Application of Fuel Cells to Fork Lift Trucks

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Introduction

The Raymond Corporation is continuing its history of innovation by investigating and evaluating the application of fuel cells to fork lift trucks. Based on its initial work, there appears to be significant potential to improve warehouse productivity if fuel cells are used in high throughput warehouse applications. Therefore, Raymond will closely follow the developments in this field so that when the technology is commercialized, our trucks and our organization will be ready.

Who is Raymond?

The Raymond Corporation leads the U.S. market in electric lift truck innovations, delivering advanced, reliable, cost-effective lift trucks that make its customers more productive.

At its three plants in Greene, New York, Muscatine, Iowa, and Brantford, Ontario, Canada, Raymond produces a full line of electric lift trucks.

It all started in 1922, when George Raymond Sr., an industrial engineer from Brooklyn, NY acquired the Lyon Iron Works in Greene, and proceeded to focus its efforts on developing new kinds of material handling equipment like hydraulic pallet jacks. George was a visionary, and an innovator.

Raymond patented the very first bi-directional entry wooden pallet in the 1930s, developed the L4P hydraulic pallet jack—which lifted 2,000 lbs.—in the 1940s; and successfully introduced the first narrow aisle lift truck in 1950. This was followed by introduction of the very first *Reach-Fork*® truck in 1954.

Narrow aisle trucks provided warehouses with a revolutionary way to store materials and increase warehouse capacity. This saved customers with distribution businesses millions of dollars each year.

As warehousing standards changed, so did customers' material handling equipment needs. In the following decades, The Raymond Corporation remained in the forefront of lift truck development by pioneering many leading-edge concepts that made material handling operations more productive and efficient.
Beginning in the late 1980s, Raymond undertook dramatic initiatives both to integrate microprocessor technology into its products, and to modernize its facilities.

Today, high-performance, reliable, *Raymond*® trucks are sold, rented, and leased throughout North and South America, as well as in Australia, China, the Pacific Rim, and the Middle East, through a network of independent dealers.
At its headquarters and manufacturing plant in Greene, over 1,000 skilled employees develop and produce *Pacer*™ stand-up counterbalanced trucks, orderpickers, *Swing-Reach*® trucks, and sideloaders, as well as several other specialized models, for government and industry.

The Raymond Corporation was acquired in 1997 by BT Industries of Sweden. Then in 2000, Toyota Industries Corporation purchased BT. Earlier this year, Toyota formed the Toyota Material Handling Group, which consists of 13,000 people worldwide with $4 billion in annual sales.

Why Fuel Cells?
Raymond started reviewing the use of fuel cells in material handling early in 2004, primarily because our customers were asking for this technology. Initially the company developed a financial model in order to evaluate the value proposition. Next it met with many fuel cell suppliers to determine their level of interest and activity in the material handling field. All this activity led to a decision in early 2005 to actively work with suppliers to gain experience with the technology. Initial suppliers were selected several months later, and proof of concept testing started shortly thereafter.

The basic question remains: why use a fuel cell rather than a lead-acid battery? There are pros and cons to each one. Lead-acid batteries are known technology and reliable. They are readily available from multiple suppliers. For a fork lift, they provide needed counterweight and are readily removable when their energy is depleted. However, lead-acid batteries have limited range. They will last one shift at most in a high use 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 plus a charger may be needed as well as room to store and maintain them. If the battery is Direct Current (DC) its voltage drops as the battery discharges, which leads to reduced truck performance. Finally, there are environmental issues when recycling batteries due to their lead and acid content.

Hydrogen fuel cells offer higher productivity simply because they can be rapidly refueled—in several minutes versus several hours—eliminating the need to change a battery. Also, the voltage delivered by a fuel cell remains constant until the fuel is depleted. Until the fuel runs out, the vehicle experiences no performance degradation—like a car and its gas tank. And hydrogen is environmentally clean: the only by-products from a fuel cell are water and heat.

In a warehouse, it should be practical to have multiple hydrogen fuel stations all fed from a central tank, which would reduce the travel time to refill vehicles' tanks. However, hydrogen fuel cell technology is new, complex and currently expensive. There are a limited number of suppliers working in the material handling field. And finally, learning how to use and handle a compressed gas is required.

A related concern is the need to add counterweight to a fork lift truck using a hydrogen fuel cell, in order to insure fork lift truck stability equivalent to using a lead-acid battery, which can weigh thousands of pounds.

Two Supply Chains

There are two supply chains involved in implementing hydrogen fuel cells in a warehouse or distribution center: one chain is needed to provide the hydrogen and the other to supply the fuel cells. Hydrogen is a readily available industrial gas in use worldwide, except in warehouses and distribution centers. Hydrogen can be delivered by trucking liquid hydrogen from a manufacturer, or by generating it on site. Either method requires equipment to compress the liquid or gas to the pressures needed on the truck as well as a dispenser to rapidly fill the on-board tank.

The second supply chain involves component manufacturers, including batteries or super capacitors for hybridization, fuel cell stacks and the balance of on-board fuel cell components, and assemblers that put the entire unit together. A forklift manufacturer may be involved at this point in selling and servicing these units or the fuel cell manufacturer may have its own distribution network. Either way, the customer needs support and maintenance as well as a means to replace the stack once it's used up.

Evolutionary Application

There is an evolution in the application of fuel cells to fork lift trucks. The first step is battery replacement. Here 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 has “no idea” that it is being powered by a fuel cell. A slightly more complex version of the battery replacement involves adding a field installable fuel cell adapter kit. This kit might include additional counterweight or a communication cable between the truck and the fuel cell. The complete battery replacement can be developed completely by a fuel cell supplier. Development of the adapter kit would require cooperation with the lift truck manufacturer.

The second step in the evolution is an existing platform modification. Here an existing truck design is used, with the fuel cell components distributed in an optimum way around the truck. The new truck would ship with a fuel cell as an option. Development of this truck would require very close cooperation between the truck manufacturer and the fuel cell supplier.

The third and ultimate evolutionary step is a clean sheet design. Here 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 the truck could not use a conventional battery. Here the truck manufacturer would do most of the development while working closely with a supplier of fuel cell components.

Fuel Cell Suppliers

Because this evolution requires close cooperation between fuel cell suppliers and lift truck manufacturers, selection of the fuel cell system supplier is a critical step for a lift truck manufacturer like The Raymond Corporation. Many fuel cell suppliers are now working in the material handling field. Some are new companies while others have established fuel cell projects. These fuel cell suppliers use different technologies, both in terms of how they integrate and hybridize the fuel cell units and in terms of the materials that they use. These companies also have different business models: some are "design only" firms while others are targeting systems manufacturing. Some make their own fuel cell stacks while others purchase stacks from third parties. And, finally, some companies are focused solely on material handling while others are looking at a wide variety of applications.

The Raymond Corporation formed a multi-departmental team early in its fuel cell investigation effort. This team had a key role in determining supplier selection criteria. Fuel cell system cost and cost of operation were critical. The supplier's experience in Class I, II and III fork lift trucks was important, as was the extent of their focus on fork lift truck applications. The supplier also needed to have a viable business that could be expected to sustain itself. It needed to have adequate manufacturing capability and support infrastructure—including technical, parts, safety, and training support. Finally, the technology used--particularly the stack life and system complexity—was crucial in supplier selection.

Financial Model

Raymond developed a financial model that explored the economics of converting an entire warehouse with a variety of trucks from batteries to fuel cells. In particular, it needed to identify the operational parameters having the most and the least impact on the Net Present Value (NPV) of a fuel cell project. The Raymond model uses incremental cash flow analysis to compare lead-acid batteries to hydrogen fuel cells. As with many exploratory models, the absolute numbers are not as significant as the sensitivity analysis and the trends observed as the parameters are varied.

For this model, the following input parameters were used:

- 100 trucks in a typical mix of Class 1, 2 and 3
- Trucks driven 5 hours per shift, three shifts per day for 280 days per year
- Pick cycles ranging from 30 to 90 per hour depending on the truck class
- Operator salary of $18.50 per hour
- Hydrogen tank size ranging from 1.5 to 3.0 kilograms
- Hydrogen price of $5.00 per kilogram
- Electricity price of $0.09 per kilowatt hour
- Fuel cell price of $4,000 per kilowatt
- Battery change time of 25 minutes, including travel time

Using these parameters resulted in 4,200 operating hours per year per truck with a savings of over 29,600 hours per year for the entire warehouse, when compared to lead-acid batteries. The NPV was positive and the Internal Rate of Return (IRR) was over 50%.

To determine the sensitivity of this result to the inputs selected, several key parameters were varied over a realistic range including low, nominal and high values. These key parameters were:

- Operator labor rate ($/hr)
- FC price ($/kW)
- Operation (shifts/day)
- FC stack life (hours)
- Hydrogen infrastructure ($/kg)
- Hydrogen price ($/kg)

- Battery maintenance (min/battery/day)
- Refurbished stack price ($/kWh)
- Hydrogen tank multiplier (%)
- Tank fill time (min/tank)
- FC maintenance ($/truck/year)

The results of this analysis are shown in the "tornado" plot. The size of each horizontal bar represents the range in NPV as a specific parameter is varied from a low value to a high value. The bars are sorted with the most sensitive parameters having the largest bars at the top, and the least sensitive parameters with the smallest bars at the bottom.

Three factors—the operator labor rate, the fuel cell price, and the length of operations (number of shifts per day)—have the most impact on the NPV. The hydrogen tank size, the tank fill time, and fuel cell maintenance have the least impact on the NPV.

In summary, the financial model shows that sites with high labor rates and multiple shifts per day are good initial targets for fuel cell technology. The price of the fuel cell system is also very important. Long stack life must be demonstrated in order for fuel cells to be commercially successful. It is acceptable to pay for the hydrogen infrastructure as a fuel surcharge, as long as it isn't too high. And finally, larger on-board hydrogen capacity (larger tank size) yields diminishing returns.

In conclusion, fuel cell technology looks like it can improve warehouse productivity while lowering operating costs. The Raymond Corporation has conducted an extensive supplier evaluation. It has already tested operational fuel cell units in its development lab, and is planning more testing in the future. With its ongoing work with fuel cells, Raymond is adding to its rich history of customer-centric innovation, so that Raymond trucks will be ready when fuel cells are commercialized.