Fuel Cell Powered Airport Ground Support Equipment MT011

Larry Pitts

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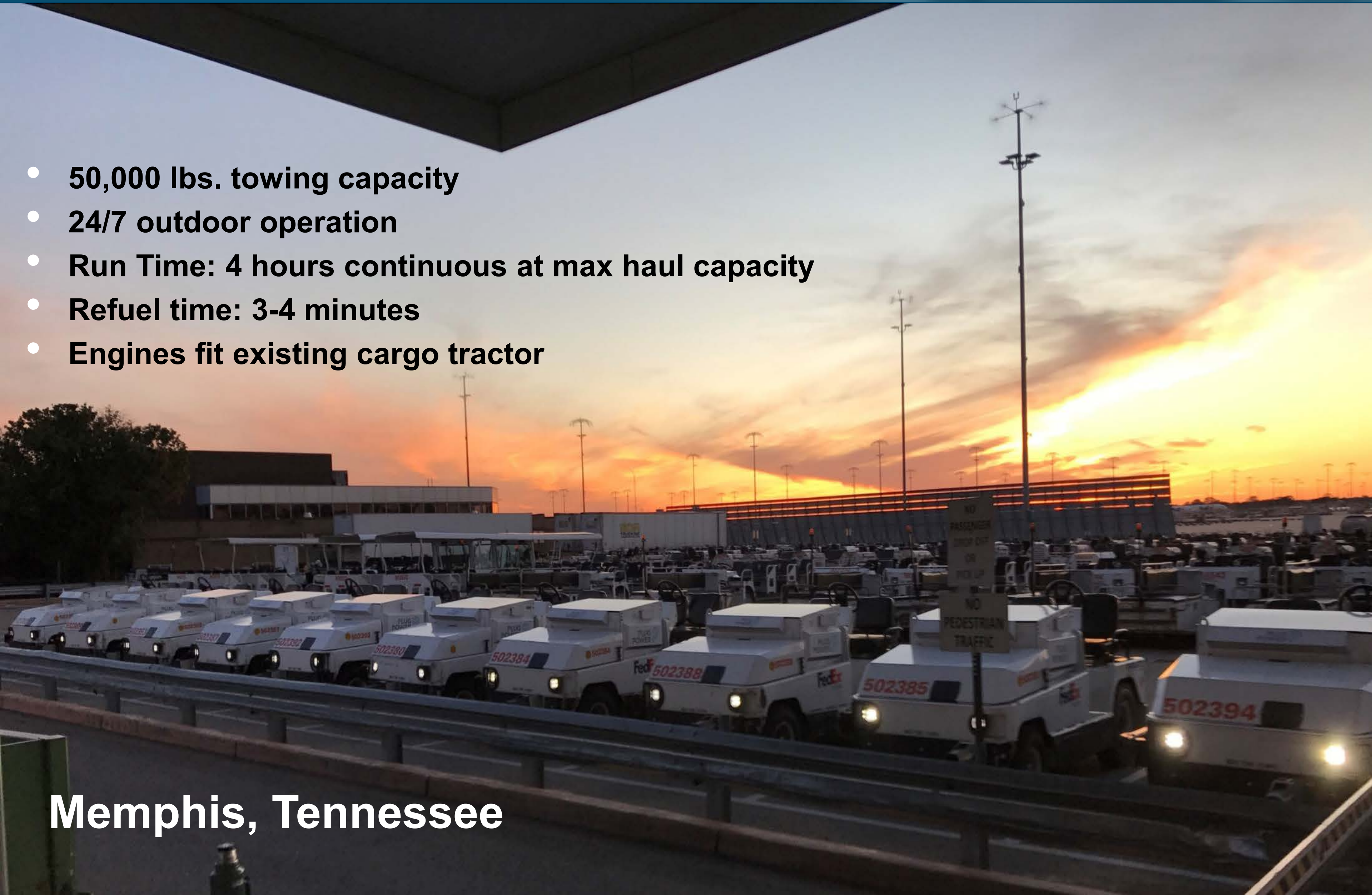
Hydrogen Cargo Tractor Fleet

- **50,000 lbs. towing capacity**
- **24/7 outdoor operation**
- **Run Time: 4 hours continuous at max haul capacity**
- **Refuel time: 3-4 minutes**
- **Engines fit existing cargo tractor**

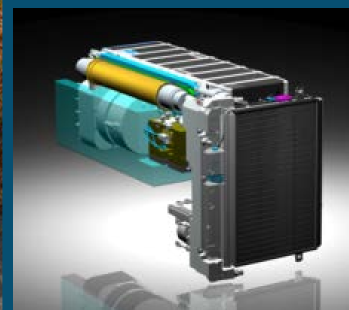
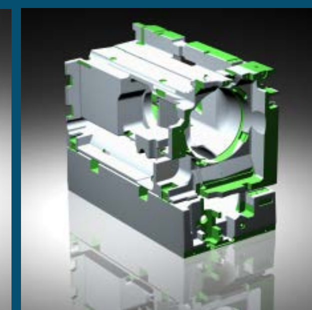


Memphis, Tennessee

Zero Emission Airport Ground Support Equipment

FedEx Express has deployed a fleet of hydrogen fuel cell cargo tractors at Memphis SuperHub

Fuel Cell System Architecture

Power: Fuel Cell / Li-Ion Battery	Energy Storage: H2 Tank	Tractor Traction: Ballast
		

Specifications

- Towing Capacity: 50,000 lbs.
- Voltage: 80VDC
- Power: 22 kW
- 100% Outdoor Operation
- Energy Storage: ~54 kWh (3.6 kg H_2)
- Hybrid PEM FC / Li-Ion Battery
- 4,000 lbs. for traction

Value Prop Drivers

- Energy efficiency: 45% FC vs. 20% diesel
- Energy recovery via regenerative braking
- Decreased maintenance costs
  - Oil changes eliminated
  - Brakes replacements eliminated
  - Starter replacements eliminated
- High Reliability / Availability
- Elimination of diesel idling

Experience in Toughest Domestic Airport

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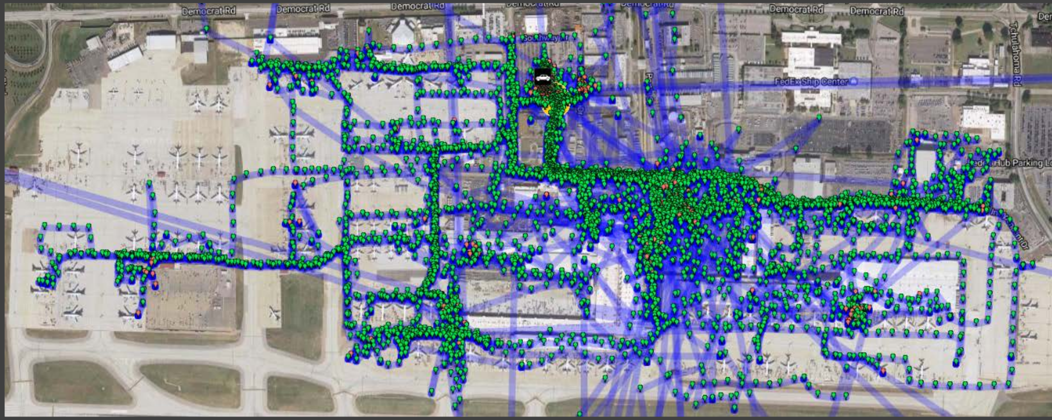
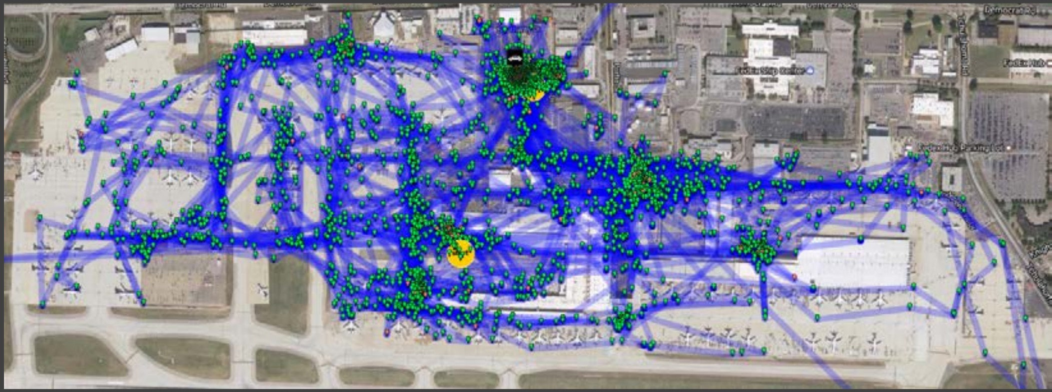
- Capable: **Usage throughout the airport in all applications**
  - **All routes, all use cases, no limitations**
- Reliable: **Greater availability than diesel tractors**
- Serviceability: **All operational issues resolved same day**
- Easy Fueling: **3-4 minute fills from liquid station on airport ramp**
- Rugged: **Withstands shock of tractor/dolly collisions**





GSE Fuel Solution: Liquid H2 Infrastructure

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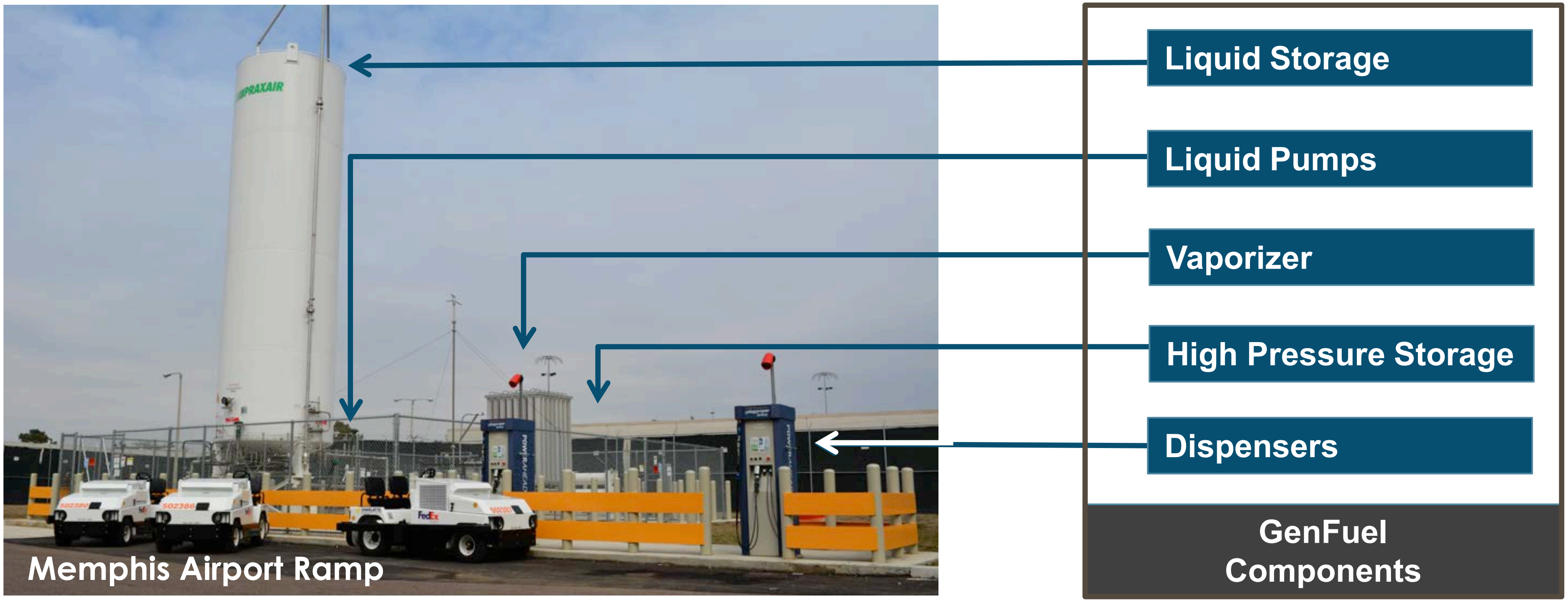
Specifications

- H2 Capacity: 15,000 gallons (4000 kg)
- Liquid temp: -253 deg C
- Liquid Pressure: 5 PSI
- Gaseous Storage: 60 kg (scalable)
- Gaseous Pressure: 350 bar (5,000 PSI)
- Dispensing Time: 1 kg/min

Mobile Refuelers can bring hydrogen from station to assets at airport gates.

Simple Dispensing



Memphis Airport Ramp

- As more hydrogen fuel is amortized over the CapEx, the all-in price drops.
- As more hydrogen is needed, little is needed to expand the site to accommodate greater fuel demands.

Value of Hydrogen GSE to Airport Operations

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Value Prop Drivers

- Energy efficiency: 45% FC vs. 20% diesel
- Energy recovery via regenerative braking
- Decreased maintenance costs

Ancillary Benefits

- Data to evaluate EV performance
- Prognostics - see issues before they happen, less downtime
- Lower noise and emissions - operator health benefits

Market Drivers

- Zero emission regulations
- Cost of compliance, creating more costly exhaust abatement
- Trend toward EV autonomy

Elimination / Reduction of Diesel Tractor Maintenance Items

- Oil changes
- DPF (Diesel Particulate Filter) changes
- Starters (policy to turn off tractor when getting off)
- Brakes (Regenerative braking minimizes replacement interval)
  - *Typical route is 1.8 miles including 10-12 stops.*
  - *Diesel tractors require heavy brake usage to stop 40,000 lbs.*

Battery Drawbacks vs. FC

- Charging infrastructure does not scale with fleet size
- Electrical infrastructure expensive to install – $30k/vehicle
- Demand charges can become significant given the energy needs of the vehicles.
- Fast charging is more costly to install and to charge.
- FC infrastructure scales very well from 10 to 1000 vehicles at a site. Incremental vehicles add little if any new cost.

2017 Summary

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2017 Accomplishments

- Remanufactured full tug fleet with Plug Power stacks
- 14 units shipped to Memphis | 1 unit maintained in Latham for testing of fleet improvements prior to roll-out to full fleet

2017 Fleet Metrics

- 11.4 MWh energy
- 7,800 FC hours
- 2,000 tractor hours
  (Disparity - FC remains on for idle / battery recharging so tractor is ready when put into drive)
- Availability > 90%
- Outlook favorable for future availability %

Mitigation of 2017 Top Issues Lists

1. Communications - board/software fixes
2. High H2 - vacuum-rated purge valves
3. Startup - software
4. High H2 - pressure regulation
5. 5V / 12V power - battery failures
6. High H2 - H2 sensor filament
7. High H2 - leaks

Planning for 2018

- Close budget period 2
- Locate 2 tractors at Albany Airport
- Explore prospects for migrating fleet from Memphis to another location in future

2017 Summary

	February	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Monthly Availability	95.9%	97.2%	97.0%	94.7%	97.7%	77.1%	92.0%	87.1%	81.9%	86.1%	84.6%
Monthly Day Utilization	49.4%	30.6%	15.0%	11.3%	19.3%	13.7%	19.2%	15.7%	22.0%	55.8%	47.6%
Monthly Night Utilization	56.5%	53.2%	32.4%	31.2%	43.3%	36.1%	49.7%	49.5%	46.3%	56.1%	47.4%
Total Energy	613.6	751.1	850.8	1121.9	1814.1	1527.6	1580.0	1452.2	1482.9	304.9	359.6
Total # of Sorts	90	104	86	94	146	102	126	137	140	318	274
Average Energy per Sort	6.8	7.2	9.9	11.9	12.4	15.0	12.5	10.6	10.6	1.0	1.3

Notes:

- Energy usage per sort increased in early months, mainly attributed to “ taking the training wheels off ” and using the tractors throughout the airport.
- July was a tough month for service (previously reported, communications issues). The high energy per sort is attributed to counting the complete sort as unit down (red) when some usage occurred during the sort, artificially raising the average.
- Energy per sort appears to be between 10 and 12 kWh as a net of energy out and energy recovery. Data collection in November and December was intermittent. Resulting estimations of usage led to higher sort counts.
- Night sort tends to use the tractors more regularly with night utilization approaching 50%.

Failure | Resolution Summary

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GSE Memphis Failures - February to October 2017						
	Shutdown	**Count**	**%**	**Root Cause**	**Failure Description**	**Improvements**
1	CAN communication	11	31%	Motor Controller Board	Board fails, which causes air blower to stop working and stops stack power generation.	1. Board re-work (containment) 2. Board redesign (long-term fix) 3. Software improvements (long-term fix)
2	High H2 detection (Safety shutdown)	9	25%	Purge Valve	Purge valves exhaust impurities in hydrogen stream from stack. Sometimes purge valves stick open longer than desired, resulting in excessive hydrogen overboard. Safety system shuts down system.	1. Clean purge valves with alcohol solution to remove impurities that gum up seating of valve (containment) 2. Identification of alternate solenoid solutions that have a strong spring to seat the valve in spite of accumulation of impurities (long-term fix)
3	System does not advance through startup sequence	5	14%	Software	Software gets hung up on a condition not being met for proper stack power export.	1. Sequence and condition improvements (long-term fix)
4	Low/high H2 pressure to stack	3	8%	H2 Pressure Regulator	Regulators reduce hydrogen tank pressure down to a specified stack inlet pressure. If the regulation is too low, there is insufficient hydrogen flow, resulting in low stack performance and shutdown.	1. Monitor H2 pressure in data (containment) 2. Adjustment as needed during regular PM checks (long-term fix)
5	Loss of 5V / 12V to System Control Boards	3	8%	Battery	Battery does not provide the 5V or 12V voltage to power the boards to operate the system.	1. Rework (containment) 2. Root cause analysis on 2 failed batteries
6	High H2 detection (Safety shutdown)	2	6%	H2 Sensor	The sensor drifts over time due to the materials used. The value in the presence of no hydrogen increases over time.	1. Monitor H2 value when H2 tank valve is closed (containment) 2. Material change in the hydrogen sensor to greatly reduce the sensor drift over time (long-term fix)
7	High H2 detection (Safety shutdown)	1	3%	H2 tubing leak	Hydrogen leaks from a fitting or tube.	1. Replacement of failed tubing (containment) 2. Redesign of tubing with thicker walls (long-term fix)
-	Other	2	6%			
	Total	**36**	**100%**			

Corporate Headquarters
968 Albany Shaker Road, Latham, NY 12110

West Coast
15913 E. Euclid Avenue, Spokane, WA 99216

plugpower.com