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Materials handling vehicles; policy framework for an emerging fuel cell market

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Abstract

There are several challenges to wide-spread commercialisation of the technology hydrogen fuel-cell technology; including reliability and cost implications, infrastructure requirements, and safety aspects of the upcoming technology.

Targeted policy initiatives are required to address two significant bottlenecks; reliability and cost constraints. Such policy measures and financial mechanisms providing incentives for manufacturers and end-users of the novel technology create an initial impetus for the introduction of the forthcoming technology into the market place.

The current approach, policy mechanisms and their impacts are reviewed in the context of demonstration projects, deploying material handling equipment, involving public-private initiatives.

Key words: Material handling vehicles; policy mechanisms; FCH JU; ARRA; EU demo projects

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1. Introduction; fuel-cell-powered material handling vehicles

Materials handling vehicles are currently powered by either electric motors based on lead-acid batteries, in particular for indoor applications, or combustion engines employing diesel or liquefied petroleum gas, when utilised outdoors. Fuel cell powered forklifts offer notable advantages over the competing technology, and consequently, have been identified as a significant early market sector for the adoption of fuel cell technology.

Many early successes for fuel cells have been in the area of battery replacement for specialty vehicles including material handling vehicles such as lift trucks. In lead-acid battery-operated forklifts power output declines as batteries discharge over a duty cycle (sometimes referred to as 'voltage droop'). One major benefit of fuel-cell powered forklifts in contrast to battery-operated models is constant power output. Fuel cells provide the required power level, even under temperature extremes such as cold storage operation. Further benefits are the elimination of periodic battery change over (averaging 15–20 minutes), recharge/cooling time (up to 8 h), freed-up battery storage space, and elimination of expensive battery chargers. In contrast, hydrogen fuelling of the fuel-cell operated models takes 1–3 minutes, leading to increased productivity when compared to traditional battery systems, notably where operating in high-throughput distribution centre and multi-shift warehouse environments.

However there are several challenges to wide-spread commercialization of the technology, including a number of technical barriers to overcome. For example, battery powered forklifts use the weight of the battery to act as a counter weight. Fuel cell systems are lighter than the battery packs, changing the centre of gravity of the forklift, which may be addressed by redesign of the power pack so that the fuel cell system is incorporated into a forklift, rather than as a battery replacement pack.

In terms of typical fuel cell packs manufactured for use in the forklift trucks in 2010, US Original Equipment Manufacturers (OEMs) indicated that they were manufacturing 5 kW FC systems, along with batteries (to supply short term peak power) for class 1, 2 forklifts; primarily competing with battery powered forklifts used in multiple shifts in indoor operations. Subsequently, the power of the FC systems for classes 1 and 2 have been increased to the range of 8 to 12 kW and new, 2-3 kW systems for the class 3 forklift market have been developed, evidence that this market is dynamic and evolving [1].

Although market growth in Europe has not been as robust as the US, and the European fuel cell shipment remained flat between 2009 and 2010 [2], several manufacturers have shown interest in capturing the region. Danish company H2Logic commenced developing Class1 and 2 materials handling vehicles, partnering with Ballard (Canada). Unlike the majority of the North American sector, H2Logic focused on replacing Liquid Petroleum Gas (LPG) or diesel forklifts, not battery powered models [3].

In terms of fuel cell systems replacing battery-powered units in forklifts, it was reported that the FC systems for class 1 and 2 forklifts with the required batteries and hydrogen storage tank were being sold at $35,000 to $40,000 retail price, in the US in 2010, before accounting for any tax credits. The cost of the system was estimated at $27,000 to $29,000 with the fuel cell (FC) cost amounting to $20,000 to $22,000 and the rest of the system costing $5,000 to $8,000 to manufacture. Costs for class 3 forklift fuel cell systems are about half that of the class 1 and 2 forklift systems. These costs were associated with sales volumes of about 150 to 200 units per year [1]. To compare the cost of ownership of a conventional battery-powered and PEM fuel-cell-powered forklift trucks (FLTs), in the class 1 and 2 markets, it is noted that typically forklift trucks have a 10-12 year useful. The cost of an advanced lead acid battery with a capacity of 20kW is about $5,000 per pack. Considering a 2 battery pack, for a 2 shift operation over a 5 year life time, requiring battery charger at a cost of approximately $2000, undiscounted battery and charger costs will be about $22,000 over the life of a truck for a 2-shift and $32,000 for a 3-shift operation respectively.

In 2010, an FC stack had a target life of about 20,000 hours, equivalent to at least 5 years on a 2-shift, and 3.5 years on a 3-shift operation pattern, after which the stack need to be replaced at a cost of approximately $10,000. The batteries in an FC-powered FLT need to be replaced every 2.5-3.5 years at a cost of about $1000, with the replacement cost of other parts over the life the FLT adding an extra $5,000. Hence the undiscounted life cycle capital cost for the system amounts to approximately $57,000 and $68,000 for 2-shift and a 3-shift operation respectively.

To be competitive on capital cost, FC system costs must be reduced by a factor of 2, and stack life increased by a factor 2. However, operating costs will still be much higher as hydrogen production costs are around $2.5 to $3 and delivered hydrogen are unlikely to be below $4/kg [1]. Developing low cost supplies of hydrogen appears to be critical to the viability if FC-powered FLTs. Hence, the fuel cost disadvantage is about $3,000 per year for a 2-shift, and $4,500 per year for a 3-shift operation pattern. For FCs to compete effectively with batteries their greater productivity over the shift, shorter refuelling time, and elimination of battery replacing would have to be highlighted, and the initial high cost of adoption should be addressed through appropriate policy mechanisms.

2. Policy framework for the promotion of fuel-cell powered technology

2.1. European Union

EU has committed itself to reduce greenhouse gas emissions by at least 20% compared to 1990 levels; increase the share of renewable energy sources in the final energy consumption to 20%; and a 20% increase in energy efficiency by 2020 [4]. Fuel cells and hydrogen (FCH) technologies are amongst the key enablers that Europe will have to rely on in order to reach its ambition of a low carbon economy [5].

The EU2020 strategy aspires to achieve a low carbon economy, geared towards a reduction of 80% of CO2 emissions by 2050. It is widely recognised that a technological shift and the widespread deployment of new clean technologies are critical for a successful transition to such a new sustainable economy. Furthermore, decarbonising hydrogen production has been defined as a clear objective, with a goal of 50% of the hydrogen for energy applications to be provided from CO2-emission free production methods [5].

The EU currently has a target of investing 3% of GDP in R&D (5). However, it was noted that R&D spending is lower in Europe (below 2%) compared to US (2.6%) and Japan (3.4%) mainly as a result of lower levels of private investment. To address the imbalance in research and development activities within the EU, one initiative was the establishment of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). At European level, FCH JU was founded in 2008 to develop and implement a targeted R&D programme, with a total budget of €940 million up to 2013, of which 50% is contributed by the EC and 50% by the private sector. The stakeholders involved in the FCH JU are the European Commission, Industry (NEW-IG) and the Research community (N.ERGHY). FCH JU focuses on four main application areas; hydrogen vehicles and refuelling stations, sustainable hydrogen production, stationary FCs for heat and power generation, and FCs for early markets. The FCH JU's objective is to promote, support and accelerate the research and deployment process of fuel cell and hydrogen technology in Europe from the point of view of the research community. Over the last four calls, the FCH JU has funded close to 100 projects, including projects in transport and materials handling sector.

The New World Energy Grouping (NEW-IG), a non-profit association representing industry in the FCH JU, published the Technology Roadmap for the period 2010-2020 [5]. The Roadmap sets out specific market penetration objectives for each sector of the fuel cell and hydrogen technologies to be reached by 2020. Industry sector's objective include contributing to the demonstration of cost-efficient fuel cell based solutions for material handling vehicles (20,000 vehicles), back-up power/UPS (20,000 systems) and portable power systems (250,000 systems), as competitive early market applications, with recognisable market shares in each of these market segments.

Furthermore, the Roadmap concluded that the total estimated amount needed for market-breakthrough of the early applications; portable fuel cells including auxiliary power units (APUs), back-up systems for the telecom market, and materials handling equipment, is in the region of €1.4 billion, of which €830 million is reserved for R&D, and €178 million should be made available for pilots and for demonstration projects. For deployment support an amount of €409 million is needed during the period of 2014 to 2020 [5].

Moreover, it also noted that current funding levels and financial mechanisms will require to be significantly increased if Europe's ambitions are to be met in 2020. In addition, NEW-IG (of the FCH JU) concluded that market-introduction support in the form of adequate incentives – similar to the US programme – will be needed to bring fuel cell forklifts to a commercial stage and to implement the necessary infrastructure. Targeted demand side stimulus is also needed for the transition to the market.

Within the material handling sector, Europe holds a strong global position, with half of the world's total production and an annual turnover of €45 billion, spread over a total of 1,000 companies and 160,000 employees [5]. However, clean technologies are not likely to play a role in future energy, or transport and logistics systems without decisive and supportive policies and incentives designed to break through the first-mover disadvantage; high initial investment costs and market reluctance to take up the new technology. To create consumer acceptance and investor security, initiatives to support continued RTD efforts, in parallel with market introduction of the new technology are required to ensure that reaching competitive volumes and costs are achieved, therefore, enabling sales without public support.

To achieve such goals, a concerted approach and shared costs and risks mechanisms with European national and local authorities, and the introduction of the appropriate standards and regulatory framework to support the deployment of hydrogen and fuel cell technologies is required.

2.2. North America: US/Canada

The United States is currently leading the material handling vehicles sector. This is mainly as a result of government incentives; fuel cell electric forklifts represent an estimated 2% penetration of annual sales of electric forklifts in the US.

At the federal level, two significant policies shaped the market for FCs. Investment Tax Credit (ITC) was established in 2008, amounting at $3,000 per kW for Fuel Cells (capped at 30% of the Fuel Cell investment) and at $200,000 for hydrogen refuelling station (capped at 30% of the investment). This mechanism is effective until 2016 [5].

Moreover, in 2009, the American Recovery and Reinvestment Act (ARRA) committed $42 million in federal funding to accelerate fuel cell commercialisation and deployment. This was matched by $54 million in cost sharing by the industry [1]. The two aforementioned policies have had a significant impact on the deployment of a significant number of fuel cell systems primarily intended for emergency backup power and material handling (plus infrastructure). In particular, Cumulative ARRA-funded sales of fuel cells to materials handling sector, 77 in 2009 increased to 572 by the end of Dec 2010 [1].

The US Department of Energy (DOE) has devoted $170 million for Hydrogen Fuel Cell R&D, demonstration and commercialization activities in 2010 and 2011, and foresees to commit more than $100 million for 2012. The ARRA provided additional funds for subsidizing purchases of FCs, based on cost-sharing contracts awarded by US DOE. In addition to the DOE federal programme, many States have financial incentives to support the installation of hydrogen and fuel cell stations; including New York (NYSERDA), Connecticut (Connecticut Clean Energy Fund), Ohio (Ohio Development Department), and California (California Energy Commission). For instance, the state of California offers additional incentives to purchasers of FCs for use in Combined Heat & Power (CHP) applications in the form of its Self Generation Incentive Program (SGIP). The size of the California SGIP incentives depend on the nature of the energy used to power the FC.

Section 1603 of the American Recovery and Reinvestment Act (ARRA) of 2009 allowed purchasers of FCs to claim a subsidy in lieu of the tax credit. The intent was to extend the subsidy to firms that might not have taxable profits in the recession years. The impacts of the ARRA purchases varied from firm to firm. For instance, ARRA purchases account for the majority of Plug Power's material handling business in 2009 and 2010. Overall, the great majority of ARRA financed units were material handling or backup power PEMFCs. Large stationary units though smaller in number were much larger in kW capacity. Table 1 indicates ARRA awards received by US companies with direct impact on material handling application by the end of 2010.

Table 1: ARRA Awards for FC Specialty Vehicles Projects within the Early Market Sector

Company	Award	Application	No of FLT *By the end of 2010*
FedEx Freight East	$1.3M	Specialty Vehicle	35
GENCO	$6.1 M	Specialty Vehicle	59
Nuvera Fuel Cells	$1.1 M	Specialty Vehicle	14
Sysco of Houston	$1.2 M	Specialty Vehicle	98

Adopted from:
(1) *Status and Outlook for the U.S. Non-Automotive Fuel Cell Industry: Impacts of Government Policies and Assessment of Future Opportunities May 2011*

Canada is also a significant player with a strong hydrogen and fuel cell industry, focussed on near-to-market application deployments. Of the top 10 fuel cell companies in the world, have headquarters in Canada; Ballard Power Systems in the British Colombia and Hydrogenics in Ontario were ranked 4th and 5th in terms of revenue in 2008. Canadian companies account for 16% of the worldwide commercial fuel cell revenues in 2008 [6]. Ballard has recently announced that they have produced the one millionth PEMFC and they are set to financially breakeven this year [7].

Canadian technology is part of the largest purchase to date of FC FL Technology anywhere in the world. One example is the purchase of 220 FC units from Plug Power by Central Grocers to power the entire truck fleet of its new distribution centre in Illinois, featuring FC technology from Ballard Power Systems. Plug Power, initially a Canadian company, currently has it's headquarter in New York [6].

At present, Nuvera (US), Plug Power (US) and Hydrogenics (Canada) offer PEM FC power systems for forklifts that are interchangeable with the standard battery systems. Oorja Protonics (US) offers a different type of system with a direct methanol FC that acts as a battery charger rather than as a direct source of motive power. It is expected that the market will evolve from battery replacement to purpose-built forklift trucks as demonstrated by Raymond Corporation's partnership with Ballard Power Systems to do-develop a new generation of FC FLTs [1].

2.3. Japan / Germany / the World

The FC market in Japan is almost completely focused on residential combined heat and power (CHP) and uses very small PEMFC units ranging in power from 0.7 to 1 kW electrical output with about twice as much heat output. However, the unit sales are quite high, with sales of over 3,500 units in 2009 and over 5,000 in 2010 [1].

In Japan, 45% of homes heat with natural gas, 45% with LPG and 10% with electricity. Three companies, Toshiba, JX Energy, and Panasonic, account for nearly Japan's entire stationary FC program, which is focused on small, 1 kW, PEM CHP units chiefly for single-family homes. The Japanese government considers stationary FCs to be one of key technologies for the future, and has spent 1 ¥ billion (roughly $10 million) on FC vehicle demonstrations in Japan to date [1]. There are 60 FC vehicles in operation and 15 public H2 refuelling stations. Japan has a small presence in larger fuel cell technologies.

Fuel Cells 2000 recently put out a press release detailing that hydrogen and fuel cell research funding in Japan topped $240 million in FY 2012. This is more than double the amount being spent by the U.S. Department of Energy in FY 2012, and three times the amount requested for 2013, according to the director of the Hydrogen and Fuel Cell Promotion Office at Japan's Ministry of Economy, Trade and Industry. The total includes financial support for residential fuel cell installations and a variety of research and demonstration activities [8].

In Germany, NOW [Nationale Organisation Wasserstoff], National Organisation for Hydrogen and Fuel Cell Technology, has been active in the promoting FCH technology. It is responsible for the coordination and management of the National Innovation Program for Hydrogen and Fuel Cell Technology (NIP), launched in 2006, with a total budget of 1.4 billion Euros for the period of 2007 to 2016. The funding is provided by the federal government - the Federal Ministry of Transport, Building and Urban Development (BMVBS) and the Federal Ministry of Economics and Technology (BMWi). NIP is a strategic alliance involving the German government, industry and academia. The programme forcuses on research and development and large-scale demonstration projects. The NIP is divided into three programme areas; "Traffic and hydrogen infrastructure", "Stationary Energy Supply" and "Special Markets“, focusing on production-ready components, specifically on strengthening the supply industry [9] .

In a recent development, Germany announced that from 1st of April 2012, subsidies of between €1,500 and €3,500 are available to customers with no access to district heating network installing μ-CHP systems, including fuel cell-powered ones. The subsidy follows up on the CHP Act, which mandates 25%

of Germany's electricity generation to come from CHP (both small- and large-scale) by 2020. The scheme is managed by the Federal Ministry of Economics and Technology through its Office of Economics and Export Control [10].

China has also invested heavily on fuel cell technology and infrastructure RD&D; reported to cumulatively amounting to $2.8 billion by the end of 2011. These efforts have focused on portable, stationary and mobile applications and on the production of hydrogen from solar, biomass, natural gas and coal resources [5].

South Korea has also committed to a programme subsidising 80% of the cost of residential fuel cells for heat and power. The subsidy will be reduced to 50% and 30% for the period of 2013-2016 and 2017-2020 respectively. South Korea has also announced an ambitious goal to supply 20% of the worldwide shipments of fuel cells by 2025 and create over half a million jobs in the country. A strategic plan for Seoul includes 47% of renewable energy generation form fuel cells by 2030 [5].

3. European and American material handling demonstration projects

The primary barriers to widespread use of hydrogen fuel cells for material handling equipment are concerns about the safety of hydrogen storage and fuelling equipment, operating costs for fuel and maintenance, and the long-term reliability of fuel cells. The purpose of demonstration projects is to confirm that hydrogen fuel cells are a safe and economical alternative to batteries for powering electric lift trucks.

There have been a number of demonstration projects in Europe. In 2000 Linde Material Handling (now part of KION Group) introduced one of the first fuel cell forklifts in Germany, developed in a joint project with Siemens. The counterbalanced FLT incorporated a 10kW PEMFC and a conventional battery to provide the start up. It had sufficient gaseous H2 ($26m^3$) on board in titanium-based hydride tanks to run a single 8-h shift. It operated at the industrial scale solar hydrogen demonstration plant in Bavaria [11].

In Munich airport, Proton Motor (a German FC manufacturer) joined forces with STILL GmbH (a German FLT OEM) and Linde Gas (Germany) to replace the traction battery of a series R60 electric forklift with a fuel cell of the same performance; a fuel system with a nominal output of 18kW with an ultra-capacitor serving as energy storage device. The logistic company Cargogate GmbH, a subsidiary of Flughafen Munchen GmbH used this prototype as the first FC-Powered vehicle in Munich airport for 2 years until the end of the project in 2006 [11].

In 2008, as part of the HyLOG project, in Austria, one logistic vehicle was converted to run on hydrogen produced from in-house solar power. The conventional lead/acid batteries in the vehicle were replaced by the Fronius Energy Cell with a replaceable hydrogen cartridge as the fuel tank. The hydrogen is then stored and made available for refuelling via an in-house filling station infrastructure [12].

In May 2010, two counterbalanced Linde FC Prototype forklifts, fitted with Hydrogenics 80V HyPX FC, began operational pilot test at the Linde gases Division Hydrogen Centre in Bavaria, replacing diesel lift trucks [11].

Overall, the total number of FC-Powered FLTs deployed in real life demonstrations has been limited in EU until recently; numbering on the order of 20 in total until the end of 2010 (see Table 2).

Two 3-year European FLT demonstration Projects commenced in 2011; Sustainable Hydrogen Evaluation in Logistics (SHEL) and HyLift demo; both projects are part-funded by the European Joint Undertaking for Fuel Cells and Hydrogen(FCH JU). The two latter projects aim to deploy 10 and 30 FLTs in representative sites across Europe, within the EU framework of system cost and lifetime targets. H2 refuelling infrastructure cost to be included within the overall financial analysis. Furthermore, the projects aim to address the requirement for a common approach at EU level to address the certification process for overall site, infrastructure, and material handling vehicle certification. Both projects aim to pave the way for much larger material handling demonstration projects and commercialisation of FC-powered forklift trucks in due course.

In contrast to small scale FLT demo projects across Europe, substantive demonstration projects have been ongoing in the US since early 2000, which gathered further momentum due to ARRA funding. In the three years 2007-2009, 450 hydrogen fuel cell powered forklifts went into operation in the US [9]. In addition, ARRA funding had a significant impact on the total number of FC-powered FLTs deployed. Quarterly operational data from the funded projects are collected and analysed by the National Renewable Energy Laboratory (NREL). Data published by the US DOE indicated that, by the end of 2011, the latter funding mechanism alone had resulted in deployment of a total of 504 FC-powered FLTs; 35 by FedEx in Arkansas, 357 by GENCO in 5 distribution centres, 14 by Nuvera in Massachusetts, and 98 by Sysco in Texas, with a potential 748 further service and distribution centres which could conceivably follow from the success of the deployment by the four aforementioned companies [14].

4. Conclusions

Materials handling equipment have been identified as an important early market adopters of fuel cell technology. The main rationale for this choice is the utilisation of the vehicles in a defined space, returning to base for refuelling, which circumvents the reliance upon an established hydrogen infrastructure. Moreover, multi-shift usage patterns of forklift trucks in large warehouses allows for significantly shorter pay-back period than other transport vehicles. Demonstration projects provide invaluable data relating to reliability of fuel cells in real application context and provide impetus for a sustained manufacturing and supply base for fuel cell products and systems. In addition, targeted government support and intervention have a significant impact on the take up of new technology.

Technologies deployed in the next 20 to 40 years will be the result of policy and funding decisions taken today. In the US, two significant policies shaped the market for FCs, provided a major momentum for adoption of FC-powered materials handling equipment, with the purchase of over 500 systems in 2010. The EU has accelerated its commitment to the FC technology by setting specific goals for adoption of technology within each market sector. This includes a commitment to contribute to the demonstration of cost-effective fuel cell based solutions for 20,000 materials handling vehicles during the 2014-2020 period, whilst conceding that market-introduction support in the form of adequate incentives – similar to the US programme – will be needed to bring fuel cell forklifts to a commercial stage and to implement the necessary infrastructure. Furthermore, it has been acknowledged that market introduction of the FC technology requires targeted demand side stimulus.

Current EU-funded demonstration projects, together with the EU commitment to support introduction of fuel-cell-powered material-handling equipment, could facilitate widespread implementation and future commercialisation of the technology. Moreover, the projects could provide an impetus for adoption of the technology within the wider context of automotive sector, hence contributing to the ambition of reaching a low carbon economy within Europe.

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Table 2: European Material Handling Demonstration

	Location	Units	Timeline	FC Type	FC stack OEM (Brand name)	System integrator	FLT OEM Model/Class	Hydrogen Supplier
Germany	Bavaria [Hydrogen Demonstration Plant]	1	2000	PEMFC		Siemens	Linde material handling (now part of KION Group)	
Germany	Munich [Airport]	1	2004-2006	PEMFC	Proton Motor	Hoppecke Batterien GmbH	STILL GmbH STILL R60-30	Linde Gas
Germany	Nordrhein-Wesfalen [Hoppecke Plant]	1	2006	PEMFC	Proton Motor (Hybrid)	Hoppecke Batterien GmbH	STILL/Linde	Linde Gas
Germany	Munich [Puchheim Facility]	1	2007	PEMFC	Proton Motor (Triple Hybrid)		STILL/Linde	Linde gas
Germany	Nordrestedt [Jungheinrich Plant]	1	2007	DMFC Hybrid	FZ Julich		Jungheinrich ECE-220	
Denmark		7+	2006-2008	PEMFC	Ballard	H2Logic	DanTruck/STILL	
Germany	Hamburg	1	2007-	PEMFC	Hydrogenics (HyPX)	Hydrogenics	STILL GmbH STILL RX60-45	Linde Gas
Germany	Hamburg [Airport]	2	2007-	PEMFC	Hydrogenics (HyPX)	Hydrogenics	STILL GmbH STILL R07, Class1/2	Linde Gas
Germany	Munster [BASF Coatings]	1	2007	PEMFC	Hydrogenics (HyPX)	Hoppecke Batterien GmbH	STILL GmbH STILL R60-25	Linde Gas
Germany	Unterschleissheim [Linde Gas Division]	1	2007	PEMFC	Hydrogenics (HyPX)	Hoppecke Batterien GmbH	STILL GmbH STILL R60-25	Linde Gas
Austria	Sattledt [HyLog Project]	2	2009-	PEMFC	Fronius Energy Cell		Linde MH P30-050	
Finland	[Plant in Espoo]	1	2009-2010	PEMFC	Nedstack (Triple Hybrid with ultracaps & battery)	VTT/TKK	Kolmar/Cargotec	In-house solar-powered Electrolyser
Germany	Munster [BASF Coatings]	2	2010-	PEMFC	Hydrogenics (HyPX)	Hoppecke Batterien GmbH	STILL GmbH STILL R60-25	Linde Gas
EU	HyLift	30	2012-					
UK Spain Turkey	SHEL	10	2012-	PEMFC	Hydrogenics (HyPX)	UNIDO-ICHET	CUMITAS	Air Products

Adapted from: [13] *Fuel cells in forklifts extend commercial reach, Fuel Cell Bulletin, September 2010, 12-19*