



## PROJECT FINAL REPORT

EUROPEAN DEMONSTRATION OF HYDROGEN POWERED FUEL CELL MATERIALS HANDLING  
VEHICLES

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## Disclaimer

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# 1 Final publishable summary report

## 1.1 Executive summary

The overall purpose and ambition of HyLIFT-DEMO was to conduct a large scale demonstration of hydrogen powered fuel cell material handling vehicles, which enables a following deployment and commercial market introduction. The detailed HyLIFT-DEMO project objectives were the demonstration of at least 30 material handling vehicles as well as the demonstration of the corresponding hydrogen refuelling infrastructure at end-user sites. Moreover, the project partnership aimed at conducting accelerated laboratory durability tests and validating the value proposition of the technology fulfilling commercial and environmental targets. Furthermore, objectives were to plan and secure the initiation of Research and Development (R&D) of the 4<sup>th</sup> product generation. Finally, the project contributed to the establishment of an appropriate Regulations, Codes and Standards (RCS) framework which will enable smooth commercialisation as well as to the motivation of European, national and regional stakeholders by performing adequate dissemination activities.

The project was conducted by a consortium of European partners that for several years have invested significantly in developing and testing hydrogen and fuel cell technology for material handling vehicles. The technology is now advanced to a 3<sup>rd</sup> generation level that allows for a large scale demonstration before commencing market deployment. The number of materials handling vehicles being demonstrated in the project was, however, reduced to 11 vehicles due to difficulties in identifying interested end-users for the vehicles. Extensive market analyses have encouraged the partners to focus on the market segments of 2.5-3.5 tons forklifts and airport tow tractors, as these segments provide the strongest value proposition for fuel cell vehicles in the materials handling sector within Europe. It was thought that the demonstration activities could lead directly to a following market deployment with a solid and proven value proposition for the vehicle end-users. Unfortunately this could not be realized and therefore further large scale demonstrations and deployment support will be required.

The fuel cell system was demonstrated in materials handling vehicles from three vehicle manufacturers, representing various market segments and system integration approaches.

The demonstration was handled in fleets of up to 4 vehicles; end-users envisaging larger fleets were preferred. Larger fleets would lead to a more viable business case for the supporting hydrogen refuelling infrastructure, but also to an efficient service and maintenance set up. As well as minimizing the final number of demonstration sites, the project endeavoured to place these as close as possible

to each other as this lowered costs both for maintenance and for hydrogen distribution. The supply of hydrogen for the sites was from local sources or through commercial subcontracting from local gas suppliers. The refuelling infrastructure was owned and operated either by project partners, the end-user, or other local partners or projects.

HyLIFT-DEMO addressed a specific and proven value proposition where hydrogen and fuel cells replace use of diesel / LPG in 2.5-3.5 ton material handling vehicles where batteries cannot provide a satisfying solution. The ambition and driving force of the HyLIFT-DEMO activities and partners were to enable a following deployment and market introduction. Therefore the targets to be reached within the project as well as the demonstration model and relations to end-users were set-up with a future commercial value chain in mind.

## 1.2 Summary description of project context and objectives

### Background

The HyLIFT-DEMO project addressed the topic “SP1-JTI-FCH.2009.4.1: Demonstration of fuel cell-powered materials handling vehicles including infrastructure” in the 2<sup>nd</sup> call of the European Fuel Cells & Hydrogen Joint Undertaking Implementation Plan (AIP 2009).

The project was conducted by a consortium of European companies and R&D institutions that for several years have invested significantly in developing and testing hydrogen and fuel cell technology for materials handling vehicles.

The technology is now advanced to a 3<sup>rd</sup> generation level that allows for a large scale demo before commencing market deployment. Also extensive market analyses have encouraged the partners to focus on the market segments of 2.5-3.5 tons forklifts and airport tow tractors, as these segments provide the strongest value proposition for fuel cell vehicles in the materials handling sector within Europe. It was thought that the demonstration activities could lead directly to a following market deployment with a solid and proven value proposition for the vehicle end-users.

The project partners together also covered the entire value chain and held all disciplines and technologies required for providing a fully working hydrogen powered fuel cell system solution to be implemented in an OEM vehicle. Also the value chain consisted of both large and SME companies in an optimal collaboration.

Also a number of non-profit organisations were participating and contributing with important supportive activities for the companies in terms of Regulations, Codes

and Standards, end-user identification and motivation, dissemination and laboratory testing and initiation of future R&D.

All project partners are European based with their headquarters and R&D facilities located in Europe and thus all the hydrogen and fuel cell technologies and the vehicles were developed in Europe by Europeans. Thus the project partners constituted a consortium that could contribute to a successful European commercialisation and success story within the area of hydrogen and fuel cell technology.

The HyLIFT-DEMO project also had a strong platform as well as a sound financial model for executing the large scale demonstration. HyLIFT-DEMO used an innovative financial demonstration model approach where FCH JU funds and company contributions enabled end-users to apply the fuel cell vehicles on a commercial basis and competitive compared to diesel / LPG vehicles.

The participation of HyRaMP (now HyER) and EHA, well known for their extensive European network, provided access to a large number of potential demonstration regions and end-users. In the forklift segment HyLIFT-DEMO had secured letters of interest from 21 forklift end-users throughout Europe that together have a total forklift fleet of 633 units of the type that was targeted for this project. Comparable activities to secure letters of interest from airports regarding the use of fuel cell tow tractors were performed in parallel. Also letters of interest had been secured from local project facilitators covering 10 demonstration regions throughout Europe. The local project facilitators tried to prepare local project set-ups with end-users that HyLIFT-DEMO could use.

### **Purpose & objectives**

The overall purpose and ambition of HyLIFT-DEMO was to conduct a large scale demonstration of hydrogen powered fuel cell materials handling vehicles, which should enable a following deployment and market introduction initially foreseen to start no later than 2013, now planned to start no later than 2015.

The initial HyLIFT-DEMO project objectives were:

#### **Demonstration of at least 30 material handling vehicles**

Conduct 12 - 18 month demonstration of at least 10 units of 2.5-3.5 tons forklifts and at least 10 units of airport tow tractors, but in total at least 30 vehicles.

#### **Demonstration of hydrogen refuelling infrastructure at end-user sites**

Conduct 12 - 18 month demonstration of hydrogen refuelling infrastructure at end-user sites throughout Europe where the fuel cell vehicles are to be demonstrated.

### **Conduct accelerated laboratory durability tests**

Perform accelerated laboratory tests on fuel cell systems to validate life time and sensitivity to shock, vibration and climate exposure, reaching 4,000 hours in laboratory.

### **Validate value proposition & reaching of commercial and environmental targets**

Conduct data acquisition from the demonstration operation and validate reaching of performance targets on durability, efficiency and costs for 3<sup>rd</sup> generation technology.

### **Plan and secure initiation of R&D of 4th generation commercial products**

Ensure that R&D of 4<sup>th</sup> generation fuel cell and hydrogen refuelling technology is initiated onwards reaching full commercial targets.

### **Ensure commercial market deployment no later than 2013**

Plan and ensure initiation of a commercial market deployment by end of 2013 of hydrogen powered fuel cell material handling vehicles. This involves planning of the companies and development of suggestions for European/national/regional deployment support mechanisms.

### **Secure RCS for enabling commercialisation**

Identify future Regulation, Codes & Standard needs in order to enable commercial high volume certification & use of hydrogen powered fuel cell materials handling vehicles.

### **European dissemination securing national & regional motivation**

Project results and experiences are to be disseminated throughout Europe to the hydrogen and fuel cell industry as well as the materials handling industry. This is to motivate national and regional actors to also initiate development and commercialisation activities within the area.

During the preparation of the 3<sup>rd</sup> Contract Amendment the HyLIFT-DEMO project objectives were revised as follows. The objectives not mentioned here remain unchanged. The reasons for the required changes were one the hand the difficulties in identifying sufficient end-users for the deployment of 30 vehicles in the available timeframe which was even tightened by the bankruptcy of DanTruck accompanied by the underestimated wish of potential customers to test drive the vehicles before placing an order and on the other hand that due to an electronic hardware dysfunction of the test system during the initial test phase shock and

climate tests needed to be cancelled. The aforementioned delays of the vehicle deployment also cause the delays in the initiation of the market deployment.

### **Demonstration of at least 11 material handling vehicles**

Conduct 12 - 18 month demonstration of at least 10 units of 2.5-3.5 tons forklifts and at least 1 unit of airport tow tractors.

### **Conduct accelerated laboratory durability tests**

Accelerated laboratory tests on fuel cell systems to validate life time and sensitivity to vibration exposure, reaching 4,000 hours in laboratory.

### **Ensure commercial market deployment no later than 2015**

Plan and ensure initiation of a commercial market deployment by end of 2015 of hydrogen powered fuel cell materials handling vehicles. This involves planning of the companies and development of suggestions for European/national/regional deployment support mechanisms.

### **Fuel cell materials handling vehicles demonstration**

In the HyLIFT-DEMO project H2 Logic demonstrated 11 units of a 3<sup>rd</sup> generation fuel cell system in materials handling vehicles from two material vehicle OEMs (after the exit of DanTruck).

H2 Logic had been developing fuel cell systems for the materials handling market since 2003. The technology has now reached a 3<sup>rd</sup> generation level that had been demonstrated within this project. Within follow-up projects the demonstration efforts is planned to be increased in volume.

Over the years H2 Logic's R&D efforts had been focused on simplification of the fuel cell system by modularisation. The simplification both helped to reduce costs and improve efficiency and the modularisation helped to expand the potential market as the fuel cell system could be integrated and used in a variety of materials handling vehicles.

The fuel cell system consists of a number of base modules that can be configured into different system set-ups enabling either direct integration into vehicles developed entirely for fuel cell operation, or replacement of standard battery boxes in electric material handling vehicles. This approach could achieve volume and reduce costs across several vehicle segments.

The vehicle integrated approach was stopped during the course of the project as a consequence of the bankrupt project partner DanTruck leaving the project in month 9.



## Hydrogen refuelling infrastructure demonstration

In the HyLIFT-DEMO project H2 Logic conducted the demonstration of hydrogen refuelling infrastructure at the end-user sites where fuel cell materials handling vehicles were used. Linde contributed with experiences and knowledge from previous activities within hydrogen refuelling infrastructure.

The supply of hydrogen for the sites was through commercial subcontracting tendering from local gas suppliers. The refuelling infrastructure was either be owned and/or operated by H2 Logic, the end-user or other local partners or projects.

The price of the supplied hydrogen fuel for the vehicles is the main parameter affecting the end-user value proposition for using fuel cell material handling vehicles. The higher efficiency of the fuel cell compared to internal combustion engines (ICE) combined with a sufficient low hydrogen price is to ensure savings on fuel costs that can leverage the extra costs of the fuel cell compared to an ICE. The target for the hydrogen supply was to reach a price level of 7-9 €/kg hydrogen, dispensed at pump.

The hydrogen price consists of two main elements, the costs of hydrogen provision to the site and the dispensing costs. Whereas the dispensing costs are well known due to exact prices on the onsite infrastructure (compressing, storing and dispensing) the costs of providing the hydrogen is greatly depending on the hydrogen source.

The supply option that enables the lowest hydrogen costs is industrial by-product hydrogen supplied by pipeline.

However, trucked-in hydrogen may also enable a sufficient low hydrogen price if the end-user sites are located nearby the hydrogen production and distribution centre. Onsite hydrogen production combined with a local project set-up can also enable reaching the price targets.

Concerning the hydrogen refuelling infrastructure at the end-user sites this had been established by H2 Logic at sites where the hydrogen refuelling infrastructure was not already present. At sites where refuelling was already available, H2 Logic performed a test of the equipment to ensure hydrogen quality and refuelling process compliance with the fuel cell vehicle requirements. This verification process also ensured that 3<sup>rd</sup> party hydrogen refuelling infrastructure did not influence the results gathered from the demonstrated fuel cell vehicles.

H2 Logic has developed and demonstrated several hydrogen refuelling infrastructure solutions in the past, and thus used HyLIFT-DEMO to assemble a solution fit for materials handling. Linde contributed to the efforts with years of

experience within supply of hydrogen and infrastructure, among others from materials handling activities in the USA.

For sites where no hydrogen refuelling solution was already available, the refuelling infrastructure was provided as compact and transportable module that allowed for fast and easy installation on site. Dispensers could be located indoor or outdoor separately from the refuelling module. Within the station hydrogen is compressed to 40-45 MPa and stored onsite, before conducting cascade refuelling through the dispensers. The refuelling infrastructure was designed to supply up to 10 vehicles that are used intensively up to 3 working shifts per day, corresponding to 60 kg per day. Also the storage capacity allows for instant refuelling of at least 3 vehicles. The capacity of the hydrogen refuelling stations varied from site to site depending on the number of vehicles in operation. When the end-user sites were selected H2 Logic and Linde defined the exact hydrogen infrastructure concept for each site based on the available hydrogen supply and the capacity needed for the vehicle fleet at the site.

## 1.3 Description of the main S&T results / foregrounds

### Summary of project achievements in the demonstration preparation phase

- Presentation of DanTruck fuel cell forklift at the CeMAT, one of the world's leading intralogistics trade fairs
- Agreement on detailed demonstration planning comprising a detailed planning of the various interfaces between the project work packages
- Draft version of Report “Overview of existing Regulations, Codes and Standards (RCS) for forklifts and refuelling stations” available
- Successful kick-off meeting in Brussels, 2<sup>nd</sup> General Assembly meeting in Herning (with DanTruck hydrogen powered fuel cell forklift prototype demonstration) and 3<sup>rd</sup> General Assembly meeting in Munich
- Monitoring and Assessment Framework (MAF) for the assessment of demo projects for material handling vehicles adapted and finalized
- Appropriate materials handling vehicles for conversion to a hydrogen powered fuel cell drive train could be identified after there was a lack of vehicles caused by the withdrawal of DanTruck from the project in SEP 2011
- In December 2011 the first fully integrated H2Drive system could be certified. Investigations with regard to the advantages and disadvantages of a type approval were ongoing at that point in time
- Performance testing phase for first vehicle prototypes could be finalized successfully
- Because of the new situation with the changed vehicle supplies there was the need of a revision of the time schedule. Afterwards a sound and realistic deployment schedule for all fuel cell materials handling vehicles and the supporting hydrogen infrastructure is available
- In order to improve efficiency and performance of the fuel cell system intense development work was performed in order to identify the optimal hybrid configuration
- Models were developed in order to define an appropriate refuelling method on the one hand to assure refuelling safety and on the other hand to refuel to the highest possible state of charge in the tank at lowest possible refuelling time
- The preparation of both durability and vibration, shock and climate testing were performed
- The cooperation with the material handling vehicle OEMs STILL and MULAG had been intensified and their interest in offering vehicles with a hydrogen powered fuel cell drive train to their customers had been inspired and strengthened
- As the new suppliers of the material handling vehicles could provide services and support all over Europe the area in which the fuel cell vehicle

demonstrations could take place was largely widened and therefore the HyLIFT-DEMO efforts to identify appropriate potential end-users had been enlarged accordingly

- In the meantime 10 fully integrated H2Drive system had been manufactured, tested and certified
- Contracts for 6 fuel cell material handling vehicles had been signed. Negotiations for further vehicles were on-going
- EMC testing of the fuel cell system and the vehicles (STILL RX60-25 FC and MULAG Comet 3FC) had been successfully finalized
- The performance testing phases for both the STILL forklift truck and the MULAG airport tow tractor had been finished with good success
- In order to improve efficiency and performance of the fuel cell system intense development work had been performed in order to identify the optimal hybrid configuration

### **Project achievements in the demonstration phase**

In its demonstration phase HyLIFT-DEMO had not fully progressed according to the updated project plan which was necessary because of the withdrawal of DanTruck. As the project was not successful in signing additional contracts with materials handling vehicle end-users the project was not able to reach the initial target of 30 vehicles in demonstration.

Nevertheless, demonstrations could be performed at several end-user sites and in total 11 vehicles, 10 fuel cell forklifts and 1 airport tow tractor, were clocking hours at several locations. Vehicle performance data were collected and processed using the Monitoring and Assessment Framework developed in the EC funded project HyLights and adapted for the specific requirements of materials handling vehicles within HyLIFT-DEMO. Publications of performance data were made. 9 materials handling vehicles were in demonstration operation at real en-user sites, two were in operation for use trials and for fuel cell system performance testing:

- 4 forklifts at Stark / Denmark
- 2 forklifts at Colruyt / Belgium
- 2 forklifts at egetæpper / Denmark
- 1 forklift in Frankfurt / Germany (several potential customers: Hassia, Viessmann, Rudolph Logistics)
- 1 forklift at H2 Logic / Denmark
- 1 tow tractor at MULAG / Germany (trials in Hamburg airport / Cologne/Bonn airport)

Further aspects:

Vibration tests were performed at JRC. Shock and climate testing had to be cancelled because of technical reasons. Durability testing was performed at H2 Logic's premises as shown below.

The mid-term dissemination workshop for European stakeholders, planned for JUN 2012, was postponed and combined with the final dissemination workshop for materials handling stakeholders because of the project's delayed demonstration phase.

The report "Suggestions for deployment support mechanisms" has been finalized in MAR 2013.



Figure 1: Climate tests of MULAG 3FC in winter @ -13°C

### **Overarching project achievements**

The HyLIFT-DEMO project conducted the demonstration of hydrogen powered fuel cell materials handling vehicles, while it tried to build the business case to enable following deployment and market introduction. This small scale batch production of these vehicles sought to validate the value proposition as well as commercial and

environmental targets by retrieving the data provided by the demonstration operation.

After the revision, the project succeeded to achieve the demonstration of 11 units of 2.5 - 3.5 tons fuel cell forklift trucks and airport tow tractors with an integrated 3<sup>rd</sup> generation fuel cell system and hydrogen refuelling infrastructure at end-user sites throughout Europe. In addition, accelerated laboratory tests were performed on a fuel cell system to validate life time resistance, planned to reach 4,000 hours in laboratory and ending up finally with 1.200 hours reached. Because of limitations of the test equipment shock and climate testing were required to be cancelled. Climate tests during two winters were performed at H2 Logic and customer sites. Vibrations tests had been performed in cooperation with a forklift OEM on an internal vibration test track, and had produced very valuable results for further product improvements.

In detail the following results could be achieved in the course of the project:

## **WP 2 - Demonstration specification & planning**

### **WP Leader – H2 Logic**

In second half of 2012, vehicle demonstrations had finally commenced. The following sites were in operation:

#### **STARK K&M City:**

- Copenhagen, Denmark
- 4 STILL RX60-25 FC
- Site started 11.2012
- 2 shifts, 5 days per week
- H2 Logic 25 MPa refuelling station

At STARK, the forklifts were working with goods handling in a large hardware store supplying materials for construction. The fuel cell forklifts were replacing the site's previous diesel powered forklifts and were therefore used intensively for the hard work at the site.



Figure 2: STILL RX60-25 FC taking a break, STARK K&M city

#### Colruyt Distributiecentrum Dassenveld:

- Halle, Belgium
- 2 STILL RX60-25 FC
- Site started 09.2012 / 01.2013
- 2-3 shifts, 6-7 days per week
- Waterstofnet / Hydrogenics refuelling station

The forklifts at Colruyt were working in a pallet sorting facility and plastic container cleaning facility, where packaging from the company's stores are recycled.

During December 2012 the two forklifts at Colruyt were returned to H2 Logic for upgrades addressing stability issues learned during the first months of demonstration. The forklifts were returned back to Colruyt immediately after New Year's 2012/2013 and demonstration recommenced in January 2013.



Figure 3: STILL RX60-25 FC at work, Colruyt Distributiecentrum Dassenveld

egetæpper:

- Herning, Denmark
- 2 STILL RX60-25 FC
- Demonstration starting 07.2013
- H2 Logic 25 MPa refuelling station

Vehicles used for internal distribution of carpets and goods dispatch at carpet manufacturer. Carpet dispatch is every Thursday and Friday, where the two vehicles were used intensively.



Figure 4: STILL RX60-25 FC at work, egetæpper carpet dispatch centre

STILL Frankfurt:

- Frankfurt, State of Hessen, Germany
- 1 STILL RX60-25 FC
- Forklift delivered 12.2012



- On road tour from 03.2013
- GHR mobile refuelling station (planned), Linde trailH2 (realized)

The STILL Frankfurt vehicle was used together with a mobile refueller for short trials at potential end-user sites.



Figure 5: Road tour kick-off, STILL Frankfurt

#### MULAG:

- trials at Hamburg and Cologne/Bonn airports and performance testing at MULAG's premises, Oppenau, Germany
- 1 MULAG Comet 3 FC
- trial vehicle also used for range and power design upgrade in WP9
- H2 Logic H2Station<sup>®</sup> MH-100 refuelling station

The MULAG Comet 3 FC prototype is used for potential end-user trials at airports, mainly in Germany and for performance testing at MULAG's premises. To support these activities MULAG had ordered one H2Station<sup>®</sup> MH-100 hydrogen refuelling station.



Figure 6: MULAG Comet 3FC on trial at Hamburg airport

#### H2 Logic:

- Herning, Denmark
- 1 STILL RX60-25 FC
- Testing started 04.2012

The first STILL RX60-25 FC built was used for shorter trials at potential end-user sites in Denmark, for testing ongoing system improvements and for operations in the H2 Logic production facility.



Figure 7: STILL RX60-25 FC excessive brake testing, H2 Logic

An overview of all demonstration and trial sites, both planned and already done are shown in Figure 8. The follow-up on the planned trial sites will be done in the HyLIFT-EUROPE project.

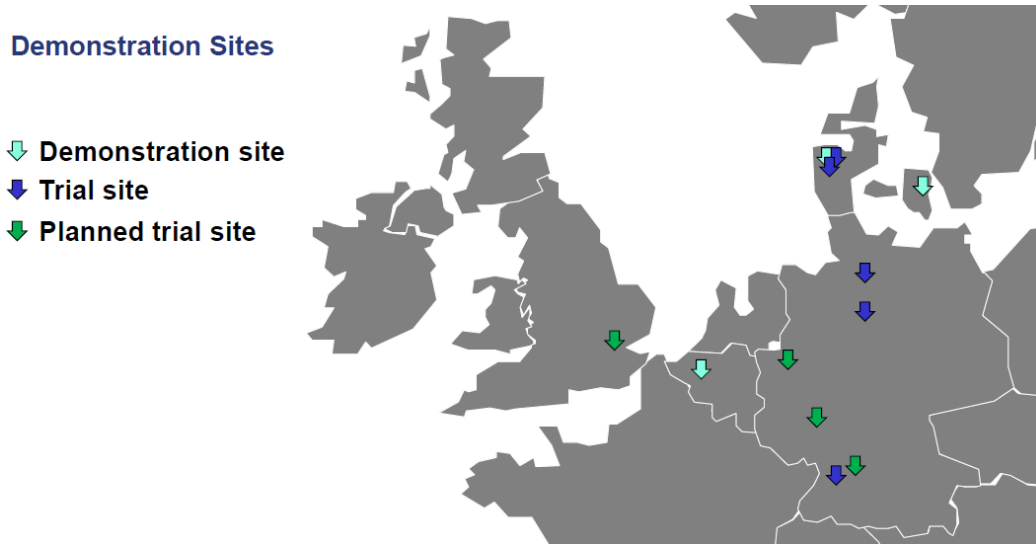


Figure 8: Demonstration and trial sites

With regards to the demonstration planning, the price of hydrogen was also a significant factor in the process of determining the viable sites for sustainable technology deployment. In relation to this, the map of focus regions, developed earlier in the project had been supplemented with a map of actually offered hydrogen prices when planning demonstrations throughout the project. The results can be seen in Figure 9.

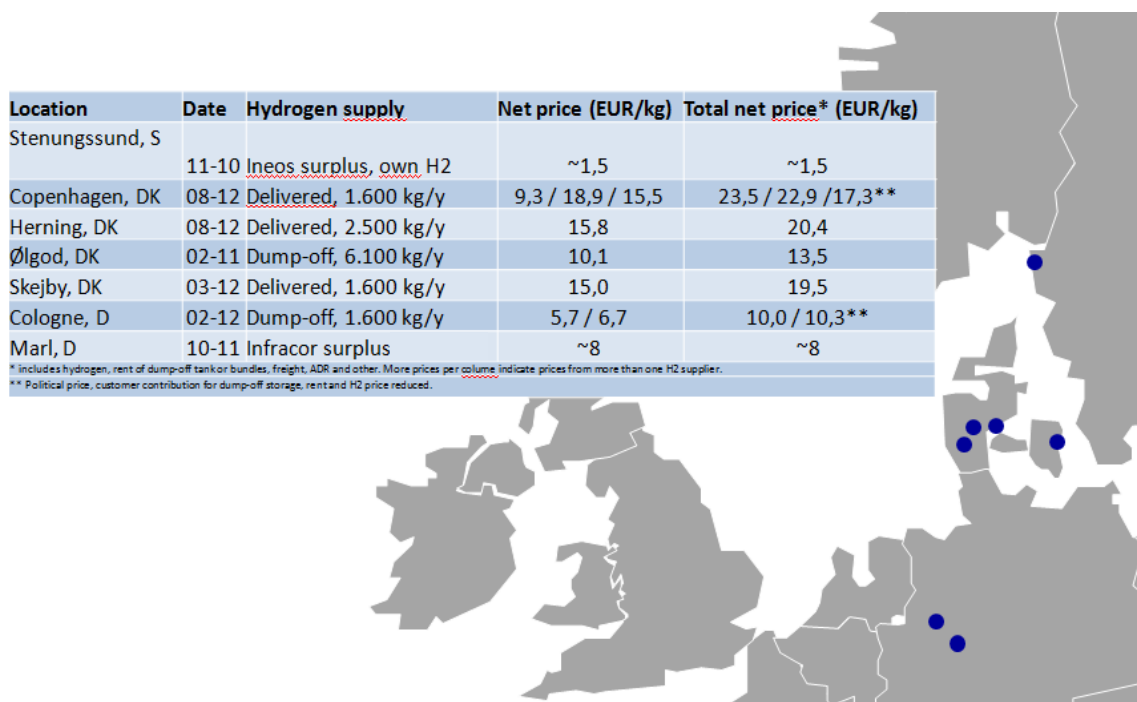


Figure 9: Offered hydrogen prices

## WP 3 – Safety certification & RCS

### WP Leader – H2 Logic

In WP3 the safety certification procedures for fuel cell systems and hydrogen refuelling stations were done according to the manufacturing of the equipment.

In addition to this, procedures for fire and rescue services at hydrogen refuelling stations were developed in collaboration with the Danish Emergency Management Agency. Although these procedures have been developed based on the Danish context they can also serve as basis for development of similar guidelines abroad. Therefore these guidelines were translated into English, organized by the FCH JU, and are available here: <http://www.fch-ju.eu/sites/default/files/DEMA.pdf>.

Furthermore, local hydrogen refuelling station operators have been trained to identify simple errors and to reset the system safely.

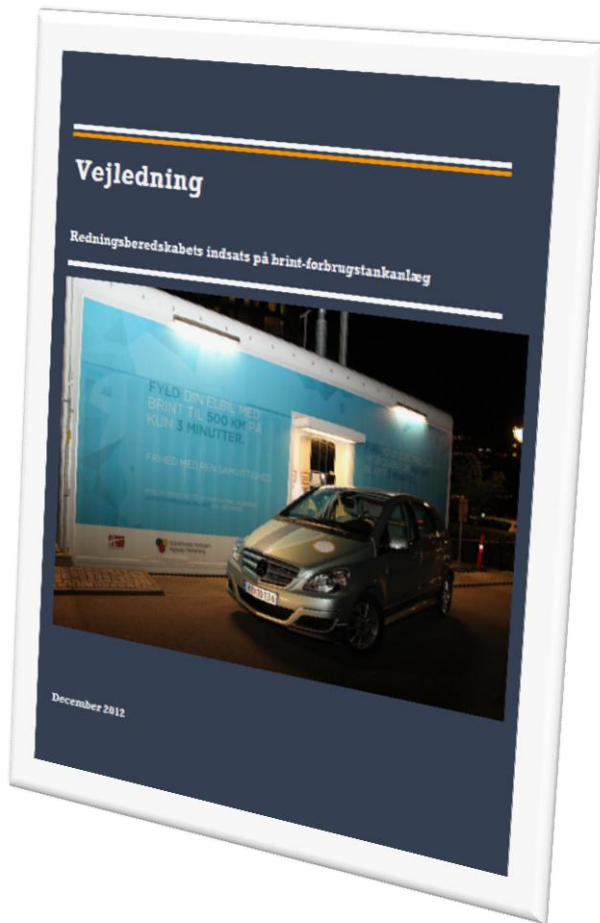


Figure 10: Guideline for fire and rescue services at hydrogen refuelling stations (Danish version)

Furthermore, one deliverable was dedicated to identify gaps in current regulations, codes and standards. The main conclusions here are that the necessary legislation is either in place or under preparation already. However, the RCS specified still need to be validated in order to ensure viable requirements being adopted across the industry.

With regard to safety procedures for materials handling vehicles it has to be taken into account that no education can be expected for end-users. Therefore fuel cell vehicles have to operate in the same way as standard battery / hybrid vehicles do. For maintenance simple instructions have to be prepared and provided. In case of any errors or maloperations the fuel cell system turns into a fail safe mode.

Finally, site evaluations were performed to ensure safe atmosphere in case of an accident. During end-user risk analysis processes specific procedures were determined in order to avoid hydrogen concentrations above 25% LEL in case of an entire storage release.



Figure 11: Leaflets with simple instructions for operation and maintenance

## WP 4 - Fuel cell forklift demonstration

### WP Leader – H2 Logic

Second half of 2012 saw the first demonstrations of fuel cell forklifts commence.

Status per May 2014:

STARK, Copenhagen, Denmark:

- H2Drive system 1047: 2,418 hours
- H2Drive system 1048: 2,716 hours
- H2Drive system 1049: 2,201 hours
- H2Drive system 1050: 2,222 hours

Colruyt, Halle, Belgium:

- H2Drive system 1044: 723 hours
- H2Drive system 1045: 968 hours

egetæpper, Herning, Denmark:

- H2Drive system 1051: 640 hours
- H2Drive system 1052: 722 hours

## H2BZ Hesse, Frankfurt, Germany:

- H2Drive system 1046: 329 hours
- Trials of this vehicle were performed at
  - Viessmann Werke, Allendorf, Germany
  - Rudolph Logistics, Baunatal, Germany
  - Hassia, Bad Vilbel, Germany

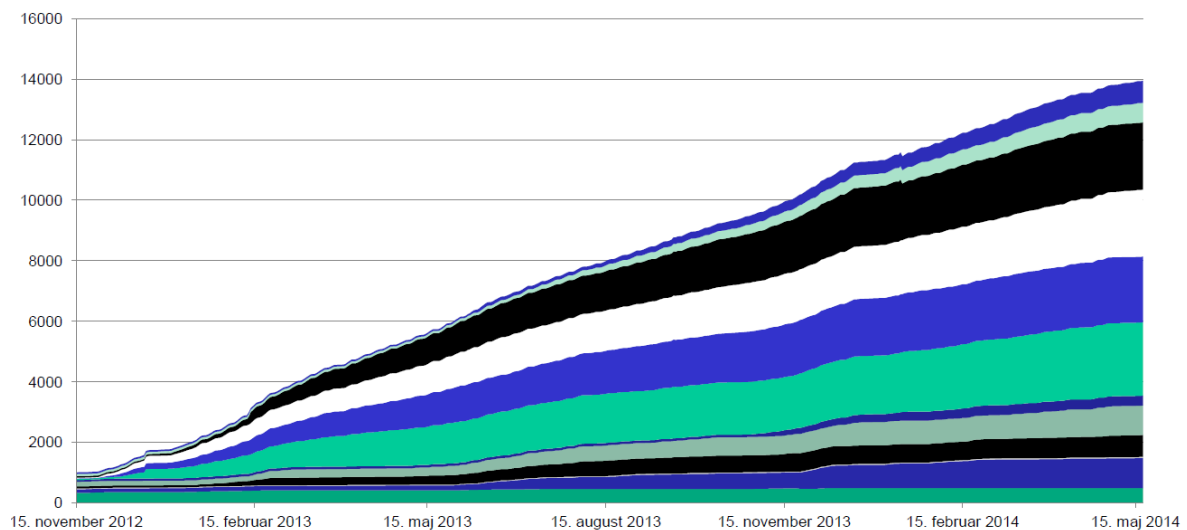


Figure 12: Operation hours of vehicles at main demonstration sites accumulating over HyLIFT-DEMO project period

## Other HyLIFT-DEMO systems:

In addition to the four main demonstration sites, the following systems were operated as part of HyLIFT-DEMO:

MULAG Comet 3 FC prototype (developed and manufactured in other project); used for potential end-user trials; 495 operation hours accumulated; system design updated

- 2 DanTruck 3000 Power Hydrogen prototypes 2<sup>nd</sup> generation; out of operation; 199 operation hours accumulated during system testing
- STILL RX60-30 FC prototype; used for continuous development and improvements, potential end-user trials and as back-up system; 992 operation hours accumulated
- Durability test system; operated in durability test rig; 1,200 operation hours accumulated

- DanTruck 3000 Power Hydrogen prototype 1<sup>st</sup> generation; out of operation; ~50 operation hours accumulated during system testing; used finally for spare parts provision
- 4 H2Drive systems 1040-1043 (MULAG type systems); systems manufactured but not put into demonstration; eventually used for spare parts
- Vibration test system; operated in vibration test rig at JRC; out of operation; ~50 operation hours



Figure 13: Operation hours of all other HyLIFT-DEMO fuel cell systems

In total, the fuel cell systems in HyLIFT-DEMO have operated for about 16,000 hours.

In the case of the hydrogen powered fuel cell forklifts the following conclusions can be drawn from operational experiences:

- Users are excited about performance and technology
- Operators are concerned with regard to vehicle availability
- Owners are evaluating costs versus branding gains

In the case of the airport tow tractors the conclusions are:

- Users were experiencing performance and range issues which requires a design update still to be done

For the H2Drive system it can be concluded:

- The system could achieve an availability >95%
- Service costs turned out to be higher than initially expected
- Hydrogen components still show several stability issues



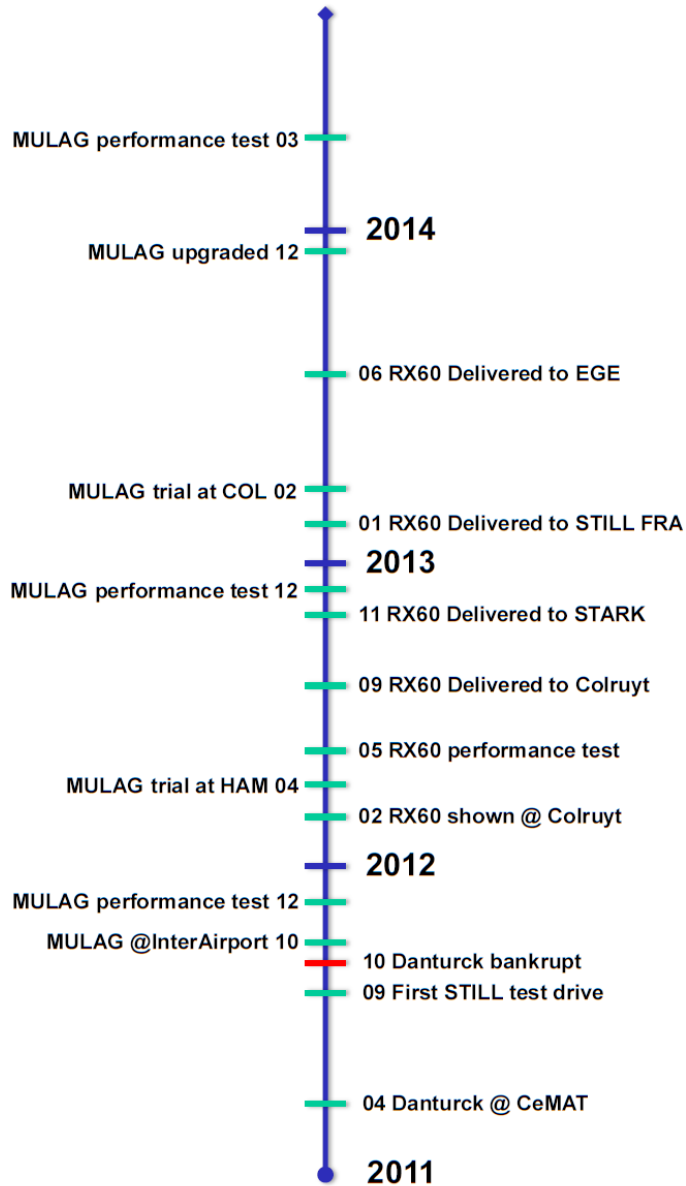


Figure 14: HyLIFT-DEMO vehicle time line



Figure 15: Fuel cell forklift at STARK Copenhagen

The first months of operation have produced a large amount of learning and both software and hardware had received updates to improve stability. Therefore, the two systems at Colruyt were returned to H2 Logic in December 2012 for a major update and reintroduced into operation again in January 2013. The impact of these updates could be sensed by increased operation stability which in consequence influenced the measured vehicle availability and the amount of operation hours. The updates were then consecutively also implemented in all other systems in operation.

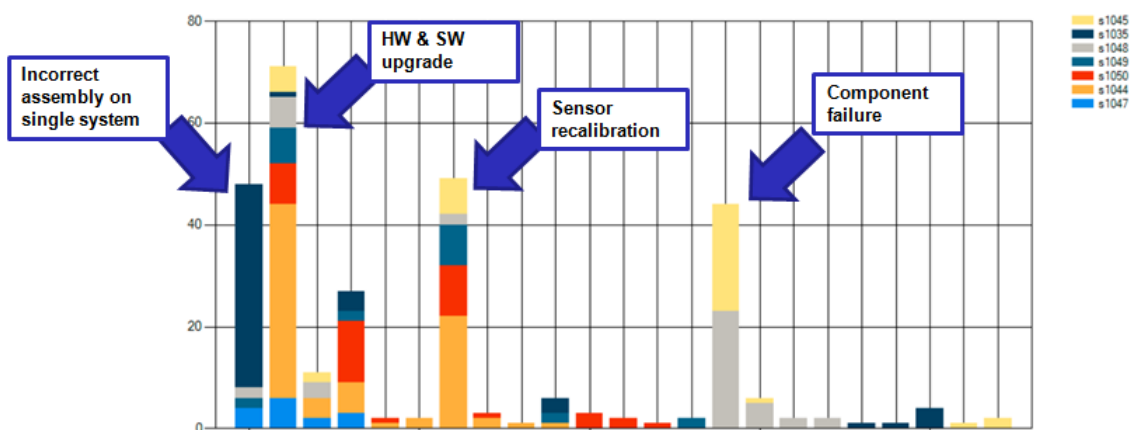


Figure 16: H2Drive error statistics

Figure 16 shows an error statistic from the early part of the demonstrations. Four main issues draw attention and have set the prioritization of the continued maturation of the H2Drive fuel cell systems.

## WP 5 – Hydrogen infrastructure demonstration

### WP Leader – H2 Logic

Within the second half of 2012, the first H2Station® MH-100 was manufactured. In early 2013 the hydrogen refuelling station (HRS) underwent thorough tests to verify performance, stability and durability. 1.500 test refuelling procedures were successfully validated. After testing was completed, MULAG had placed an order for an MH-100 HRS to support continued end-user trials of the Comet 3 FC tow tractor.



Figure 17: H2Station® MH-100 (35MPa)

At demonstration sites, the vehicles were refuelled by either 3<sup>rd</sup> party refuelling stations procured or rented by the end-users or other parties separately or by the fleet of available 25 MPa HRSs from H2 Logic:

STARK, Copenhagen, Denmark: H2 Logic Mini 25 MPa; number of refuellings made: 3,689 (04/14)

Colruyt, Halle, Belgium: HRS provided by WaterstofNet; no information available

egetæpper, Herning, Denmark: H2 Logic Mini 25 MPa; number of refuellings made: 634 (04/14)

H2BZ Hesse, Frankfurt, Germany: H2BZ Hesse organized a mobile hydrogen refuelling solution outside the HyLIFT-DEMO project

MULAG, Oppenau, Germany: H2 Logic H2Station® MH-100; number of refuellings made: 11 (04/14); Linde refuellers used for trials at Hamburg and Cologne/Bonn airports

Average daily capacity <i>Base configurations</i>		25 kg/day <i>@1MPa inlet</i>	60 kg/day <i>@2.5MPa inlet</i>	100 kg/day <i>@5MPa inlet</i>
1st hour instant capacity <i>1.6 kg tank size</i>	<i>No. of refuelings</i>	2-4	3-5	5-6
	<i>Hereof back-to-back</i>	1-2	1-3	1-3
Refueling pressure, protocol & pre-cooling		35MPa   OptiH-fill™   Active pre-cooling		
Hydrogen supply		External hydrogen source 0.5-20MPa inlet pressure		
Integration & transportability		All equipment integrated into one transportable module		
Local site works required		Power connection & flat foundation for station & vehicle		
Installation time		2 days		

Figure 18: Specification of H2Station® MH-100

In the case of hydrogen refuelling stations for material handling vehicles the following conclusions can be drawn from the HyLIFT-DEMO experiences:

- A first unit was built and ~1,500 refuellings could be performed at H2 Logic's premises
- The OptiH-fill protocol could be validated with intensive testing for 1.6 kg type 3 tanks
- Users were gaining confidence with use and operation of the hydrogen refuelling stations. Especially trained users committed to daily usage
- Utilisation of trucked-in hydrogen was an issue: site procedures caused premature exchange of bulks while the hydrogen returned to the supplier has not been refunded
- Availability of 99%+ was successfully shown in the HyLIFT-DEMO project, pointing out the readiness of the H2Station® technology.

The following conclusions can be drawn from the HyLIFT-DEMO HRS operations:

	Start Mass (Avg)	End Mass (Avg)	Used Mass	Utilization
Cologne, 35MPa Linde HRS	0,84	1,63	0,78	50,0%
STARK, 25MPa, H2 Logic old HRS	0,39	1,10	0,71	65,1%
H2Station MH- 100	0,77	1,65	0,89	56,5%
Colruyt, 35MPa, Hydrogenics HRS	0,72	1,45	0,73	46,5%

Figure 19: Calculation of vehicle tank utilization rate

- 15% of hydrogen tank capacity is not used (below 3.5 MPa)
- 35MPa HRSs normally refuel to ~90%, H2Station MH-100 refuel to 95-100% SOC
- Operators tend to make opportunity refuelling, when they have a natural break in operation or they drive the vehicle until the “refuel” light becomes red
- Improvement of the tank utilization rate is depending on training of drivers and experiences



Figure 20: Refuelling at STARK in Copenhagen

## WP 6 – Demonstration monitoring & target validation

### WP Leader – SINTEF

Work package 6 foresaw the conduction of demonstration monitoring / validation as well as of accelerated tests to be performed by experienced organisations. SINTEF has extensive laboratory equipment and experience in accelerated durability tests and JRC on shock, vibration and climate tests. The data parameters collected and monitored were defined with inspiration from the HyLights MAF Handbook I (demo project level) that was developed by project partner LBST in agreement with the HyLights industry partners.

#### Monitoring and Assessment Framework (MAF)

H2 Logic and LBST have developed a data acquisition and analysis system for the handling of the key performance indicators to be collected from the demonstrated fuel cell material handling vehicles and hydrogen refuelling stations. In the course of the project but before its practical use LBST improved the system based on its experiences made in the H2moves Scandinavia project and thereby could solve some minor issues. However, the finalisation of the MAF took place in due time

(before first vehicles enter into the demonstration phase) and allowed for a smooth and efficient data gathering and handling during the demonstration phase.

According to the performance indicators defined within HyLights MAF Handbook I, four EXCEL templates were prepared to collect real life data and lab data for both HRSs\_ID and material handling vehicles. In the figure below, an example for a sheet from 1 of the 4 EXCEL files is shown.

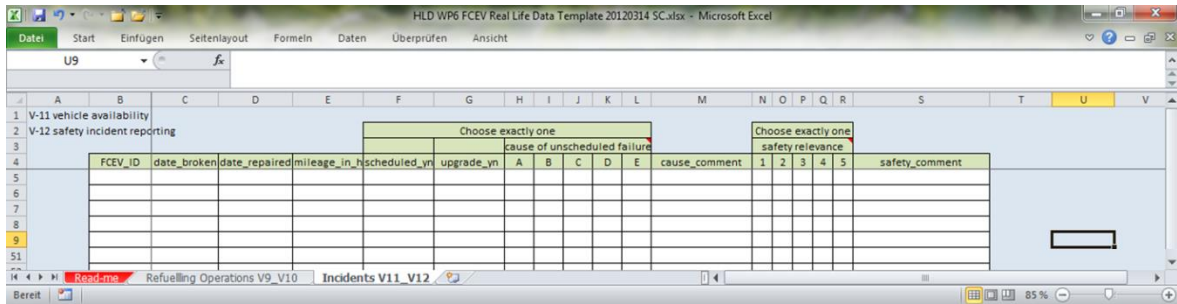


Figure 21: Example of EXCEL sheet for collecting data

Data collected with these templates were sent via email to LBST in defined periods. At LBST, the data sets were consolidated in an ACCESS database. The automatic data import has been significantly improved and simplified within the first project phase. Additionally, selected key figures could be inserted manually in a convenient way, as shown in the figure below.

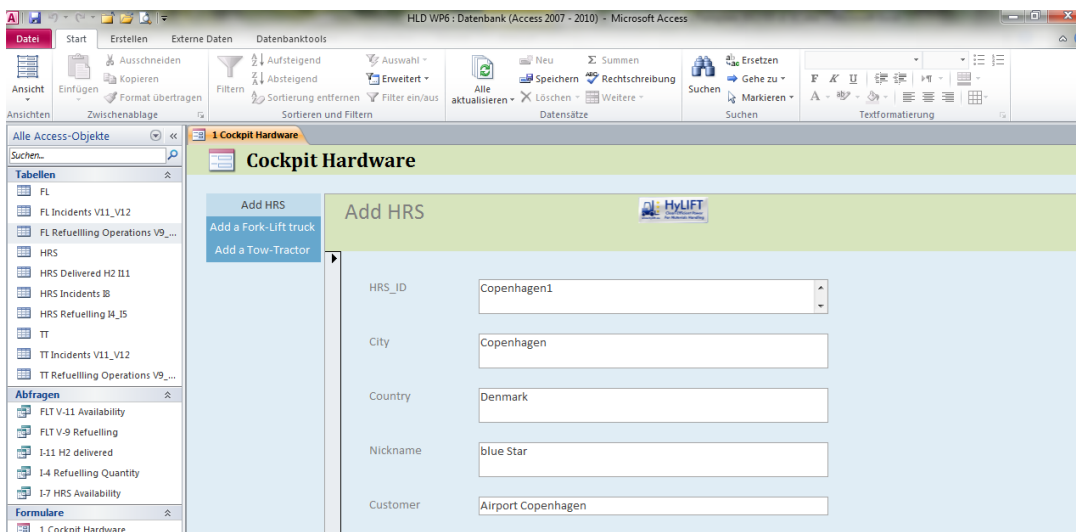


Figure 22: ACCESS graphical user interface for manually entering new hardware specifics

The structure of the data base is as shown in the figure below. Both, the lab data and the real life data were collected here. The data sets are linked to each other to ensure consistent data sets. E.g. when the data set from a refuelling process is added, it is checked whether the FCEV ID actually does exist. By importing the data sets from EXCEL sheets into ACCESS, it is ensured that the data format of each individual cell is correct; otherwise ACCESS aborts the importing process.

The templates for collecting data for ForkLift Trucks (FLT) and Tow Tractors (TT) are identical to the greatest possible extent. There are only few exceptions; one of them is the lifting speed which is only relevant for FLT. However, data for FLT and TTs are collected in entirely separated tables in the ACCESS database, as different patterns of usage are expected.

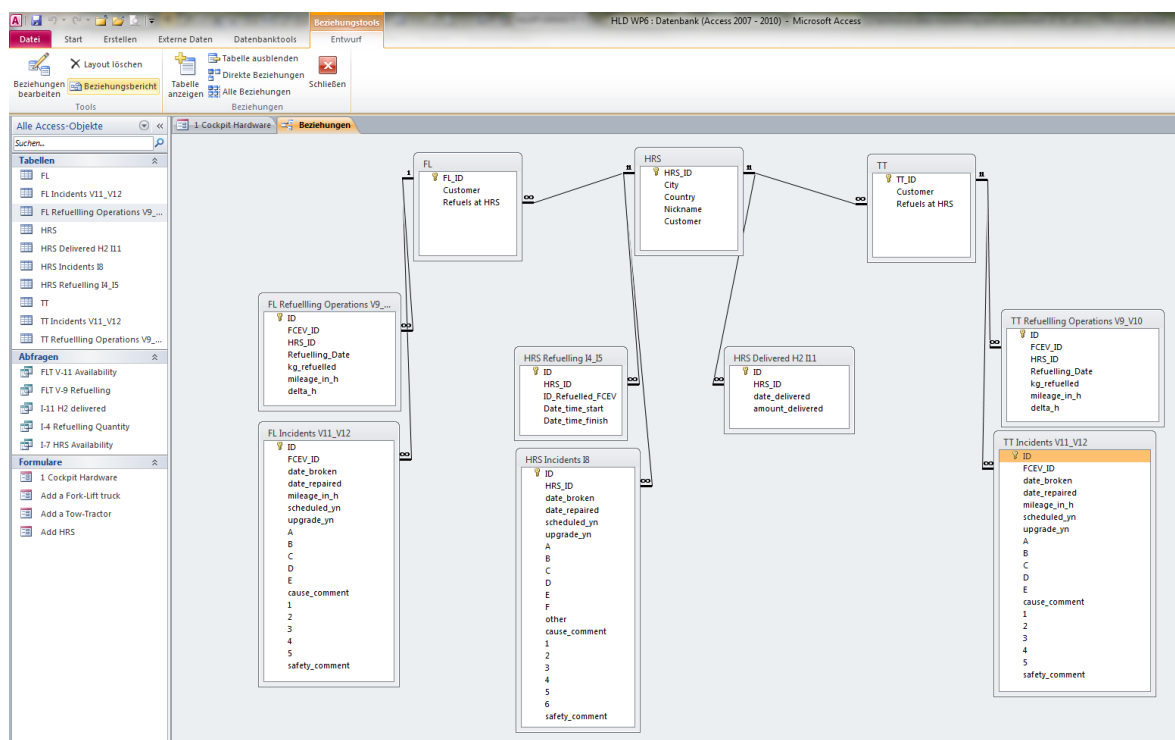


Figure 23: Structure of ACCESS database for consolidating collected data

Data collected from real life operations were processed automatically. EXCEL sheets were set up to generate the graphs, an example is shown in the figure below. The table on the left side is linked to the ACCESS data base. It can be updated with one mouse click, which leads to a new calculation of the histogram shown on the right side.



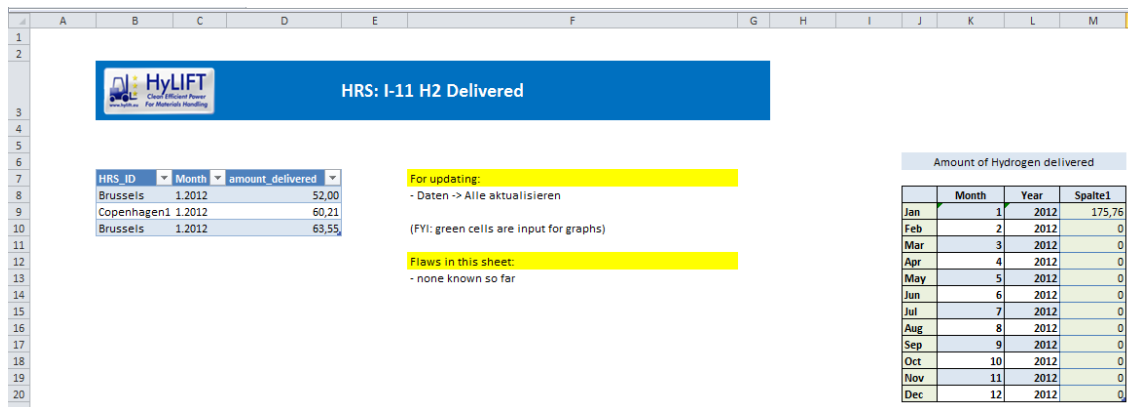


Figure 24: Automatic data evaluation in EXCEL (dummy data)

The corresponding graph is part of the “dashboard” sheet shown in the figure below.

All graphs generated within data evaluation follow the same design scheme to simplify usage in presentations and publications.

First ideas regarding the utilisation of the results of this data acquisition and analysis were collected and developed in order to make best use of the information gathered and processed.



Figure 25: Dashboard in EXCEL evaluation sheet (dummy data)

Monitoring of demonstration

The demonstration of the 11 fuel cell vehicles and the 3 HRS in the project was monitored by H2 Logic during the project. Modems were installed in the H2Drive

systems and the H2Stations and live data were sent to a server at H2 Logic with operation, failures and statistics information. Screenshots of the KPI (key performance indicator) website for H2Drive are shown below.

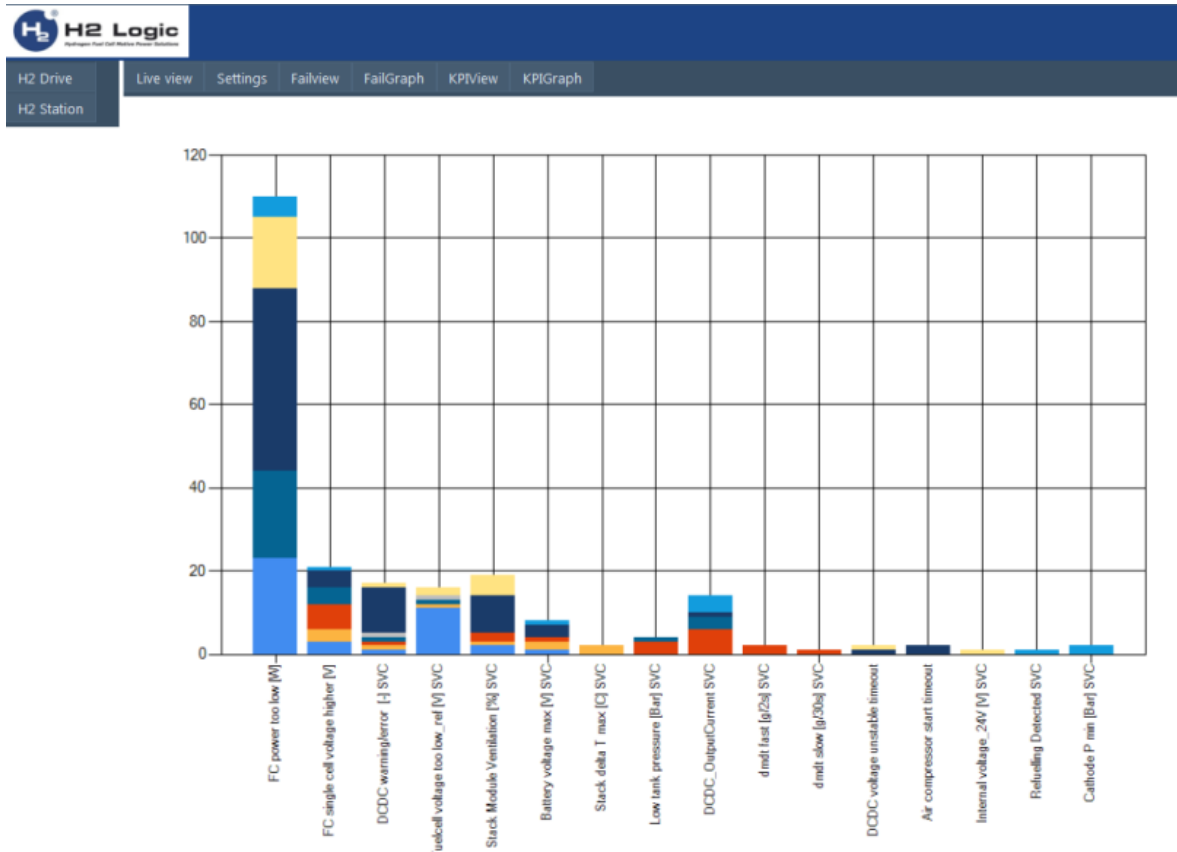
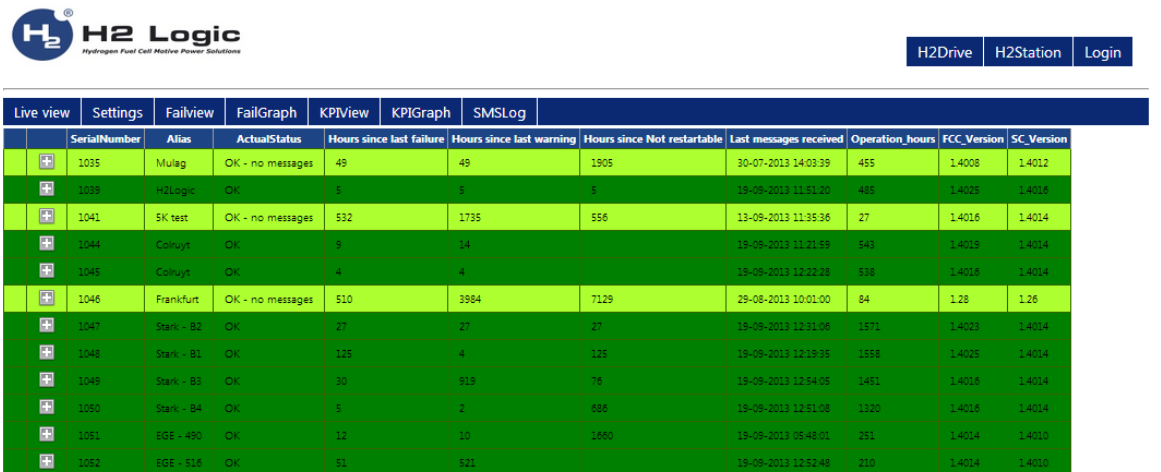


Figure 26: Monitoring of key performance indicators



Live view	Settings	Failview	FailGraph	KPIView	KPIGraph	SMSLog				
+	1035	Mulag	OK - no messages	49	49	1905	30-07-2013 14:03:39	465	1.4008	1.4012
+	1039	H2Logic	OK	5	5	5	19-09-2013 11:51:20	485	1.4025	1.4016
+	1041	SK test	OK - no messages	532	1735	556	13-09-2013 11:35:36	27	1.4016	1.4014
+	1044	Coluyt	OK	9	14		19-09-2013 11:21:59	543	1.4019	1.4014
+	1045	Coluyt	OK	4	4		19-09-2013 12:22:28	538	1.4016	1.4014
+	1046	Frankfurt	OK - no messages	510	3584	7129	29-08-2013 10:01:00	84	1.28	1.26
+	1047	Stark - B2	OK	27	27	27	19-09-2013 12:31:06	1571	1.4023	1.4014
+	1048	Stark - B1	OK	125	4	125	19-09-2013 12:19:35	1558	1.4025	1.4014
+	1049	Stark - B3	OK	30	919	76	19-09-2013 12:54:05	1491	1.4016	1.4014
+	1050	Stark - B4	OK	5	2	686	19-09-2013 12:51:08	1320	1.4016	1.4014
+	1051	EGE - 490	OK	12	10	1680	19-08-2013 05:48:01	251	1.4014	1.4010
+	1052	EGE - 516	OK	51	521		19-09-2013 12:52:49	210	1.4014	1.4010

Figure 27: Fuel cell system data logging interface

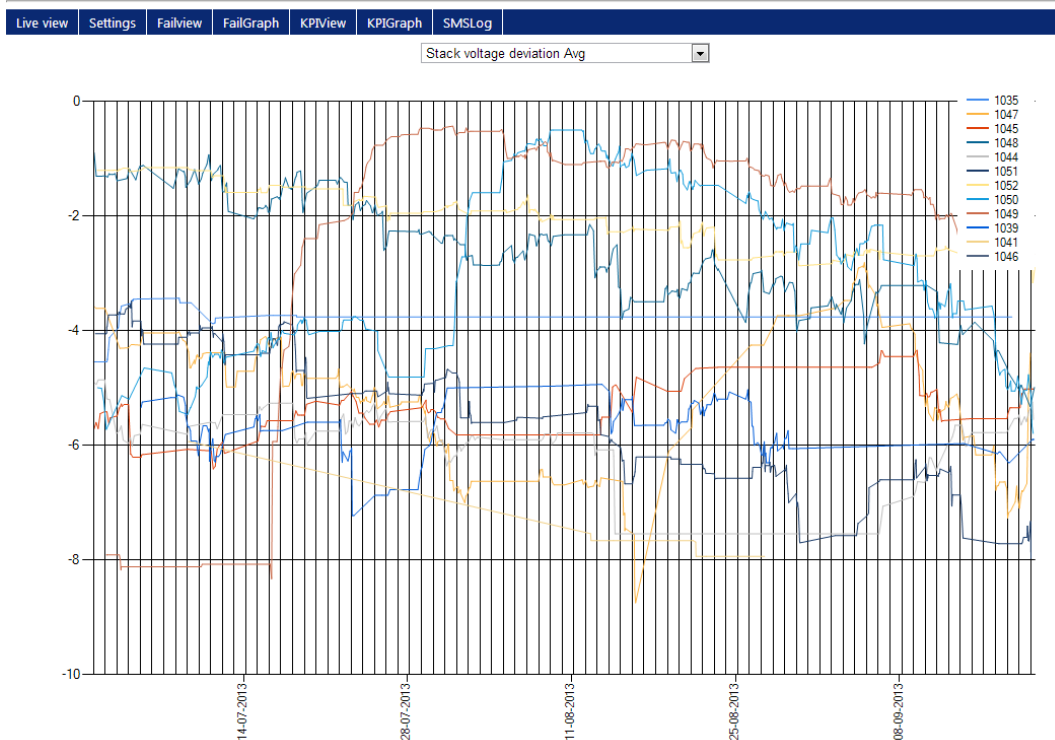


Figure 28: Example for operation data logging (average stack voltage deviation)

The operation data were also collected from the SD-Cards in the H2Drive and data were then shared with LBST for the MAF.

From November 2012 to May 2014, real life data from the HRSs and material handling vehicles (MHVs) were collected from H2 Logic and sent to LBST in customized EXCEL files. At LBST, these data were consolidated in an ACCESS database. Using Microsoft Query to access this data, it was evaluated with the Pivot functionality of EXCEL. Therefore it was possible to nearly fully automatically evaluate the data. HRSs and MHVs were still in operation in June 2014, but as all work on the individual WPs needed to be concluded in June towards the end of the project, it was not possible to consider the data from the final month. Three final reports were prepared in June 2014:

- Public presentation to be published on the HyLIFT-DEMO website
- Project internal presentation for project partners and FCH JU
- Confidential presentation to which only LBST, H2 Logic and FCH JU have access

For benchmarking, publically available data from NREL were compared with the results from HyLIFT-DEMO.

A selection of significant results from the data evaluation is shown in the following graphs:

For detailed data evaluation, data was available for the following HRS and MHVs:

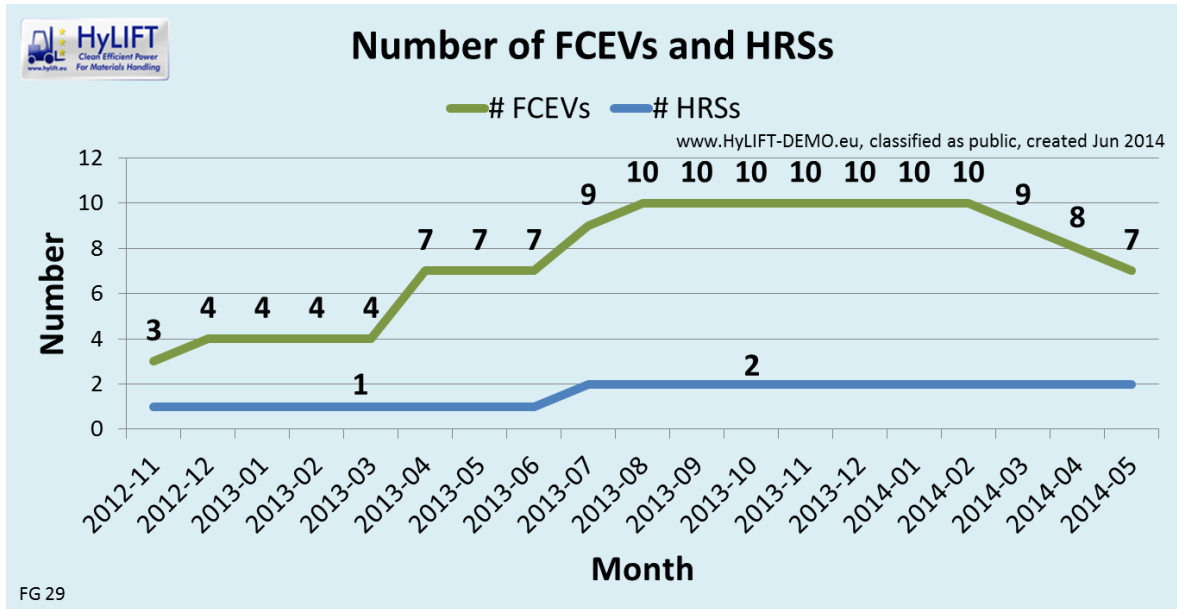


Figure 29: Number of fuel cell electric vehicles and hydrogen refuelling stations in the HyLIFT-DEMO project

Throughout the project, the FCEVs were operated for more than 12,413 hours. This corresponds to more than 2,200 work shifts.



Figure 30: Cumulative operation hours of vehicles in the HyLIFT-DEMO project

Over 12 consecutive months, the availability of the vehicles was 95.01% on average.

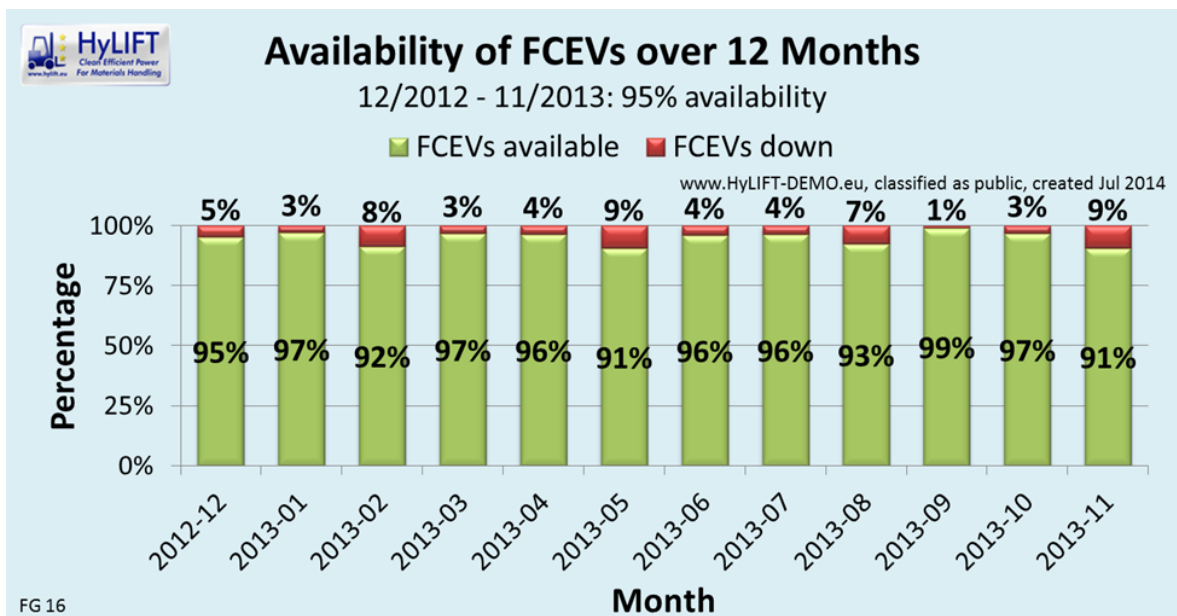


Figure 31: Availability of vehicles in the HyLIFT-DEMO project

The HRS availability throughout the project is 99.5 %.



Figure 32: Availability of hydrogen refuelling stations in HyLIFT-DEMO

94% of all HRS down-times were repaired within 24 hours.

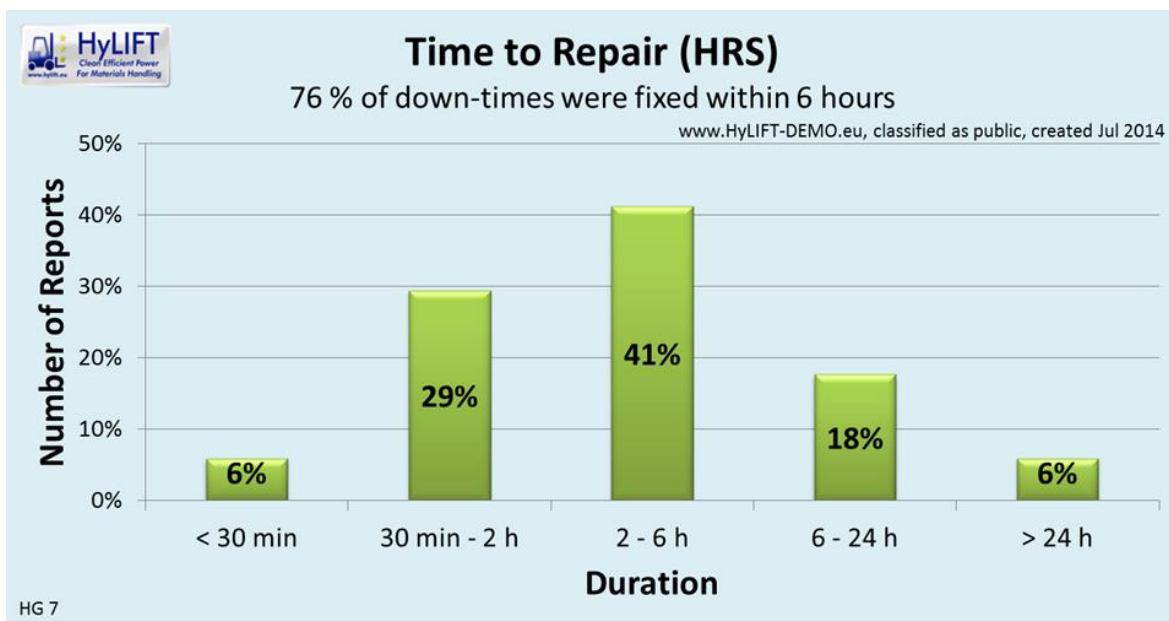


Figure 33: Time to repair of hydrogen refuelling station in HyLIFT-DEMO

When comparing data from HyLIFT-DEMO with NREL data, most results are comparable. One example is the average duration per non-availability which is slightly better for HyLIFT-DEMO.

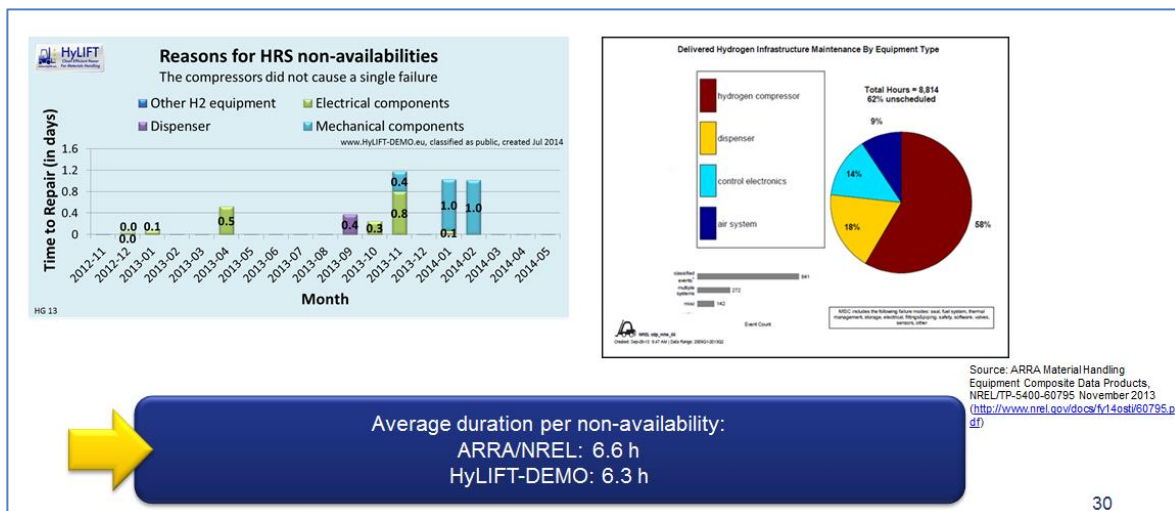


Figure 34: Comparison of average duration per non-availability between NREL and HyLIFT-DEMO

### Long-term testing

This task was unable to meet its specified objective of 4,000 hours of fuel cell system testing. Several problems have beleaguered the system testing rig: a burst hydrogen line from the electrolyser to the purification unit in January 2013, a pump failure in the refuelling station that was providing the compression for the system in March 2013, and another burst hydrogen line in the purifier in May 2013. In summer 2013 the limited cooling capability of the container housing the equipment (including a 40 kW alkaline electrolyser) hampered operation. Later, issues with control of the refuelling procedures surfaced and caused further delays, since without automated refuelling the system could be run only a few hours at a time; in particular, some safety safeguards designed for manual operation had to be worked around.



Figure 35: Durability test rig

The rig was finalised in spring 2014, but the limited time available until the end of the project made it impossible to achieve 4,000 hours testing; the system had until then logged 1,200 hours in total. At the same time, it was known that several forklifts had been operating in field tests for up to 2,500 hours at the Copenhagen site. The issue was presented to the coordinator and discussed with the project manager at FCH JU, and at the General Assembly meeting of 20 May 2014 it was decided that the long-term testing activity would be discontinued, as monitoring of forklifts in real operation provided already more data than what could be provided by the test rig. The operation of the test rig was demonstrated live at the same General Assembly meeting via remote desktop. The delays had no impact on other activities of the project, as no other activity depended on it. A significant result of the activity was a direct consequence of some of its difficulties: it was noticed that the H2Drive system, when subjected to the load profile specified in the course of the project, would regularly trip because of undervoltage or overvoltage. Since this problem did not occur in the forklifts deployed at the demo sites, it was concluded that the prescribed test protocol cannot be representative for real operation conditions.

### Vibrational tests

The vibrational tests suffered several delays initially, but could be completed finally.



The task showed that the H2Drive's compressor was very vulnerable to vibrations at low frequencies (10 to 30 Hz) and all directions. Other vulnerable components were the tank valve, the DC-DC converter and the receptacle. By the end of the vibrational tests, the battery had heavily damaged the unit, which had to be shipped back to H2 Logic before further tests could be performed.

### Validation of attainment of pre-commercial targets

The validation of the customer acceptance was happening throughout the project. Through the project it became clear that there are different interests among the stakeholders within a customer company.

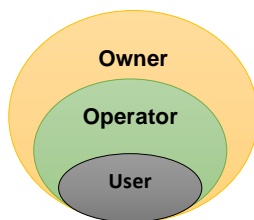


Figure 36: Various stakeholders within a customer company

Owner: The person responsible for the costs of the fuel cell forklift truck; concerned about green branding and HSSE (health, safety, security and environment); responsible for additional costs of fuel cells compared to conventional technology

Operator: The fleet manager that has the responsibility to move goods with forklift trucks; concerned about performance, reliability and operation costs (service, fuel and time wasted to refuel or service trucks)

User: The drivers of the trucks; concerned about the power, the noise and vibrations of the trucks, and the operation time between each refuelling

The User targets were met in the HyLIFT-DEMO project. The power of the trucks is better than that of batteries, and the drivetrain is as easy to use as batteries. The refuelling is easier than battery change or charge, which is positive from the User's point of view.

The Operator targets have to some extent been met. The operation costs at STARK is an example of not meeting the targets, since fuel consumption was about 30 % higher than expected. The detailed analysis showed that the reason was that users run the electrical heater 24/7. The performance of the trucks at the egetæpper demo site was acceptable; Colruyt and STARK experienced downtimes higher than they would accept for a commercial product.

The Owner target was overall met. Zero emissions, HSSE improvements and the CAPEX of the project were in line with expectations. However, reports from

Operator to Owner tend to make the Owners consider the demonstration as semi-successful.

Recommendations for future large scale demonstrations are quite clear: focus on the Operator.

- Improve reliability of the fuel cell systems and trucks
- Reduce the price of fuel cell systems by up-scaling of production
- Enable large sites with high utilisation of the HRS → lower H<sub>2</sub> prices
- Include gas companies for the supply of H<sub>2</sub> from the very beginning of the project

## WP7 - Securing & planning commercialisation

### WP Leader – H2L

Securing and planning of commercialisation for hydrogen and fuel cell technology in the materials handling sector turned out as one of the most difficult tasks in the course of the HyLIFT-DEMO project as technology is still too immature for immediate full commercial deployment in the next step. Instead, further large scale demonstration projects such as HyLIFT-EUROPE and HAWL as well as appropriate deployment support mechanisms are urgently required.

Nevertheless, the project managed to collect some focal points to be dealt with in the further approach of fuel cell materials handling vehicle commercialisation. The summarized focal points to be addressed are:

- End-user sensitivity to the hardware costs
- Requirements to service platform (local, 3<sup>rd</sup> party, fast reaction, etc.)
- Viable hydrogen supply solutions
- Scale up from small start-up fleets to large fleets
- Cost reductions (total cost of ownership - TCO)

The main technical objectives to ensure commercial viability for both fuel cell systems and hydrogen infrastructure are already starting to firm up.

- Fuel cell system:
  - Reliability: 98%+ availability → ongoing
  - Reproducible manufacturing quality → starting
  - Cost reductions through re-engineering and scale-up → awaiting
  - Target price for 10 kW system: <25,000 € → possible
- Infrastructure:
  - Reliability: 99%+ availability → ongoing
  - Min. refuelling to 95% nominal capacity → ongoing
  - Target price for 20 kg/day HRS: <200,000 € → possible

- Hydrogen delivered at ~6 €/kg → onsite / delivered

Business case considerations small versus large fleets

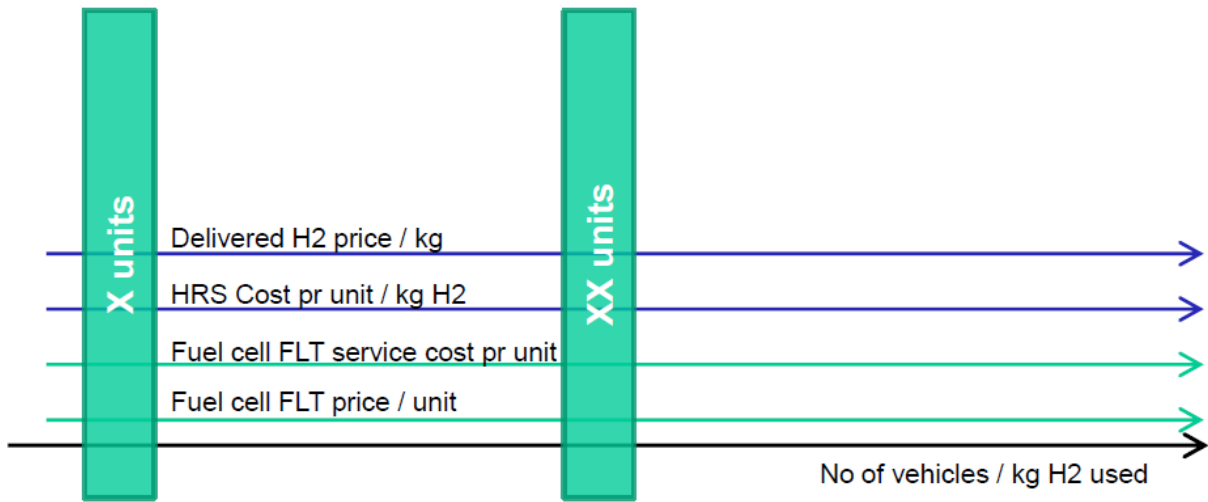


Figure 37: Customer interest in fleet growth

- X units ... then evaluation of economics after period of 1-2 years
- XX units ... then evaluation of economics after period of n years

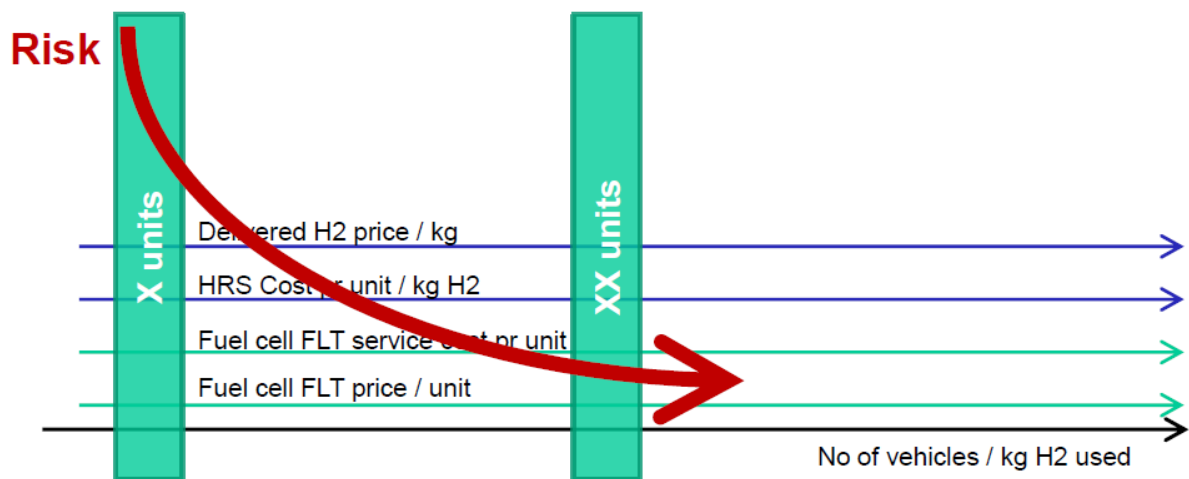


Figure 38: Financial risks drop by number of units in operation

- Risk on forklift trucks can be covered by public financial support
- Risk on hydrogen and hydrogen refuelling stations is not covered by public financial support

Considerations for planning the commercialisation of fuel cell materials handling vehicles in Europe:

- The risks associated with market initiation of fuel cell technology in the

materials handling sector was shown by Plug Power in the USA

- A similar approach is currently happening in Europe
- The risk handling at the beginning of market deployment is impossible for SMEs
- The public funding can be a good support and give good IRR in the long run, but taken such risks is typically a task for large companies
- The potential for large fleets can be exploited if other (smaller) FLT sizes are taken into account as well, but then the technology to be outrivaled is no longer ICEs but batteries
- In the HyLIFT-DEMO follow-up project HyLIFT-EUROPE this becomes already clear now, and the set-up of the project has to be changed after recognition of this matter

## **WP8 – European networking & dissemination**

### **WP Leader – LBST**

As there is a specific section on networking and dissemination in this report please refer to chapter 1.4 “Potential impact and main dissemination activities and exploitation results” to learn more about the project’s activities in this field.

## **WP9 – R&D on fuel cell system, tow tractor and HRS**

### **WP Leader – H2 Logic**

#### R&D on H2Drive fuel cell system

A high pressure test rig could be completed and was connected to one of the H2Drive systems that completed operations at STARK. Tests could be performed at the very last phase of the project. The critical components tested were:

- 35 MPa tank solenoid valves
- Pressure sensors
- Pressure regulators

The specifications for the tests were done together with suppliers / partners. Different sealing materials for the pressure regulator seat were tested with limited effect. Recommendations for future actions are presented in the respective HyLIFT-DEMO report.

#### R&D on airport tow tractor

The vehicle trials at Hamburg and Cologne/Bonn airports showed need for

- More peak power to cope with inclines at overpasses
  - High load on steep inclines and declines caused power management
  - Expectations for technology is hybrid power, not battery
- More range to run one entire shift without refuelling
  - Long distances at airports means refuelling during shift is not viable
  - Resulting is frequent topping up and running dry

In order to cope with the requirements documented above the following hybrid system upgrades were realized:

- The H2Drive standard battery was replaced by a MULAG hybrid battery (110 Ah → 240 Ah) allowing to run at higher average power and to widen the dynamic range of the battery pack
- The battery technology used will no longer be closed AGM but open lead acid. This will lead to improved regeneration robustness and less balancing issues
- The battery will no longer be part of the H2Drive system. That simplifies the H2Drive delivery
- In order to increase the driving range of the vehicle the storage system will be upgraded as well. Therefore the tank capacity will be increased from 1.8 kg to 3.6 kg by adding a second tank system. This will increase the loaded operation range to 6.5 hours.

#### R&D on hydrogen refuelling station

A hydrogen refuelling station (H2Station<sup>®</sup> MH-100) was manufactured and started up. Refuelling protocol simulations were completed to ensure that safe refuelling could be made with any kind of vehicle that would attempt to refuel from a materials handling station. Simulations were made and upgrades were implemented in the station. Refuelling tests could be performed at the very last phase of the project and validated safe refuelling of different size of cylinders.

## 1.4 Potential impact and main dissemination activities and exploitation results

### Potential impact

The following section seeks to describe the impact the HyLIFT-DEMO project has with regard to reaching the targets / objectives of the Annual Implementation Plan (AIP) that has called for this project.

#### AIP objective:

Demonstrate advantage of fuel cell forklifts compared to conventional technologies.

Corresponding project objectives / targets:

HyLIFT-DEMO addresses a specific and proven value proposition where hydrogen and fuel cells replace use of diesel / LPG in 2.5-3.5 tons forklifts where batteries cannot provide a satisfying solution. The higher energy efficiency of the fuel cell compared to the combustion engine enables the end-user to gain savings on fuel costs that lead to a payback time of 3 years, at commercial price targets.

#### Achievements:

In the case of forklifts the use of fuel cell systems was appropriate to replace 2.5-3.5 tons diesel / LPG forklifts. In case of airport tow tractors the performance of the same fuel cell system was not sufficient both in power and capacity to fulfil the requirements. Because of small fleet sizes and thereby small hydrogen consumption savings on fuel costs could not be realized.

#### AIP objective:

Developing certification procedures and identification of RCS needs, with relevant agencies

#### Corresponding project objectives / targets:

The well experienced TÜV SÜD certification agency will support the certification of the fuel cell materials handling vehicles and the hydrogen refuelling infrastructure to be demonstrated. JRC will identify existing RCS and conduct a gaps analysis in terms of future RCS needs in order to enable fast and standardized certification at high volume production and market deployment.

#### Achievements:

In principle sufficient RCS is in place to get certifications for fuel cell systems, fuel cell material handling vehicles and hydrogen refuelling stations. However, further

standardisation is required to enable reduced efforts for certification procedures on a European and a global level.

AIP objective:

Conceived envisaging of continuation of efforts in high volume deployment.

Corresponding project objectives / targets:

The ambition and driving force of the HyLIFT-DEMO activities and partners are to enable a following deployment and market introduction starting no later than 2015. Therefore the targets to be reached within the project as well as the demonstration model and relations to end-users are set-up with a future commercial value chain in mind. One work package (WP7) within the project will be dedicated to planning the commercialisation and ensure initiation of market deployment.

Achievements:

Commercial market deployment could not be achieved within this project. The technology applied in this project is far from being fully commercial. Therefore deployment support mechanisms are required beyond HyLIFT-DEMO (and also beyond HyLIFT-EUROPE) and therefore have to be reflected in the FCH 2 JU in the context of Horizon 2020.

AIP objective:

Dissemination of results to wide audience (end-users and associations).

Corresponding project objectives / targets:

LBST and HyRaMP-EHA will handle the dissemination in the project. LBST is well experienced from previous projects on this task. HyRaMP-EHA brings to the project the access to an extensive network of European companies, regions and municipalities active on hydrogen and fuel cells, thus a strong network through which the dissemination can happen. Also the specific material handling industry will be targeted for dissemination through collaboration with trade-associations like the European Federation of Material Handling Industry. One work package (WP8) within the project will be dedicated to European networking and dissemination of project results.

Achievements:

For a long period of time as the demos were not started the project has limited material to disseminate. Later, as the demonstrations were ongoing and the data evaluation was producing results, dissemination was intensified. A dissemination

workshop was performed at a customer site and vehicles were exhibited at the CeMAT and the InterAirport fairs.

AIP objective:

Demonstrate at least 10 vehicles at a single site including coupling with hydrogen refuelling infrastructure.

Corresponding project objectives / targets:

11 (previously at least 30) fuel cell material handling vehicles will be demonstrated at end-user sites throughout Europe, including establishment of hydrogen refuelling infrastructure at each site.

Achievements:

11 materials handling vehicles were in demonstration in total for at least one year each.

AIP objective:

Prove durability of fuel cell systems, functionality of refuelling infrastructure and end-user acceptance.

Corresponding project objectives / targets:

The project partners have for years conducted R&D and demonstrations of earlier fuel cell and hydrogen refuelling infrastructure generations that already reach or surpass the targets as set-up in the call text. Thus the HyLIFT-DEMO project is to push targets even further by demonstrating 3<sup>rd</sup> generation technology. WP6 in the project will be dedicated to demonstration monitoring and assessment. It will gather operation results in order to validate reaching of the targets. Furthermore, durability laboratory tests of the fuel cell systems will be conducted by SINTEF and JRC in order to identify issues and mechanisms in the fuel cell system that may be adjusted to optimize and improve durability.

Achievements:

Durability of fuel cell systems: 4,000 h durability test could not be finalised because of test rig issues; some vehicles accumulated up to 2,400 operation hours.

Functionality of refuelling infrastructure: availability of HRSs was 99.5% throughout the project.



AIP objective:

Consortium to include industry test-sites, fuel cell system developers, certification agencies, vehicle OEMs and end-users

Corresponding project objectives / targets:

The project covers the entire supply chain for ensuring complete operable hydrogen powered fuel cell system solutions to be easily integrated into formerly battery powered OEM vehicles. This includes the fuel cell developer H2 Logic and gas competence provider Linde. Also competent certification agencies as TÜV SÜD and JRC are participating. Letters of interest from 21 end-users representing a fleet of 633 forklifts were secured together with letters of interest from local project facilitators covering 10 potential demonstration regions throughout Europe.

Achievements:

HyLIFT-DEMO included partners to cover the entire supply chain. Industry test-sites respectively end-users were not included in the project deliberately in order to showcase the regular purchasing pathways as far as possible.

AIP objective:

Total costs of fuel cell system <4,000 €/kW

Corresponding project objectives / targets:

The 3<sup>rd</sup> generation fuel cell systems to be demonstrated are to reach a price of 2,500 €/kW.

Achievements:

The FCH JU target has already been reached with past generation fuel cell systems that were demonstrated in advance of HyLIFT-DEMO.

AIP objective:

System lifetime >5,000 hours

Corresponding project objectives / targets:

The 3<sup>rd</sup> generation fuel cell systems to be demonstrated are to reach a life time of >10,000 hours (with service & stack replacements).

Achievements:

The FCH JU target has already been reached with past generation fuel cell systems that were demonstrated in advance of HyLIFT-DEMO.

AIP objective:

System efficiency >40%

Corresponding project objectives / targets:

The 3<sup>rd</sup> generation fuel cell systems to be demonstrated are to reach system efficiency of >45%.

Achievements:

The FCH JU target has already been reached with past generation fuel cell systems that were demonstrated in advance of HyLIFT-DEMO.

AIP objective:

Refuelling time <5 min.

Corresponding project objectives / targets:

The fuel cell systems will use either type 1 or type 2 hydrogen storage tanks with metal liner, thus allowing for fast refuelling (2-3) minutes without any issues related to the increase of temperature inside the tank due to the speed of pressure increase. Also the cascade filling from the refuelling station will allow for rapid and fast refuelling, thus this will not depend on e.g. compressor capacity.

Achievements:

A refuelling time < 5 min could be achieved in the project.

AIP objective:

Hydrogen refuelling price at pump <13 €/kg

Corresponding project objectives / targets:

The hydrogen refuelling infrastructure to be demonstrated is to enable a price of <9 €/kg.

Achievements:

The hydrogen refuelling price at pump is mainly depending on the local source of hydrogen and the costs of it. Therefore no general statement can be given here.

## **Dissemination activities**

### **General dissemination**

The HyLIFT-DEMO website [www.hylift.eu](http://www.hylift.eu) is up and running and comprises an internal as well as an external section. While the internal section is used for all means of project internal information exchange the external section is used for project dissemination of public deliverables as well as of further information of relevance in this field.

EHA and LBST have facilitated the presentation of the HyLIFT-DEMO project at various events in Europe and beyond. In total in more than 10 dedicated presentations the intermediate results of HyLIFT-DEMO and its lessons learned were communicated to interested stakeholders from various sectors. Furthermore, the project was included within EHA's presentations at events of interest as a concrete example of the state of European progress in the demonstration of fuel cells and hydrogen in materials handling applications.

At the beginning of the project (as DanTruck was still on board) in a YouTube video the performance of the hydrogen powered fuel cell forklift "DanTruck 3000 Power Hydrogen" has been produced and could at that time for attracting potential new customers in that early phase.

Various brochures and dissemination material has been produced in the course of the project to attract potential customers to participate in the trials and demos and to spread the message of the opportunities and benefits hydrogen and fuel cells can offer in the field materials handling:

- Brochure "DanTruck 3000 Power Hydrogen"
- Brochure "H2Drive<sup>®</sup> - Unbegrenzte und CO<sub>2</sub>-emissionsfreie Energie für Gabelstapler und Flughafenfahrzeuge"
- Brochure "H2Drive<sup>®</sup> - Unlimited and zero emission power for forklifts"
- Final brochure "Lifting European Materials Handling Vehicles (MHVs) to New H<sub>2</sub>eights"

### **Material handling business sector dissemination and networking**

Dissemination to materials handling stakeholders has included the identification of stakeholders, and distribution of promotional material to network contacts. A comprehensive list of stakeholders for the HyLIFT-DEMO project has been created in a database including companies and organisations which can play an integral role in the dissemination of the progress and results of the project demonstration activities. The following categories have been included: Airports, Development Agencies, European/National Associations, European Hydrogen Community, Intermediary/Facilitator, Knowledge Institutes, Logistics Consultancies, Logistics

Service Providers, Original Equipment Manufacturers (OEM), Ports, Publications, Regional/Local Authorities. The stakeholder list has grown during duration of the project; the final list includes nearly 1,500 contacts.

In preparation of the 2011 CeMAT, the HyLIFT-DEMO partners have prepared and sent out a first press release announcing the presence of project partners H2 Logic and DanTruck at this large and important logistics fair. This was sent to EHA and the European Regions and Municipalities Partnership for Hydrogen and Fuel Cells (HyRaMP) contact networks reaching nearly 6,000 contacts, and to the full HyLIFT-DEMO stakeholder database as described above.

DanTruck and H2 Logic have then participated in the CeMAT fair in Hannover, one of the world's leading intralogistics trade fairs. The visitors were impressed and several new contacts could be established. Also, new OEM partners for H2 Logic could be identified, which has become the starting point for a later cooperation.

Pictures from the CeMAT fair:



Figure 39: DanTruck hydrogen powered fuel cell forklift 3000 Power Hydrogen at CeMAT fair 2011



Figure 40: Overview on DanTruck's booth at CeMAT fair 2011



Figure 41: HyLIFT-DEMO poster at DanTruck's booth at CeMAT fair 2011

### European dissemination and networking

The European Hydrogen Association website ([www.h2euro.org](http://www.h2euro.org)) and newsletter has included a featured section on European funded hydrogen projects. This section is utilised to showcase any developments within European projects in

which EHA is a partner. The HyLIFT-DEMO project was featured on the EHA website since February 2011.

The EHA monthly newsletter, sent to the entire EHA network of over 5,000 contacts each month, is an electronic publication which presents updates in the hydrogen industry, policy developments, national and EU activities and events relevant to the hydrogen field. The HyLIFT-DEMO project launch was featured in the February 2011 edition of the EHA newsletter. A promotional video created by project partners H2 Logic and DanTruck was featured on the homepage of the EHA ([www.h2euro.org](http://www.h2euro.org)) and HyRaMP ([www.hy-ramp.eu](http://www.hy-ramp.eu)) websites, and project meetings were announced on the EHA website and latest newsletter editions.

In an effort to collect reliable data for dissemination, EHA has developed an online project survey distributed to EHA national members. Hydrogen forklift truck installations were addressed in the survey by requesting identification of target locations in each state, authorisation procedures, and incentives available for private industries to install related applications.

Furthermore, a dissemination workshop was performed to spread the results of the HyLIFT-DEMO project and to generally inform on the status quo of hydrogen and fuel cells in the materials handling sector:

On 23 JUN 2014 the HyLIFT-DEMO project, the first European demonstration of fuel cell powered forklift trucks (FC FLT) funded by the FCH JU, presented its final results. Co-organized by the EHA and FAST and hosted by one of the HyLIFT DEMO test locations, Colruyt, the Belgian supermarket chain, an overview was given of the current FC FLTs, with already commercial activities in the USA and insight was given in the challenges and opportunities in introducing the applications in Europe. Hubert Landinger presented various forklift truck operations successfully underway in the USA. In total around 5,400 materials handling vehicles were in operation in the USA, thanks to an increasing sensitivity on labour costs, availability of cheap hydrogen, significant governmental financial support and tax credits for FC systems until end 2016. In Europe only 70 vehicles have been put into operation. Colruyt FC FLT coordinator Jonas Cautaeerts referred to the results of 10 years of verifying the possibility of integrating FC FLT and the need to standardize authorisation procedures, better alignment of different suppliers of the various FC FLT components and systems. In order to accelerate price reductions end customers need to team-up to share experiences and together with the suppliers improve FC FLT operations. Jean Luc Delplancke, programme head of unit of the FCH JU presented the FCH JU intention to conduct a market study on FC materials handling vehicles and indicated that in the upcoming FCH JU program FC FLT applications could be supported as part of other innovation projects. The EHA is supporting the dissemination of the follow-up project HyLIFT-

EUROPE that will be setting a Vehicle Users Group to speed-up exchange of best practice and cost reductions.

### **Exploitation of results**

It was the ambition of the participating companies in HyLIFT-DEMO to ensure market introduction of fuel cell material handling vehicles and hydrogen infrastructure by 2015. One work package (WP7) in the project was dedicated to the commercialisation planning and preparation.

First step was to build upon the results of the 3<sup>rd</sup> generation demonstration and secure initiation of product maturation of 4<sup>th</sup> generation material handling vehicles and infrastructure, reaching full commercial targets in 2015, thus enabling market introduction. Specifically a commercialisation plan should be developed as part of the project and corporate decisions within the involved companies should be secured so that the plan could be initiated and market introduction could commence in 2015.

The early sales should be targeted to end-users with attributes that gives strongest value proposition and lowest Total Cost of Ownership (TCO) for fuel cell materials handling vehicles, as this should ease sales and lower customer's switching barriers. The following end-user attributes were foreseen:

- Material handling vehicle fleet size of more than 10 vehicles, intensely used at least 3,000 hours per year
- Customers with high LPG / diesel price
- Customer sites with access to low cost hydrogen (e.g. surplus industrial hydrogen)
- Customers with corporate social responsibility policies and need for emission reductions

The commercialisation efforts were directly linked with the business plans and efforts of the HyLIFT-DEMO project partners.

Unfortunately it turned out that commercial market deployment could not be achieved within this project. The technology applied in this project is far from being fully commercial. Therefore deployment support mechanisms are required beyond HyLIFT-DEMO (and also beyond HyLIFT-EUROPE) and therefore have to be reflected in the FCH2 JU in the context of Horizon 2020.

Therefore in the HyLIFT-DEMO follow-up project HyLIFT-EUROPE the timeline for market deployment has been adapted as follows:

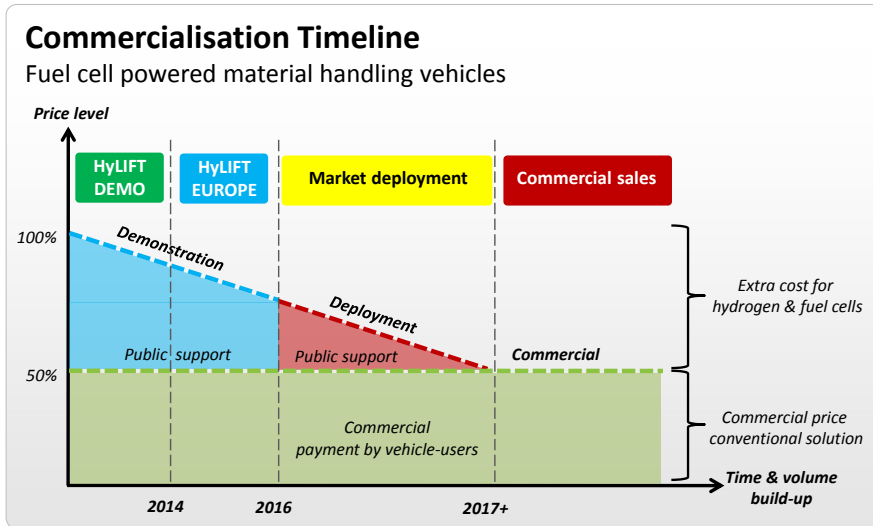


Figure 42: Updated commercialisation timeline for hydrogen powered fuel cell material handling vehicles



## 1.5 Address of project website and relevant contact details

The HyLIFT-DEMO project information and public results can be found at [www.hylift-demo.eu](http://www.hylift-demo.eu).

The HyLIFT-DEMO logo:



Figure 43: HyLIFT-DEMO logo

Beneficiaries of HyLIFT-DEMO:

Beneficiary name	Beneficiary short name	Country	Date enter project	Date exit project	Contact
Ludwig-Bölkow-Systemtechnik GmbH	LBST	DE	1	42	<a href="http://www.lbst.de">www.lbst.de</a>
H2 Logic A/S	H2L	DK	1	42	<a href="http://www.h2logic.com">www.h2logic.com</a>
DanTruck A/S	DANT	DK	1	9	<a href="http://www.dantruck.com">www.dantruck.com</a>
Technical University of Denmark	DTU	DK	1	42	<a href="http://www.dtu.dk">www.dtu.dk</a>
Linde AG	LINDE	DE	1	42	<a href="http://www.linde.com">www.linde.com</a>
European Commission, Directorate-General Joint Research Centre, Institute for Energy and Transport	JRC	BE	1	42	<a href="http://www.ec.europa.eu/jrc">www.ec.europa.eu/jrc</a>
Stiftelsen SINTEF	SINT	NO	1	42	<a href="http://www.sintef.no">www.sintef.no</a>
European Regions and Municipalities Partnership for hydrogen and fuel cells and European Hydrogen Association c/o The Italian Federation of Scientific and Technical Associations	HyRaMP-EHA	IT	1	42	<a href="http://www.hyer.eu">www.hyer.eu</a>
TÜV SÜD Industrie Service GmbH	TUV	DE	2	42	<a href="http://www.tuv-sud.com">www.tuv-sud.com</a>

## **2 Use and dissemination of foreground**

### **Section A (public)**

#### **Part A1 List of scientific publications**

No scientific publications relating to the foreground of the project were produced in the course of the project. Therefore no table A1 is included in this report.

#### **Part B2 List of dissemination activities**

See next page.

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities <sup>1</sup>	Main leader	Title	Date/Period	Place	Type of audience <sup>2</sup>	Size of audience	Countries addressed
1	Oral presentation to a wider public	Ludwig-Boelkow-Systemtechnik GmbH	HyLIFT-DEMO - European demonstration of hydrogen powered fuel cell forklifts	05/10/2011	Brussels, European Parliament Thematic Session	Scientific community (higher education, Research) - Industry - Policy makers - Medias		Europe
2	Oral presentation to a wider public	Ludwig-Boelkow-Systemtechnik GmbH	Overview and Status Quo of the HyLIFT-DEMO project	25/10/2011	Malmö, H2FC in Nordic Countries	Scientific community (higher education, Research) - Industry -		Nordic Countries

<sup>1</sup> A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

<sup>2</sup> A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

						Policy makers - Medias		
3	Oral presentation to a wider public	Ludwig-Boelkow-Systemtechnik GmbH	European demonstration of hydrogen powered fuel cell forklifts – HyLIFT-DEMO	22/11/2011	Brussels, FCH JU Review Meeting	Scientific community (higher education, Research) - Industry - Policy makers - Medias		Europe
4	Oral presentation to a wider public	FAST - FEDERAZIONE DELLE ASSOCIAZIONI SCIENTIFICHE E TECNICHE	HyLIFT-DEMO - European demonstration of hydrogen powered fuel cell materials handling vehicles	05/05/2012	Toronto, World Hydrogen Energy Conference	Scientific community (higher education, Research) - Industry - Policy makers - Medias		World
5	Oral presentation to a scientific event	Ludwig-Boelkow-Systemtechnik GmbH	HyLIFT-DEMO – European demonstration of hydrogen powered fuel cell materials handling vehicles	06/11/2012	Berlin, Meeting of fuel cell task force of German airports	Scientific community (higher education, Research) - Industry - Policy makers		Germany
6	Oral presentation to a wider public	Ludwig-Boelkow-Systemtechnik GmbH	European demonstration of hydrogen powered fuel cell materials handling vehicles – HyLIFT-DEMO	29/11/2012	Brussels, FCH JU Review Days	Scientific community (higher education, Research) - Industry -		Europe

						Policy makers - Medias		
7	Oral presentation to a wider public	Ludwig-Boelkow- Systemtechnik GmbH	European demonstration of hydrogen powered fuel cell materials handling vehicles – HyLIFT-DEMO	11/11/2013	Brussels, FCH JU Review Days	Scientific community (higher education, Research) - Industry - Policy makers - Medias		Europe
8	Oral presentation to a wider public	Ludwig-Boelkow- Systemtechnik GmbH	HyLIFT-DEMO – European demonstration of hydrogen powered materials handling vehicles	13/03/2014	Seville, European Hydrogen Energy Conference	Scientific community (higher education, Research) - Industry - Policy makers - Medias		Europe
9	Oral presentation to a wider public	Ludwig-Boelkow- Systemtechnik GmbH	Internationale Perspektiven für Brennstoffzellen in der Intralogistik	25/03/2014	Linz, Final Conference E-Log- BioFleet	Scientific community (higher education, Research) - Industry - Policy makers - Medias		Austria
10	Oral presentation to a wider public	FAST - FEDERAZIONE DELLE ASSOCIAZIONI SCIENTIFICHE E TECNICHE	Lifting European Material Handling Vehicles (MHVs) to New H2ights	23/06/2014	Halle, Final workshop HyLIFT- DEMO	Scientific community (higher education, Research) -		Europe

						Industry - Policy makers - Medias		
11	Oral presentation to a wider public	Ludwig-Boelkow- Systemtechnik GmbH	International Perspectives for Fuel Cells for Materials Handling Vehicles (MHVs)	23/06/2014	Halle, Final workshop HyLIFT- DEMO	Scientific community (higher education, Research) - Industry - Medias		Europe
12	Organisation of Workshops	FAST - FEDERAZIONE DELLE ASSOCIAZIONI SCIENTIFICHE E TECNICHE	Lifting European Material Handling Vehicles (MHVs) to New H2ights	23/06/2014	Halle, Final workshop HyLIFT- DEMO	Scientific community (higher education, Research) - Industry - Policy makers - Medias		Europe
13	Web sites/Applications	Ludwig-Boelkow- Systemtechnik GmbH	www.hylift- demo.eu	01/01/2011	Internet	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias		World
14	Press releases	Ludwig-Boelkow- Systemtechnik GmbH	HyLIFT-DEMO Project Showcases Hydrogen Powered Fuel Cell Forklift	02/05/2011	n.a.	Scientific community (higher education,		World

			Trucks at CeMAT logistics Fair May 2-6			Research) - Industry - Civil society - Policy makers - Medias		
15	Press releases	Ludwig-Boelkow-Systemtechnik GmbH	Hydrogen to revolutionise drive trains of materials handling vehicles in Europe	11/06/2013	n.a.	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias		World
16	Flyers	Dantruck A/S	DanTruck 3000 Power Hydrogen	02/05/2011	n.a.	Industry		Europe
17	Flyers	H2 Logic A/S	H2Drive®. Unlimited and zero emission power for forklifts	02/05/2011	n.a.	Industry		Europe
18	Flyers	H2 Logic A/S	H2Drive®. Unbegrenzte und CO2-emissionsfreie Energie für Gabelstapler und Flughafenfahrzeuge	02/05/2011	n.a.	Industry		D/A/CH
19	Flyers	FAST - FEDERAZIONE DELLE ASSOCIAZIONI SCIENTIFICHE E TECNICHE	Lifting European Material Handling Vehicles (MHVs) to New H2ights	23/06/2014	n.a.	Scientific community (higher education,		Europe

						Research) - Industry - Policy makers - Medias		
20	Posters	Ludwig-Boelkow- Systemtechnik GmbH	HyLIFT-DEMO	29/11/2012	Brussels, FCH JU Review Days	Scientific community (higher education, Research) - Industry - Policy makers - Medias		Europe
21	Posters	Ludwig-Boelkow- Systemtechnik GmbH	HyLIFT-DEMO	11/11/2013	Brussels, FCH JU Review Days	Scientific community (higher education, Research) - Industry - Policy makers - Medias		Europe



## **Section B**

### **Part B1 List of applications for patents, trademarks, registered designs, etc.**

No patents, trademarks, registered designs, etc. were applied in the course of the HyLIFT-DEMO project.

### **Part B2 List of exploitable foregrounds**

No exploitable foregrounds were produced in the course of the HyLIFT-DEMO project.

## **3 Report on societal implications**

The report on societal implications has been submitted online via the Participant Portal.