

Alternative energy sources for forklifts – a way to make intralogistics green

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Growing awareness of environmental problems, and in particular with well-published issues such as acid rain, chlorofluorocarbons (CFCs) and global warming, "greenness" become a catchword in logistic as a heart of modern transport systems since early of 1990s. To overcome these problems new field of logistic research is emerging, focusing on the adaptation of logistical systems and supply chains to climate change. Therefore, it is a trend in intralogistics sector in recent years to invest more in green technologies. In the last few years, the success from fuel cell demonstrations has moved rapidly into commercial forklift operations. This paper addresses the potential benefits in using the fuel cells and triple hybrid drives in forklift trucks as a field of potential improvements in intralogistic.

***Keywords:** intralogistics, adaptive logistics, forklifts, fuel cells, triple hybrid drives*

1 INTRODUCTION

Growing awareness of environmental problems and in particular with well-published issues such as acid rain, chlorofluorocarbons (CFCs) and global warming, "greenness" become a catchword in logistic as a heart of modern transport systems since early of 1990s. "Greenness" suggests compatibility with the environment or a code-word for a range of environmental concerns. Basic characteristics of modern logistic development have several inconsistencies between the goals and objectives with regards to environmental compatibility (Table 1) [1].

Table 1. Paradoxes of Green Logistics

Dimension	Outcome	Paradox
Costs	Reduction of costs through improvement in packaging and reduction of wastes. Benefits are derived by the distributors.	Environmental costs are often externalized.
Time / Flexibility	Integrated supply chains. JIT and door to door provide flexible and efficient physical distribution systems.	Extended production, distribution and retailing structures consuming more space, more energy and producing more emissions.
Network	Increasing system-wide efficiency of the distribution system through network changes (Hub-and-spoke structure).	Concentration of environmental impacts next to major hubs and along corridors. Pressure on local communities.
Reliability	Reliable and on-time distribution of freight and passengers.	Modes used, trucking and air transportation, are the least environmentally efficient.
Warehousing	Reducing the needs for private warehousing facilities.	Inventory shifted in part to public roads (or in containers), contributing to congestion and space consumption.
E-commerce	Increased business opportunities and diversification of the supply chains.	Changes in physical distribution systems towards higher levels of energy consumption.

To overcome these problems new field of logistic research is emerging, focusing on the adaptation of logistical systems and supply chains to climate change. The concept reverses the traditional causality of green logistic research, which examines the effects of logistical activities on the environment, to consider how logistics will have to be modified in response to the effects of climate change. The response can either be direct where logistics systems must be modified to minimize adverse climate impacts or indirect, where climatic change alters the demand for logistical services and systems must be reconfigured accordingly. Also the impact of mitigation efforts by businesses, governments and individuals to cut their greenhouse gas (GHG) emissions to logistic and supply chain could be included (Figure 1). [2]

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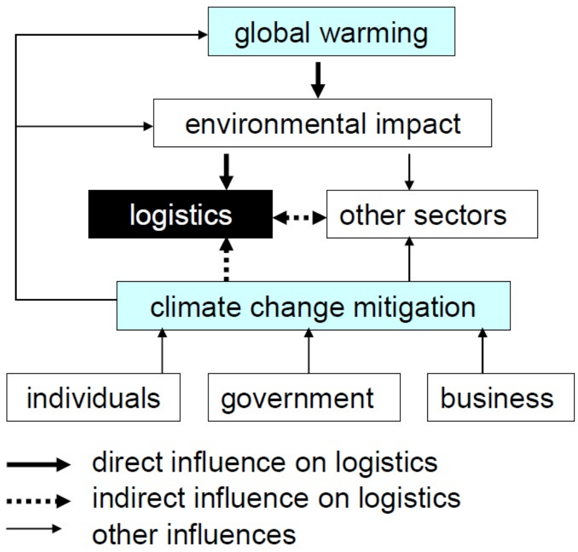

Figure 1. Direct and Indirect Pressures on Logistics to Adopt to Climate Change

One of the biggest uncertainty is the nature and scale of the environmental change. The science of climate change is probabilistic, forecasting within wide confidence limits. Some report on the economics of climate change [2], shows the 5% and 95% confidence limits for particular concentrations of GHGs (expressed as parts per million of CO_2-eq) raising average global temperature by differing amounts, Figure 2. It is the mean values, represented by the vertical lines, which are generally quoted, particularly the link between 450 ppm and a 2^o C temperature rise, though, given the accuracy of current climate models, the degree of warming may vary within quite wide margins. As also shown in Figure 2, the concentrations of CO_2-eq in the atmosphere by 2050 or beyond could also vary widely, partly dependent on the effectiveness of carbon mitigation efforts over the next few decades.

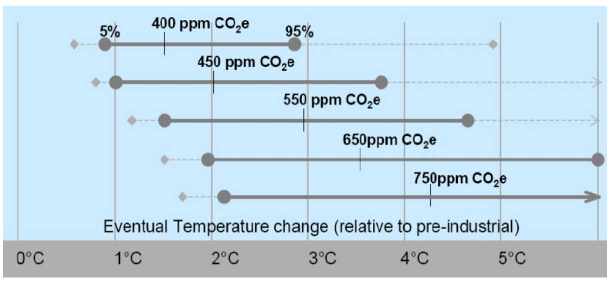

Figure 2. Estimated changes in average global temperatures for different GHG concentrations

Although scientists have greatest confidence in predictions of global mean temperature rises, this confidence is much lower on predictions of other climatic effects such as rainfall and the incidence and intensity of storms.

2 KEY THEMES IN ADAPTIVE LOGISTICS [2]

These themes can be divided in three categories:

1. Responses to direct environmental impacts
2. Responses to indirect environmental impacts
3. Effects of climate change mitigation measures on logistics

2.1 Assessments of the climate change effects on transport

Assessment of, for example, US transport infrastructure has been made with focus on five climatic effects: the number of hot days / heat-waves increase, Arctic temperatures increase, rising sea-level, the number of 'intense precipation events' increase and 'hurricane intensity' increase. It acknowledged that the climatic tolerance limits within which transport infrastructure has been built will need to be widened to cope with the effects of global warming.

Several studies have focused on the possible impact of sea-level rise and storm surges on port infrastructure.

2.2 Assessments of the exposure of supply chains to climate change risks

Some of these risks will be transport infrastructure-related. Others will be related to the nature and location of logistical facilities, particularly distribution centres and freight terminals. Heavy snow cover on the roofs of some distribution centres in Germany during the severe winter of 2009-10 increased the risk of collapse to the level where staff had to be evacuated and operations disrupted.

2.3 Analysis of the impact of climate-induced changes in agricultural patterns and human settlements on logistical systems and supply chains

According to the Intergovernmental Panel on Climate Change from 2007, changes in temperature regimes, water availability and disease will cause significant shifts in agricultural zones. Supply chains will have to be reconfigured to the new geography of food production and distribution.

2.4 Analysis of the impact of economy-wide decarbonisation programmes on logistical systems and supply chains

The demand for freight transport services will be affected by carbon reduction measures in other sectors. National governments and multi-national organisations have set economy-wide targets for the reduction in GHG emissions by years ranging from 2020 to 2050.

Critical to the creation of low carbon economies will be the decarbonisation of electricity generation (Committee on Climate Change, 2008).

2.5 Exploring the logistical implications of the geo-engineering options that may be required to rescue mankind from runaway climate change

Should current efforts to cut GHG emissions drastically over the next few decades fail or prove inadequate, it may be necessary to resort to the much more radical, geo-engineering options. These fall into two categories: carbon dioxide removal (CDR) and solar radiation management (SRM).

CDR techniques which absorb (or 'sequester') CO_2 from the atmosphere, artificially reinforcing the earth's natural systems for keeping CO_2 concentrations in check.

SRM techniques would weaken the greenhouse effect by reflecting a small proportion of the sun's rays back into space. The most promising SRM option is to disperse aerosols, mainly of sulphur dioxide, in the stratosphere in more northerly and southerly latitudes.

3 POTENTIALS IN INTRALOGISTICS SECTOR

Processes in internal logistics - known by the term "intralogistics" - provide the potential for optimization both from an economic as well as a sustainable standpoint.

"Green" intralogistics has a direct influence on just "how green" the entire supply chain network can become. In the end, the goal should not merely be to optimize fuel usage and CO_2, emissions from transportation between facilities, while at the same time allowing potential savings in energy and emissions for storage and production facilities as weỉl as conveyor technology to remain unexploited [3].

Possible measures for implementing "green" intralogistics occur at four different operational levels:

1. level 1: internal processes and operations;
2. level 2: components and drive mechanisms;
3. level 3: machinery and equipment;
4. level 4: inter-process operational conditions.

Intralogistics can be influenced directly and meets the categories: facility layout, means of transport, stock, the assignment of new technologies respectively systems as well as transport packaging, which will be explained below.

3.1 Building layout

In the area of intralogistics the layout of production plants determines logic costs extensively, which cannot always be influenced. Lean production approaches, which also demand optimal choice of locations for the particular steps of manufacturing, are preferable. This appendage can be pursued, when a new production location is planned as a greenfield project, for example. Here, locations can be chosen in an early stage, so that between particular production locations and warehouse only rare logistical activities are necessary. It is more difficult for already existing plants, which cannot be changed concerning their structural engineering [4].

3.2 Fixed transport systems

In operations that use mechanized technology such as conveying and sorting systems, there are opportunities to reduce the amount of energy required. Conveying and sorting systems are tupically turned on at the beginning of the day and run full speed all day until turned off at the end of the day. However, typical operations do not have high rate material flow throughout the shift.

Package, conveying and sorting technology can be designed to automatically slow down and operate in slow speed during periods of low carton flow activity. Control systems monitor activity on the system, and slow down or speed up to meet throughput demands and therefore use only sufficient amount of power to do the job required. Operating at slower speeds means reduced energy consumption as well as reduced wear and tear on equipment, therefore increasing the life of the system while reducing maintenance costs. Furtheremore, when there is no carton flow for a pre-set period of time, control systems detect the lack of activity and can turn off sections of conveyor where there is no carton flow.

In addition, new conveyor technology is making it easier to save energy. Low voltage, 24 or 48 volt, motorized roller conveyor is inherently more energy efficient, and motorized roller conveyor systems typically do not use compressed air systems to operate, further reducing energy costs. New sorter systems now operate at slower speeds while still providing high sort rates.

The Dematic introduced the all-belt conveyer solution that enables the user to select the desired gap between items for max buffer, for sorting, or for proper pitch prior to one in-line scale. The user can also select speed from 21 m/min to 122 m/min. Intelligent controls give individual sections the ability to speed up or to slow down. The Dematic Plug & Convey modules are engineered to reduce the maintenance and designed for fast installation. Compare to conventional conveyer systems, it reduces power consumption up to 30%, reduces labor up to 20%, and coveys a wider variety of products.

3.3 Conventional transport systems

Due to absence of emissions and low noise level, battery-operated vehicles now dominate over half of the forklift trucks market and are the main choice for closed areas. The battery that strongly dominates is lead–acid battery, because of its low cost compared to other battery types. But, its drawback is low specific energy of 30Whkg−1 and much shorter life, which makes them less suitable for advanced high-performance battery-electric vehicles [5]. Their second problem is that increasing the current per battery capacity results in deteriorating charge and discharge efficiency. Good substitution are lithiumion batteries with the potential for high specific energy of up to 2000Whkg−1 [6], longer service lives and stable charge and discharge efficiency even when the current is increased.

3.4 Stock (inventory) keeping

The stock of manufacturing plants is part of the activities in the category of intralogistics. They contain potentials with great impact. About 50 % of intralogistics costs, in particular 35 % of heating - and ventilation engineering and 15 % of lighting engineering is caused by the storage area. On closer inspection of these areas in most of the factories potentials do exist and could be changed without bigger efforts and investments. Depending on the material group and the product it can be necessary to have several stocks available. One of the reasons for appliance of multiple stocks is the specific product which has to be stored. For example, for flammable materials strict rules have to be followed and thereby these have to be stored separately. Furthermore, an additional stock can be necessary, if several manufacturing plants exist and if these are located in great distance. At this point, an integral analysis, which has to answer basic questions, is necessary.

During the last years the trend has moved towards high bay racking, which reduce the energy demand in combination with software applications [4].

3.5 Green IT

According to a study of the US federal environmental agency in about 10% of the electric power consumption is spent by information and communication technique. Thereby about 33 million tons of CO_2 emissions are discharged each year.

By using innovative and environmentally friendly IT infrastructure savings of energy can be generated. In practice for nearly every application a separate server is installed, which only uses its own performance level. Moreover, each commission working space is arranged with its own computer system, which boosts the amount of computers. By using visualizations of servers and thin clients the amount of computer can be reduced drastically [4].

4 ALTERNATIVE ENERGY SOURCES FOR FORKLIFTS

4.1 Fuel cells

Fuel cell converts the energy stored in several kinds of gases, among which hydrogen and methane, into electricity. The principle of fuel cells was discovered in 1839 by William Grove, and their first development only preliminarily started in 1932 through Francis Bacon's exploratory work, but their first use was in the early 1960s when NASA appointed them as the principal replacement of batteries in spacecraft (Bacon, 1969), because of it's ability for high power levels sustained during long discharge times, which batteries of that time were unable to provide. The most common type of fuel cell is the polymer electrolyte membrane (PEMFCs) fuel cell and direct methanol fuel cells (DMFCs) [5].

Materials handling (MH) forklifts powered by proton-exchange (PEMFCs) and direct methanol fuel cells (DMFCs) are operating at airports, manufacturing plants, hospitals, mega retailers, food distributors, and military depots.

DMFC serves as an auxiliary power source for existing battery power in the form of a continuous trickle charger. Generally, methanol fuel provides higher energy density than hydrogen.

In a PEMFC fuel cell, an electrolyte membrane is sandwiched between a positive electrode (cathode) and a negative electrode (anode). Hydrogen is introduced to the anode and oxygen to the cathode. The hydrogen molecules travel through the membrane to the cathode but not before the membrane strips the electrons off the hydrogen molecules. The electrons are forced to travel through an external circuit to recombine with the hydrogen ions on the cathode side, where the hydrogen ions, electrons, and oxygen molecules combine to form water. The flow of electrons through the external circuit forms the electrical current needed to power a vehicle (Figure 3) [5].

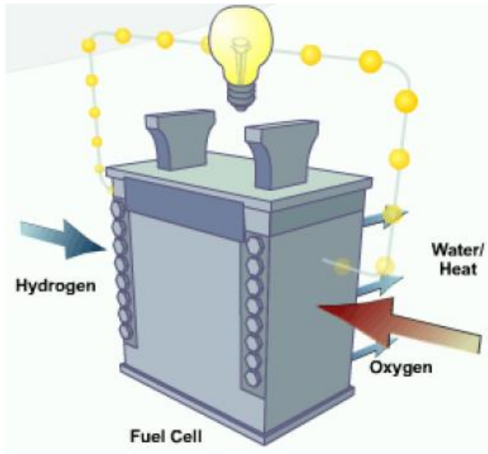

Figure 3. The principle of fuel cell [5]

Regarding PEMFC systems currently available, it is clear that fuel cell stack life has increased dramatically; trucks can last for 20.000 hours, and MH fuel cell systems are already tested to 12.000 hours.

By the end of 2010, more than 1000 fuel cell systems designed for electric forklifts were in operationor on order worldwide. Five years of demonstrations and pilot projects have transitioned into commercial materials handling applications where fuel cells are stacking up well against traditional batteries [8].

In the last few years, the success from these fuel cell demonstrations has moved rapidly into commercial forklift operations.

The most immediate benefit reported in the fuel cell-for-lead acid batteries swap is the elimination of 'voltage droop', or the waning of full power as batteries discharge over a duty cycle. First and foremost, fuel cells provide a constant power output at a battery-comparable power level. This is true even under temperature extremes such as cold storage operation. Coinciding benefits encompass the elimination of battery changeout (averaging 15–17 minutes) and recharge/cooling time (up to 8 h), hydrogen fueling in 1–3 minutes, freed-up battery storage space, and elimination of expensive battery chargers [8].

At Crown's 2300 m^2 dedicated Fuel Cell Test Center, qualification tags are created based on examination by Crown engineers of the interaction between various forklift/fuel cell combinations. Using computer modeling and application testing, Crown determines the specific design modifications needed to ensure that a fuel cell powered forklift matches the performance, efficiency, and safety standards to which the truck was initially designed.

The best known fuel cell stack original equipment manufacturers are Ballard Power Systems stacks, Hydrogenics, Nuvera, and Oorja Protonics (DMFCs) and others.

Fuel cell OEMs are stating that current systems can last nine to ten years, but the justification template for forklifts is based on five years, which is present average lease term. What's exiting is that today's fuel cells have the potential to power two generations of lift trucks, especially since some conventional batteries don't lat five years.

Determening the return-on-investment (ROI) potential for fuel cells as replacement for batteries to run forklifts must factor in multiple parameters. These include power system life-time, refuling time and labor savings, overall energy usage, the costs of hydrogen storage and dispensing infrastructure, service/maintena-nce (tasks, intervals, and equipment), floor space gains, and safety/operational training.

Ballard Power Systems simulation which compared fuel cells with battery systems showed interesting results. Operating costs were estimated, as well as reduction of lost productivity and hours of work time recovered per year, savings in total ownership costs. Results showed the ROI was less than 2 years.

Early small-scale demonstrations have convinced operators now converting whole fleets that fuel cells are as reliable as batteries, and have the potential to extend the lifetime of materials handling equipment. This all translates to higher productivity and better cost margins, primarily from significantly reduced labor expenses and increased uptime.

Suppliers continue to refine designs and materials to reduce the price of materials handling fuel cell systems, and while difficult to qualify, end-users testify to the value of this technology within the 'greening' of their corporate environmental goals. According to a representative for the UNFI distribution center in Florida that will utilize GenDrive systems in Raymond forklifts, reductions of carbon emissions on the order of 132 tons a year are expected, along with an annual saving of some 640 MWh of electricity.

Plug Power company has more than 650 fuel cells curently operating in various forklift models, with an uptime log over 1,5 million hours. Their customers are reporting 15 to 30 percent productivity gains , and 70 to 80 percent greenhouse gas emmition reductions onsite.

Yale Materials Handling Corporation installed in 2010 Plug Power GenDrive systems in 220 of its forklifts at one of their major distribution centers, with total anticipated savings of $ 1,5 million over 10 years.

Plug Power estimates there are 1.7 million trucks in use in North America, and Jungheinrich cited global lift truck demand for the first quarter of 2010 at 379 000 units, with the potential to reach 700 000 units by the end of the year (encompassing all power/fuel options).

These figures seem to indicate that there is a vast revenue field available, depending of course on how much of the total electric forklift market fuel cell technology could capture.

4.2 Ultracapacitors

An ultracapacitor, also known as a double-layer capacitor, polarizes an electrolytic solution to store energy electrostatically. Though it is an electrochemical device, no chemical reactions are involved in its energy storage mechanism. This mechanism is highly reversible, and allows the ultracapacitor to be charged and discharged hundreds of thousands of times.

In an individual ultracapacitor cell, the applied potential on the positive electrode attracts the negative ions in the electrolyte, while the potential on the negative electrode attracts the positive ions. A dielectric separator between the two electrodes prevents the charge from moving between the two electrodes. Figure 5 depicts an ultracapacitor, its modules, and an ultracapacitor cell [10].

Once the ultracapacitor is charged and energy stored, a load (the vehicle's motor) can use this energy. The amount of energy stored is very large compared to a standard capacitor because of the enormous surface area created by the porous carbon electrodes and the small charge separation (10 angstroms) created by the dielectric separator. However, it stores a much smaller amount of energy than does a battery. Since the rates of charge and discharge are determined solely by its physical properties, the ultracapacitor can release energy much faster (with more power) than a battery that relies on slow chemical reactions [10].

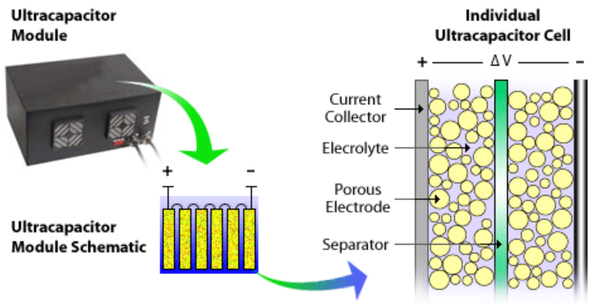

Figure 4. Ultracapacitor diagram [10]

Ultracapacitors usage downsizes the batteries and makes them so small that it could not alone provide the electrical power required to accelerate the vehicle or recover all the available energy during braking.

The cycle life of the ultracapacitors in the mild hybrids vehicles is approximately 500 000 cycles.

Ultracapacitors are not suitable for use in hybrid electric vehicles as the primary energy storage technology. The present performance of ultracapacitors is suitable for use together with either internal combustion engines or fuel cell as the primary energy converter [5].

4.3 Triple hybrid configuration

Some German companies are examining what might be called 'the power of three': a triple hybrid system that combines fuel cells, ultracapacitors, and nickel metal hydride (NiMH) batteries. The companies are fuel cell OEM Proton Motor Fuel Cell GmbH (Puchheim), forklift OEM STILL GmbH (Hamburg), battery OEM and system integrator Hoppecke Batterien GmbH (Brilon), and hydrogen supplier Linde Gases Division (Figure 5) [9].

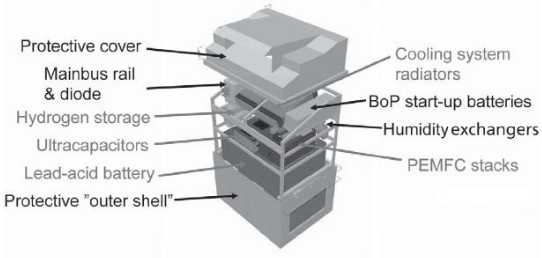

Figure 5. Triple hybrid configuration diagram [9]

Proton Motor's company ran its first forklift demonstration on a STILL R 60-30 for two years at Munich Airport, starting in 2004. This unit hybridized an 18 kW Proton Motor PEMFC and a fiber nickel-cadmium battery manufactured by Hoppecke. Cargogate GmbH used the STILL forklift at the airport, and was able to run a full eight-hour shift with 7 liters of gaseous H_2 [9].

Figure 6. Still GmbH RX-60-45 forklift runs on HyPX 1-855 PEMFC from Hydrogenics [9]

The 5 kW PEMFC is combined with a Sanyo 80 V NiMH battery and Maxwell ultracapacitors to provide 30 kW of peak power. Fuel cell provides primary operational energy, the supercapacitors store recovered braking energy, while the battery buffers energy over longer peak demand times. Proton reports a 50% energy saving with the triple hybrid configuration compared to diesel engine forklifts and fuel cell-only systems, and hydrogen refueling took only one minute.

Common to these projects and various STILL model forklifts is a system architecture encompassing PEMFC, supercapacitors to store energy from braking, pressurized hydrogen storage tanks, a radiator and compressor, and additional ballast to compensate for the lighter-weight power system compared to batteries.

5 CONCLUSION

The negative outcomes of global pollution forced the introduction of adaptive logistics, a new field of logistic research, focusing on the adaptation of logistical systems and supply chains to climate change.

As the quarter of all logistic costs are caused by intralogistics different categories such as, building layout, transport systems, stock keeping and even IT as potentials for resource-saving and at the same time environmentally friendly processes are available. Fuel cell powered forklift trucks finding increasing application in materials handling applications, since they offer significant advantages. Using fuel cell power in such vehicles can increase equipment uptime resulting in labor and time savings. But these increased economics values (compared with the traditional use of lead-acid batteries) is not the only benefit. Main advantage is a reduced carbon footprint, through reducing greenhouse gas emissions associated with the use and charging of lead-acid batteries. Today's early commercial fuel cell powered forklift adoption that could help facilitate large-scale fleet conversions to this green technology in the future, promises to maybe become a "silver bullet" replacement for batteries, diesel or gasoline power among other competing technologies.

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