INCREASE PRODUCTIVITY WITH LOWER CARBON EMISSIONS: THE IMPACT OF HYDROGEN ON POWERED INDUSTRIAL VEHICLES

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INTRODUCTION

This paper will explore the history of hydrogen as a fuel for industrial vehicles, the current state of PIVs, and the potential for hydrogen fuel cells as a power source for PIVs. We will also highlight current developments by OneH2, a hydrogen fuel production and distribution company seeking to create a zero-emissions future by expanding access to hydrogen fuel. Finally, we will highlight the benefits hydrogen provides as a fuel source for PIVs compared to those of ICE and BEV vehicles.

Whether managing a small warehouse or a large-scale distribution center, today's material handling operations require reliable fleets of powered industrial vehicles (PIVs) such as forklifts or pallet movers. Traditionally, PIVs have run on internal combustion engines (ICE) powered by fossil fuels such as gasoline, propane, or diesel. In recent decades, many operations have transitioned their fleets to battery electric vehicles (BEV) powered by lead-acid batteries.

Both ICE and BEV options create several operational and logistical challenges. ICE-powered PIVs create carbon emissions that make them ill-suited for indoor use. PIVs powered by lead-acid batteries require lengthy downtimes to recharge and experience decreased power over the life of the battery. BEV also require a robust electrical infrastructure that requires significant space and must adhere to strict safety procedures when handling batteries due to their strong acid content.

Technological improvements in hydrogen fuel and fuel cells have created a viable alternative fuel source for PIVs. A recent pilot program by the U.S. Postal Service tested hydrogen fuel cell-powered PIVs in its Washington Distribution Center. The results from this study indicated that hydrogen fuel cells offered the zero-emissions benefits of BEVs at a lower cost.

	PROS	CONS
INTERNAL COMBUSTION ENGINES	Quick refuel time Availability of replacement parts	Require frequent maintenance High carbon emissions Fuel and oil leaks create slip hazards
BATTERY ELECTRIC VEHICLES	Zero carbon emissions Improved indoor air quality	Lengthy recharge times Decreased power over battery life Potential burn risk
HYDROGEN FUEL CELLS	Zero carbon emissions Improved indoor air quality Quick refuel times No burn risks	Require hydrogen fuel source (on-site or delivered)

BACKGROUND

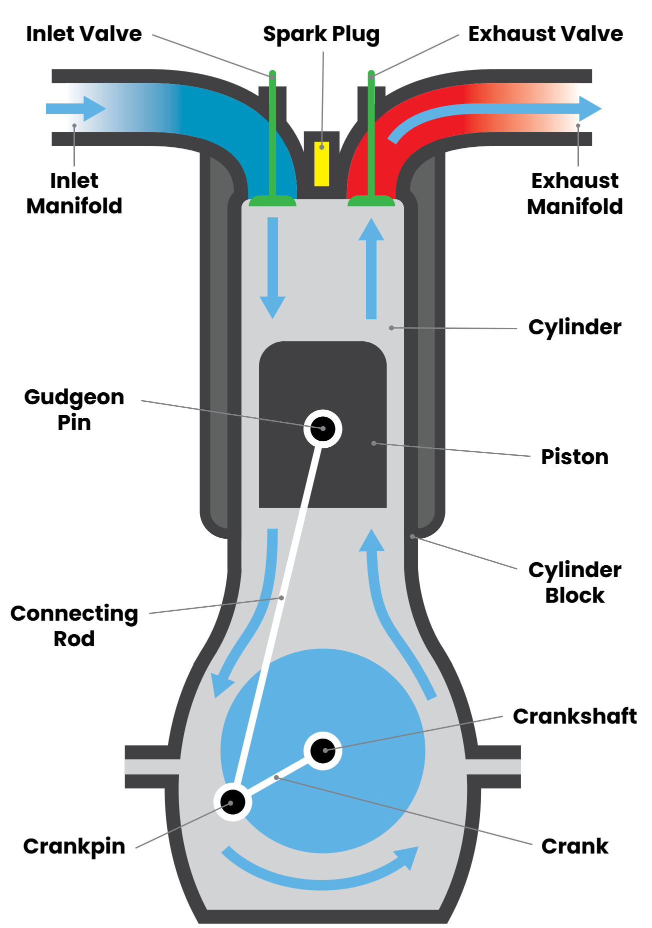
Hydrogen was first identified in 1766 by Henry Cavendish. Shortly afterward in 1800, British scientists William Nicholson and Anthony Carlisle discovered electrolysis, the process wherein water molecules are split into oxygen and hydrogen gasses by applying an electric current (National Hydrogen Association, 2023). In 1839 Sir William Bell harnessed the energy-carrying power of hydrogen by producing the first fuel cell. Francis T. Bacon expanded on this discovery in 1958 by creating the first practical hydrogen fuel cell. Bacon's innovation has been used as an onboard energy supply for NASA space missions and provides the basis for many of today's efforts to utilize hydrogen as a clean energy solution (Grimaldo-Guerrero et al., 2021).

Fuel cells share similarities with both batteries and internal combustion engines. Like an ICE, fuel cells are open systems that rely on external fuel storage (Encyclopedia Britannica, 2023). However, like a battery, fuel cells convert chemical energy into electricity without the need for a combustion reaction within the system (Energy.gov, 2023). Fuel cells offer the efficiency of a battery without the limitations of depleted power capacity over time.

Today, many companies have converted their industrial vehicle fleet to battery electric vehicles (BEVs). Despite the growing popularity of BEV fleets, internal combustion engines still power the majority of forklifts and other industrial vehicles currently in use due to their superior convenience and performance. Internal combustion engine (ICE) vehicles can be refueled quickly but require regular maintenance to ensure the engine is working properly. Emissions from ICE vehicles pose potential health hazards, particularly when operated indoors. Fuel and oil leaks can also create exposure and slip hazards for workers (United States Department of Labor, Internal Combustion 2023).

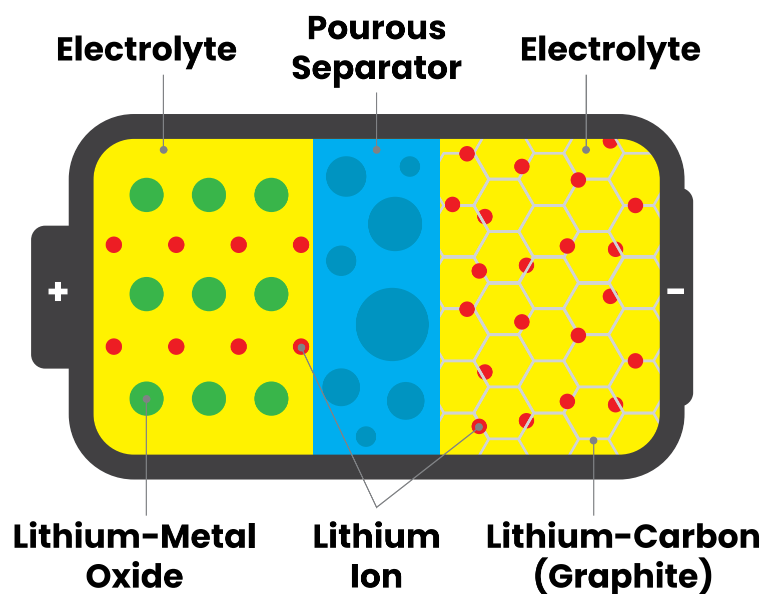
While battery vehicles offer the workforce clean-air alternatives to combustion vehicles, the caustic, lead-acid batteries required for BEV increase the risk of burns and lifting

INTERNAL COMBUSTION ENGINE

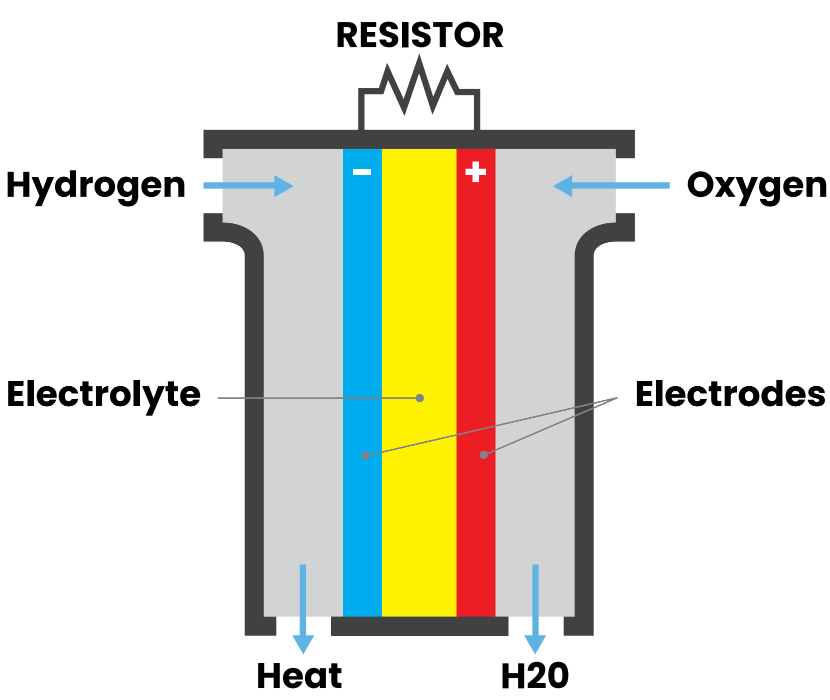


injuries, while also making extra work for employees (United States Department of Labor, Electric 2023). BEVs also require lengthy recharge times, which can decrease profitability due to decreased uptime or increased labor time for workers changing out vehicle batteries. Spacing requirements to house batteries for BEV while they recharge can also pose an issue for operations seeking to maximize the productivity of their footprint.

LEAD-ACID BATTERY



HYDROGEN FUEL CELL



Industrial vehicles powered by hydrogen fuel cells offer the zero-emissions benefits of BEVs without the added risk of injury from lead-acid batteries. They provide quick refueling times to maximize uptime and decrease labor hours. When industry-recommended safety procedures are followed, hydrogen fuel is safer than fossil fuels or BEVs.

With the emissions benefits of BEVs and the quick refueling time of vehicles with internal combustion engines, hydrogen fuel cells provide the optimal combination of the advantages ICE and BEV vehicles offer, while avoiding the disadvantages of each.

USPS CASE STUDY

Recently, The United States Postal Service implemented a pilot project to determine the operational and financial impacts of switching its powered industrial vehicles (PIVs) from lead-acid batteries to hydrogen fuel cells. The pilot took place in the Washington Network Distribution Center (NDC) from February 2017 to March 2018.

Prior to the pilot project, the United States Postal Service (USPS) predominantly used lead-acid battery systems for the PIVs in its Processing and Distribution Centers. PIVs used included forklifts, tow motors, and pallet jacks. The battery systems negatively impacted productivity due to their extended charging times, short lifespan, and intensive labor time required to charge them. While the battery systems decreased emissions compared to engines powered by fossil fuels, they posed an additional health risk due to their sulfuric acid content.

Under the pre-pilot system, the lead-acid batteries had to be swapped out three times per day due to their 8-hour run time per charge. For every 8 hours of runtime a battery offered, it had to undergo 16 hours of downtime; 8 hours to recharge and 8 hours to "cool down." This required each PIV to have three batteries to maintain a 24-hour uptime schedule. Batteries take approximately six to eight minutes to change over. They offer a three-year lifespan however, as they age the batteries' ability to power the PIV decreases, resulting in slowed operations.

LEAD-ACID BATTERIES ARE...

COSTLY TO OPERATE AND MAINTAIN

- Require 8 hours to charge, must be replaced 3x/day
- Takes 6-8 min to swap batteries for each powered industrial vehicle (PIV)
- Each PIV requires 3 batteries for 24-hour uptime:
  - Charging (8 hours)
  - "Cool-Off" (8 hours)
  - Active (8 hours)
- Batteries have a 3-year lifespan
- PIV power decreases as the battery charge decreases

ENVIRONMENTALLY UNFRIENDLY

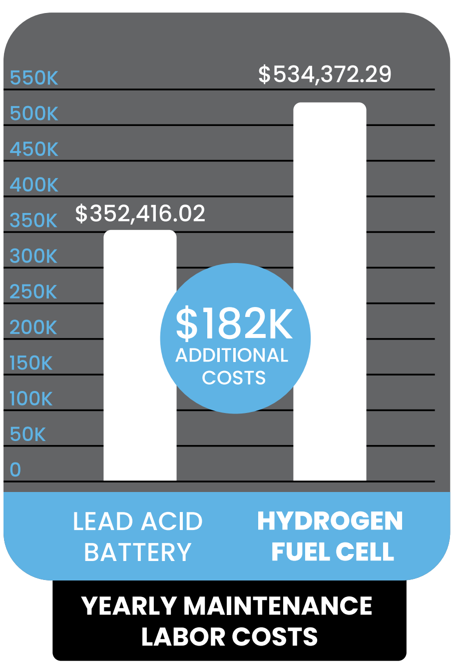
- The sulfuric acid contained in lead-acid batteries:
  - Is monitored under federal reporting
  - A hazardous material that can cause severe burns and injuries
  - Requires maintenance employees to wear protective equipment when handling

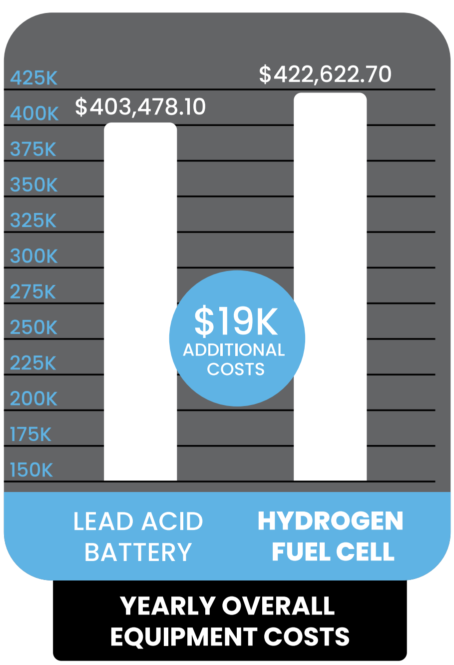
The goals for the USPS study fell into two main categories; operating costs and sustainability. The Washington NDC wanted to explore hydrogen fuel as a lower-cost alternative to battery-powered PIVs. They theorized that reduced time swapping out batteries and reduced electrical consumption would lead to decreased operation costs. However, they wanted to maintain the emissions-free operations of the current BEVs.

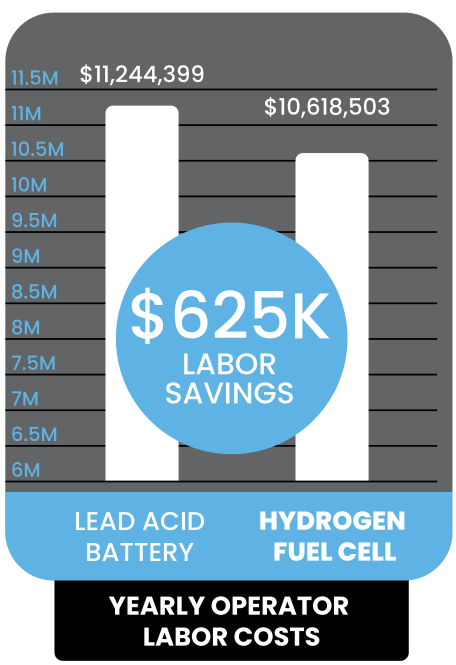
For the study, OneH2 supplied the on-site hydrogen generation system. The on-site generation system included two generators/reformers, three storage tanks, three compressors, one chiller and fan skid system, and two hydrogen dispensers. Fuel cell systems were incorporated into Class 1 and Class 3 PIVs. The exterior footprint for the hydrogen generation system was 7,216 square feet and the interior footprint was 1,045 square feet for a total project footprint of 8,261 square feet.

The system used steam methane reformation (SMR) to generate hydrogen for the PIVs.

After installing the hydrogen fuel systems, USPS encountered some equipment and reporting challenges to implementing the pilot program. Equipment challenges included; difficulty estimating hydrogen capacity for USPS operations, upgrading the electrical system to accommodate increased demands, and the concrete slab originally slated to house the hydrogen generation and storage equipment was not rated for the weight of the equipment. Another challenge arose in reporting the results of the pilot program. USPS needed to develop metrics for productivity to compare the new hydrogen fuel system to the previous lead-acid battery system. For this metric, they opted to compare the number of containers moved during the year-long study to that of the previous year.



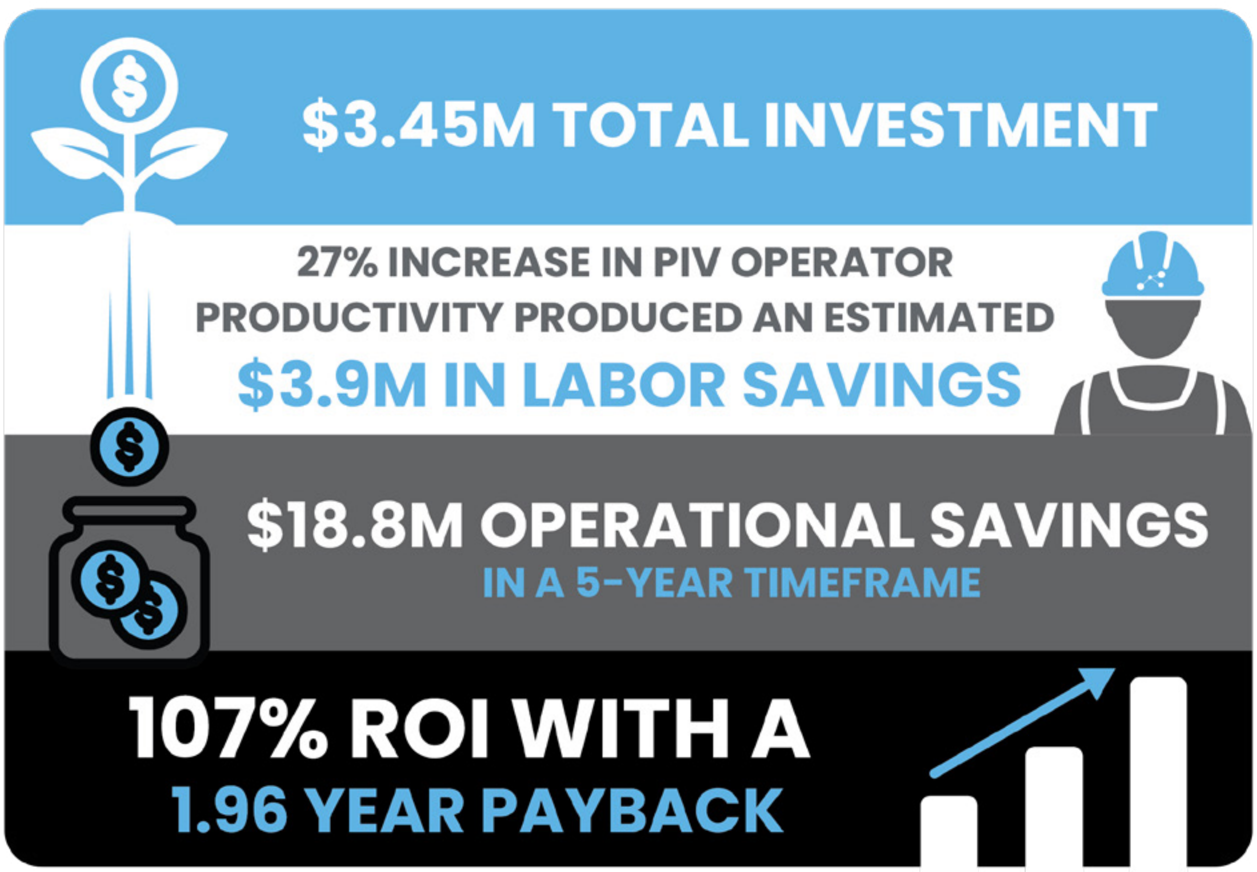




Upon completion of the year-long study, the USPS found that switching to hydrogen-powered forklifts had a significant impact on productivity and operating expenses. PIV operator productivity increased by 27%, realizing labor savings of approximately $3.9 million. In spite of slight increases in maintenance labor hours ($182,000), and equipment costs ($19,000), the USPS found a net decrease in overall operating costs due to increased productivity. PIV operators' labor decreased by 11,000 hours, resulting in a cost savings of $625,000. Using the previous lead-acid battery systems, the Washington NDC would have needed an additional 70,862 labor hours to move the same amount of containers as it did while using the hydrogen-powered forklifts.

The decreased labor costs came as a result of increased uptime made possible by the hydrogen-powered forklifts. The hydrogen fuel systems required less operator time to recharge/refuel and did not require batteries to be swapped out every eight hours. The forklifts also maintained steady power throughout the year, as opposed to battery-powered systems which lose power capacity over the life of the battery and throughout the working day as the charge deteriorates.

FINANCIAL IMPACT



During the study, the USPS distribution center realized net savings in electricity costs of $188,000. The hydrogen fuel system had lower electricity requirements than the previous lead-acid battery systems and decreased greenhouse gas emissions by 1,570 metric tons.

The overall financial impact of the study revealed that switching the Washington NDC industrial vehicle fleet to hydrogen fuel cells generated substantial cost savings compared to the startup investment. After the one-year pilot program, the Washington NDC found that its initial $3.45 million investment could generate $18.8 million in operational savings over five years and generate 107% ROI in just under two years. Additional savings could have been realized by closing a previously-operated battery room and eliminating or reassigning three full-time equivalent positions. Moving forward, USPS planned to replace older PIV models that were not compatible with hydrogen fuel cells with newer, compatible models to facilitate broader adoption of hydrogen power throughout the fleet. It also intended to convert additional distribution center fleets to hydrogen-powered vehicles (U.S. Department of Energy Hydrogen Program, 2023).

ONEH2 SOLUTIONS

For companies looking to adopt clean energy alternatives for their operations like the USPS Washington NDC did, OneH2 provides cost-effective and scalable hydrogen energy solutions. Founded in 2015, OneH2 develops new approaches to generating, distributing, and storing hydrogen fuel with the goal to support a zero-emissions future by offering hydrogen fuel as a clean alternative to fossil fuels.

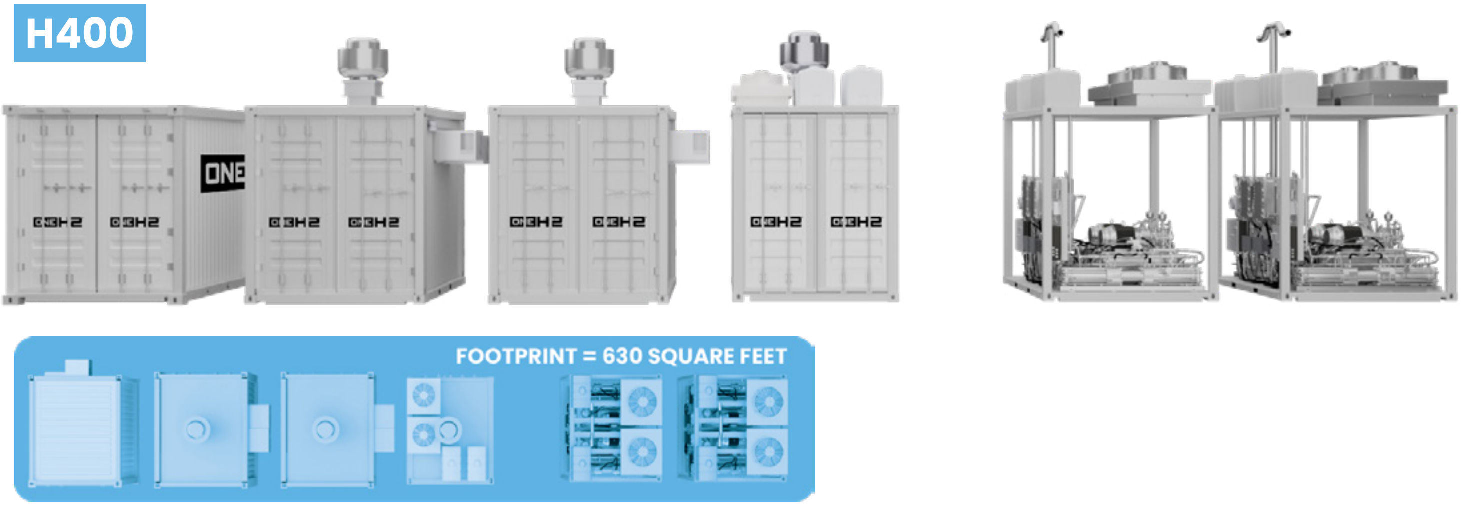
OneH2 offers on-site hydrogen-generation equipment similar to that used in the USPS pilot program. Due to OneH2's continued improvements in hydrogen-generation technology, their current hydrogen solutions further strengthen the positive outcomes in cost savings and performance advantages seen in the USPS case study. For companies that aren't ready to invest in an on-site hydrogen terminal, or who need to supplement their on-site generation, OneH2 also offers hydrogen delivery services by the kg.

OneH2's solutions are unique in their flexibility. Companies can select on-site and/or delivered hydrogen. For companies with on-site hydrogen generators, OneH2 offers scalable packages to tailor the hydrogen output to fit each company's unique energy needs. If a company generates more hydrogen fuel than it can use internally, OneH2 provides a hydrogen buy-back service. This allows the client to recoup some of its investment in hydrogen generation and supports OneH2's hydrogen delivery program.

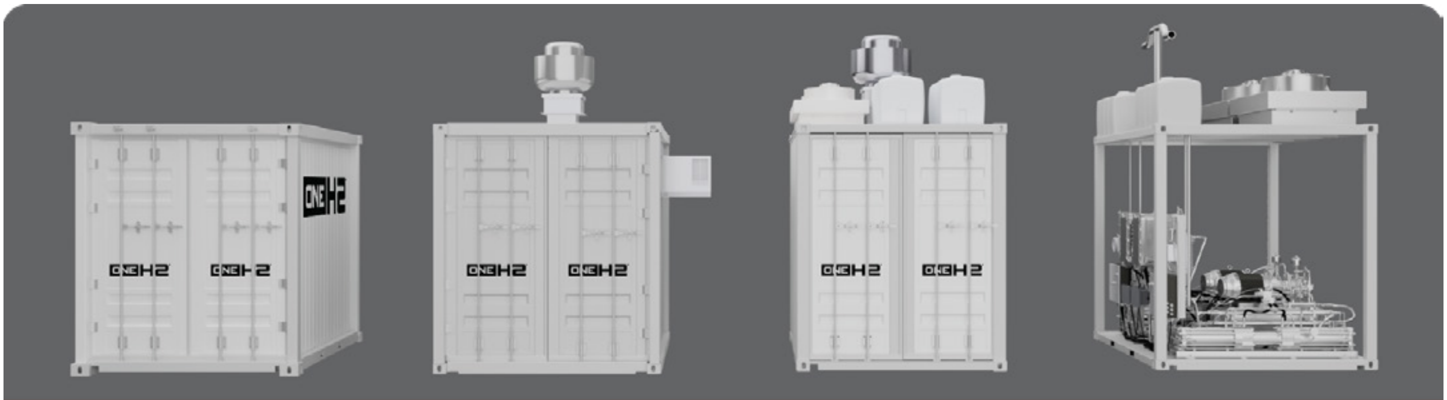
OneH2 offers both steam methane reformation (SMR) and electrolysis generator options. Currently, SMR generators are more widely used due to the availability of feedstock. This method of producing hydrogen fuel creates some carbon emissions during the generation process. However, there are no emissions generated when the fuel is used, making it a zero-emissions energy source according to current emissions standards.

OneH2's on-site hydrogen generators are available in two models, the H200 and the larger H400, named for their output capacity (200 kg and 400 kg per day, respectively). These generators can work as single units or be combined to provide increased capacity for larger operations. When combined with interior hydrogen dispensers, OneH2's generators are ideal for fueling industrial vehicle fleets such as those in the USPS pilot program. OneH2 designed its generators and dispensers with simplicity in mind, making them more reliable and easier to operate and maintain. Through service agreements, OneH2 delivers, installs, maintains, and monitors all of the hydrogen-generation systems to ensure their clients meet their uptime requirements. OneH2 offers leasing or purchase options on all of its generators and equipment.

H400



H200



W400 MODULE	G400 MODULE	P400 MODULE	C200 MODULE
Purifies and stores potable/city water ready to generate hydrogen.	Combines purified water (from W400) and methane (from Grid) to generate raw hydrogen gas.	Purified gas recieved from G400 to >99.99% purity and conformance with SAE J2719 standard.	Compresses gas received from P400 to 14,000 PSIG / 965 BAR. Interfaces with OneH2 gas distribution modules.

For companies that are not ready to invest in on-site hydrogen generation, or that want to supplement their on-site generation systems, OneH's delivered hydrogen program offers a reliable way to run their operations with hydrogen fuel. With this program, OneH2 provides trailers of hydrogen gas carriers on a scheduled or as-needed basis. Trailers include live monitoring systems to track the fuel level in each trailer and automatically set up replacement deliveries so clients never experience downtime due to fuel shortages.

These systems can be wet-hosed to in-warehouse dispenser systems or use the on-trailer dispenser option.

Hydrogen fuel can be utilized across many industries. From powering industrial vehicles such as those used in the USPS case study to hydrogen-powered semi-trucks, OneH2 continues seeking new hydrogen fuel applications. OneH2's goal is to help build a national hydrogen infrastructure by helping more companies incorporate on-site hydrogen generators.

TRAILER DELIVERY

DISPENSER

FUTURE OF HYDROGEN FOR PIVS

With companies like OneH2 continuing to refine the technology for generating, distributing, and storing hydrogen fuel, the barriers to entry for hydrogen-fueled powered industrial vehicles (PIVs) will continue to decrease. As electrolysis-based hydrogen technologies develop, hydrogen fuel will become an even cleaner energy source. Transitioning from steam methane reformation (SMR) to electrolysis as the primary method of hydrogen generation will allow it to be virtually emissions-free both in the production and utilization processes. Since electrolysis does not require methane, it offers a method for further reducing the environmental impact of hydrogen fuel and reducing the reliance on fossil fuels.

Transitioning internal combustion engines to hydrogen fuel offers an additional opportunity for reducing carbon emissions. Utilizing this existing technology with a zero-emissions fuel alternative, like hydrogen could provide added efficiency to operations at a reduced cost. Using hydrogen fuel to power ICE vehicles could also mitigate the higher costs associated with manufacturing hydrogen fuel cell drivetrain systems and training technicians to repair them.

Federal and state investments in hydrogen generation will benefit early adopters of this fuel technology. With incentive programs available, and many government representatives seeking to regulate carbon emissions, companies who transition their operations to be powered by hydrogen fuel will be able to capitalize on incentive programs and stay ahead of regulatory trends.

CONCLUSION

Hydrogen fuel is an economically viable clean energy source that will empower directors of material handling operations to streamline their operational costs and improve production efficiency, all while conforming to new emission regulations and helping the planet. This is evidenced by the outcomes seen in the USPS case study. Over the course of the one-year pilot program, the Washington NDC realized significant cost savings in both labor and electricity and saw substantial gains in productivity.

For companies looking to replicate the success USPS found in the pilot program, OneH2 offers innovative hydrogen fuel solutions that can be designed to fit their operational needs. As hydrogen fuel technology and infrastructure improve, OneH2 will continue to support efforts to expand access to this innovative clean energy alternative.

To learn more about OneH2's hydrogen fuel solutions, visit **oneh2.com**

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