



# MT011 Ground Support Equipment Demonstration

Jim Petrecky

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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





## 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

### BUDGET

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

### BARRIERS

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

### PARTNERS

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



## DOE Fuel Cell Technologies Objectives

- Create a H<sub>2</sub> 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 Charlotte 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 County Airport
- Permitting with Memphis Fire Services Bureau
- 2 years of demonstration in airport operations
- Use learning to make improvements



## 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 <b>175,200 gallons of diesel fuel reduced.</b>
Reduce emissions at airports	AT 9.8 kg CO2 per gal of diesel, there will be upwards of <b>1717 metric tonnes of CO2 eliminated at airports.</b>
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). <b>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.</b>
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 <b>drawbar capacity of the fuel cell-powered tractor is 5,000 lbs.</b>
Accelerated development of FC-powered GSE	<b>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.</b>

# APPROACH: Project Phases

- Project Phases

## Phase 1: Development

Plug Power develops, builds and tests the 80V fuel cell system for the cargo tractor application

1 system in simulated conditions

## Phase 2: Demonstration

Fleet of fuel cells deployed in electric cargo tractors at FedEx Express Memphis under real world 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

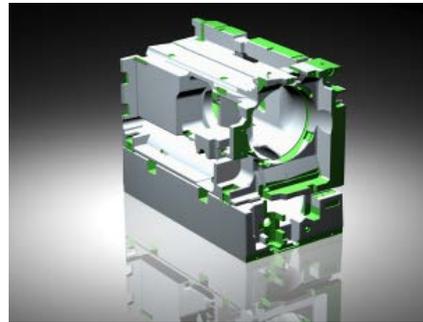
## Drop-in-Place Replacement For 80V Battery

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

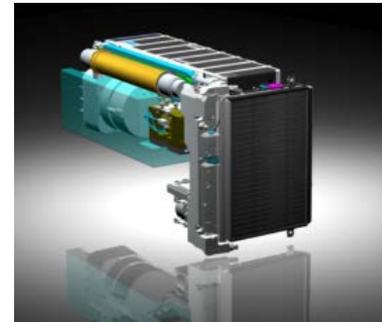
- Stack: power (~22 kW, 30 hp)
- Battery: handle transients
- Ballast: weight (traction)
- H2 Tank: run time for application



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

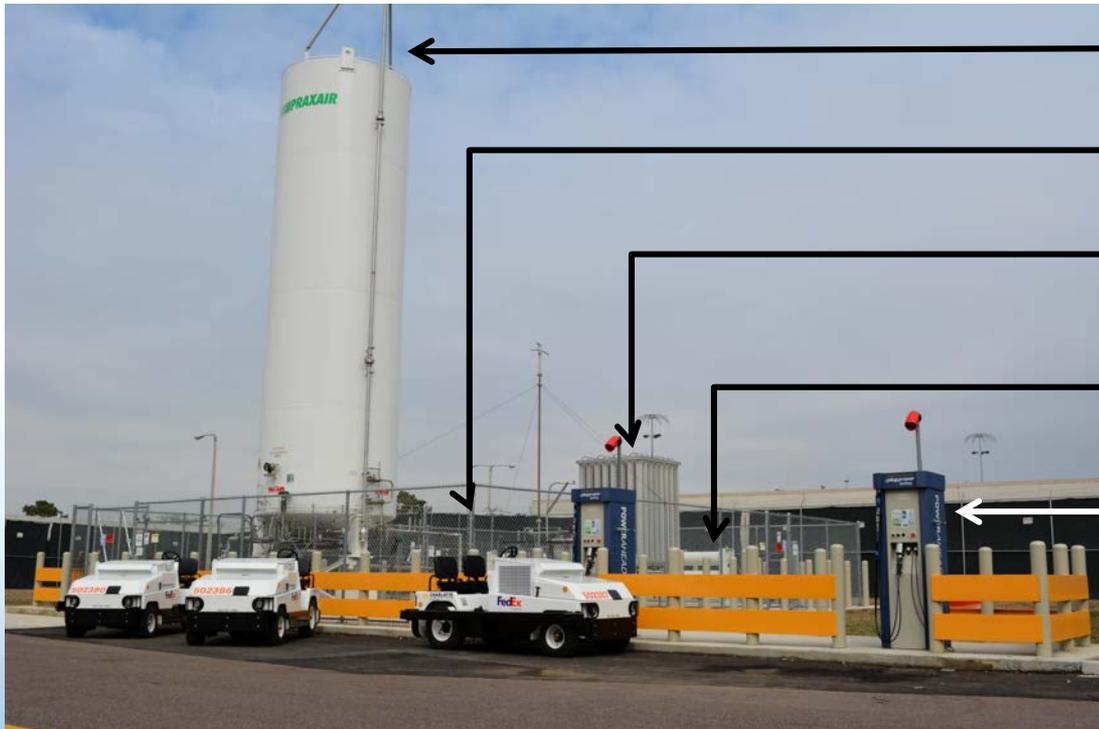


## Liquid Hydrogen infrastructure at FedEx Airport Ramp

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
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: Financials

## PARTNERS \$2.5 MILLION

- FedEx: Operator Labor
- FedEx: 1/2 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
- 1/2 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 Charlotte 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 26<sup>th</sup>, 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
- Charlotte CT5E tug
- FedEx Express dollies

## 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 was a volunteer operator*

## Shock Testing

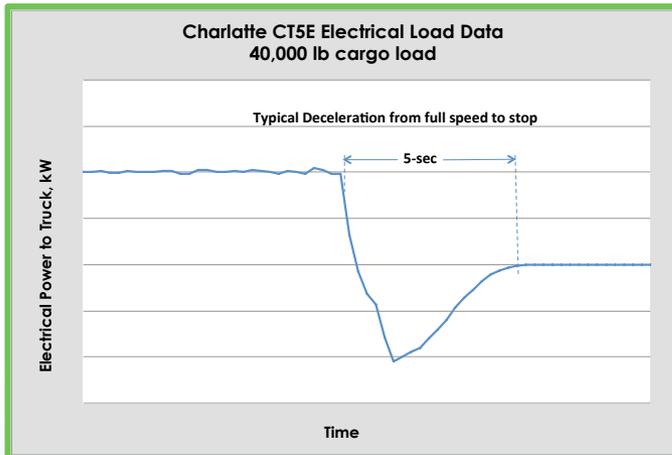
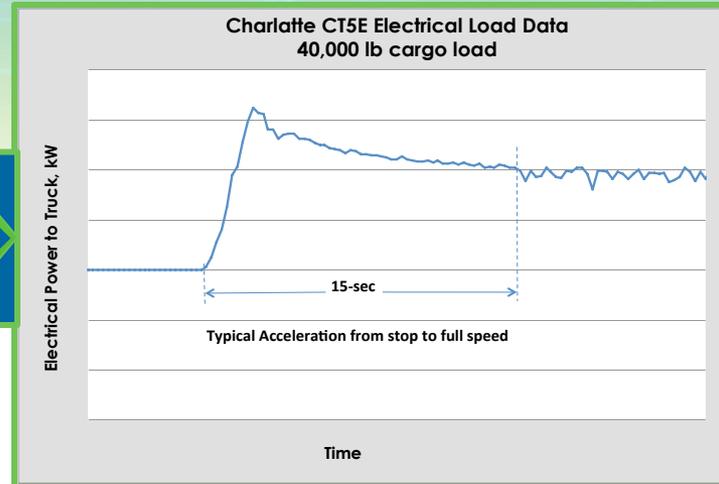
- Captured G forces in 6 directions on 6 tractors in application



# ACCOMPLISHMENTS: Requirements

## Acceleration: Drives Battery Sizing

- Maximum Power Draw
- Time to Constant Velocity

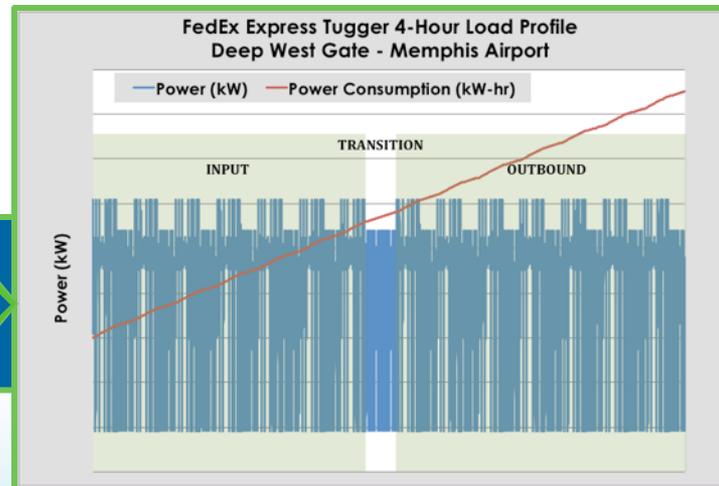


## Deceleration: Drives State-of-Charge Controls

- Maximum Regeneration (Energy Recovered)
- Frequency of Start / Stops

## Load Profile: Drives Stack Size and H<sub>2</sub> 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

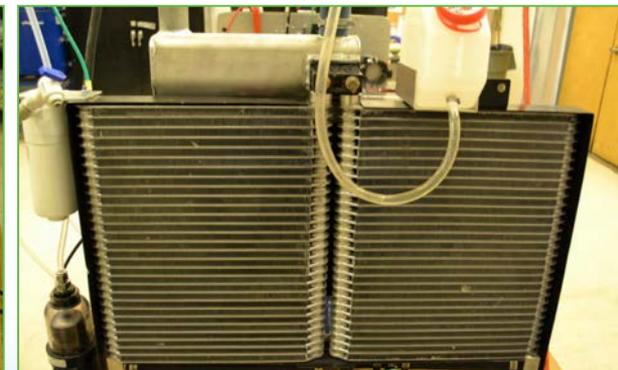
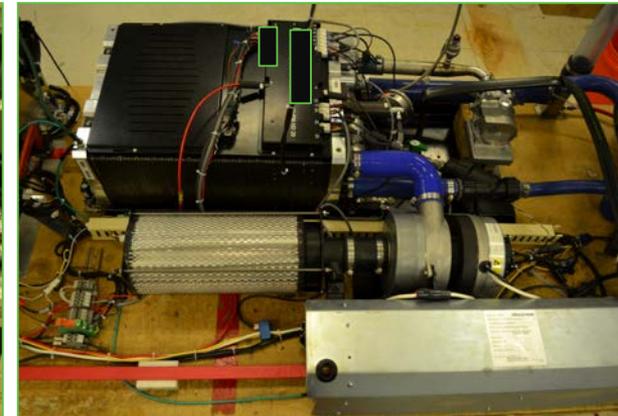


## Alpha Breadboard

- Bench testing

## Testing Achievements

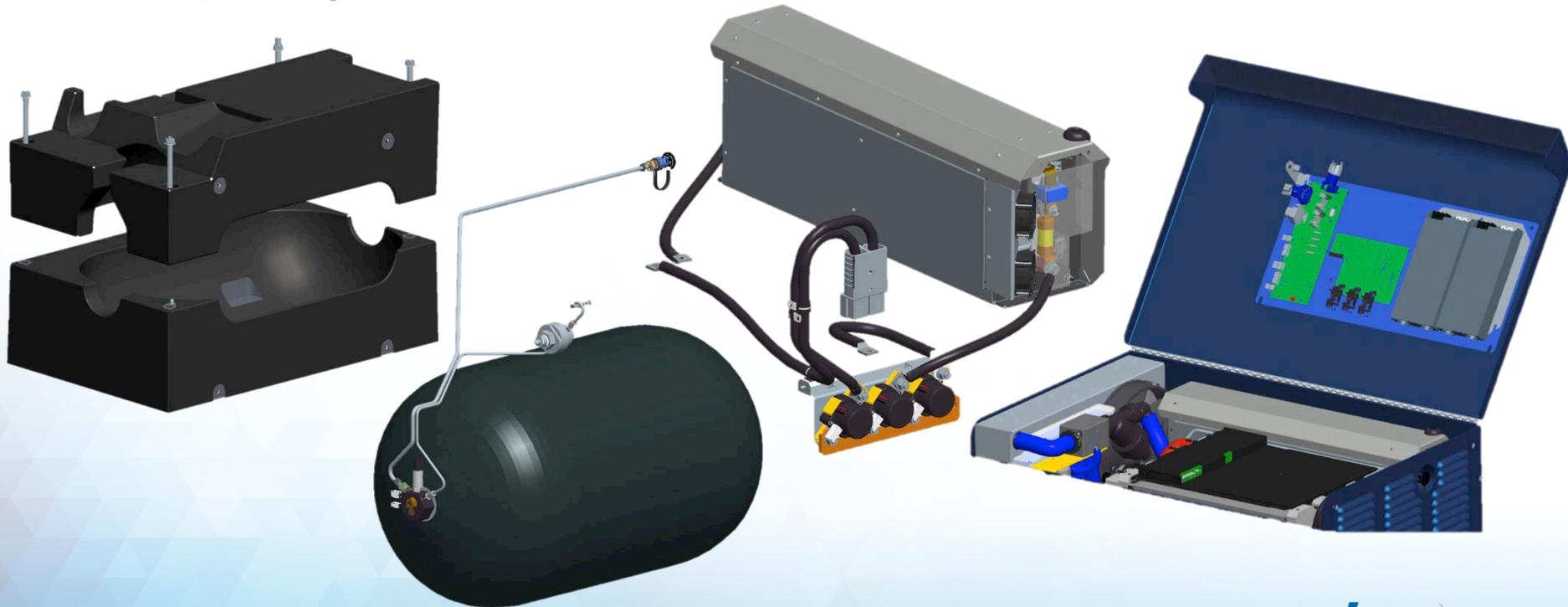
- Automated testing
- Graphic interface
- Liquid-cooled load banks
- Safety sensors/E-stops
- Computer-controlled load profile management



# ACCOMPLISHMENTS: Alpha Prototype

## Alpha Prototype

- Advanced packaging design
- Easy top serviceability of all major components
- 150 liter (3.6 kg) H<sub>2</sub> 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

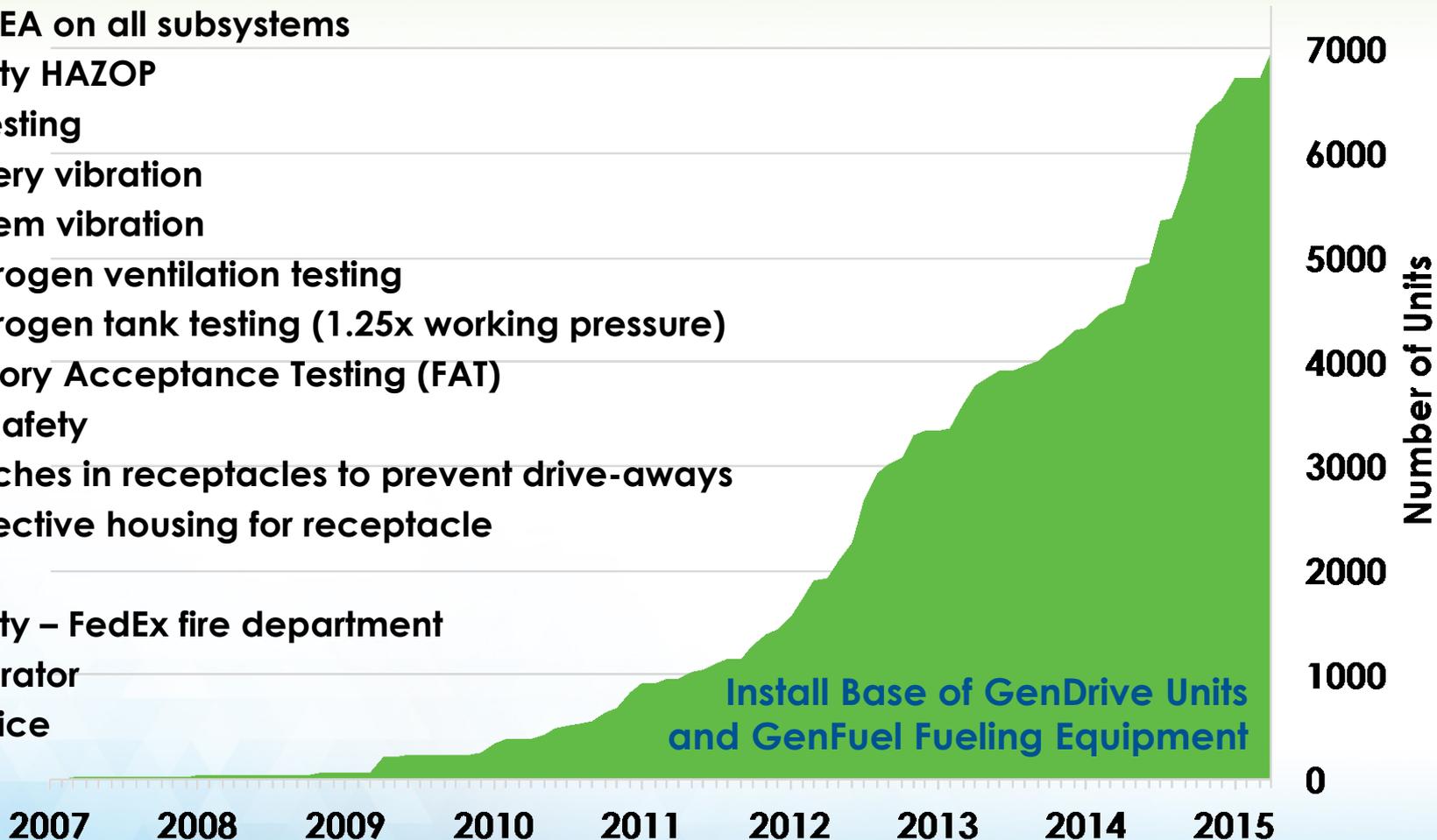


# ACCOMPLISHMENTS: Fuel Cell Safety



- 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
- 3<sup>rd</sup> 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

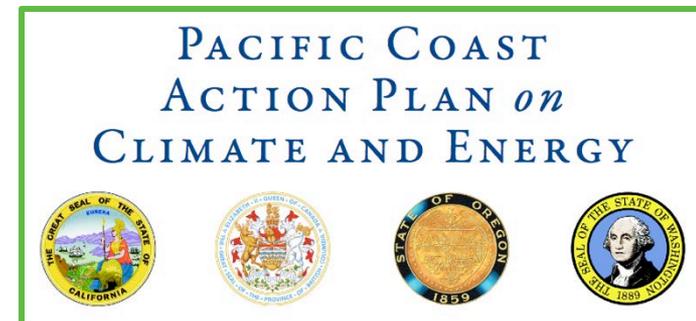
- Consolidation of electronic boards
- Repackaging to allow greater air flow for ventilation and heat rejection
- Protected user interface
- Fueling receptacle placed behind protective hinged door
- Empirical data in Memphis confirmed usage profile
- Further high temperature testing



# ACCOMPLISHMENTS: Marketing

## Market Drivers

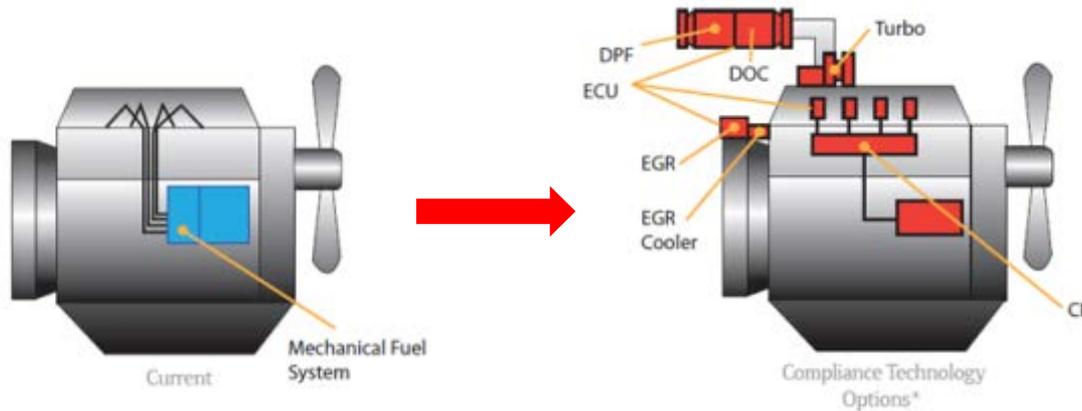
- Fuel savings
- Cost of compliance
  - EPA Tier 4 emissions standards (40 CFR part 1039)
    - Ozone non-attainment zones
    - Reduction of PM and NO<sub>x</sub> by ~90%
  - Pacific Coast Action Plan
    - “Expand the use of zero-emission vehicles, aiming for 10% of new vehicle purchases in public 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



**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

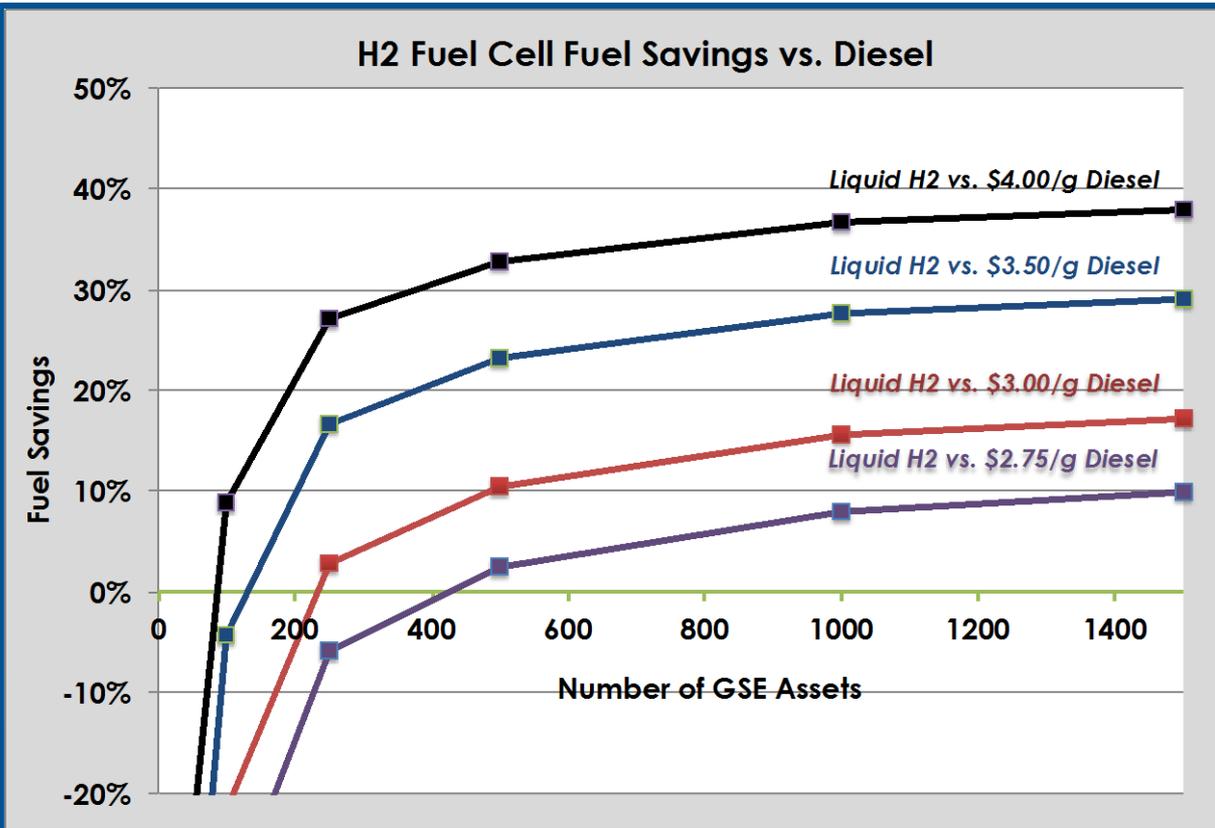
### Operational Costs

- 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 H<sub>2</sub> / 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 H<sub>2</sub> cost is to amortize infrastructure with more H<sub>2</sub> 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. & Charlotte 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: 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.**



## 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.**

## Ground Support Demonstration Program Team



Program Management



System Integrator

Station Permitting



Cargo Tractor OEM

H2 Supply



End User

Airport Authority



# 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**



## 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 Charlotte 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



## 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
- Charlotte: 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





968 Albany Shaker Road  
Latham, New York 12110

518.782.7700

[www.plugpower.com](http://www.plugpower.com)