

Applying Hydrogen Fuel Cells to Lift Trucks

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Introduction

The Raymond Corporation is continuing its history of innovation by investigating and evaluating the application of hydrogen fuel cells to lift trucks. Based on its research, there appears to be significant potential to improve warehouse productivity if fuel cells are used in high-throughput warehouse applications. Now that hydrogen fuel cells are commercially available, it is important to understand that switching to fuel cells can have an impact on the operation of a lift truck originally designed to use lead-acid batteries. In addition, case-by-case considerations must be made to determine whether a facility will benefit from converting its lift truck fleet to use hydrogen power.

Raymond's Fuel Cell Research

Raymond is a global provider of electric lift truck innovations, delivering advanced, reliable, cost-effective lift trucks and solutions that make its customers more productive. Raymond offers a full line of electric lift trucks. *Raymond*[®] branded products are produced at three different factories, each of which specializes in the manufacture of distinct product lines.

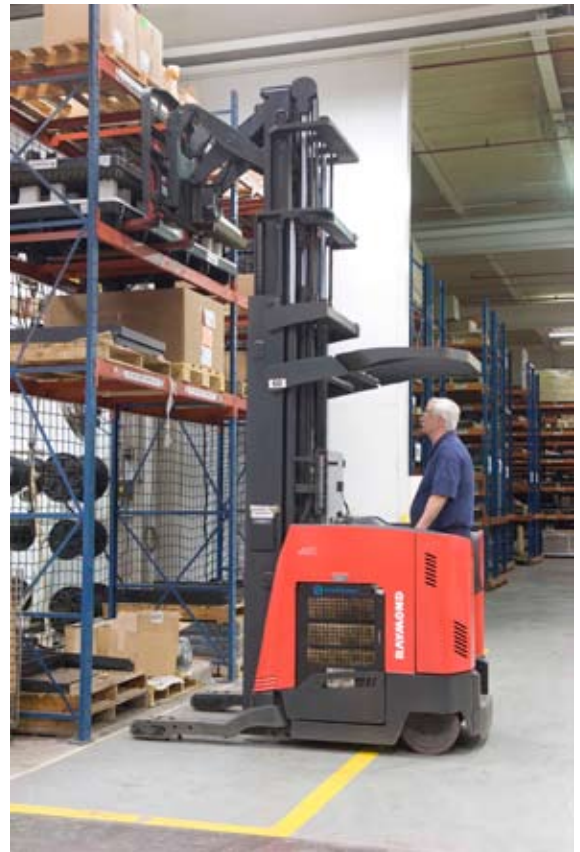
Raymond started reviewing the use of fuel cells in material handling early in 2004, primarily because customers were inquiring about this technology. Raymond evaluated fuel cell suppliers and continues to actively work with all the major companies to gain experience with the technology.

In 2007, Raymond developed a research program with a contract from the New York State Energy Research and Development Authority (NYSERDA) and the New York Power Authority (NYPA) to perform a study on the performance of hydrogen fuel cells in lift trucks and the use of indoor hydrogen fueling stations in a real-life manufacturing environment. Early findings in the study indicated that, in comparison with battery-powered lift trucks, hydrogen fuel cell-powered lift trucks maintain comparable performance while significantly reducing refueling time.

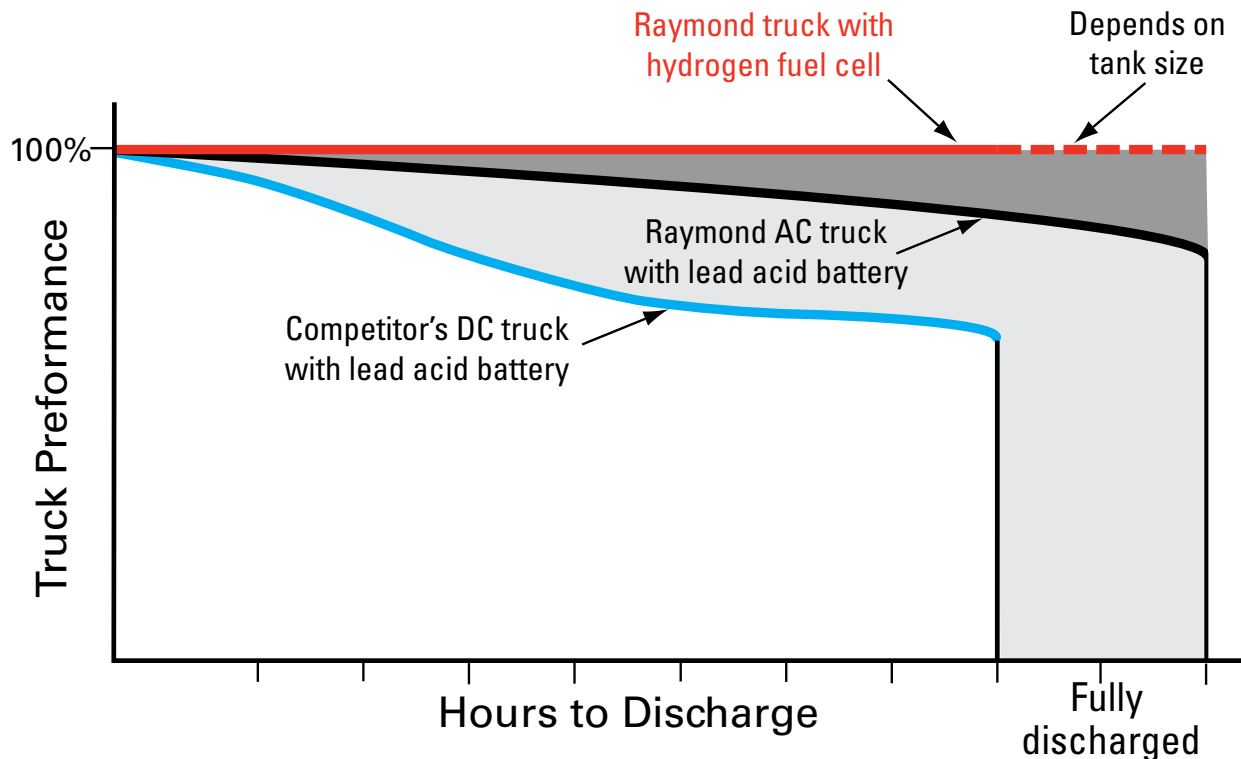
In 2008, Raymond signed a joint development agreement with a major fuel cell developer to begin research on designs for fuel cell-powered lift trucks. The goal of this partnership is to develop a prototype using the next generation of fuel cell technology to power Raymond lift trucks.

Fuel Cell Benefits

The basic question remains: What are the benefits to using a fuel cell rather than a lead-acid battery? Lead-acid batteries are a reliable, familiar technology that is readily available from multiple suppliers. In the design of a lift truck, batteries also provide needed counterweight.



However, lead-acid batteries have limited range. At most, they will last one shift in a high-throughput warehouse. The recharging cycle is long, typically taking one shift to charge and then another shift to cool down. For a three-shift operation, three batteries and a charger may be needed, as well as room to store and maintain them. Battery voltage drops as the battery discharges, which leads to reduced truck performance. Finally, special care is needed when disposing of batteries due to their lead and acid content.



During the first two years of its research program, Raymond uncovered several assessments and benefits of hydrogen fuel cell-powered lift trucks, compared with battery-powered lift trucks:

1. Maximum travel and lift speeds of hydrogen fuel cell-powered trucks are equivalent to that of battery-powered lift trucks.
2. Refueling a fuel cell truck at an indoor hydrogen refueling station takes only a couple of minutes compared with the up to 20 minutes it takes to remove and replace a battery from the same truck model.
3. In today's electric lift truck designs, the battery acts as part of the counterweight. Hydrogen fuel cell components do not weigh the same as heavy lead-acid batteries, so additional weight must be added to the fuel cell unit. This weight must be distributed within the fuel cell system so the center of gravity is the same as that of the battery it replaces. Future lift trucks will likely have the fuel cells wholly incorporated into the design of the trucks to address these issues.

Hydrogen fuel cells offer higher productivity simply because they can be rapidly refueled by the operators, eliminating the need to change, store and maintain batteries. In addition, fuel cells produce constant voltage. There is no voltage drop towards the end of a shift like there is with batteries, so productivity does not decline. Unless the fuel runs out, the vehicle experiences no performance

degradation — like a car and its gas tank. And hydrogen is environmentally clean: the only byproducts from a fuel cell are water and heat.

Although fuel cell-powered lift trucks are not yet rated for the low temperatures of freezers, fuel cells could perform better than battery-operated lift trucks in cold storage environments. When lift trucks with lead-acid batteries are driven in freezers, the range and performance of the truck is reduced because the cold temperatures significantly reduce battery run time between charges. Performance is maintained in a lift truck with a fuel cell because the voltage and current remain the same at cold temperatures.

Lead-acid Batteries	Hydrogen Fuel Cells
Reliable, familiar technology	New technology; additional testing in progress
Provide needed counterweight in lift truck design	Additional weight must be added to the fuel cell unit to maintain counterweight
Typically last one shift in a warehouse; takes up to 20 minutes to change	Can be refueled in minutes during a shift
Recharging cycle is long: one shift to charge and one shift to cool down	No recharging required
Multiple batteries and chargers required for multishift operations; storage space is necessary	No batteries, chargers or battery room required
Lift truck performance drops as battery discharges or in cold temperatures	No performance degradation as hydrogen depletes or in cold temperatures

Evolutionary Application

There is a three-stage evolution in the application of fuel cells to lift trucks, which affects lift truck design.

Battery replacement.

In this step, the lead-acid battery is removed and replaced with a fuel cell system of the same size, weight and energy capacity. The truck operates as before and does not know it is being powered by a fuel cell. A slightly more complex version of the battery replacement step involves adding a field-installable fuel cell adapter kit. This kit might include additional counterweight or a

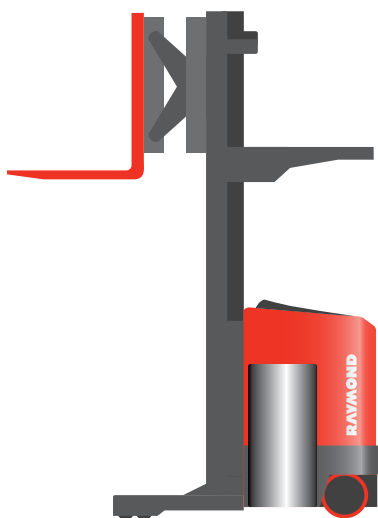


Figure 1:
Battery Replacement

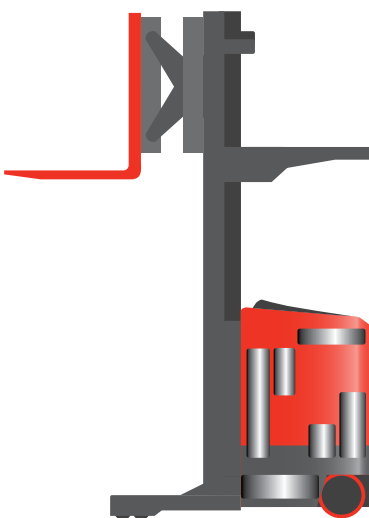


Figure 2:
Existing Platform
Modification

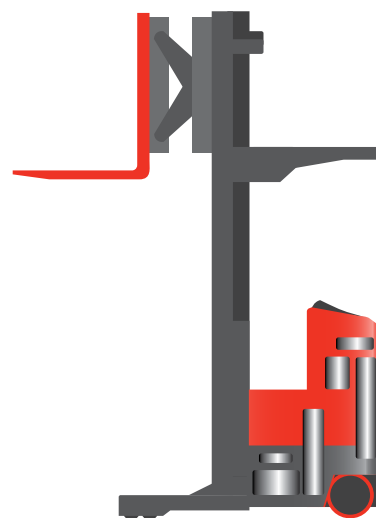


Figure 3:
Concept Design

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communication cable between the truck and the fuel cell. While the complete battery replacement can be developed by a fuel cell supplier, development of the adapter kit requires cooperation between the fuel cell supplier and lift truck manufacturer.

Existing platform modification.

In this case, an existing truck design is used, with the fuel cell components distributed in an optimum way around the truck. The new truck would be available with a fuel cell option. Development of this truck would require very close cooperation between the truck manufacturer and the fuel cell supplier.

Clean sheet design.

Ultimately, a new truck is designed from the ground up to take full advantage of the modular nature of the fuel cell system. The fuel cell would be completely integrated into the truck and could not use a conventional battery. The truck manufacturer would do most of the development while working closely with a fuel cell supplier.

Using Fuel Cells Today

Raymond does not build fuel cells, but works closely with major fuel cell suppliers to ensure that fuel cell technology is compatible with *Raymond* trucks now and in the future. Raymond's intention is to provide customers the widest range of options and be prepared to meet their fuel cell needs.

Because the evolution of hydrogen fuel cell-powered lift trucks requires close cooperation between fuel cell suppliers and lift truck manufacturers, Raymond has been actively involved in the Industrial Truck Association's Energy Storage System (ESS) committee to facilitate discussions between lift truck manufacturers and ESS manufacturers. This discussion ensures fuel cells or other ESSs — such as lithium-ion batteries or supercapacitors — meet lift truck requirements.

These criteria can help ensure the ESS meets the minimum lift truck requirements and operates as an effective lead-acid battery replacement. By helping to define these criteria, lift truck manufacturers can make it easier for fuel cell manufacturers to design a power source that integrates with today's lift trucks.

Future lift trucks may fully encompass the fuel cell in the design, but according to the preliminary work of the ESS committee, today's lift trucks require the fuel cell to emulate batteries in five key areas:

Size.

In today's lift trucks, the hydrogen fuel cell needs to fit in the same space occupied by the battery. Defining the available space for the hydrogen fuel cell, which varies in different types of lift trucks, ensures the fuel cell will fit in a lift truck designed for a lead-acid battery.

Weight.

When hydrogen fuel cells are used as battery replacements, they must meet the same minimum and maximum weight requirements listed on the lift truck's specification tag for batteries. Meeting the weight requirement is a critical factor in ensuring the stability of the lift truck. Hydrogen fuel cells can be significantly lighter than lead-acid batteries, so fuel cell manufacturers typically add steel plates to their fuel cell units to make up for the weight required.



Center of gravity.

In a lift truck powered by a lead-acid battery, the center of gravity of the battery is the geometric center of the battery box. In a fuel cell unit that is being used as a battery replacement, the unit incorporates many separate components, including a hydrogen tank, a fuel cell stack and steel counterweight added to meet the minimum weight requirements. Balancing the placement of these components is necessary to ensure the proper center of gravity. Lift truck manufacturers need to perform tests or analysis on each lift truck they intend to use or approve for use with a fuel cell to determine the exact tolerance for where the center of gravity can be located.

Power delivered.

Different types of lift trucks are designed for different applications and capabilities, and varying amounts of power are required to accomplish these tasks. Specifying the current and voltage delivery requirements of the lift truck at various time durations ensures the lift truck receives the power from a hydrogen fuel cell that is necessary to maintain acceptable performance in various applications.

Power absorbed.

When electric lift truck brakes are applied or forks are lowered, they can create regenerative energy. This energy must be absorbed by the energy source, and hydrogen fuel cells are not able to recapture energy like lead-acid batteries. Therefore, all hydrogen fuel cell units are actually hybrids and contain a battery or supercapacitors. It is necessary to define how much regenerative energy each lift truck creates that needs to be absorbed by the battery or supercapacitors. As with power delivered, lift truck manufacturers can specify the maximum and minimum current and voltage generated by the lift truck as it brakes from various speeds or lowers forks with different amounts of weight for different time durations. If the fuel cell unit is unable to absorb the energy generated, then a fault code would be generated that could potentially disable the lift truck.



Return on Investment

Return on investment for facilities that switch to hydrogen fuel cells depends on many variables specific to each facility's applications. Typically, the larger the fleet, the quicker the payback will be. Cost savings can come from several areas. Battery changes, which may take 15 or 20 minutes each, are not necessary in a fuel cell fleet. A fuel cell truck may run up to three times longer than a battery-powered truck, and refueling takes less than 5 minutes. Labor savings and productivity increases multiplied across a large fleet running two or three shifts can be hundreds of hours per month. While fuel cell users need to buy hydrogen, electricity use will decrease because no batteries are being charged. Cost per kWh may decrease as well because peak electric usage is reduced.

An investment in fuel cells and the required hydrogen fueling infrastructure can be justified in lift truck fleets of approximately 40 or more trucks with a two-shift operation. Fleets of this size will typically see a return that justifies the investment. Individual warehouses and distribution centers need to conduct a detailed financial analysis, including the local cost of hydrogen, to determine whether switching to hydrogen fuel cell-powered lift trucks is appropriate for their operation. A lift truck manufacturer or dealer can assist in conducting a thorough investigation and evaluation of fuel cells.

An investment tax credit (ITC) is available from the U.S. federal government to those who purchase fuel cell technology. The ITC provides business property owners with a credit of 30 percent of the cost of the fuel cell units or \$3,000 per kW of capacity, whichever is lower. The credit has been extended to 2016 and has a significant impact on the financial viability of a fuel cell project. Also, a tax credit is available for the purchase and installation of the hydrogen infrastructure for 30 percent of the cost of the project, up to \$200,000. Some states also provide tax credits for fuel cell purchases. Companies should check with their own tax advisors for information on the potential financial benefits of taking this tax credit.

Considerations for Getting Started

The first step in choosing to make the switch to hydrogen fuel cell-powered lift trucks is to evaluate the facility's interest in and commitment to new technologies. The facility must thoroughly evaluate the cost of implementation, potential cost reductions and productivity gains that can be realized by using hydrogen power.

Companies choosing hydrogen fuel cell-powered lift trucks will need to work with multiple vendors to supply fuel cells, hydrogen and hydrogen storage systems. In addition, no single supplier currently provides fuel cells for Class I, II and III electric lift trucks.

Facilities also will need to determine how hydrogen will be delivered and stored on site, or if the hydrogen will be generated on site. With either method, a hydrogen infrastructure and indoor refueling system will need to be installed.

The scope and scale of the project must be determined to develop a plan for how fuel cell-powered lift trucks will be implemented in the warehouse or distribution center. Some facilities choose to begin with a pilot project using a small subset of their lift truck fleet. In other cases, facilities choose to switch their entire fleet to hydrogen power. In either case, it is necessary to ensure the lift trucks are properly prepared for fuel cells in order to make the switch from batteries to fuel cells as smooth as possible.

Ongoing Evaluation

Currently, Raymond is continuing to test, monitor and analyze many other areas of fuel cell research, including:

- > Operation details of the hydrogen infrastructure and refueling
- > Hydrogen consumption and refueling frequency
- > Longer-term reliability, maintenance and repairability of fuel cell systems
- > Voltage delivered by a fuel cell and how it compares with the specifications for all the electrical components and options on a lift truck

Today, early industry adopters are using fuel cell technology in their facilities. However, the areas for ongoing evaluation, among others, must be analyzed before the material handling industry adopts a widespread use of hydrogen fuel cell-powered lift trucks.

Material handling trade associations, such as the Industrial Truck Association, are reviewing the technology with its Energy Storage Systems group. NYSERDA



has created a Fuel Cell Advancement team to support New York state companies in the development of fuel cell systems and projects. The US Department of Energy (<http://www.hydrogen.energy.gov>) and The National Hydrogen Association (www.hydrogenassociation.org) also are promoting fuel cell research, development and deployment. Information on hydrogen initiatives, listed alphabetically and by state, can be found on the Web site www.hydrogenassociation.org/policy/initiatives.asp.

Through its ongoing work with fuel cells, Raymond is adding to its rich history of customer-centric innovation and continuing to be at the forefront of this alternative energy source for electric lift trucks.

About the Author

Steve Medwin is manager of systems and advanced engineering at The Raymond Corporation. Since 2004, he has been evaluating the application of fuel cell technology to the material handling business. Before joining Raymond, Medwin spent 20 years in research and development at DuPont. He holds nine U.S. patents and is a member of the UL 2267 Standards Technical Panel for Fuel Cell Power Systems for Industrial Electric Trucks and chairman of the new Energy Storage Systems committee of the ITA.

Medwin received his bachelor's degree in mechanical engineering from Cornell University in Ithaca, N.Y., and his master's degree in mechanical engineering from the University of Pennsylvania in Philadelphia. He also has completed the Executive MBA program at Binghamton University in Binghamton, N.Y.

