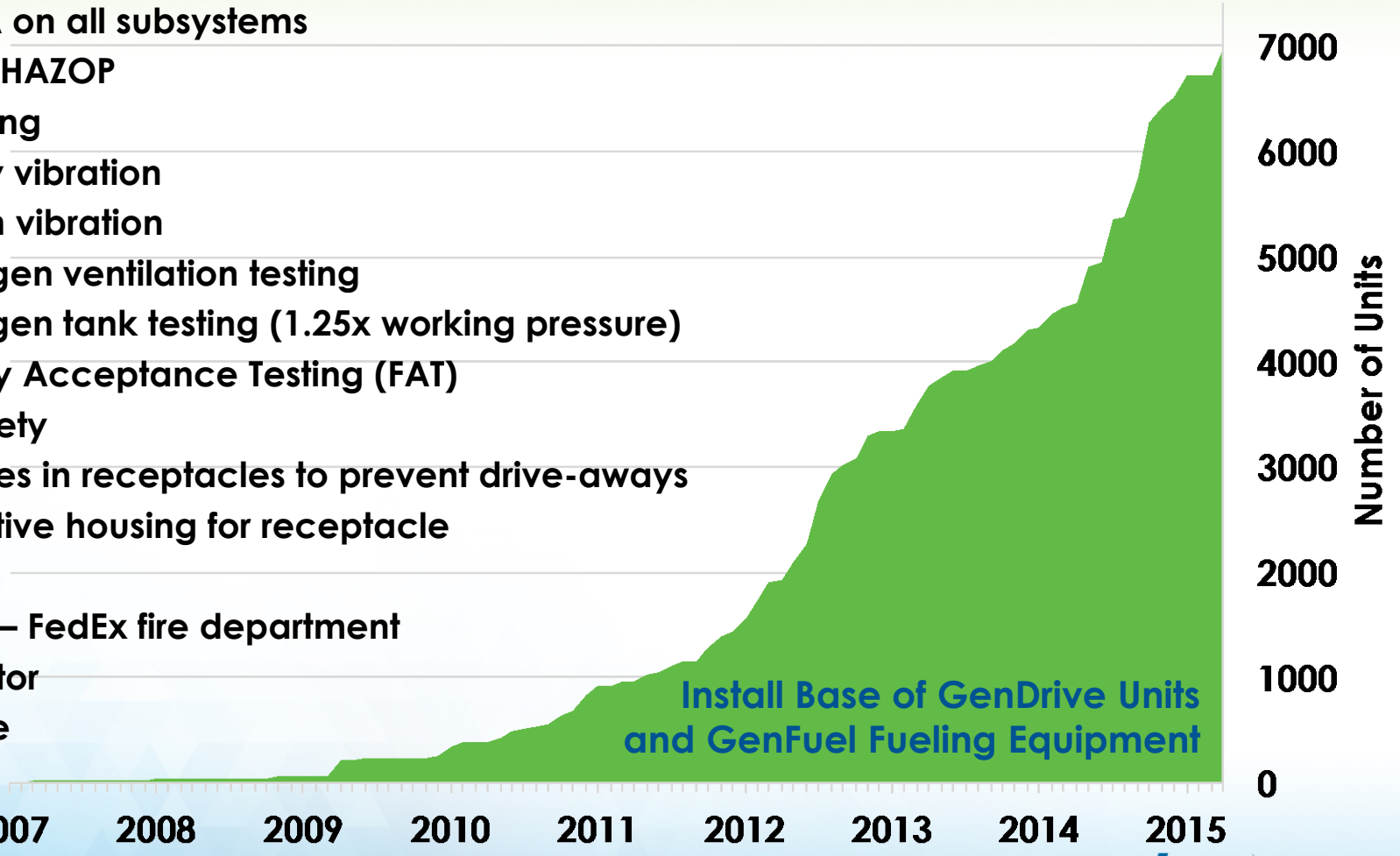
Wind Driven Rain Testing

- Rain at 30 mph at 6 different angles

ACCOMPLISHMENTS: Fuel Cell Safety

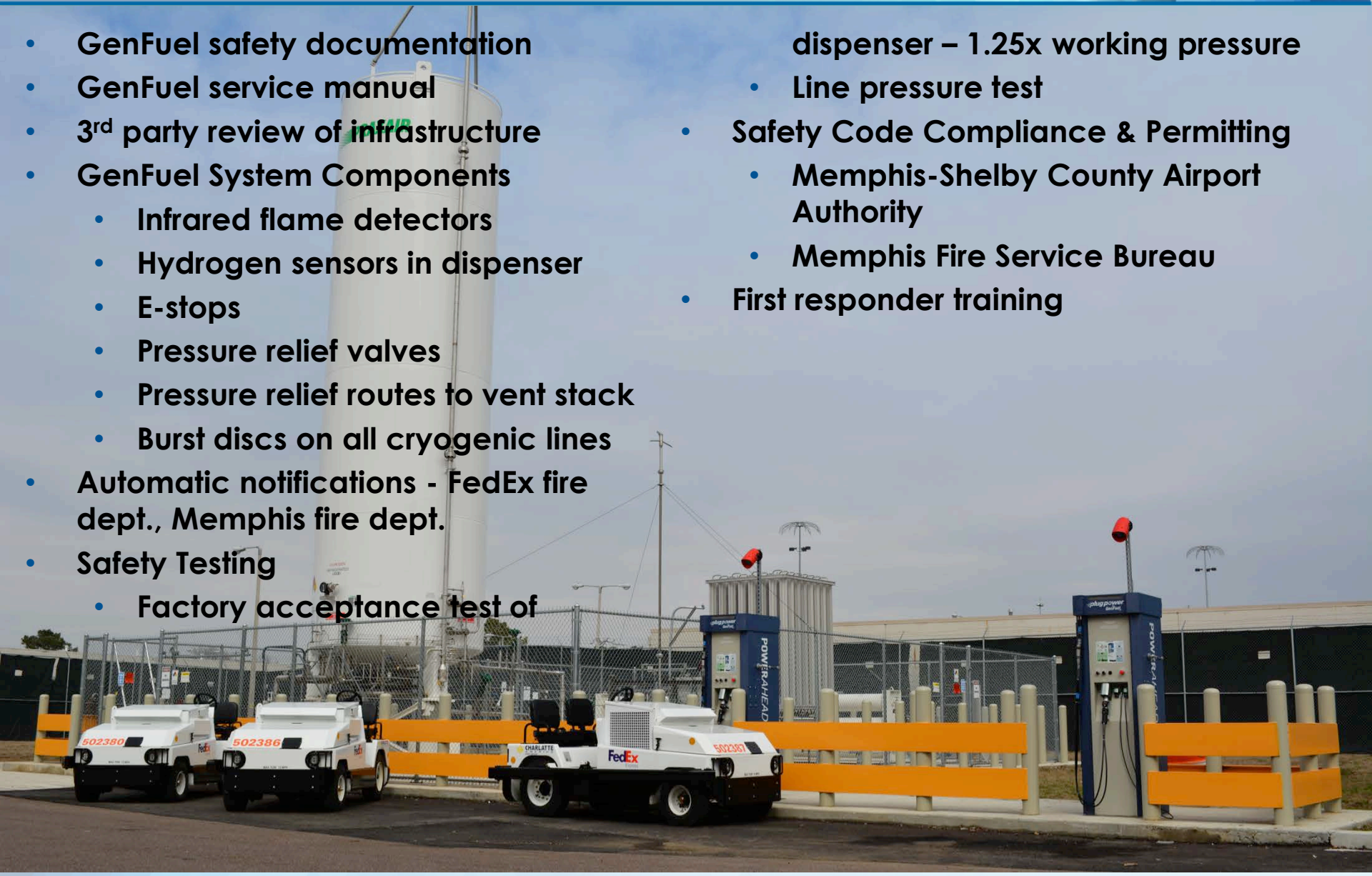
- Safety Documentation
  - GSE System Requirements Document
  - GSE Safety Concept
  - Answers to PNNL Hydrogen Safety Team review
  - DFMEA on all subsystems
  - Safety HAZOP
- Safety Testing
  - Battery vibration
  - System vibration
  - Hydrogen ventilation testing
  - Hydrogen tank testing (1.25x working pressure)
  - Factory Acceptance Testing (FAT)
- Fueling Safety
  - Switches in receptacles to prevent drive-aways
  - Protective housing for receptacle
- Training
  - Safety – FedEx fire department
  - Operator
  - Service

Same safety architecture used in 6,000+ fielded GenDrive units



ACCOMPLISHMENTS: H2 Infra Safety

- GenFuel safety documentation
- GenFuel service manual
- 3rd party review of infrastructure
- GenFuel System Components
  - Infrared flame detectors
  - Hydrogen sensors in dispenser
  - E-stops
  - Pressure relief valves
  - Pressure relief routes to vent stack
  - Burst discs on all cryogenic lines
- Automatic notifications - FedEx fire dept., Memphis fire dept.
- Safety Testing
  - Factory acceptance test of dispenser – 1.25x working pressure
  - Line pressure test
- Safety Code Compliance & Permitting
  - Memphis-Shelby County Airport Authority
  - Memphis Fire Service Bureau
- First responder training



ACCOMPLISHMENTS: Beta Build

Bench → Alpha → Beta | Further refinement

- Consolidation of electronic boards
- Repackaging to allow greater air flow for ventilation and heat rejection
- Protected user interface
- Fueling receptacle placed behind protective hinged door
- Empirical data in Memphis confirmed usage profile
- Further high temperature testing

ACCOMPLISHMENTS: Marketing

Market Drivers

- Fuel savings
- Cost of compliance
  - EPA Tier 4 emissions standards (40 CFR part 1039)
    - Ozone non-attainment zones
    - Reduction of PM and NO_x by ~90%
  - Pacific Coast Action Plan
    - "Expand the use of zero-emission vehicles, aiming for 10% of new vehicle purchases in public and private fleets by 2016"
- Operational Flexibility
  - No need to idle to keep warm
  - No need to idle for regeneration
  - Less maintenance
    - No need for oil changes
    - No moving parts in stack

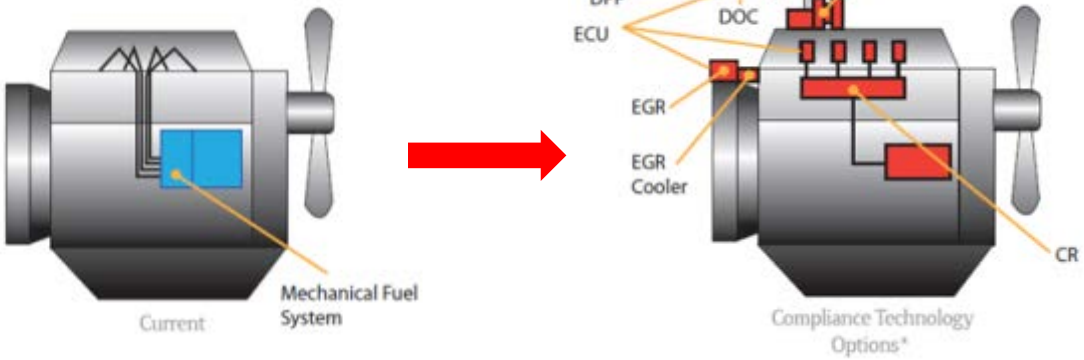
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

PACIFIC COAST ACTION PLAN *on* CLIMATE AND ENERGY

New emissions changes have historically lead to new problems and downtime

ACCOMPLISHMENTS: Marketing

GSE Market Driver – EPA Tier 4 Emissions



Possible Engine Changes

CR - Common Rail fuel injection
PM - Particulate Matter (90% less diesel soot)
DOC - Diesel Oxidation Catalyst (catalytic converter)
EGR - Exhaust Gas Recirculation (cooled)
Turbo - Turbocharger
DPF - Diesel Particulate Filter (with active soot regen)
ECU - Engine Control Unit

Impact to Operations

Capital Costs

- Advanced exhaust gas aftertreatment
- Advanced electronic control systems
- Features not found on current systems
- Many components not retrofittable
- New components
- Higher prices - less production volumes

Service

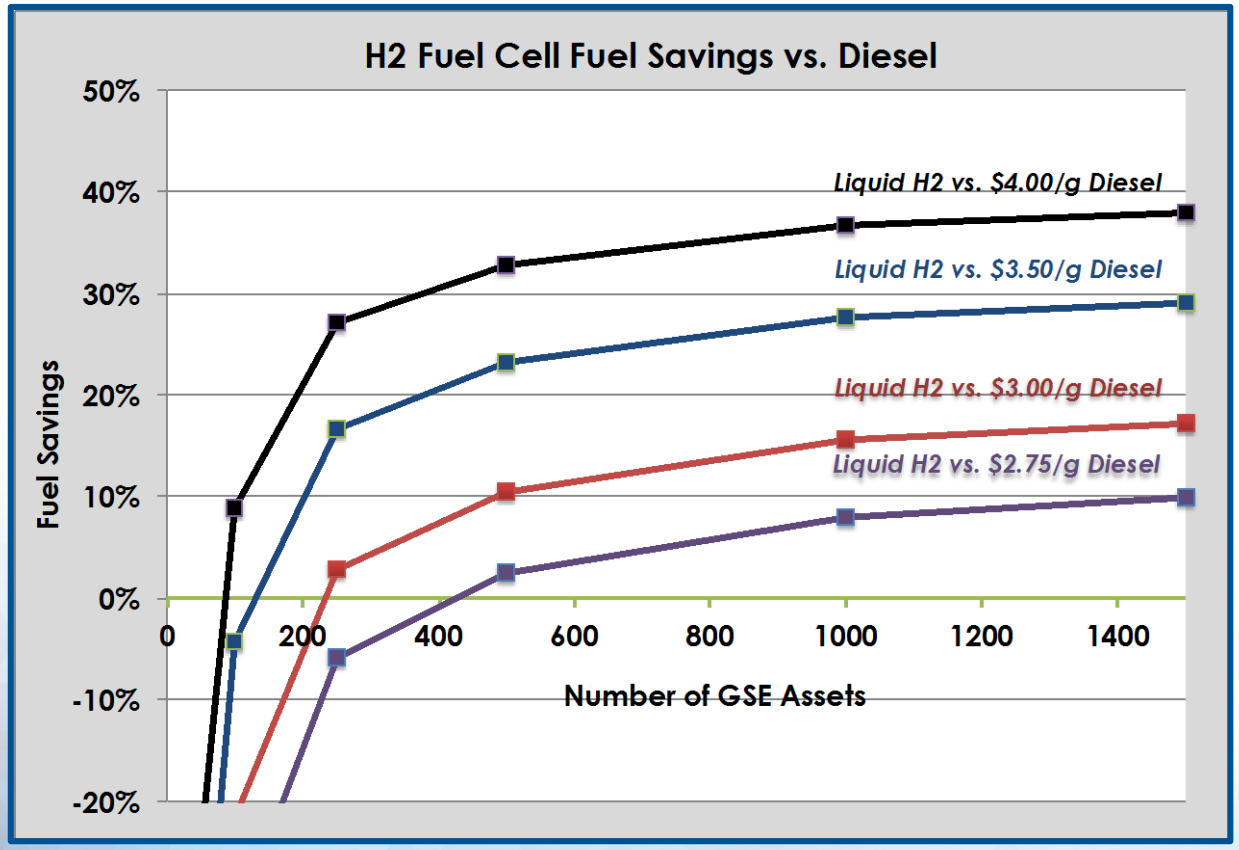
- Increased maintenance expense
- Computers required to diagnose some issues

Operational Costs

- Increased training for operators and service technicians
- Positive impact to fuel economy

ACCOMPLISHMENTS: Efficiency / Fuel Savings

Fuel Economy	Units	Hydrogen	Fuel Economy	Units	Diesel
Hydrogen Consumption	kg/day	3.07	Diesel Consumption	gal/day	6.00
Energy Content	kW-hr / kg	33	Energy Content	kW-hr/gal	37.95
Energy Consumed	kW-hr	101.2	Energy Consumed	kW-hr	227.7
Fuel Cell Efficiency	%	45%	Engine Efficiency	%	20%
Energy Powering Truck	kW-hr	45.5	Energy Powering Truck	kW-hr	45.5



More hydrogen consumption improves fuel savings

Capital infrastructure is amortized over more molecule

ACCOMPLISHMENTS: More Assets, More Savings

GenFuel Liquid H2 / Compression, Storage, & Dispensing Solution

Buses
20 kg/day

Forklift Trucks
1.25 kg/day

Belt Loaders
2 kg/day

Cargo Tractors
4-8 kg/day

Cargo Loaders
10 kg/day

Best strategy to decrease H2 cost is to amortize infrastructure with more H2 molecules

ACCOMPLISHMENTS: Marketing

US Airline GSE Market			
Type of Equipment	Units	% of Market	Cumulative
Tow Tractors	27,978	45%	45%
Belt Loaders	12,395	20%	65%
Pushback Tractor	6,068	10%	75%
Ground Power Unit (GPU)	4,591	7%	82%
Cargo (Container) Loader	4,493	7%	90%
Airstarts	2,526	4%	94%
Other	3,859	6%	100%
Total GSE Market	61,910	100.0%	

Belt Loaders

Loads from ground level to aircraft storage areas by way of conveyer belt

Pushback Tractor

Pushes airplane backwards away from the gate

Ground Power Unit

Supplies power/air conditioning to the aircraft while at gate or during loading

Container Loader

Loads containers from ground level to aircraft by lifting via a platform

Airstart

Provides the initial rotation to start gas turbine engines

ACCOMPLISHMENTS: Marketing Outreach

International Air Expo

Discussions and interest from most major transport and commercial airlines

American Association of Airport Executives

ACCOMPLISHMENTS: 4/9/15 Event

"FedEx Works with US DOE, Plug Power Inc. & Charlatte America to Roll out World's First Zero Emissions, Hydrogen Fuel Cell Ground Support Equipment"

- Steve Cohen, US Congressman for TN, 9th District
- John Dunavant, VP of the FedEx Express World Hub in Memphis, TN
- Mitch Jackson, VP of Environmental Affairs and Sustainability, FedEx Corp.
- Andy Marsh, CEO, Plug Power
- Reuben Sarkar, DOE Deputy Asst. Secretary

TECHNOLOGY TRANSFER: PPA Model

GenKey
Power • Fuel • Serve

- *GenKey: makes transition to fuel cells seamless*

~~*Power*~~	***GenDrive*** ~~hydrogen fuel cell system~~
~~*Fuel*~~	***GenFuel*** ~~hydrogen infra and fuel~~
~~*Serve*~~	***GenCare*** ~~customer service~~

- ***Plug Power handles power, fueling, and service so operations can focus on their business***

Complete Solution. One Invoice.

TECHNOLOGY TRANSFER: Removing Hurdles

Power Purchase Agreement

- "I don't have the budget for capital purchases." – **PPA OpEx model**
- "My service techs don't know hydrogen. Batteries are simpler to maintain." – **Dedicated Plug Power service techs**
- "The pricing for hydrogen infrastructure from the IGC is too high." – **Bulk agreement with Praxair**
- "How can I be sure that the fuel cells will be as efficient as you say?" – **Set monthly invoice amount (within fleet hourly usage range)**
- "What if the fuel cells are not as reliable as you project?" – **Guaranteed uptime**
- "Corporate takes the tax credit. My P&L will be underwater." – **Leasing company takes credit**
- "The airport owns infrastructure. The airline owns the vehicles." – **Airport does not have to buy infrastructure. Flexible location.**

COLLABORATIONS

Ground Support Demonstration Program Team

plug power FUEL CELL SYSTEMS

Program Management

System Integrator

CHARLATTE AMERICA FAYAT GROUP

Cargo Tractor OEM

FedEx Express

End User

Station Permitting

MEMPHIS DIVISION OF FIRE SERVICES F D TENNESSEE

H2 Supply

GenKey Power • Fuel • Serve

Airport Authority

MEMPHIS INTERNATIONAL AIRPORT
Memphis-Shelby County Airport Authority

plug power

FUTURE WORK

2015 will focus on learning and improvements during the first year of demonstration

Budget Period 1

- Task 1: Definition of Requirements – Complete
- Task 2: Alpha Prototype – Complete
- Task 3: BTT Beta Builds – Complete
- Task 4: BTT Testing and Certification – Complete

Budget Period 2

- Task 5: Site Preparation – Complete
- Task 6: Commissioning – Complete
- Task 7A: Demonstration During Budget Period 2 – April 2015
  - Weekly performance reporting to FedEx
  - Quarterly data reporting to NREL
  - Dedicated service tech onsite, escalation from Plug Power Latham
- Task 8: Assessment after Year 1 – April 2016

Budget Period 3

- Task 7B: Demonstration during Budget Period 3 – April 2016 to April 2017
- Task 9: Assessment after Year 2 – April 2017

2014 AMR Comments

Schedule

- Reviewer: Compression of schedule due to the long design phase. Challenge to meet the September goals based current schedule.
- Presenter:
  - Important to increase Alpha development / testing time to make sure the solution met the needs of the application
    - Bench → Alpha → Beta (2 stages of refinement instead of 1)
  - Post-Alpha schedule (2H 2014) was also lengthened to add features requested by FedEx and Charlatte at the first go/no go, as follows:
    - Implemented a protected user interface
    - Fueling receptacle placed behind protective hinged door
    - Empirical data in Memphis confirmed usage profile
    - Further high temperature testing

Air Quality

- Reviewer: Need to get air quality
- Presenter: Air quality measurements were taken at two locations:
  - 2013: Ontario, CA Airport
  - 2014: Memphis, TN Airport

2014 AMR Comments

Requirements – Applicable to California

- Reviewer: California location was dropped. Not clear how issues that prevented deployment in California will limit application at other airports. Important for project to identify impediments to adoption of fuel cells in this market.
- Reviewer: Project should identify requirements basis for implementing fuel cell technologies in GSE and provide recommendations for how open California market by addressing barriers.
- Response: A goal of the project was to support similar activities in California. The decision to limit the scope to Memphis was made with FedEx Express. The airport usage case is much less severe in California. FedEx: "If it works in Memphis, it will work anywhere." Decision was made to demonstrate in worst case scenario.

Marketing / Economics

- Reviewer: Need for more market analysis and economics
- Reviewer: The project should add economics.
- Response: High-level market analysis and economics were included in the 2015 AMR presentation. The market information includes confidential information that cannot be shared with the public due to NDAs. Economics demonstrate order of magnitude for payback analysis.

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: FC system integrator
- Charlatte: Testing with CT5E tug
- PP: Liquid Hydrogen Installation
- FedEx Express: End User Evaluation

Fuel Cell Development

- Alpha prototype fully tested
- Beta prototype fully test
- Demo units received in 2014

H2 Infrastructure

- Site planning through Q3 2014
- Installation in Q4 2013
- Hydrogen site permitted in March 2015

Demonstration

- Started April 2015
- Event at FedEx Memphis in April 2015

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