4.1 Final publishable summary report

4.1.1. Executive summary

The SHEL project addressed the topic *"SP1-JTI-FCH.2009.4.1: Demonstration of fuel cell-powered materials handling vehicles including infrastructure"* in the 2nd call of the European Fuel Cells & Hydrogen Joint Undertaking Implementation Plan (AIP 2009).
SHEL project, "Sustainable Hydrogen Evaluation in Logistics" was a collaborative demonstration project funded by the FCH JU. The overall purpose of the project was to demonstrate the market readiness of the technology and to develop a template for future commercialization of hydrogen powered material handling vehicles for demanding high logistic operations.

The project had the target to demonstrate 10 fuel cell forklift trucks (FLT) and associated hydrogen refuelling infrastructure across four sites in Europe. Real time information was to be gathered to demonstrate the advantage of using fuel cells to current technologies and fast procedures were to be developed to reduce the time required for product certification and infrastructural build approval. Moreover, to ensure the widest dissemination of the results, the project was to build a comprehensive State Holder Group of partners to pave the way for wider acceptance of the technology.

Since the beginning of the project, Consortium was facing diverse challenges. While in period 1, the main challenges were solved successfully, the new events arised in the period 2 made the project suffered a significant setback mainly due to the enforced withdrawal of UNIDO-ICHET, and triggered the Consortium decide to terminate the project.

Main conclusions of the project could be summarised as follows:

1. The FCs system purchase was seriously affected by two main factors: a) The price of the systems and b) Their market availability.
The first point influenced **UNIDO-ICHET** bid in particular. The target price (4,000€/kW) indicated in the FCH JU call was misleading the budget preparation as the responses from the market were instead around 6,500 plus €/kW. Therefore a further tender publication and an extra budget effort was necessary to acquire the foreseen number of systems. A combination of the two factors penalized the bid published by **CRES** as the tender did not receive any formal offer during the first two rounds of publication. This delayed all the FLT assembly scheduling.

2. PMLDs needed to negotiate their agreements with the sites in terms of liabilities and insurance issues. This section resulted to be a very delicate aspect for all the demos, as end users wanted to assure that all possible options regarding safety, operation and maintenance issues were taken into account. The objective was to achieve agreements in place before the start of each demo.

4.1.2. Summary description of the project context and the main objectives.

The overall purpose of the SHEL project was to demonstrate the market readiness of the technology and to develop a template for future commercialization of hydrogen powered fuel cell based materials handling vehicles for demanding high intensity logistics operations. This project targeted to demonstrate 10 FC FLTs and associated hydrogen refuelling infrastructure across 4 sites in Europe. Real time information was to be gathered during the project to develop design improvements which will address the key technical requirements of the call.

The consortium, coordinated by IK4-CIDETEC, was consisted of the following organizations:

- United Nations Industrial Development Organization, UNIDO-ICHET, Austria-Turkey.
- AirProducts, AP, United Kingdom.
- Centre for Renewable Energy Sources and Saving, CRES, Greece.
- Joint Research Centre. European Commission, JRC, Netherlands.
- Asociación de Investigación de la Industria del Juguete, Conexas y Afines, AIJU, Spain.
- Instituto Nacional de Técnica Aeroespacial, INTA, Spain.
- Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, FHA, Spain.
- The University of Hertfordshire Higher Education Corporation, UH, United Kingdom.
- Federazione Delle Associazion Scientifiche e Tecniche / European Hydrogen Association, FAST/EHA, Italy.
- HyGear B.V, Hygear, Netherlands.
- Cega Multidistribución S.A., CEGA, Spain.
- Cukurova Makina Imalat Ve Ticaret AS, Cumitas, Turkey.

During the whole project, the current technology were compared with hydrogen fuel cell powered forklift truck with the conclusion that neither battery powered nor ICE powered FLTs had the benefits of good performance, short refuelling times and suitability for indoor uses. Key stakeholders were also identified in order to identify suitable future demonstration site for FC FLTs and to prepare subsequent sustainable market rool out.

Regarding to the hydrogen installations of the demonstrations, a prototype hydrogen refuelling wasn´t considered suitable and leasing options wasn´t interested enough. Therefore, it was decided to purchase favourable 2 Hydrogen Refuelling Stations (HRS) for 2 of the sites (Turkey and Spain). In regards to the **Spanish demo**, a prototype electrolyser was developed and the HRS to be used in CEGA was to be purchased by CEGASA, however due to the enforced ending of the project, the purchase was stopped. Moreover, electrolyser was CE-marked in order to ensure equipment safetyness.**UK demo** was to host AirProducts (AP) commercial HRS. The **Greek Site** negotiated with Air Liquide the H2 refueling strategy and decided to deliver hydrogen in tube trailers at 200 bars (12 pressurized vessels of 50 lt each) and then free flow refilling (~ 180 bar max on truck).

In order to develop rapid procedures for 4 European countries and to reduce the time required for product certification and infrastructural build approval, a simplified and common procedure for each demo site based on HyApproval recommendations has been identified. A risk assessment analysis for each demo was commenced to perform in order to ensure safety for each demo site. The analysis was expected to be completed in the beginning of the second period, once the brand and model of HRS´s are defined, but was stopped due to the enforced end of the project.

Remote monitoring cards were also set up to be used to gather real data of the FC operation and relay these data to a FTP for post-processing. Besides, different hybrid configurations for FLT and other electric vehicles powered by batteries/supercapacitors and fuel cells available in literature were under study. With regards to the FC purchasing, only 4 FCs were bought by UNIDO-ICHET, being the purchase of the rest postponed until period 2 in which the third bid was published by CRES. The 4 purchased FCs integration was done 2012.

Up to the end of the project the preparatory work for the four demo sites were initiated. More in details, the PMLDs were negotiating their agreements with the sites in terms of liabilities and insurance issues, as end users wanted to make sure that all possible options regarding safety, operation and maintenance issues were taken into account.
Last but not least, dissemination activities were undertaken during the whole project by some partners.

In regards to the project management, the consortium was facing several challenges appeared during execution of the whole project. While in period 1, all the new challenges were undertaken successfully, in period 2 the events arising in the project, triggered the Consortium decide to terminate the project. Thus, the first event that shook the project was that at the end of 2012, CIDETEC as SHEL coordinator learned from International Centre for Hydrogen Technologies (ICHET), partner of the project, that United Nations Industrial Development Organization (UNIDO) was contacted by the Turkish Ministry of Energy and Natural Resources (MENR) to inform about the close down of ICHET on midnight, 31st December 2012. From this date, all ICHET operations were ceased, and all ICHET property was reverted to the Ministry with the Ministry assuming responsibility for all equipment and projects.

In this scenario, the main difficulty came from UNIDO-ICHET that in the beginning of 2012 purchased four fuel cell systems to be integrated into the forklift trucks to be used in two different demo sites (Felixstowe Port in UK and Petkim Petrochemical Complex in Turkey). UNIDO-ICHET bought also a hydrogen refuelling station to be installed in Petkim´s facility. These four fuel cell systems were completely integrated in CUMITAS trucks as planned in the DoW at the end of 2012 and the refuelling station was started building by the supplier in order to be ready by March 2013. However, as mentioned in above paragraph, the problem was that these equipments belonged to MENR.

Although CIDETEC did received an extra-official information confirming the willingness of MENR to donate the equipment to SHEL consortium via the remaining Turkish partner within SHEL, the situation with the Turkish Ministry went into at a deadlock, and it was not yet clear when the proper hand-over of the equipment would take place. As this uncertainty situation was not compatible with the need to build a solid timeframe for the demonstrations within the current duration of the project, a reduced continuation plan was proposed in which the demonstrations in Turkey and UK would be removed.

The second event was related to the Mid Term Review held in January 2013 were two major commitments were defined in order to face the difficulty after ICHET shutting down:

- A scenario with 5 HFLTs demonstrated in two sites during a full year trial.
- A contingency plan for each demo site.

Since the Mid Term Review Consortium was trying to sort out the new challenges had come out, trying to fix all open issues related to the starting of the re-scheduled demonstrations on time –i.e., in June 2013- as well as the contingency plan. However, 3 months later than the Mid Term Review the above mentioned challenges still remain opened leading to a new scenario where the 5 HFC FLTs could not be demonstrated during at least the specified full year trial, assuming that the end date already agreed for the project could not be further delayed.

Thus, Consortium decided that it would not be possible to reach the goals of the project demonstration activities as expected on due time was forced to propose a closure of the project to FCH JU.

4.1.3 Description of the main S & T results/foregrounds

Work Package 1. Project Coordination

The coordination of the project was facing several challenges since the beginning of the project towards reaching main project objectives. The main challenges in period 1 were undertaken successfully, being the main objectives of the Project Management (iK4-**CIDETEC**) in this period: (i) preparation and submission of the amendment; (ii) supervision of the activities in each of the different work packages (tasks, deliverables and milestones) were carried out in line with the agreed budget and timing; (iii) coordination of the communication among the project´s partners; (iv) management of the communication with the FCH JU and the respect to the reporting and financial management as detailed in the contract between FCH JU and SHEL consortium. However, new challenges occurred in period 2, led the project at a deadlock and forced Consortium to define the closure of the project.

Consortium Management Tasks and Achievements

As a general overview, the following tasks were carried out during the whole project:

Task 1.1: Establishment and running of the Project Steering Committee (PSC) by PM.

During the kick of meeting of the SHEL project held in **CIDETEC**, a Project Steering Committee was established. The names of the agreed representative persons in the PSC were shown in the table 25 from 1st periodic report.

During the 2nd period, Project Steering Committee was held while the Mid Term Review in FCH JU facilities in Brussels. The PSC was used to internally evaluate the progress and perspectives of the project after the amendment 1 and first Review.

Task 1.2: Develop Project Quality Plan (PQP) by Quality Manager

As the Quality Manager (QM) of the Project, **FAST/EHA** developed the Project Quality Plan (PQP). The main objective of the PQP report was to define the quality standards, methodologies, procedures and tools for performing the quality assurance activities within the work of the SHEL project.

Task 1.3: Establishment and delivering of a Communication Plan (CP) by QM

FAST/EHA developed a Communication Plan. The overall objective of this report was to define means and methodologies for communication among partners. The report defined the procedures for internal partner communication within the project, while reviewing also the procedure to be taken into account when the project is presented to a further audience outside the project consortium.

Task 1.4: Development of a Technical Plan (TP) by TM

UNIDO-ICHET, with the support of **CIDETEC** and **AIJU**, developed the Technical Plan (TP) as scheduled in DoW. The TP intended to provide the four demo sites with some guidelines on how to carry out the testing and final evaluation of the SHEL FLT fleet.

Task 1.5: Development of an Exploitation Plan (EP)

HyGear contributed to this task with a complete Exploitation Plan (EP) for the SHEL project. The EP was reviewed by Quality Manager (**FAST/EHA)** and Project Coordinator (**CIDETEC**) as planned in the DoW.

List of Project Meetings

In general four Project Meetings took place at the dates and locations shown in the next Table. The average participant of each meeting was 20.

Table List of Project Meetings

Date	Meetings	Venue
Month 1, 26th-27th January 2011	Kick Of Meeting	San Sebastian (Spain)
Month 12, 30 November - 1st December 2011	General Assembly	Istanbul (Turkey)
Month 18, 13rd-14th June 2012	General Assembly	Milano (Italy)
Month 22, 23rd October 2012	General Assembly	Alicante (Spain)

Moreover, following FCH JU rules a **Mid Term Review** was held in Brussels in the latest week of January 2013. Together with the Mid Term Review, a **Project Steering Committee** was held as collaborative, decision making units in order to maintain project focus and direction, ensuring that the project stays on track, according to defined goals, requirements and deliverables.

Project Changes

During the first period, Description of Work Annex I underwent a thorough revision. The new version replaced the previous one. Coordinated by **IK4-CIDETEC**, project partner's submitted changes and the revised version was accepted by the FCH JU in a letter dated on the 28th of September 2012.The key change was the extension of the project from 36 months to 42 months. The new closing date for the project was June 30th 2014.

During the 2nd period, a **Project Steering Committee** was held in the end of January 2013. As a result to make the project afloat, a reduced continuation plan was decided in which the demonstrations in Turkey and UK would be removed.

In addition, during the Mid Term Review held in January 2013 two major commitments were defined in order to face the difficulty after closure of UNIDO-ICHET:

- A scenario with 5 HFLTs demonstrated in two sites during a full year trial.
- A contingency plan for each demo site.

Since the Mid Term Review Consortium was trying to sort out the new challenges had come out, trying to fix all open issues related to the starting of the re-scheduled demonstrations on time –i.e., in June 2013- as well as the contingency plan. However, 3 months later than the Mid Term Review the above mentioned challenges still remain opened leading to a new scenario where the 5 HFC FLTs could not be demonstrated during at least the specified full year trial, assuming that the end date already agreed for the project could not be further delayed.

Thus, Consortium decided that it would not be possible to reach the goals of the project demonstration activities as expected on due time and submitted, on the 22nd of April 2013, a letter to FCH JU with a proposal for finalizing the project.

Work Package 2: Benchmarking
The aim of WP2 was to provide up-to-date cost information of the use of hydrogen and fuel cells for forklift applications and define and identify appropriate stakeholders.
Task 2.1: Benchmark current SoA for FC FLT deployments
The main aim of the task is the analysis of the current State of Art across various international demonstrations to date.
This task was led by **AP**, with inputs from **CRES**, **FAST/EHA**, **HYGEAR**, **UNIDO-ICHET**, **CUMITAS** and **UH**. A draft of the report was completed within the 3 month deadline and the report was submitted to the project coordinator for final comment and approval. A final sign off of the report was delayed due to changes in AP´s representation on the project. Nevertheless, is expected to be completed during November 2012.
A State of the Art (SoA) report is the first deliverable of this Work Package. The SoA report compares current technologies with hydrogen fuel cell powered forklift trucks (FC FLTs). The report concludes that neither battery powered nor ICE powered trucks have the benefits of good performance, short refuelling times and suitability for indoor use that are associated with FC FLTs.
The report examines also the potential CO2 reduction of hydrogen fuelled FLT fleets compared to incumbent technologies. It shows the possibility to reduce significantly the greenhouse gas(GHG) and CO2 emissions by switching to hydrogen. However, it concludes that the production methods 12
for hydrogen influence the outcome and that the **electrolysis from renewable electricity** has the lowest overall environmental impact, despite the high energy used.
The performance of FC FLTs from previous projects is covered in the report, with the conclusion that refuelling times are significantly lower than in battery technology, with the added benefit of improvements in productivity. The costs of the trucks are also compared.
A hydrogen cost calculation model was devised as part of the SoA report. This element of the report was lead by **HyGear**. The model considers different sources for the hydrogen production including steam reforming of natural gas, bio-ethanol, biogas and electrolysis of water. The model was developed for refuelling ten fuel cell propelled fork lift trucks a day. This model can easily be extended to higher refuelling capacities. The calculation is based on the fuel costs of the year 2011. Looking at natural gas and electrolysis as hydrogen sources can be concluded that almost € 3 cost difference per kg of hydrogen. The other two bio-based sources are more expensive than the others, resulting in higher costs per kg of hydrogen.
The report also reviews some energy saving technologies for FLTs, namely regenerative braking and lowering.

Task 2.2: Establish Stake Holder Group (SHG)
This task´s objective is the identification of key stakeholders within Europe for a future EU FC FLT industry.The establishment of a Stakeholder Group (SHG) is the second deliverable of this work package.
The SHG report contains European based stakeholders and supporters for future commercialisation. The SHG would also become the main focal point for project dissemination. The membership comprises stakeholders from the following areas:

- Leading industrial partners (FLT OEMs, Trade Bodies, Leasing Agents),
- Early customers for FC FLTS e.g. Airports Operators, Airlines, Ports Operators, Logistics Organisation,

- International Standards Bodies,
- Industrial Gas Suppliers,
- National Hydrogen Associations.

In the first three months of the project, the SHG was established with a database of over 1450 stakeholders from across Europe, working in the categories described above. This creates the opportunity for engaging with the SHG throughout the rest of the SHEL project.

The most important aspect of this engagement will be the setting up of a number of stakeholder workshops where the progress of the project will be reputed and key aspects of operating FC FLTs will be shown.

Task 2.2 was led by **EHA** and **FAST** and was completed on time. The Database is being kept updated during the full duration of the project by the EHA and the workshops will be held while the demonstrations are running.

Task 2.3 Develop an Operation Cost Model

The third task of this work package was to develop a high level cost model as a tool for the determination of the future economic viability of continuation projects.

The model (deliverable D2.3) incorporated economic parameters identified in the SoA report (Task 2.1) and allowed integration with H2 site simulation models developed in Task 3.1. The model could be used to determine cost of ownership, H2 refuelling costs, operation costs and break-even analysis linked to future sites. The task was led by **FHA** and was completed on time.

The deliverable D2.3 was revised by the FCH JU during the Mid Term Review and rejected it and provided a suggestion of merging it with the D3.7. FHA started preparing the new deliverable (enabling D2.3 together with D3.7) when the Consortium brought to the conclusion of define the closure of the project.

Work Package 3: Hydrogen Infrastructure

The objective of WP3 was: (1) to develop a simulation model analysis for most common hydrogen pathways for FC FLT refuelling, (2) to identify a design for FC FLT refuelling station which can be used to improve and simplify the current complex process for certification and (3) to develop a hydrogen infrastructure plan for each demonstration site.

Task 3.1: Simulation Model for Sites

INTA developed, with the support of the University of Seville, several simulations for the Spanish site, using ESSFER simulation tool. These simulations included hydrogen production in an alkaline electrolyser from PV panels or hybrid configurations (PV+wind), the storage of hydrogen, and the supply to the forklift trucks, according to CEGA´s consumption requirements and the technical specifications of the fuel cell power system.

FHA developed, with the support of **INTA**, a new tool that allowed the user to calculate or estimate the final price of the hydrogen dispensed on each demonstration site. This information was included and explained in the deliverable D3.7.

HyGear contributed to this task with an extensive hydrogen cost calculation model. The detailed model was given in the internal report *HYG-SHL-RP.002 – Hydrogen Filling Station, Economic Evaluation*. The model considered different sources for the hydrogen production as steam reforming of natural gas, bio-ethanol, biogas and electrolysis of water.

During the Mid Term Review, held in period 2, the D3.7 was rejected. After the Mid Term Review **FHA** started to work in the assessment of Total Cost of Ownership for the FLT following the recommendations marked by the PO and the reviewers. The final goal would be to merge the deliverables D2.4 and D3.7. During February 2013, FHA made a first assessment of the main aspects of the FLT that should be taken into account for doing the Excel tool but the analysis was stopped due to the uncertainty about the progress of the project"

Task 3.2: Design Hydrogen Infrastructure
This task includes two subtasks, as follows:

i) An electrolyser for deployment in the Spanish demonstration
During the 1st period, AIJU built an alkaline electrolyser to fulfil the refuelling needs of the Spanish demonstration at CEGA Logistics.
While in the 2nd period, the electrolyser was CE-marked. The CE Marking stated that the electrolyser was accessed before being placed on the market and met with EU safety, health and environmental protection requirements.
In addition, the electrolyser complied with:

- ATEX Directive 94/9/EC
- Pressure Equipment Directive 97/23/EC
- Electromagnetic Compatibility Directive 2004/108/EC
- Low Voltage Directive 2006/95/EC

After finishing the assembly of the electrolyser, different tests were made to know the purity of the hydrogen gas stream, to check the general system, to know the efficiency of the electrolyser, to tune the purification system and to verify the regeneration of the dryer beds.

ii) A modular hydrogen refuelling station design concept for each demo site which is capable of deliver a simplified certification process for EU deployments.
SHEL project strategy was to demonstrate 4 different hydrogen supply mechanisms across 4 countries: UK, Turkey, Spain and Greece. This strategy would permit to evaluate different types of infrastructures based upon future possible commercial hydrogen resources available in Europe.

Demo at Port of Felixstowe (UK demo).	Demo at Petkim (TK demo).
Hydrogen resource: distributed hydrogen. *Filling Station:* AP S125 or S100 *FLT:* 4 counterbalanced trucks of 2.5 ton supplied by Cumitas. *FC:* Hydrogenics 12 kW provided by UNIDO-ICHET.	*Hydrogen resource:* by-product hydrogen gas. *Filling Station:* Commercial unit. *FLT:* 4 counterbalanced trucks of 2.5 ton supplied by Cumitas. *FC:* Hydrogenics 12 kW provided by UNIDO-ICHET.
Demo at Cega (SP demo)	**Demo at AB Vassilopoulos supermarket (GR demo)**
Hydrogen resource: on-site hydrogen generation from an electrolyser. *Filling Station:* Commercial unit. *FLT:* 2 reach trucks by Toyota. *FC:* still undefined (the 3th bid will close in December).	*Hydrogen resource:* distributed hydrogen. *Filling Station:* Free flow is not allowed in Greece so it is not clear how they will refill the trucks, but the device will be supplied by Air Liquide Hellas or Linde. *FLT:* 1 counterbalanced truck of 1.5 ton from previous Ecolift project developed by UNIDO-ICHET and 3 counterbalance trucks of 2.5 ton supplied by Cumitas. *FC:* still undefined (the 3th bid will close in December).

CIDETEC, with **AIJU´s** support, contributed with the search of the appropriate refuelling station for the Spanish demo. In the very beginning of the project, CICETEC and AIJU travelled to UK in order to validate the conformity of a prototype refuelling station. The final decision between the Spanish partners (**FHA, AIJU, INTA, CEGA and CIDETEC**) was that the prototype refuelling station didn´t meet the requirements for Spanish Demo, mainly in relation with Safety issues and was necessary to find a suitable HRS for this site in leasing option. This change in using a commercial HRS was submitted in the amendment and approved by the FCH JU.

Several offers of HRS in leasing option were received by the Spanish partners, but neither of them was found to be suitable. In the last month of the first reporting period and in order to face the difficulties in finding a appropriate HRS, a purchasing of station by **CEGASA INTERNATIONAL** Company, a sister company of the SHEL partner CEGA Logistics, belonging both to CEGASA GROUP, was decided. A supplier would be defined after the Mid Term Review but the purchasing was stopped due to the uncertainty about the progress of the project.

The work carried out in this WP by **AP** was related to the discussions with original UK site (Newcastle airport) including a site visit and preliminary work on approvals for this location. Once the change of the location of the UK demo was accepted by the FCH JU, subsequent work related to contractual issues between UK PMLD (**UH**), HRS supplier (**AP**) and Felixstowe Port Company were undertaken.
CRES contributed to this WP by working in the Design Hydrogen Infrastructure for the Greek demo site. The final design was agreed between CRES and Air Liquide, where H2 refuelling strategy was based on H2 delivery in tube trailers at 200 bars (12 pressurized vessels of 50 lt each) and then free flow refilling (~ 180 bars max on truck).
CRES also contributed in the site preparation (ventilation system, fire protection, lightning protection installation, etc.).

UNIDO-ICHET contributed to this WP working in the Design Hydrogen Infrastructure for the Turkish demo site. It worked with Petkim setting up its facilities to deploy the HRS (required hydrogen piping/network), checking the hydrogen availability in Petkim and looking for a suitable supplier of a hydrogen refuelling station.

It also contributed in the site preparation (electricity, hydrogen piping connection, exterior design, etc.)

The **University of Hertfordshire (UH)** developed a framework as an aid to the safety analysis relating to FC-powered FLTs for the demo phase of the SHEL project in 4 EU countries. The framework included all aspects of safety during all phases of operation (preparation, installation, operation, decommissioning) and identifying risks involved as well as roles and responsibilities of all engaged.
CEGA contributed to this WP in the site preparation (electricity, hydrogen piping connection, water requirements, exterior design, etc.)

Work Package 4: Certification and Planning
The main objective of WP4 was to investigate current Hydrogen Certification projects in four Member States. This WP was separated into 3 separate tasks and would run until the certification for the all demonstrations is obtained

Task 4.1: Establish Certification (simplified) for 4 EU sites
The main goal of this subtask was to define the roadmap and schedule for the certification process in all Demo sites. For this purpose, HyApproval recommendations were followed in order to develop a simplified and common procedure for all demo sites.

FHA developed the D4.9 with the information that **UH**, **CIDETEC**, **CEGA** and **CRES** shared related to the task 4.1 of all demo sites. This Deliverable included all the roadmaps for the certification process which should be followed in case of the project would have continued. The HyApproval was assumed as baseline for the assessment of this part of WP4. **FHA** assessed the task 4.1 results in order to give some conclusions and recommendations which are summarized in D4.9.

INTA contributed to deliverable D4.9, providing the form for "Approval requirements for HRS (Hydrogen Refuelling Station)" issued in the HyApproval European project.
The progress undertaken by each partner involved in the demo site relating the certification process is explained below:

i) Spain Demo
The HyApproval Annex template was completed for this demo. **INTA** and **FHA** supported **CIDETEC** and **CEGA** in the first stage of the certification process with their knowledge. The HRS taken into account to support the Spanish demo certification process are one deployed by FHA in their facilities and another one deployed in Seville, under Spanish HERCULES project. This information was used to compare the certification procedure in different regions of Spain, and was found to be very useful to support the certification procedure at the Spanish demo site.

CEGA subcontracted a specialized engineering company to identify all the procedures required to follow and to certify the installation. The engineering company worked closely with the local authorities (city council and Industry Department of Pais Vasco community) for this purpose. The process started in March 2012 and therefore it was expected that the certification process would have been completed in due time.

ii) United Kingdom Demo
AirProducts and **University of Hertfordshire** worked in this task. **AP** supported with its previous experience. HyApproval Annex was also completed.

iii) Turkey Demo
UNIDO-ICHET led this action in Turkish demo. In the same way as in Spain, a HyApproval Annex was completed for the Turkish demo site. The complete information was submitted in the Deliverable 4. 9.

iv) Greece Demo
CRES led this action in Greek demo. In the same way as in Spain and Turkey, a HyApproval Annex was completed for the Greek demo site. The complete information was submitted in the Deliverable 4. 9.

Task 4.2: Safety Study
A Qualitative Risk Analysis (QRA) was to be developed in each demo site in order to ensure safety during the operation. Each PMLD (**UNIDO-ICHET** for TK demo, **UH** for UH demo, **CRES** for Greek demo and **CIDETEC** for Spanish Demo) chose the more convenient methodology in each case study.
HyGear supported this task with the report "Case Study on External Safety of the Hydrogen Refuelling Station in Arnhem". This case study is based on the experience acquired during the planning and installation of a public hydrogen refuelling station in the city of Arnhem.

i) Spain Demo
The methodology selected for the risk assessment was the FMEA (Failure Mode and Event Analysis), which was proposed by **INTA** based on its experience in the field of risk assessment. The partners **FHA, CIDETEC, CEGA, AIJU** were involved in the realization of this task as well. The operation of the main units (electrolyser, compressor, storage and dispenser) and their integration in the installation were to be studied. However, the task was uncompleted due to the enforced finalization of the project

ii) United Kingdom Demo
UH developed a document that described those aspects of demo phase that required safety analysis at each stage of the process. It represented a framework to capture roles and responsibilities of various stakeholders at each phase of the project.
The safety analysis was to be finished by **AirProducts** with **UH** support once hydrogen filling station type would be selected for the Demo in UK. However the complete document wasn´t finalised due to the end of the project was accelerated.

iii) Turkey Demo
The methodology selected by **UNIDO-ICHET** for the risk assessment was a HAZOP. This analysis was supposed to be done once hydrogen refuelling station supplier was defined. Although in the end of November 2012, the HRS supplier was selected the

unforeseen closure of UNIDO-ICHET in December 2012 mad the task to be uncompleted.

iv) Greece Demo
HAZOP analysis was to be done before the end of 2012. However, the task was uncompleted due to the finalization of the project

Task 4.3: Certification delivered for 4 planned sites
This task was supposed to be completed once each demo site would have obtained the certification approval with the main conclusions, lessons learned and improvements for future certification process. Due to the finalization of the project, the work related to this task wasn´t undertaken.

Work Package 5: FLT Preparation
The main objective of WP5 was the delivery of 9 optimised FC FLTs for the demonstration, plus as existing FLT FC prototype developed by **UNIDO-ICHET** and their partner in the ECOLIFT project, FLT company- Cukurova Makina Imalat ve Ticaret (**CUMITAS**). This would give to the project a total of 10 vehicles: one prototype, seven counterbalanced type vehicles and 2 reach trucks.

Task 5.1: Develop remote monitoring
AIJU led this task. Through the interaction with **UNIDO-ICHET** and **CIDETEC,** the remote monitoring card was set up on the basis of the previous software installed on the Ecolift FLT prototype developed by **ICHET** in cooperation with **Cumitas**. The system was subsequently updated according to the latest FC system produced by Hydrogenics that were purchased to be integrated in the SHEL fleet. A member of **AIJU** and **CIDETEC** staffs participated in the training provided by Hydrogenics to **ICHET** personnel on the FC systems.

The remote monitoring system would be used to gather data of the FC operation and relay these data to a FTP for post-processing. The whole system was composed of four different parts:

- Computer on module operating under Linux 2.6.35;
- Specific electronic card (Base Board) for each model of FCPP;
- Specific monitoring software;
- Web application that stores logged data.

Two different electronic cards were developed: one generic for any FLT and one specific for the FLT owned by ICHET. Embedded monitoring /telemetry software and a web application to be linked to the hardware have also been programmed.

Task 5.2: FLT Hybrid System Analysis
INTA was task leader and analysed different hybrid configurations for FLTs and other electric vehicles powered by batteries/supercapacitors and fuel cells available in literature. Moreover, a theoretical analysis on alternative solutions in comparison with present hydrogen storage systems used in FC FLTs available in the SHEL project was initiated.

Task 5.3: FC FLTs preparation for demonstrations
This task was led by **Cumitas**, the FLT manufacturer in charge of preparing the counterbalanced trucks. Four FC FLT units were prepared at Cumitas workshop in Tarsus, Mersin-Turkey. Cumitas staff also integrated the monitoring cards (developed in Task 5.1) into the FLTs frame.

CIDETEC as a Spanish PMLD together with **CEGA** identified specific needs in terms of integration as well as homologation of FC in FLT. The homologation requirements were identified after several conversations undertaken with the FLT manufacturer. Although the previous FLT manufacturer was considered to be CUMITAS, after some site requirements analysis it was decided to use different type of FLT in CEGA comparing to the ones to be used in the rest demo sites. Thus, the manufacturer of this type of FLT (reach trucks) expressed its intention to support either the integration of the FC into the FLT as well as any work related to the FLT operations. However the manufacturer also expressed the need to comply with FC FLT homologation. Therefore, CIDETEC and CEGA were together working on the identification of homologation needs while Consortium was forced to decide the termination of the project.

CRES was in charge of supplying five (5) new fuel cell systems for a fleet of ten units to be demonstrated in different European sites in Turkey, UK, Spain & Greece. During period 1, two factors penalised the two bids published by **CRES** as the tender did not receive any formal offer during the first two rounds of publication. During the period 2, CRES announced the 3rd International open procedure call for tenders on 11/10/2012 and the deadline for bid submission was set for Monday 3/12/2012 at 12:00 am. Once CRES followed technical as well as Finantial analysis of the offers, decided and there was only one supplier that could meet with all requirements. However, due to the decision of end the project it wasn't possible to sign the contract with the successful bidder.

Task 5.4: FLT Testing & Evaluation
UNIDO-ICHET selected the software that would be used to support the well to wheel performance analysis, being GaBi, a software tool developed within the HyGuide project.
Moreover, **JRC** developed the deliverable D5.13 named "Test protocols for H2 and FC FLT". The objective of this deliverable was to present the test protocols to be undertaken while testing of the hydrogen fuelled fuel cell system for the fork lift trucks.

Work Package 6: Demonstration
The main objective of this WP was to demonstrate 10 FLTs at four individual sites, there were several targets that should be met to obtain successful trials: a) Real time data gathering from actual operations within likely early market applications to evaluate key performance criteria as determined by the JTI: indicatively, b) well-to-wheel efficiency of 40%; c) rapid fill in less than five minutes; c) evaluate lifecycle performance over 5,000 hours, d) cost data linked to future stack price (4,000 euro per kw) and d) cost of hydrogen (under 13euros/kg) from different hydrogen pathways (distribution, renewable (using simulation in conjunction with an electrolyser) and off-gas from petrochemical operations).

Up to the end of the project only task 6.1 of WP6 was undertaken although the preparatory work regarding in particular task 6.3, was also initiated. More in details the

PMLDs were negotiating their agreements with the sites in terms of liabilities and insurance issues. This issue was resulting to be a very delicate aspect for all the demos, as end users wanted to assure that all possible options regarding safety, operation and maintenance issues were taken into account. The objective was to achieve agreements in place before the start of each demo.

Task 6.1: Installation of H_2 all sites and vehicle handover.

Spanish Demo

Regarding to the purchase of the HRS to be installed in Spanish demo, firstly CEGA, actively advised by CIDETEC, analysed deeply all the technical information received from different HRS suppliers. Once the technical information was supervised, the best two choices of the HRS suppliers were selected taking into the required hydrogen supply for covering FLT operation of 3 shifts per day and 7 days per week. Afterwards, CEGA started the negotiation with each provider and continued with this work until Consortium deemed to close down the project.

Greek Demo – Major risks & Contingency plan

As explained in period 1, the Greek demo was going to be at the new central logistic center of AB Vassilopoulos supermarket chain in an area of 115000 m2 (55000 m2 indoor area, with more than 300 employees) at Oinofyta, about 55 klm north of Athens.

The H2 refuelling strategy involved H2 delivery in tube trailers at 200 bars (12 pressurized vessels of 50 lt each) and then free flow refilling (~ 180 bars max on truck).
CRES was to be responsible for the good operation of the whole facility. Both 3G & WiFi were available to integrate AIJU acquisition system. CRES was expected to collect all data and AB would be responsible for the site preparation (with the assistance of CRES); Air Liquide Hellas was to sponsor the H2 supply covering the operation for 4 hours shift per day (5 days/week) for both indoor (warehouse and outdoor FLT services). One indoor electrical 3-wheel FLT and one outdoor diesel engine 4-wheel FLT would be replaced by the 3 newly developed counter-balanced FC FLTs. The site had already an ATEX for ammonia and an industrial insurance that was to be properly extended and cover all additional legislation requirements for H2 use.

Major risks:

i) In case Air Liquide Hellas would not sponsor the H2 supply or the offering quantities would not be sufficient enough for covering the operation for 4 hours shift per day (5 days/week)
ii) According to the Greek legislations, the FLT vehicles had to be registered with Greek plates from the Ministry of Transportation prior to their use at the demo site. This could easily be done (obtain Greek plates) once the FC-integrated FLTs had already acquired a European vehicle approval. Otherwise, it would be necessary to run this procedure in Greece, as soon as the FLTs would be delivered to AB.

Contingency plan:

i) The first major risk was to be solved by AB & CRES assuming to cover with their own resources all necessary hydrogen cost for the operation of 3 FLTs for at least 2 hours shift per day each (5 days/week)

ii) The second risk would be solved by acquiring a temporary vehicle approval from the Ministry of Transportation to run the required procedure in parallel with the demo without any further delay.

However, as Consortium decided that it would not be possible to reach the goals of the project demonstration activities as expected on due time, CRES couldn´t complete all the activities related to H2 installation.

UK demo
Regular contacts were made with UNIDO ICHET technical staff to follow the developments in the FC integration, and FLTs final weight, as well as lessons learned from negotiations relating to the contractual agreement between ICHET & Petkim.

Extensive efforts continued to finalise a workable contract agreeable to all signatories involved in the UK Demo. These included over *one thousand* email exchanges, many telephone calls and teleconferences, as well as face-to-face meetings. The legal department at the **UH** were heavily involved in the negotiations, spend considerable time and made strenuous effort to bridge the gap between the parties involved.

Felixstowe provided Consortium with the first version of a draft contract in Feb 2012, soon after they provided an MOU. Felixstowe had an entirely reasonable perspective; they wanted to know who would be responsible should anything go wrong.

Discussions were on-going with Felixstowe on a regular basis to keep them on board until the very last moment and, on many occasions, they were reassured that the project is delayed but will happen.

Task 6.2: Handover & Training (all equipment)
Due to the enforced end of the project, demonstrations weren´t started and therefore the scheduled task "Handover & Training" wasn´t performed.

Task 6.3: Demonstration
Due to the enforced end of the project, demonstrations weren´t started and therefore the planned task "Demonstration " wasn´t performed.

Work Package 7: Continuation Plan and Dissemination
These were the main objectives of the WP7:

- Disseminate the results of the project to a wide number of key potential stakeholders. The dissemination plan will be based on an economic model to engage key potential customers at local level in the deployment of FC FLT.
- To develop a Continuation Plan for wider Commercialisation to include a further 10 site deployments, the first potentially being in Greece.
- To undertake a supply chain analysis and gap analysis covering equipment providers for units to be supplied under the continuation plan.

Task 7.1: Dissemination of Project
The work done in this task will be explained in the next section.

Task 7.2 Continuation Plan

As initially planned, the results and experience derived from the project would be used in big logistic centres in Greece at a large-scale. More specifically, fuel cell-driven forklifts would replace conventional forklifts in one of the central warehouses of a Greek super market chain (ALFA-BETA VASSILOPOULOS SA, www.ab.gr).

The above-mentioned company, which is a member of DELHAIZE Group, currently holds the 2nd place in the Greek market and expressed its interest to use fuel-cell driven forklifts in its facilities. Fuel cell-driven forklifts would be operated in the largest storage and distribution centre of the company in Inofyta, Boetia, 70 km from Athens. The specific warehouse covered an area of 115,000 m^2. In this warehouse, the company was using over 100 forklifts of various sizes. During the project implementation and after the 1st amendment, AB Vassilopoulos became an official demo site within the SHEL project where a fleet of 4 fuel cell-driven forklifts would be tested in real case applications.

The continuation plan, however, would provide further detailed information on the total number and the size of forklifts that could be replaced by fuel cell-driven forklifts. It would also contain a pre-feasibility study and techno-economic analysis of the whole investment and would also incorporate the basic design of a local hydrogen production and filling station.

In that context, fuel cell-based forklifts were pre-evaluated from a techno economical perspective. From a technical point of view, the usage of a PEMFC-based hybrid power source for the forklift power trains were revealed as a feasible and reliable [1] option that had been developed as a final product by several companies.

The economical assessment was done through a financial feasibility methodology, where the NPV and IRR of the comparison between fuel cell forklift fleets and equivalent battery forklift ones were estimated for different scenarios. A scenario represented a hypothetical project defined by giving specific values to some assumptions. The first assessment carried out was defining and analyzing a reference scenario that simulated the FLT-fleet of AB. Thus, this scenario considered the size fleet of 100 vehicles (75% class I and 25% class II & class III) working 3 shifts per day, where hydrogen would be acquired from the market and there was no prior battery-based fleet. This scenario was called "reference" because meant to be the basis of any comparison. In order to evaluate the influence of the assumptions over the financial parameters (NPV and IRR), some other scenarios were defined considering different fleet sizes and hydrogen sources. To analyze the influence of the fleet size, the reference scenario assumptions were taken (hydrogen is purchased from market, there are 3 working shifts per day and no prior battery fleet) and only the fleet size was modified. To have a wider picture, two more scenarios were initially defined using 35 and 150 vehicles respectively. The final plan was to include in the analysis the real demo application scenario in AB (3 class I FC-FLTs and 1 class II FC-FLT) and compare the simulation results with the obtained real data.

The hydrogen source influence was assessed by creating some new scenarios. Again, the reference scenario assumptions were taken, changing only the hydrogen source. Two scenarios were defined considering on-site natural gas reforming and an autonomous PV-based onsite water electrolysis.

The preliminary analysis of all the different scenarios under different assumptions provided an overview of when an investment in a fuel cell forklift fleet was economically interesting. The first results showed that the bigger was the fleet the most profitable (and less risky) the investment was. Regarding the hydrogen source, only the market and onsite natural gas reforming were seen as real options right now, although the usage of water electrolysis with an optimized planning for the electrolyzer seemed an option to be considered if prices for the equipment go down.

Altogether, it could be concluded that fuel cell-based materials handling vehicles were technical and economically viable for intensive users. However, the fleet size and hydrogen source influenced assessments and the sensitivity analysis showed the impossibility of generalizing, making caseby- case strongly recommended before taking the decision of shifting to PEMFC-based materials handling vehicles.

[1] NREL. Fall 2011 Composite data products ARRA material handling equipment [presentation]. Available at: http://www.nrel.gov/hydrogen/cfm/pdfs/fall11_arramhe_cdps.pdf; September 2011.

Task 7.3: Supply Chain Identification

UH collected information on entities active on the FCH scene in Europe (and worldwide). Information relating to suppliers and active parties in the field of FCH, primarily in the EU, was gathered from many sources. The sources of information included other European Projects (such as Autostack), WHEC conference (Canada), F-Cell (Stuttgart), and other networking events attended, as well as information gleaned from the internet. A number of websites had been identified which themselves were a depository for information about relevant companies, research establishments, and other stakeholders. Relevant European projects had been reviewed, and their approach to obtaining information and engaging with the stakeholders scrutinised.

The plan was to collate the gathered information in a database with a short description of the relevant entity, the web address, and location (country & address). This effort had commenced and was on-going. The stakeholder list collated by EHA (WP2) would have also been incorporated.

The next step would have been to devise an online questionnaire and send to entries on the database to ascertain more detailed information regarding their current capability and future prospects. This would have enabled quantitative analysis of the active parties. Subsequently, a selection of the latter group would have been contacted to obtain more in-depth information. This qualitative analysis, combined with the former quantitative information obtained via the online query would have enabled a significant output for the supply change analysis within the EU.

4.1.4 Potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and the exploitation of results

Potential impacts

The overall aim of the SHEL project was to demonstrate the market readiness of the technology and to develop a template for future commercialization of hydrogen powered fuel cell based materials handling vehicles for demanding, high intensity logistics operations.

The consortium briought together a strong cluster of partners from Europe's hydrogen and fuel cell sector with key industrial partners (a major industrial gas company (AP), a Fork Lift truck OEM (Cumitas) and a leading logistic company (CEGA) who on successful completion of the demonstration can move towards full scale commercialisation. The project would directly support the development and testing of a Fuel Cell prototype Fork Lift Truck developed by Cumitas (supported by UNIDO-ICHET) and the development of a low cost modular hydrogen refuelling unit designed to support rapid site certification.

The project was fully compliant with the technical content and scope of the topic 'Demonstration of fuel-cell materials handling vehicles and infrastructure' and aimed to achieving the impacts required by the work programme as detailed below.

- The deployment of 10 FLT across 4 sites in Europe, would give the participant partners in-depth field experience (both technical and operational) to accelerate medium term (3 to 5 years) commercialisation across the EU member states. Each site has been selected to be representative of current identified niche market opportunities:
- This proposed large-scale demonstration of second-generation pre-commercial products would confirm system specifications, lifecycle costs and training needs for product installation and use, and demonstrate public acceptance. The evaluation of a mixture of fuel cell retrofitted and OEM FLTs will demonstrate both of the important routes to market, providing detailed operational information on service intervals and operational match between the technology and user requirements including handling and ease of use, including training requirements.
- The development of a monitoring system for real-time data analysis and a simulation model for detailed analysis of the existing demonstration current duty cycle of forklift trucks and material handling equipment on site would pave the way for future commercial installations by enabling the preparation of full operational protocols for deployment of fuel cell vehicles including CO_2 reduction analysis (comparing existing and FC FLT alternatives); training procedures; safety protocols and real-time data on preventive maintenance.
- The demonstration benchmarks would prove performance versus the call's technical requirements (an expected outcome).
- The proposed development of a low impact hydrogen refuelling system for FLT operations would demonstrate a flexible, low cost refuelling station capable of

delivering low cost hydrogen from multiple sources. The project would provided detailed models for medium to long-term hydrogen integration, specifically: 1) distributed hydrogen distribution model most suitable for short to medium term commercialization; 2) an on-site generation model for hydrogen generation from embedded renewable energy generation) and low cost hydrogen storage. 3) the use of waste hydrogen from petrochemical sites.

- Fostering education and public acceptance were pivotal topics to be addressed in order to achieve a spread of hydrogen applications to the broader public. Sites were selected with high public presence to promote greater public awareness and acceptance.
- One of the barriers to successful commercial introduction of fuel cell powered materials handling systems was the current regulatory environment. The SHEL project would identify and improve the speed of certification from the relevant European Agencies, promoting international standards and developing procedures for certification within the European member states.

However, due to the enforced end of the project, only the following impacts have been reached:

- A certification report detailing methodologies / procedures for simplified hydrogen infrastructure approvals have been developed. This roadmap will permit a successful commercial introduction of FC FLT due to elimination of regulatory barriers.