Interreg
EUROPEAN UNION
North-West Europe
HECTOR Project
European Regional Development Fund

Pre-operation preparations for the deployment of hydrogen fuel cell waste trucks

Practical handbook to prepare for the deployment of hydrogen fuel cell waste trucks.

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1. Introduction

The HECTOR project - Hydrogen Waste Collection Vehicles in North West Europe - is an Interreg North West Europe project which aims to demonstrate that fuel cell waste trucks provide an effective solution to reduce emissions from road transport in the North West Europe area.

The HECTOR project aims to introduce zero-emission technology into operational fleets. It will lay the grounds for upscaling and further deployment of fuel cell waste trucks in these fleets in the near future. Each deployment site will aim to continue the operation of the trucks after the end of the project and to gradually replace conventional fuel trucks by hydrogen fuel cell trucks.

The 7 pilot sites across the north west Europe area are:

- Aberdeen (Scotland),
- Groningen (Netherlands),
- Arnhem (Netherlands),
- Duisburg (Germany),
- Herten (Germany),
- Touraine Vallee de l'Indre (France),
- Brussels (Belgium).

The aim of this document is to act as a frame of reference to help support operators and interested parties to deploy hydrogen refuse trucks into their fleet. This document has been developed using the experience and learning from the project partners and will highlight the most important elements of the pre-operation phase including how to build the business case through to the procurement process.

The overviews, indicative prices and lessons learned mentioned in this document can be used as a starting point for the pre-operation preparations. This is based on the steps taken by our partners in the Interreg North West Europe HECTOR Project. Information and prices in this document are a snapshot of our experiences and no rights can be derived from this.

The HECTOR project involves collating information from all stages of the deployment process. Many of the vehicles within the HECTOR project are first generation therefore it is important to learn from their deployments to improve the performance of future generations. Information is being collected throughout the different stages of the project including procurment & vehicle specification, training and maintenance and real life operations.

We are providing our experience with this document. We will update this document progressively throughout the project to continue to present new best practices and approaches.

Lessons learned from the HECTOR partners during the pre-operation phase include:

- The hydrogen waste truck market is still relatively small therefore there are a limited number of manufacturers to choose from.
- Small market for hydrogen, little competition and small production might drive up prices.
- Small market for hydrogen and little worldwide competition might increase delivery time

Collaborative working

In 2019, three European projects, HECTOR, Revive and Life n Grab Hy, who are all developing and deploying hydrogen powered waste trucks, signed a letter of cooperation to share and collect lessons learned and experiences across each project. The experiences shared have helped inform this handbook.

All three projects aim to show that fuel cell waste trucks offer a low carbon, non-polluting and quieter alternative to conventional diesel trucks.

The HECTOR project is part funded by Interreg North West Europe and aims to demonstrate that fuel cell waste trucks provide an effective solution to reduce emissions from road transport in the North West Europe area. The project will see 7 trucks deployed at pilot sites across 4 European countries. Further information can be found here: https://www.nweurope.eu/projects/project-search/hector-hydrogen-waste-collection-vehicles-in-north-west-europe/

The Revive project is part funded by the fuel cell and hydrogen joint undertaking (FCH JU) and is developing and validating the technology necessary for the operating conditions of refuse trucks. The technology is tested by deploying 15 fuel cell refuse trucks across 8 sites in 3 European countries. Further information can be found here: https://h2revive.eu/

The LIFE 'N Grab HY! Project (which has now been completed) is part funded under the EU-LIFE programme. It addresses the critical issues of fuel cell garbage trucks and tests the vehicles under various operating conditions in 10 different sites across Europe. Further information can be found here: https://www.lifeandgrabhy.eu/

The aim of these projects is to demonstrate that fuel cell waste trucks provide an effective operational solution to reduce emissions from road transport. The projects cooperate on the creation of awareness for fuel cell vehicles in waste collection through the joint organisation of events and the dissemination of project materials and outputs. They share and collect lessons learned and experiences from real life operational conditions to help inform fleet operators, OEMs and policy makers.

2. General overview

When thinking about introducing alternatively fuelled vehicles there are three important questions to consider – the delivery timescale, the cost and the operational capability. This section provides a high-level overview of the cost considerations and timescale for deployment. The operational capacity will be tested during the project lifetime and will be added to this report at a later date.

Table 1: General costs of deploying a fuel cell waste truck. Please note these prices are indicative and will be explained further within the capital and fuel costs section.

Component	Fuel cell truck	Conventional Diesel truck
Capital costs		
Chassis	100.000 euro	100.000 euro
Build-up	200.000 euro	200.000 euro
Conversion	400.000 euro	-
Fuel costs		
For same distance	1 kg = 10 euro	10 l = 10 euro
Maintenance*		
Per year	7.000 – 10.000 euro	10.000 – 20.000 euro
Storage		
Alterations to fleet depot**	50.000 euro	-
Training		
Drivers	1000	1000
Maintenance technicians	3000	3000
Rough estimation price of truck**	**700.000 euro**	**300.000 euro**

* depends highly on extent of the maintenance contract whether outsourcing or in-house maintenance

** this is highly dependent on individual depot conditions and should be assessed by an expert.

***depends highly on services and depot adjustments required.

Table 2: Preparation and deployment phases and associated timescales. Please note this is further explained within the body of the document.

Task or Topic	Timeframe (approx)
Making necessary adaptations to fleet depot	3-6 months
Planning and building a permanent refuelling station (temporary solutions may take less time to implement)	2 years
Average maintenance contract currently offered by manufacturers	2-5 years
Standard lease/rental period for the trucks	5 years
Estimated operational lifespan of truck	10 years

3. Building the Business Case

3.1 Capital costs

The capital cost of a fuel cell waste truck is considerably higher (by approx. 2-3 times) than a conventional diesel truck due to the immaturity of the market at present.

This section provides an estimate of the capital costs for hydrogen waste trucks based on the experience of HECTOR partners. All the waste trucks in this project were newly manufactured and prices quoted are for trucks purchased between 2019 and 2020.

The fuel cell trucks used in the HECTOR project are built using conventional truck chassis, in electric or diesel configuration. This chassis is then converted to a fuel cell truck with a build-up for specialist equipment needed for their tasks for example to collect waste.

The total price of a conventional diesel truck with refuse-collection function ranges from €220.000,- to €300.000,- (depending on the build-up).

The total price of a fuel cell refuse truck is (estimated) between €630.000,- and €751.000,- (excluding VAT).

The price for the fuel cell conversion is estimated between €380.000 and €490.000 (excluding VAT). This price varies depending on a number of factors including experience of the manufacturer/version, engine design/strength, the size and number of tank, the competition between fuel cell manufacturers etc. The price for the diesel combustion engine chassis is between €85.000 and €115.000.

Based on our experiences in the 7 pilot sites, a fuel cell refuse truck is around 3 times as expensive as an equivalent conventional truck. In general, the difference in capital cost between a conventional diesel truck and a fuel cell truck are determined by the additional conversion costs of the truck. In the table below you can find a general overview of the differences in prices. These prices are indicative as the actual costs will depend on various factors.

Table 3: Capital cost comparison

Element	Conventional diesel truck	Fuel cell truck
Chassis	85.000 - 115.000 euro	85.000 - 115.000 euro
Specialist Waste Collection Equipment	200.000 euro (see*)	200.000 euro (see *)
Conversion to fuel cell	-	380.000 - 490.000 euro
Total price	220.000 - 300.000 euro	630.000 - 751.000 euro

* These prices include the addition of specialist waste collection equipment. These costs differ according to the specialist equipment specified. Table 4 provides some examples from the HECTOR project:

Table 4: HECTOR project examples of specialist equipment cost

Specialist Equipment	Estimated Cost (euro)
Crane with adaptor and compaction unit	€205.740
Crane and compacting body	€165.000
Front Loader frame and hydraulically operated compaction unit with scraper elements	€130.000 - 145.000

3.2 Fuel Costs

A fuel cell truck with an electric motor is two to three times more efficient than an internal combustion engine running on diesel.

The fuel cell waste trucks have a storage capacity of 15-20 kg (one tank of 20 kg or 4 x 5 kg) and operate at either 350 bar or 700 bar pressure.

Fuel consumption will vary depending on the operational conditions of the truck. The HECTOR waste collection vehicles expect a range of around 120km, however true operational capabilities will be tested throughout the project.

From the previous experience of the HECTOR partners, most trucks operating in urban areas reach a range of 120 km on a full tank. In rural areas this reaches up to 240 kms.

The price of hydrogen is generally determined by the fuel station operator and is subject to external factors such as the price of electricity, the demand for H_2 in the area, the number of suppliers in the area. In our experience, 1 kilogram of hydrogen fuel will cost between €8 - €10 therefore the prices for hydrogen and diesel are comparable when driving 100kms.
It is worth noting that to derive the maximum environmental benefits and carbon reduction the way in which the hydrogen is produced is important. Green hydrogen is the optimum choice. This is when the electricity used to produce hydrogen comes from a renewable source such as wind, solar or hydro. Often green hydrogen is the ultimate goal however grey or blue sources are often used in the transition period.

Blue hydrogen is when natural gas is split into hydrogen and CO_2 either by Steam Methane Reforming (SMR) or Auto Thermal Reforming (ATR), but the CO_2 is captured and then stored.

Grey hydrogen is a similar process to blue hydrogen – SMR or ATR are used to split natural gas into Hydrogen and CO_2. But the CO_2 is not being captured and is released into the atmosphere.

3.3 Maintenace and parts

To ensure optimal operation of the fuel cell waste truck it is important to use a hydrogen specialist for maintenance..

This could be done by training in-house your own staff or by outsourcing to a specialist company. Based on the experiences in our project, most partners split maintenance between the manufacturer and external specialists. The maintenance costs therefore depend on which option is chosen. Table 5 gives an indication on price.

4. Pre-Operation Considerations

4.1 Refuelling Infrastructure
To successfully deploy any fuel cell vehicle, it is necessary to plan how the vehicle will be fuelled since building a refuelling station can take up to 2 years - from planning to commissioning.

Most of the HECTOR partners will utilise a pre-existing hydrogen refuelling station provided by an external party, but it is possible to build your own refuelling station to gain some control over the price of hydrogen.

If building a new hydrogen station, it is necessary to consider:

- **The daily hydrogen demand** – generally the higher the hydrogen demand the lower the price per kg h_2 to produce. Our experience in the Hector project is that one truck will use one full tank per day (approximately 15-20kg) however this is dependent on multiple factors including route type, volume of waste collected etc.

- **The pressure at which the vehicle will refuel.** The waste trucks within the HECTOR project are mostly specified to refuel at 350 bar pressure however one truck will refuel at 700 bar.

- **That the commissioning of the refuelling station coincides with delivery of the vehicle/s.**

- **The type of contracts for refuelling** and price per kg of H2 for example take or pay arrangements or pay at pump.

4.2 Fleet depot & workshop alterations
In order to safely store and maintain the fuel cell truck, it might be necessary to update your storage depot and/or workshop. As a first step it is recommended that experts are engaged to carry out an assessment of the depot. This assessment should review the risk associated with operating and maintaining hydrogen vehicles within the depot, whilst also evaluate existing maintenance practices in terms of explosion risk. The explosion risk derives from the accumulation of gas in combination with a possible ignition source.

There is currently no dedicated national hydrogen technology regulation or standard available which address hydrogen depots however a variety of European regulations and directives do apply for example ATEX 79/2009.

A list of items that operators may need to consider has been developed and is included as Appendix A, however since every depot is different each partner must check against their own country's regulations and should seek expert advice before carrying out any works.

Within the HECTOR project, most partners already have their own facility to store fuel cell trucks, except for one. In certain cases, adjustments needed to be made to the storage facility to make it suitable for hydrogen trucks. Examples of changes that needed to be undertaken are:

- Creating a dedicated parking space with an electricity charging infrastructure
- Securing safe distances in case of fire from surroundings (not in all countries applicable. Check your national guidelines on this).
- Installing safety signs and signals, fire extinguishers and ventilation flaps in the ceiling
- Installing hydrogen sensors to open gates or ventilation system

The estimated costs of making necessary changes to the storage facility vary considerably within our project, with estimates between €25.000 and €50.000. Naturally, these costs will heavily depend on the amount of adjustments that are needed to make the facility suitable for hydrogen vehicles, which differs per case. The process of executing these adjustments is estimated to take between 3-6 months.

Depot & workshop upgrades recommendations:

- The adjustments should comply with applicable regulations.
- Safe distances should be kept from surroundings.
- Frost protection points should be installed for overnight storage.
- In case of indoor storage: automatic ventilation should be installed.
- The heating system should be compatible with hydrogen.
- Certain specific ignition sources should be avoided.
- For parking hydrogen vehicles outdoors, the above-mentioned safety procedures might not apply (except for the absence of ignition sources). Check your local legislation for more information.

4.3 Training

Most manufacturers offer some form of training on the topic of hydrogen for the drivers and the maintenance technicians however at present this is not formalised and differs per manufacturer.

Within the HECTOR project the level of training has differed per partner. One partner has detailed their training plan below:

- Early intervention by inviting drivers to meet with manufacturer to get to know the vehicles prior to delivery;
- Short introductory training was held followed by more in depth training once the trucks were delivered;
- Instructors from the manufacturer remained onsite at the start of operations and followed the trucks in their own personal vehicles to support training as drivers used the trucks on real routes.

It is advisable to provide additional training on general hydrogen safety and refuelling.

Training Recommendations:

- Clarify what training is provided by the manufacturer and when; It is advisable to do this at the procurement stage.
- Ensure any training that is provided adheres to the latest legislation and is regularly reviewed in line with industry standards.
- Provide drivers with appropriate refuelling training prior to starting operations and also provide refresher training at regular intervals to prevent accidents and/or damage to the refuelling station.
- Ensure training is undertaken by any new member of staff prior to working on, driving or refuelling a fuel cell vehicle, this is especially important if there is a high staff turnover within the organization. It is good practice to use a “train the trainer” model – i.e. having an expert trainer train internal employees to become trainers. These internal employees, now trainers, can then train others within the organisation using what they have learned.

4.4 Route Planning & Testing

It is important to consider the route in which the waste truck will operate on at the procurement stage.

The HECTOR project will test a variety of operational routes from city centre stop start routes to more rural routes with greater distances between each collection point.

Most partners in the HECTOR project will implement a testing period at the start of truck operations, some will also (temporarily) have a diesel truck available for back up. The hydrogen trucks will operate on the same route as conventional diesel trucks. In most cases, the location of the refuelling station is incorporated into the planned route. There may be certain elements in the planned routes that could significantly influence the hydrogen consumption, such as hills, busy roads and traffic lights.

5. Procurement

Fuel cell refuse trucks are still in the demonstration phase. Manufacturers are currently building vehicles on a small scale therefore capital costs remain high. The original aim of the HECTOR project was to jointly procure the waste trucks in order to reduce the capital cost however, due to the differing specializations required by each operator and the small order of the partnership as a whole this was not possible.

Increasing demand is key to reducing the capital cost. This has been demonstrated by the various fuel cell bus projects. For example in Aberdeen, the capital cost of a fuel cell bus reduced by approx 50% over a period of 5 years (2014-2019). This is due to consolidation of orders bringing down capital costs.

In addition, there is a relatively small number of manufacturers currently offering fuel cell waste trucks. Therefore, it was not always possible for our partners to choose from a list of manufacturers. When multiple options were available, partners based their decision on experiences from previous orders, the price-quality ratio, local supply chain and availability of operational support, the fuel pressure and the experiences in the partnership.

Procurement Recommendations:

- Consolidate orders to drive down capital cost. Establishing a joint procurement framework is a way to do this.
- Be clear about the specific data monitoring requirements during the procurement process and ensure it is written into the tender so the supplier is accountable.
- Clarify the level of training the manufacturer will provide, how and when it will be delivered and what topics will be covered.
- Be realistic about delivery timescales. There is not a lot of competition on the H2 manufacturers market. This can influence the price and the delivery time because there are also not many suppliers of parts, which can cause delays. Also, manufacturers are gaining operational experience from earlier deployments and will potentially evolve the truck design to eradicate previous faults which may add to the delivery timescale.

5.2 Type of contract – to lease or buy?

Manufacturers offer various types of contracts ranging from leasing to supply only or supply with maintenance. The contracts within the HECTOR project vary, some partners have a lease agreement, while others have a contract for both supply and maintenance of the vehicle.

It is important to keep in mind that the decision on the type of contract may also depend on the manufacturer: one partner indicated that the manufacturer wished to keep control of the truck and therefore proposed a lease agreement. From the experience in the HECTOR project, the lease agreements were set for 5 years with prices around €6.500 per month for vehicle lease only and approx. € 11.000 per month for vehicle lease and maintenance.

The partners that purchased the vehicle indicate that the expected operational lifespan of the vehicle is estimated to be around 10 years. It is even expected that the electric driven hydrogen engine will enhance the lifespan of the truck. This is due to less wear on the parts due to less mechanical load compared to a conventional diesel truck.

It is also important to consider end of life, particularly if the vehicle is purchased outright, as the second hand market is not sufficiently established at the moment. For most HECTOR partners there is no fixed strategy yet on whether to resell or dispose of the vehicle at the end of its operational life.

Contract Type Recommendations:

- Evaluate the best ownership model for your organisation and ensure the manufacturer is able to deliver this.
- Consider end of life options in advance – a secondhand market may not be established or very limited.

5.3 Manufacturers – Original Equipment Manufacturers (OEMS) and Integrators

To find a suitable provider of the fuel cell truck, there are options to contract with one company who does everything in house or to contract with one company who subcontracts the different elements to separate companies. Table 6 outlines the companies used within the Hector project.

Table 5: Companies used by the HECTOR partners

Contracting Entity	Specialist H2 Integrator	Waste Truck Components & Integration
E-Trucks (will work with any body/chassis manufacturer)	E-Trucks	ESA, the Netherlands HIAB CDK Belgium Autohaus Wietholt HS Fahrzeugbau
Geesinknorba	Holthausen	Geesinknorba
FAUN	FAUN	FAUN
SEMAT	SEMAT	SEMAT

Appendix A:
Checklist for Depot Alterations for Fuel Cell Vehicles

There is currently no dedicated national hydrogen technology regulation or standard available which address hydrogen depots however a variety of European regulations and directives do apply for example ATEX 79/2009.

A list of items that operators may need to consider has been developed however since every depot is different each partner must check against their own country's regulations and should seek expert advice before carrying out any works.

Infrastructure & Equipment

The following list is an example of the types of infrastructure and equipment that may need to be considered when retrofitting a depot for hydrogen vehicles. However, the extent of works required will depend on the individual depot, whether maintenance will be carried out there, the number of vehicles and volume of hydrogen.

1. **Hydrogen detection system:** Due to the nature of hydrogen gas (no smell, clear, tasteless and highly flammable) it is important to be able to detect any leaks that may occur. Therefore, it is recommended to install a fixed hydrogen detection system with an alarm throughout the depot and/or workshop.

2. **Hydrogen detectors:** Handheld/portable hydrogen detectors are also recommended for use when carrying out maintenance activities. These can be directed towards the vehicle to detect levels of hydrogen.

3. **Natural air exchange/ Venting:** Air exchange within the depot and/or workshop may need to be improved to ensure build up of hydrogen in the event of a leak is minimized. Some vehicles may require a vent hose pipe to be attached when being maintained to safely guide a possible hydrogen leakage to the outside.

4. **Anti-spark floor/Grounding:** The workshop floor should discharge static charges as per EN 61340-5-1 (Electrostatics. Protection of electronic devices from electrostatic phenomena) and grounding points and respective cables may be required to be connected to the vehicle during maintenance activities. Depends per country if this is necessary.

5. **Protective clothing:** All maintenance staff should be provided with the appropriate clothing to meet health and safety requirements. For hydrogen vehicles the key things would be non-flammable clothing and shoes to discharge static. Depends per country if this is necessary.

Processes (depending on country, might not be relevant to some countries)

1. **Risk assessment:** A risk assessment should be developed and approved which assesses the maintenance activities, considering what could go wrong, and deciding on suitable control measures. These control measures should eliminate, reduce or minimise the risks of loss, damage or injury in the depot.

2. **Danger prevention plan:** Explosion prevention is fundamental and procedures outlining how an explosive atmosphere will be avoided is required.

3. **Emergency response plan:** Should be developed in conjunction with the appropriate emergency services e.g. fire, police, ambulance. This plan should outline the procedures to be undertaken in the event of an incident.

4. **Local Fire Service requirements:** the local Fire service should be informed of the vehicles early in the process and be kept informed throughout the project as they may have their own requirements to satisfy. For example, they may want to know where the nearest water connection is or want to review access to the depot. The local Police service may also want to be kept informed.

5. **Safety procedures addressing the secure management of suspected gas leaks:** procedures outlining how any suspected leaks will be dealt with within the depot are essential and will need to be prepared in advance of the vehicles arriving. It is essential for workers to be trained and fully aware of these procedures.

6. **Allowed standard maintenance & repairs:** A list of what maintenance and repairs can be undertaken within the depot and/or workshop must be prepared and approved by the manufacturer and client.

7. **Signaling and signposting:** It is essential to have appropriate signs within the depot which provide warnings on such things as no smoke, fire or sources of ignition within the depot. Signs showing the procedure for handling of hydrogen and the hydrogen systems would also be recommended.

8. **Hydrogen awareness training:** Awareness training should be developed and provided to all staff to encourage buy in however it is important to provide bespoke safety training to employees working in the maintenance depot and bespoke maintenance and repair training for technicians working directly on the vehicles.

9. **Refuelling strategy:** How and where the vehicles will be refueled with hydrogen should also be considered. Refuelling should not take place within the depot unless in adherence to applicable international and/or local legislation.

Appendix B:
Fuel Cell Waste Truck Specifications

Vehicle type	Main contractor	Chassis	Make & output of fuelcell	Battery & output	Pressure/ no of tanks / kg	Anticipated KMs on full charge
Refuse vehicle municipal waste	Geesinknorba (Holthausen)	Mercedes Econic low entry cab in electric configuration Geesinknorba – supplier of collection body equipment & chassis	Hydrogenics	145 kWh	350 bar 4 x 5 kg tanks Total 20 kg	120 km on H2
Refuse vehicle municipal waste	E-trucks	DAF CF truck GVW 27 ton	1 x 40 kW	136 kWh	15 kg 350 bar	120 km on H2
Refuse vehicle municipal waste as private operator under contract	E-trucks	DAF diesel base HIAB crane VDK Belgium compacting body	Proton Motor 1 x 45 kW	136 kWh	15 kg 350 bar	120 km on H2
Refuse vehicle	FAUN	Daimler	Hydrogenics 3 x 30 kW	85 kWh	350 bar 4 x 4.1 kg tanks Total 16.4 kg	300km
Refuse vehicle	FAUN	Mercedes Econic chassis	1 x 30kW	85 kWh / 112 kWh	700bar	± 200 kms
Refuse vehicle within a small fleet	SEMAT	Mercedes	2 x 30 kW	85 kWh / 112 kWh	700 bar 4x5 kg tanks Total 20 kg	400 kms (only in drive-modus and without

Vehicle type	Main contractor	Chassis	Make & out-put of fuelcell	Battery & output	Pressure/ no of tanks / kg	Anticipated KMs on full charge
Waste in containers/ diesel front loader	E-trucks	DAF Diesel front loader from Autohaus Wietholt, body HS Fahrzeugbau, Hydrogenics fuel cell.	Hydrogenics 1 x 40 kW	136 kWh	350 bar 4 x 5 kg 20 kg	260 kms (only in drive-modus)


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