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Application of Fuel Cells to Fork Lift Trucks

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Introduction

The Raymond Corporation has been 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.

Why Fuel Cells?

Raymond started reviewing the use of fuel cells in material handling early in 2004, primarily because its 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.

Raymond has been testing numerous fuel cell powered vehicles such as this pallet truck

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 truck 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, such as 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.

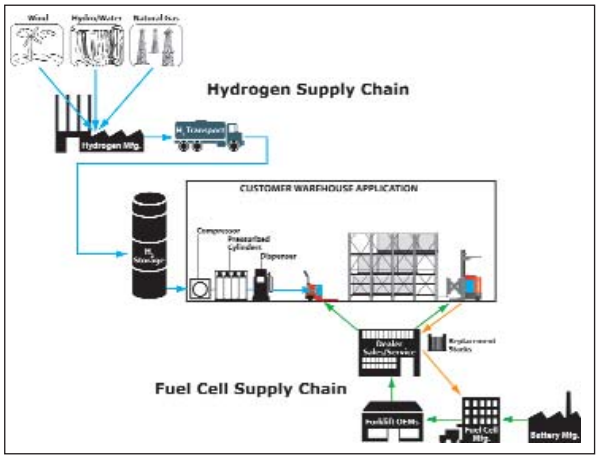
A related concern is the need to add counterweight to a fork lift truck using a hydrogen fuel cell, in order to insure fork lift truck stability equivalent to using a lead-acid battery, which can weigh thousands of pounds.

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.



Hydrogen/Fuel Cell Supply Chains

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 Corp. 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 Corp. 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 five hours per shift, three shifts pe 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 trave 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

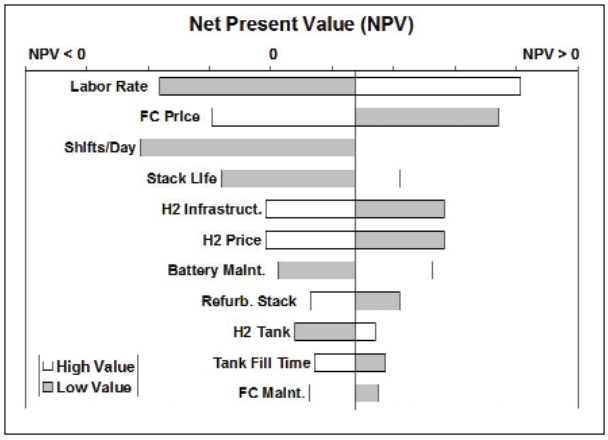
Return (IRR) was over 50 percent.

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.



Key parameters/Tornado plot

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.

Raymond's Plans

The Raymond Corp. is continuing its work on fuel cell technology for electric lift trucks. To illustrate the potential application of a fuel cell in a fork lift, Raymond exhibited a fuel cell-equipped pallet truck at the ProMat show in Chicago, Illinois in January, 2005. At a press conference held at the show, Raymond Corp. CEO James J. Malvaso said:

"We are working with developers of emerging technologies (including fuel cells) to ensure that our trucks will be compatible with or incorporate these innovations as they become practical and commercially available."

Raymond has recently evaluated some fuel cell units and plans on evaluating more later this year. The company is gradually building its hydrogen infrastructure. And it is identifying the best potential customers for this technology. Raymond continues to monitor fuel cell industry progress so that its trucks will be ready when these units are commercialized.

In conclusion, fuel cell technology looks like it can improve warehouse productivity while lowering operating costs. The Raymond Corp. 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.

Steve Medwin worked for over 20 years at DuPont's Engineering Development Laboratory on a wide variety of materials and technologies. With relocation to upstate New York in 2001, Steve started working for the Raymond Corporation, in the Test and Reliability group. He soon became manager of Test Engineering. In 2003, he was named manager of Advanced Research and charged with evaluating the application of fuel cell technology to the material handling business.

He is named the inventor on eight US patents with another pending. He is on the UL 2267 Standards Technical Panel for Fuel Cell Power Systems for Industrial Electric Trucks and the Industrial Truck Association (ITA) Fuel Cell Task Force.

The Raymond Corporation is a North American provider of materials handling solutions that improve space utilization and productivity, with lower cost of operation and greater operator acceptance. High-performance, reliable, ergonomically designed Raymond products range from a full line of manual and electric pallet trucks and walkie stackers to counterbalanced trucks, reach-fork trucks, orderpickers and dual-purpose (pallet handling/case picking) swing-reach trucks. For more information contact Raymond at (607) 656-2311 or www.raymondcorp.com.

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