

## **Hydrogenics and Maxwell Combine Technologies to Bring the Material Handling Equipment Market Improved Productivity with Clean, High Performance Fuel Cell Power**

### **About Hydrogenics Corporation:**

Hydrogenics is a leading developer and manufacturer of hydrogen and fuel cell products for a wide range of energy and industrial applications. The material handling market has been identified as one of the more commercially viable markets for HyPM® Fuel Cell Power Pack (FCPP). Hydrogenics is continuously seeking opportunities to offer value for commercialization with strategic partners in identified vertical markets.

### **About Maxwell Technologies:**

Maxwell Technologies applies industry-leading capabilities in power and computing to develop and commercialize electronic components for customers in multiple industries. Maxwell Technologies' BOOSTCAP® ultracapacitor products are the world's leading high-performance production ultracapacitors.

### **Background:**

Industrial and commercial material handling equipment offer a unique market niche for fuel cells and ultracapacitors to compliment one another. Deployed in lift trucks they demonstrate real time benefits for improved productivity and greater fuel efficiency.

Lift trucks operating in multi-shift, high productivity internal distribution centers provide a unique opportunity to roll out this technology in an environment where performance is easily evaluated as they:

- do not require the large public infrastructure
- typically operate as 'captive fleets'
- enable easy and centralized refueling with hydrogen
- work on fairly predictable duty cycles.

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In partnership with Maxwell, Hydrogenics is motivated to invest in this market because fuel cell-ultracapacitor hybrids offer a compelling value proposition as they:

- run silently compared to Internal Combustion Engines (ICEs)
- contribute to significant labor cost reductions
- have the potential to replace standard lead-acid batteries and their associated recharging infrastructure
- operate in extended run cycles - with significantly lower maintenance
- provide improved health and safety due to zero emissions.

These benefits and others offer material handling operators improved productivity and significant reductions in labor costs which tend to dominate total cost of ownership.

### **Fuel Cell Power for Lift trucks?**

The industrial material handling market is currently dominated by electric lift trucks powered by lead-acid battery technology. It is recognized industry wide that limitations inherent in battery based operations, such as the loss of charge as shifts progress, negatively impacts productivity. It is common to incur ongoing overhead expenditures for:

- additional battery packs per lift truck
- associated personnel cost directly associated with battery maintenance
- battery recharging infrastructure
- chemical disposal
- related costs associated with lost facility space.

Charging lift truck batteries during a shift leads to considerable downtime which effects overall efficiency of multi-shift (24/7 & 24/5) operations. In addition toxic chemicals used in these vehicles present environmental and health risks when the batteries are ultimately disposed of. By substituting the conventional lead-acid battery power train with a fuel cell electric hybrid power pack, Hydrogenics brings to the material handling market a clean power solution that offers increased productivity through the following benefits:

- fast refueling feasible by the lift truck operator
- consistent and abundant power
- extended run time
- reduced maintenance
- reduced infrastructure costs.

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In addition to the above-mentioned material benefits there are harmful emissions of either Green House Gas (GHG) or Criteria Air Containment (CAC) at point of operation (e.g. CO, CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub>). Operators also appreciate that there are no offensive odors or fumes from the fuel cell hybrid compared to those produced from operational batteries

**A Question of Design:**

When designing the Hydrogenics HyPM FCPP for lift trucks, Hydrogenics sought to deliver a power solution that was compact, offered dynamic response and was competitively priced. Typically the power output from a fuel cell registers some lag time at start-up. This lag can range from a few seconds to a minute, depending on the application. A design focal point for Hydrogenics was delivering dynamic response, so that the lift trucks would start without delay regardless of temperature, load or other variables.

Another important design requirement was management of the power coming from the power system during periods of peak load without incurring loss of power to other electrical functions of the lift truck. To enable this, Hydrogenics designers had to compensate the fuel cell power module's configuration with additional surge capability in order to prevent a dip in voltage. Finally, to create the most fuel-efficient design, Hydrogenics engineers were interested in building a regenerative braking capability into the lift truck, to capture the energy involved in vehicle braking and store it for power and acceleration. In addition to the electrical power design requirements, Hydrogenics needed to reduce the overall footprint of the fuel cell hybrid power pack making it as compact, lightweight and as low-cost as possible.

**Solution and Implementation:**

To meet the above design requirements, Hydrogenics' fuel cell-based system had to include an augmentation solution that would provide bridge power during dynamic loads and engine starts. This would ideally provide enough power in a compact format to fit within the footprint designed to accommodate the lift truck's battery pack.

While reduced weight is often considered a benefit over incumbent technology, in the case of the fuel cell powered lift truck the original lead-acid battery provided a portion of the counterbalance; however with the relatively lighter fuel cell it was necessary for additional weight to be added to provide sufficient counterbalance.

In partnership with Maxwell Technologies, manufacturer of the BOOSTCAP ultracapacitors, Hydrogenics developed a compact hybrid power system which consists of a HyPM 10 Fuel Cell Power Module for base load requirements combined with a bank of Maxwell's BOOSTCAP ultracapacitors for energy-storage, to handle load peaks and large-duration transients and to capture regenerative braking.

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As compared to batteries, BOOSTCAP ultracapacitor cells:

- deliver up to 10 times the power
- last up to 10 times as long
- operate more reliably in high and low temperature conditions
- require far less maintenance
- and reduce the environmental issues associated with battery disposal.

Other key components that complete the HyPM Fuel Cell Power Pack include hydrogen storage, power electronics and controls and thermal management. Hydrogenics integrated this hybrid power system into two Hyster Class 1 5000 lb. sit-rider lift trucks in the original battery compartment of the lift truck. To complete the fuel cell lift truck solution, Hydrogenics also developed a first-of-its-kind indoor hydrogen refueling station, based on the companies HySTAT™-P Hydrogen Station technology.

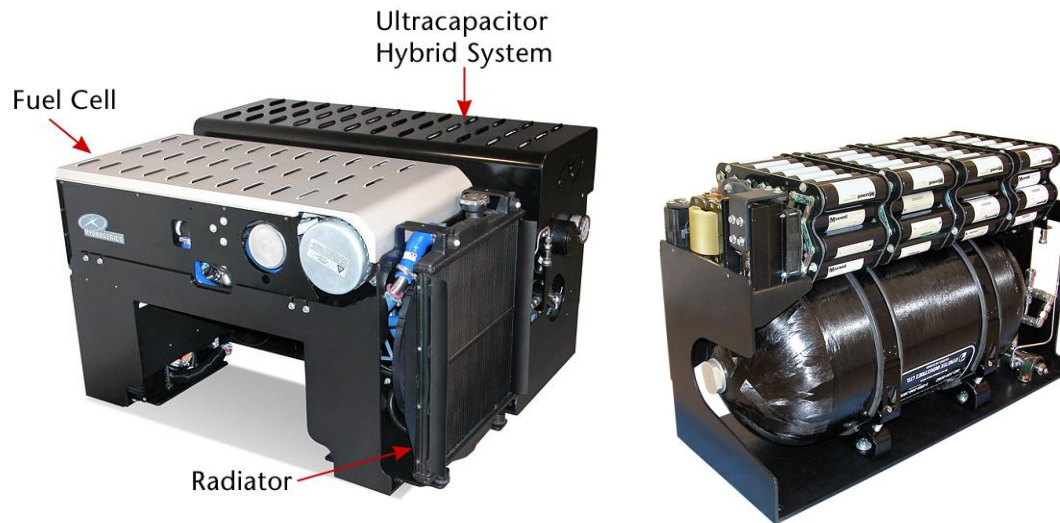
Hydrogenics' first fuel cell lift truck deployment was completed in April 2005 at General Motor's Oshawa, Ontario automotive assembly plant. After a twelve week period of engaging in day to day operations these lift trucks subsequently underwent a two month trial period at Federal Express (FedEx) Canada's logistics hub located at the Toronto Pearson Airport.

**Conclusion:**

Hydrogenics and Maxwell have achieved an important milestone in validating the value proposition for fuel cells in applications such as material handling. By including BOOSTCAP ultracapacitors in the design of the HyPM FCPP, Hydrogenics realized the goals for meeting customer needs for a zero emission power solution, capable of driving productivity improvements with consistent abundant power and high performance.

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**HyPM Fuel Cell Power Pack with BOOSTCAPS Ultracapacitors:**

The key benefits of this hybrid system design are:

1. Instantaneous response – resulting in improved system performance
2. Increased fuel efficiency – from regenerative braking
3. Flexibility to handle long duration transients, and load peaks
4. Reduced system cost – due to a smaller fuel cell footprint

To meet industry-specific needs for improved productivity and system operations, the fuel cell ultracapacitor design provides abundant clean power with fast refueling. Unlike battery electric lift trucks, which require changing, watering and recycling, fuel cell lift trucks can operate for 12 hours before refueling, which on average takes only 2 minutes from empty to full. Operators can refuel their own of lift trucks eliminating the need for a “refueling shift”.

A significant benefit for multi-shift enclosed environments – **fuel cells are emission free**. In addition they offer reduced infrastructure and costs eliminating the need for multiple battery packs per truck, a battery re-charger per truck, battery swapping equipment, battery facility space and associated personnel.

While widespread adoption of fuel cells for automobile applications may take several more years, it is anticipated that fuel cell lift trucks will start to significantly improve productivity of some of the most demanding manufacturing facilities and distribution centers around the world well before then.

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