UNITED STATES POSTAL SERVICE®

Hydrogen Fuel Cells for Powered Industrial Vehicles

Department of Energy Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting

June 14, 2018

Project Overview

Project Overview
Background

USPS utilizes lead-acid battery systems to power its Powered Industrial Vehicles (PIVs) at Processing and Distribution Centers

USPS PIV Fleet

Forklifts
Class 1 MHE

Tow Motors
Class 3 MHE

Pallet Jacks
Class 3 MHE

PIVs are used to move mail and equipment throughout USPS processing centers

Project Overview
Key Issues

Current lead-acid battery systems are…

Costly to Operate and Maintain

- 8 hour charge, replaced 3x/day
- 6-8 min to replace battery per PIV
- 3 batteries/PIV: Charging (8 hours), “Cool-Off” (8 hours), Active (8 hours)
- 3-year battery lifespan
- Deteriorating charge slows PIV

Environmentally Unfriendly

- Batteries contain a regulated substance, sulfuric acid, which is:
  - Subject to federal reporting
  - Hazardous and can cause severe burns/injuries
  - Handling requires protective equipment for maintenance employees

Project Overview
Key Benefits

Hydrogen fuel cells (HFCs) provide USPS with an industry best-in-class alternative that deliver several benefits over lead-acid batteries (LABs).

Vehicle refueling and battery replacement costs

- Reduce refueling time
- Reduce PIV maintenance costs
- Eliminate or reduce the need for battery room operators

Plant and equipment productivity

- Increase PIV availability
- Reduce PIV fleet size required
- Increase PIV operator productivity

Environmental, health, and safety risks

- Reduce electricity consumption and greenhouse gas emissions
- Reduce regulated waste exposure and disposal cost
- May reduce regulatory Federal EPCRA reporting obligations if the battery room is closed

Washington NDC Pilot

Washington NDC Pilot
History

- Project started as a Lean Six Sigma Project at the Washington NDC to reduce costs and increase Powered Industrial Vehicle (PIV) Operator productivity
- Washington NDC worked with the Department of Energy and hydrogen fuel cell industry to evaluate the potential of the HFC system at the NDC
- Once the concept was understood, the Washington NDC identified Sustainability as an Executive Sponsor for the project
  - Performed economic analysis
  - Developed business case

Washington NDC Pilot
Pilot Objectives

The Office of Sustainability and the Washington NDC partnered to obtain approval and funding for the pilot project.

Washington NDC Objectives:

- Increase PIV Operator productivity
- Decrease PIV refilling and battery change costs
- Reduce electricity consumption
- Reduce regulatory reporting obligations and associated costs

Sustainability Objectives:

- Identify a cost-effective and more environmentally friendly alternative to lead-acid batteries
- Reduce greenhouse gas emissions
- Scale solution nationwide once technology proven in USPS operating environment

USPS Leadership approved the Hydrogen Fuel Cell Pilot Project on July 15, 2016.

Washington NDC Pilot
Equipment Acquisition

USPS selected Plug Power and Nuvera to provide the hydrogen fuel cell system.

NUVERA
Making hydrogen make sense.

- Installed the onsite generation system which includes;
  - 2 Generators/Reformers
  - 2 High Pressure storage tanks (62kg)
  - 1 Low Pressure storage tank (180kg)
  - 3 Compressors
  - 1 Chiller and Fan Skid system
  - 2 Hydrogen Dispensers
- Provides maintenance support of equipment

PLUG POWER®

- Provided and installed hydrogen fuel cells on PIVs
  - Total of 36 Class 1 Fuel Cells
  - Total of 49 Class 3 Fuel Cells
- Provides onsite maintenance support of fuels cell

Washington NDC Pilot
Facility and Equipment Map

Washington NDC Example System Space Requirements

HFC Space Requirements	
Interior HFC System	1,045 sq ft
Exterior HFC System	7,216 sq ft
TOTAL	**8,261 sq ft**

Washington NDC Pilot
Deployment Challenges

USPS was faced with a number of challenges when establishing and deploying the HFC technology at the Washington NDC.

Equipment Challenges:

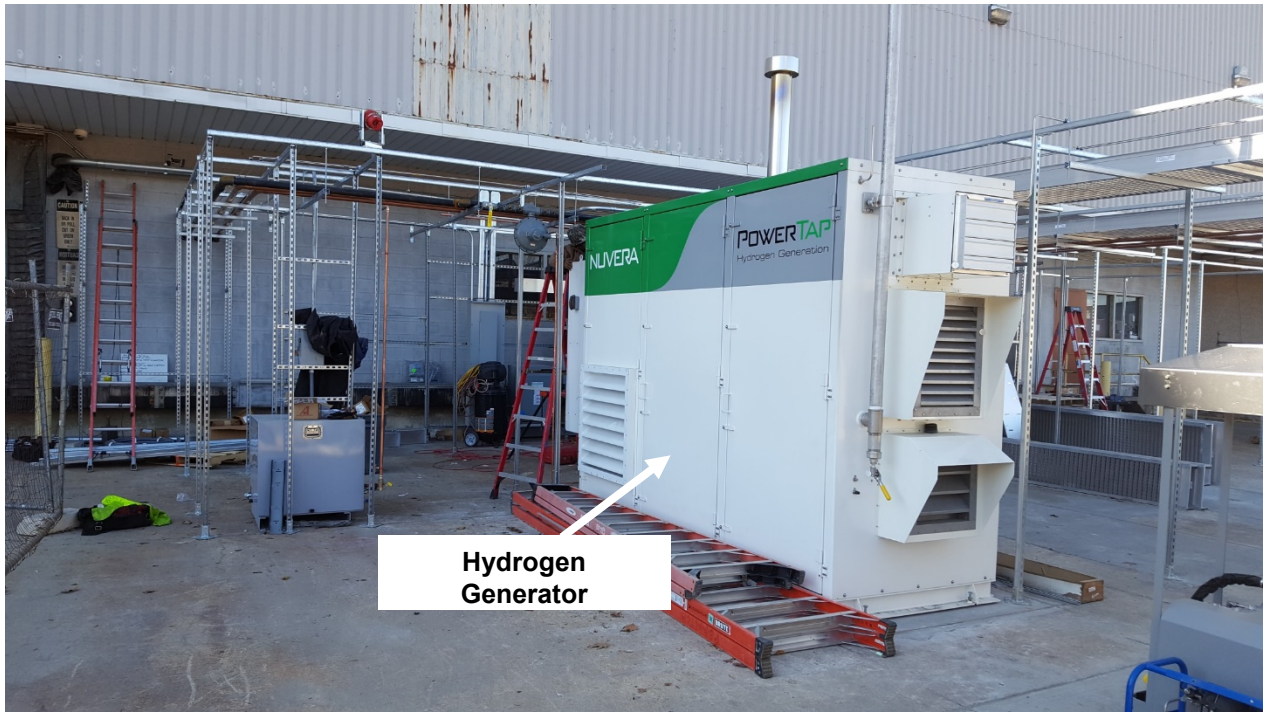
- Hydrogen capacity difficult to project due to the unique operation of the Postal Service
  - Lifting loads requires more hydrogen, then moving them around the facility
- Electrical system needed to be upgraded due to the age of the facility and the demands of the new system
- Concrete slab identified for H2 production and storage equipment was not suitable to hold weight of equipment.

Performance Measurement:

- Lacked adequate data collection and reporting systems and processes
- Required a suitable productivity metrics for technology
  - Picks per hour not a suitable metric in USPS' operating environment

Washington NDC Equipment
Nuvera Hydrogen Generator

Nuvera PowerTap Hydrogen Generator (PTG) (2 Units)
Generates hydrogen via steam methane reforming process



PTG generator dimensions (without vent stack):
15.1 ft (l) x 4.9 ft (w) x 9.0 ft (h)

Washington NDC Equipment
Nuvera Hydrogen Compressors

Nuvera PowerTap Hydrogen Compressor (PTC) (3 Units)
Uses electricity to compress hydrogen before storage

Washington NDC Equipment
Nuvera Hydrogen Chiller & Fan

Nuvera Hydrogen Chiller and Fan Skid

Washington NDC Equipment
Nuvera Hydrogen Storage Tanks

Nuvera PowerTap Hydrogen Storage (PTS)
Stores produced hydrogen at various pressures

Technical Specifications:
Storage:

- High Pressure (2 Units): Cascade Storage System (Hydrogen Accumulators) hold up to 62 kg each
- Low Pressure (1 Unit): Hydrogen Ground Storage (Hydrogen Reserve) Tank holds up to180kg
- Pressure: 431 bar (6,250 psig)

Operation at Performance Basis

- Operating temperature:
  - -10°C to 45°C (14°F to 113°F) standard
  - -30°C to 45°C (-22°F to 113°F) with cold weather package
- Natural gas consumption: 10.9 Nm3/h (2.25 gal/sec, 413 scfh)
- Electrical consumption: 8.2 kW

Washington NDC Equipment
Nuvera H2 Generation (Exterior)

Nuvera HFC System and NDC Pad Area

Exterior System Space Requirements	
Generators (2), Compressors (3), Storage (3), Chiller/Fan Skid, Safety zone	7,216 sq ft

Washington NDC Pilot
Nuvera Hydrogen Dispensers

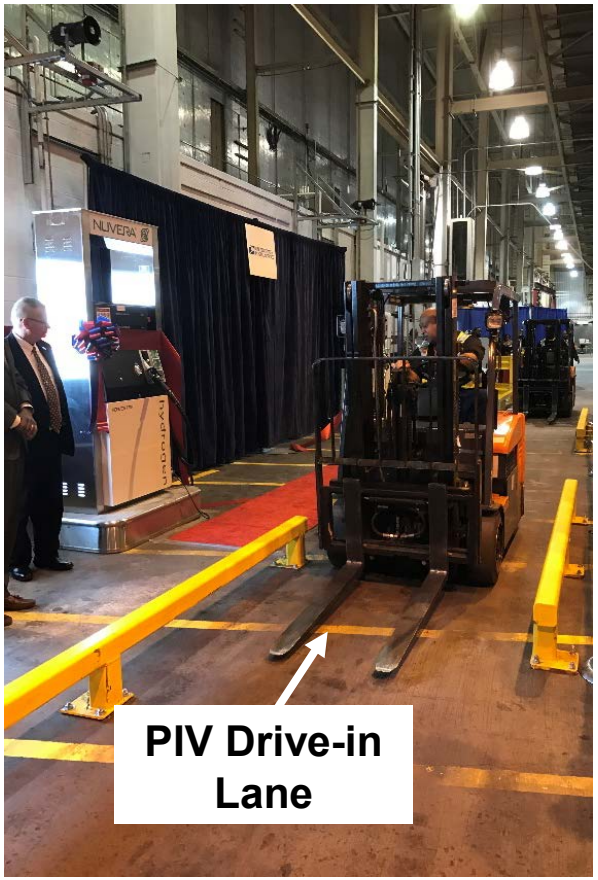
PowerTap Hydrogen Dispenser (PTD)
Indoor/outdoor dispenser with integrated leak check for fast, safe and simple refueling. Equipment used to refuel the PIV's fuel cell.

Technical Specifications:
- PTD dispenser area: 1.2 m x 1.2 m (4 ft. x 4 ft.)
- Electrical Hazard Area: Class 1 electrical hazard with 15 ft. radius from equipment
- Dispenser nozzle compliance: SAE J2600 - H 35 Type A

Hydrogen Output:
- Purity: 99.995% or greater (configurable)
- Dispensing pressure (settled): 350 bar (5,000 psig) at 15°C (59°F)
- Dispensing rate: 0.5 kg/min (211 scf/min)

Washington NDC Pilot
Nuvera Dispensers and PIV Lane

Nuvera HFC System and NDC Dispensing Area



Interior System Space Requirements	
Dispensers (2) and PIV Lane	1,545 sq ft

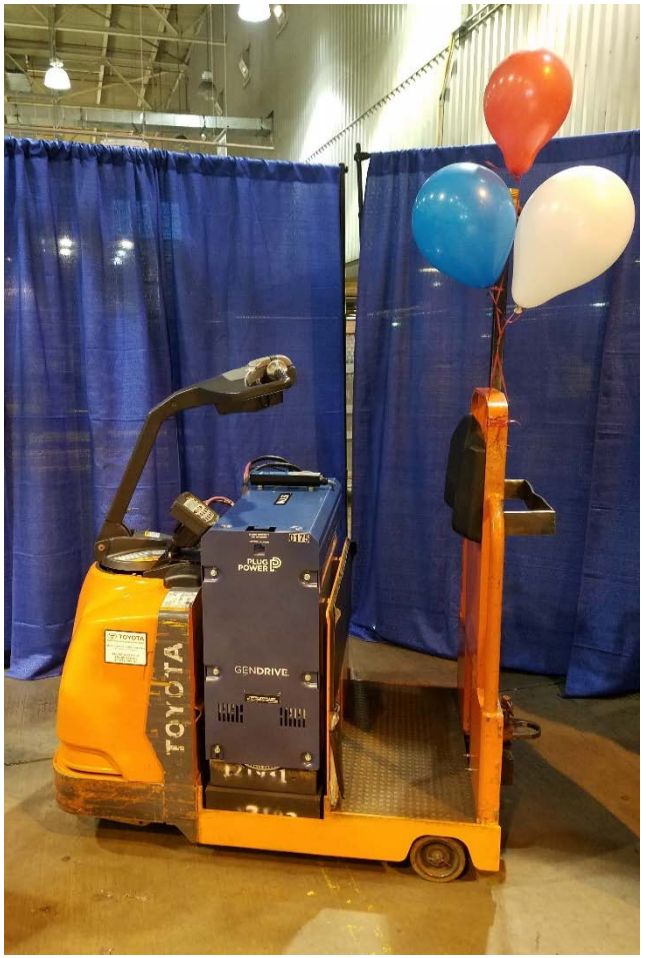
Washington NDC Pilot
Plug Power Hydrogen Fuel Cells

GenDrive 1000

GenDrive 3000

Washington NDC Pilot
Equipment Commissioning

The Washington NDC celebrated the commissioning of the Hydrogen Fuel Cell System on February 16, 2017



Washington NDC Pilot
Compatibility Issues

Following commissioning, the Washington NDC experienced an issue with the Class 3 PIVs

Forklifts
Class 1 MHE

Tow Motors
Class 3 MHE

Pallet Jacks
Class 3 MHE

Washington NDC Pilot
Compatibility Issues

Following commissioning, the Washington NDC experienced a singular issue with the Class 3 PIVs

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Tow Motors
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Pallet Jacks
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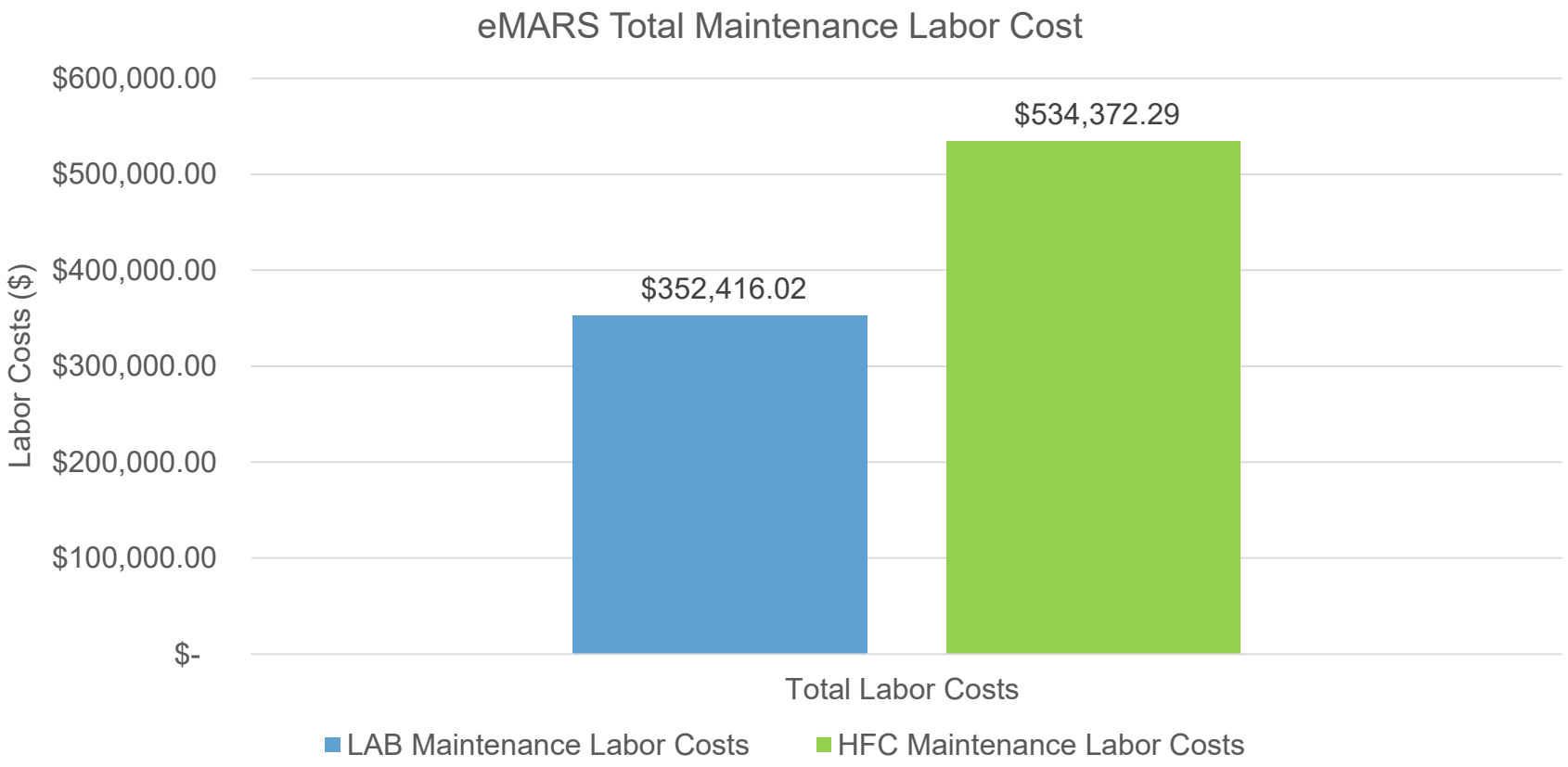
Washington NDC Pilot Performance Evaluation

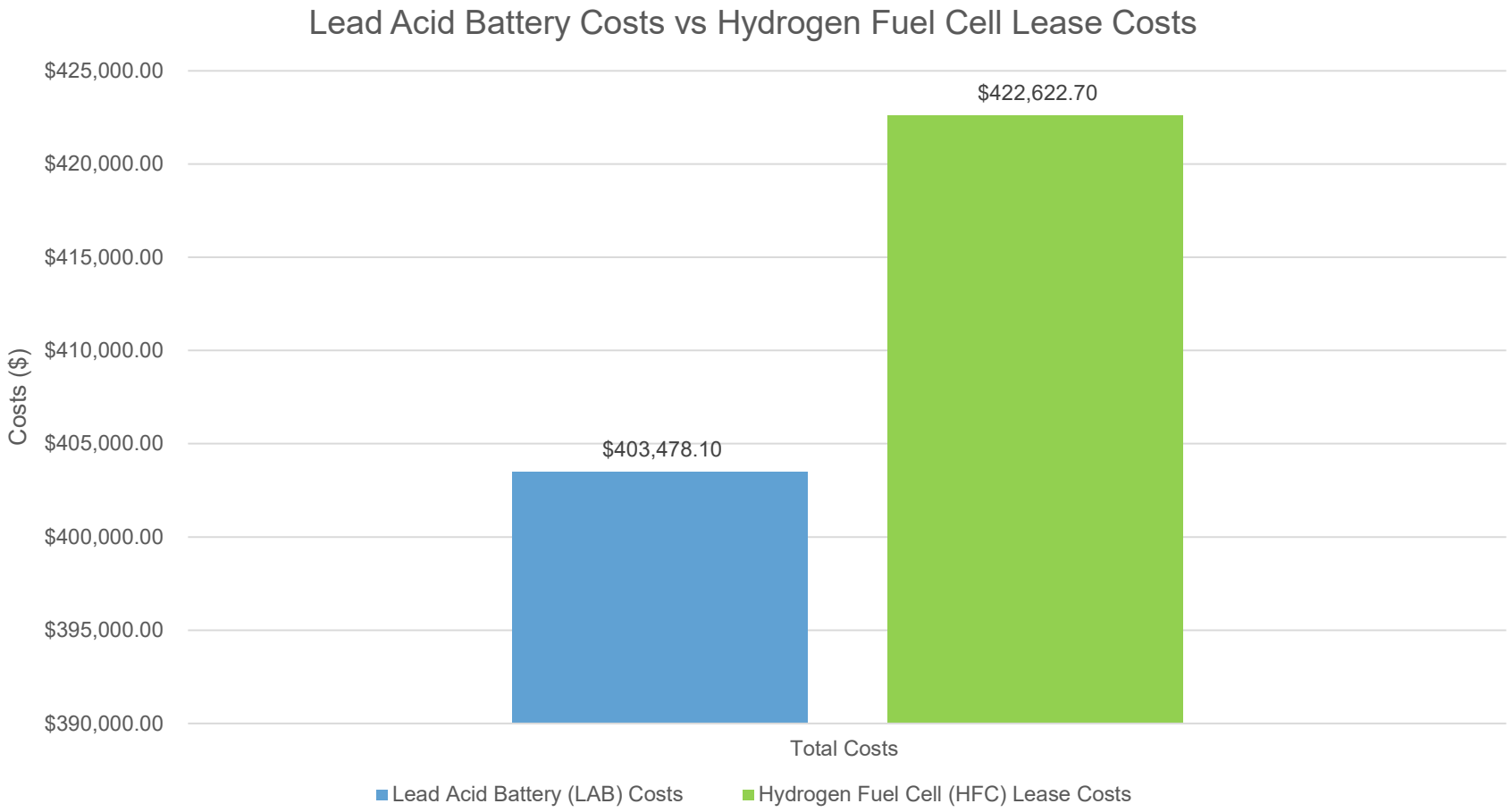
eMARS Data System
LAB vs HFC Maintenance Costs

Year-over-year maintenance labor hours increased due to the maintenance costs of the HFC system resulting in approximately $182k in additional costs



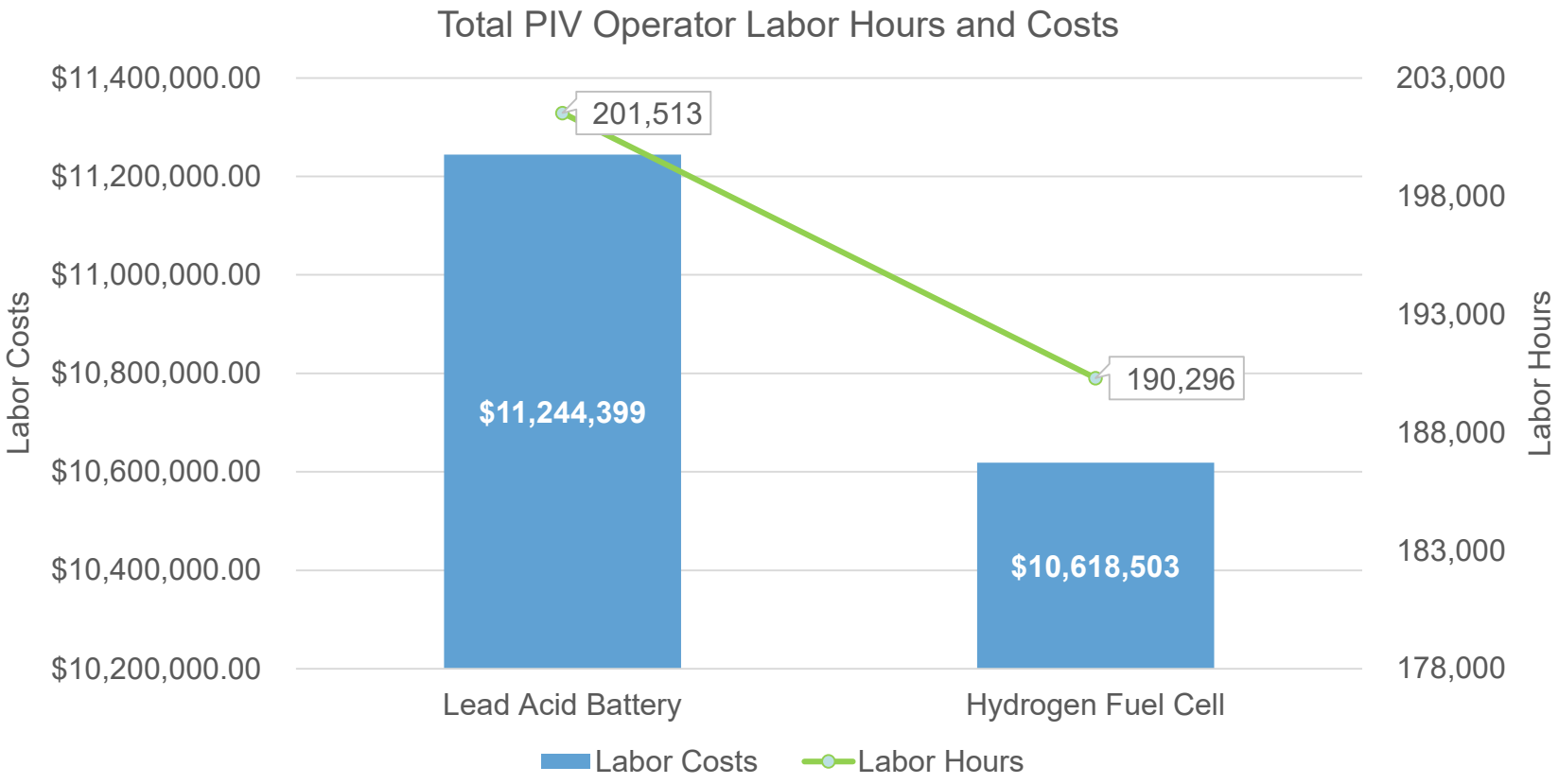
Washington NDC Pilot
LAB Costs vs HFC Lease Costs

Year-over-year overall equipment costs increased due to the lease costs of the HFC system resulting in approximately $19k in additional costs



Washington NDC Pilot
LAB vs HFC PIV Operator Hours

After HFC commissioning, PIV Operator Labor Hours decreased by approximately 11K hours, equating to a $625k labor savings



Cost Savings Breakdown
Productivity Labor Reduction

An estimated $3.9M in labor savings was realized due to a 27% increase in PIV Operator productivity.

Labor Productivity	LAB (2016-17)	HFC (2017-18)	Change	% Change
Total Containers	2,407,143	3,119,631	712,488	23%
PIV Operator Total Hours	201,513	190,296	(11,217)	-6%
Containers/Hour	11.9	16.4	4.4	27%

- **70,862 additional hours** would have been needed to load/unload the 3.1M in inbound/outbound containers this year utilizing the productivity rate associated with the lead-acid battery system
- This reduction in additional hours needed saved the NDC an estimated **$3.9M in PIV operator labor**

Washington NDC Pilot
Additional Cost Savings/Avoidance

The Washington NDC may realize additional labor, maintenance, and regulatory cost savings/avoidances once the battery room is closed.

Labor and Maintenance

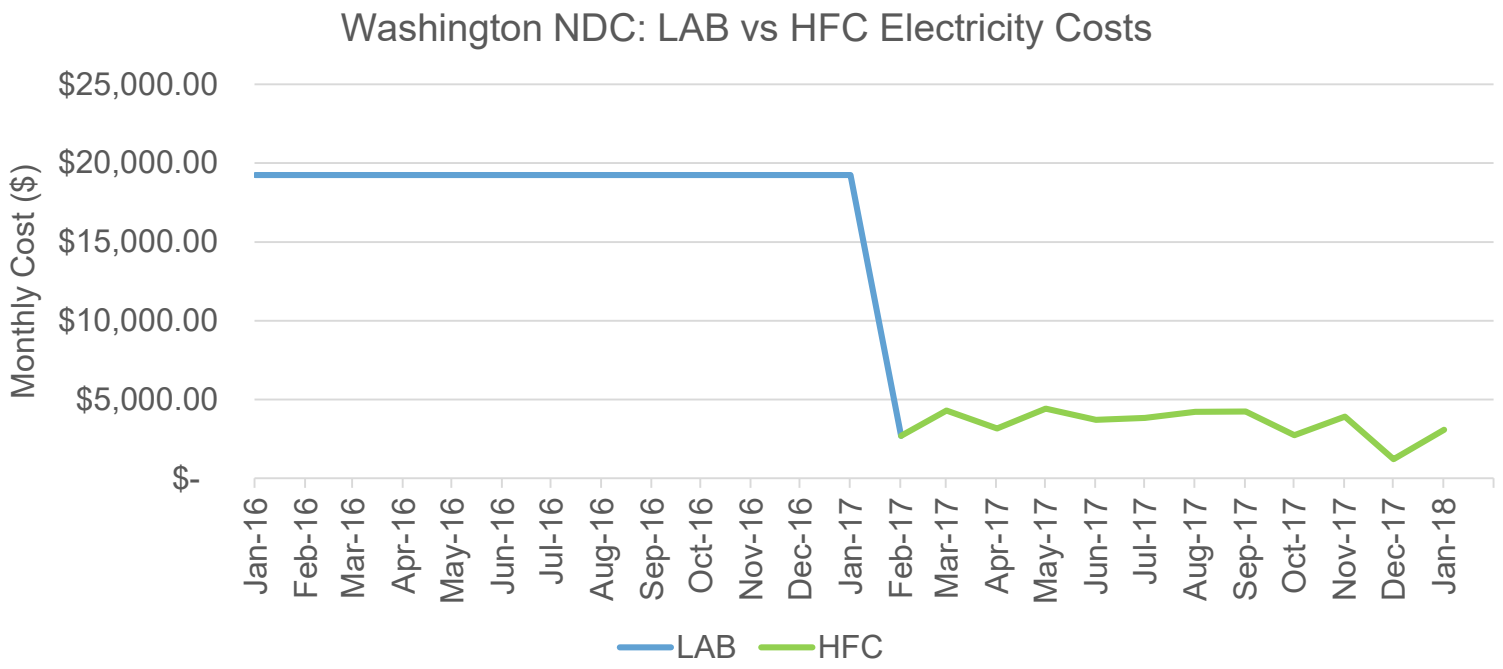
- **$652,897** in annual cost savings/avoidance will be realized as:
  - Battery room operators will be eliminated or reassigned
  - Preventative and corrective maintenance for batteries and associated equipment will be eliminated

Regulatory

- Annual administrative costs associated with completing Tier-2 reporting requirements
- Manpower costs for inspections
- Corrective action costs for any non-compliance issues based on regulator findings

Washington NDC Pilot
LAB vs HFC Utility Costs

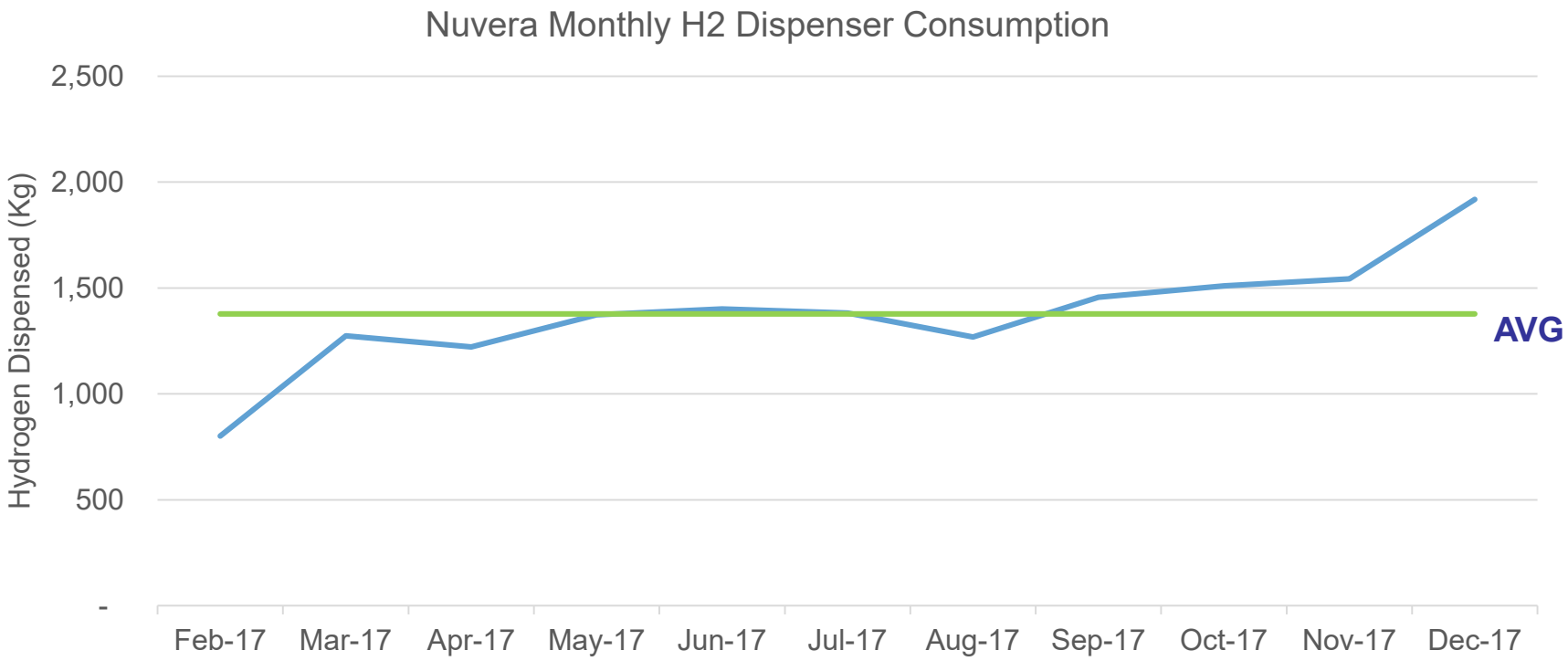
The Hydrogen Fuel Cell system saved the NDC an estimated $188k in electricity cost.



The HFC System saved over 2.1M KWH and reduced USPS greenhouse gas emissions by 1,570 metric tons.

Hydrogen Consumption
Nuvera Dispenser, 2/17-12/17

From 2/17 to 12/17, H2 consumption fluctuated monthly and averaged ~1,377kg/month



The overall daily average consumption of the system is currently 47kg/day, well below the 100kg/day threshold designed for the system at the Washington NDC

Hydrogen Consumption
Cost per Kg of Hydrogen

Cost per kg of H2 Generated		
Cost Factor	**Total Average Cost per Kg of H2**	
Electricity (kWh)	$	2.51
Gas (Therms)	$	2.84
Water (Gallons)	$	0.01
Sewer (Gallons)	$	0.01
Total	$	5.37

15 years useful equipment life and no salvage value.

The overall daily average consumption of the system is currently 43kg/day, well below the 100kg/day threshold designed for the system at the Washington NDC

Hydrogen Consumption
Cost per Kg of Hydrogen

Cost per kg of H2 Generated		
Cost Factor	**Total Average Cost per Kg of H2**	
Electricity (kWh)	$	2.51
Gas (Therms)	$	2.84
Water (Gallons)	$	0.01
Sewer (Gallons)	$	0.01
Equipment Depreciation (15 Years)	$	10.91
Maintenance	$	13.75
Total	$	30.03

15 years useful equipment life and no salvage value.

The overall daily average consumption of the system is currently 43kg/day, well below the 100kg/day threshold designed for the system at the Washington NDC

Washington NDC Pilot Project
Financial Summary

- **$3.45 M Total Investment**
- **$18.8M Operational Savings in a 5-Year timeframe**
- **107% ROI with a 1.96 year payback.**

Note:
This does NOT include the savings associated with the closure of the Battery Room and the 3 full-time equivalent positions that could be eliminated. *All* of which are achievable outcomes that would drive payback down to approximately 1.5 years and an even higher ROI.

Washington NDC Pilot Next Steps

The pilot project ended March 2018.

Next steps for the project include:

- Replace older non-compatible PIVs with newer models
- Close battery room at the NDC to realize additional savings and cost avoidance opportunities
- Prepare Final Pilot Performance Report
- Present pilot findings to Executive Leadership
- Plan for the deployment of the technology at additional sites

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Questions?