HYDROGEN FUEL CELL TRUCK

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1. PROJECT GOALS

The objectives of the H2 Truck project are:

- to develop a value-adding utility vehicle with a fully integrated hydrogen fuel cell system that has twice the operating time compared to standard battery electric utility vehicles,
- to develop a refueling station with possibility for fast refueling compared to hours of recharge-time of batteries,
- to put a small fleet of vehicles in pilot test and gather operational experiences,
- to determine if there would be an early market for fuel cell utility trucks,
- to prepare development of H2 Truck version 3 (v3) and rollout of 50-100 demo vehicles in 2008.

The H2 Truck is designed to be used for small-scale transportation purposes, and its flexibility in different configurations makes the H2 Truck ideal for hydrogen demonstration projects where budgets are limited. The demonstration costs of the H2 Truck are a fraction of the demonstration costs of a hydrogen bus or hydrogen car.

The project aims for the production in small batches of 10-15 trucks from the fall of 2006. The trucks will be applied at hospitals, airports and other test locations in Denmark.

2. GENERAL DESCRIPTION OF PROJECT

H2 Truck is a complete hydrogen vehicle concept, including a vehicle and a hydrogen filling station, both CE certified and ready to plug in. It represents Europe's first batch-produced hydrogen vehicle, the first vehicle of its kind to be ready on a commercial market for customers that are interested in demonstrating the new hydrogen technologies.

One of the unique elements of the H2 Truck concept is a safe and low cost hydrogen supply. Hydrogen is stored in a large bulk magazine (a rack with pressurized cylinders) delivered by the local gas company.

In the H2 PowerUnit of the H2 Truck, a fuel cell converts hydrogen into electricity that powers an electric motor. Hydrogen refilling is made simple and safe with the aid of the H2 Canister exchange system specially developed for this project. The vehicle is intended for different internal transportation purposes at hospitals, airports, warehouses etc. It can be custom-made for different transportation applications.

In January 2004 Ringkøbing County granted the funds to develop a hydrogen powered truck. The project partners and the time frame of the project are summarized in Tables 1 and 2.

Table 1: Project partners

Partner	Responsibility
H2 Logic	Fuel cell system developer, project leader
AF Truck	Manufacturer of utility trucks
Greencity Denmark	Non-profit organization
Ringkøbing county	County government
Aarhus county	County government
Municipality of Herning	Local government

Table 2: Project time frame

January 2004	Start of project
April 2004	Demonstration of H2 Version 1 (v1)
November 2004	Concept of H2 Version 2 (v2) completed
September 2005	Presentation of prototype Version 2
February 2006	Delivery of 6 vehicles to customers
January 2007	Evaluation of v2 and startup of H2 Truck v3
February 2007	Official end of demonstration of H2 Truck v2
January 2008	Expected start of 50-100 vehicles production

H2 Logic was chosen to supply the fuel cell system and AF Truck (A. Flensborg, Herning Maskinfabrik A/S) to supply the truck. The first truck was successfully demonstrated in April 2004. Based on the field experience from the H2 Truck Version1 and the results of a market analysis, H2 Logic and partners started to develop an improved version of the H2 Truck in November 2004.

The new and much more compact H2 Power Unit developed by H2 Logic is an integration ready unit, consisting of a fuel cell and a metal hydride storage tank. The metal hydride storage provides a high energy density around 1.9 wt%. When the canisters are taken into the calculation, the storage density is 1.25 wt% (corresponding to 0.36 kg H2 in 29 kg cartridge). At the same time metal hydride storage ensures higher safety due to the much lower storage pressure (maximum filling pressure 20 bar and maximum operating pressure 10 bar).

The H2 Truck is to be produced in a larger number and therefore the hydrogen supply must also be provided. H2 Logic developed a dispenser unit where the metal hydride storage tank can be refilled. This unit is one of the few commercial systems in the world to refill metal hydride systems.

After the first demonstration of H2 Truck Version 2 in September 2005, six systems were delivered to customers in February 2006. The locations and the type of applications of these six vehicles are listed in Table 3. The system has undergone a number of field trial tests and the vehicles show excellent test results. After these successful tests, AF Truck and H2 Logic will work to establish a demonstration fleet of 50-100 vehicles for delivery in 2008.

Table 3: Location of the H2 Truck systems delivered in February 2006

Customer	Location	Application
City hospital	Holstebro	Towing tractor of laundry carts
City hospital	Herning	Towing tractor of food carts
City hospital	Skejby (Aarhus)	Towing tractor of various carts
City hospital	Skejby (Aarhus)	Maintenance/utility vehicle
Waste plant	Herning	Maintenance/utility vehicle
Municipality	Herning	City cleaner

3. DESCRIPTION OF COMPONENTS

H2 Truck is more than just yet another hydrogen vehicle. It is a complete hydrogen transportation concept, including[1]

- a hydrogen vehicle (H2 Truck™)
- a hydrogen power generator (H2 PowerUnit™)
- a hydrogen filling station (H2 FillingStation™)

3.1 H2 Truck Version 1

In the first version the truck was built as a hybrid machine, where two smaller batteries and a fuel cell system replaced the normal 135 Ah batteries. A fuel cell and a hydrogen storage tank have been placed in the space previously reserved for the batteries. Hydrogen was stored at 20 MPa (200 bars) pressure in a gas cylinder.

The fuel cell system delivers 1.2 kW net output at a hydrogen consumption of 18 l/min. It charges the batteries and supplies power for an electrical engine. In situations with power peak the batteries supply the peak power. The fuel cell system runs independently from the two installed batteries. It is producing power from hydrogen after an initial 15 sec starting procedure. The fuel cell operation temperature is maximum 70 °C.

3.2 H2 Truck Version 2

The main components of the system H2 Truck Version 2 are shown in Figure 1.

3.2.1 The hydrogen vehicle

The development of the hydrogen vehicle in v2 was based on the initial requirements shown in Table 4. It is designed for operation on fuel cells only. This makes it possible to take advantage of all the design flexibilities a fuel cell provides and thereby design a completely new truck. The truck manufacturer AF Truck in close co-operation with H2 Logic and external designers again handled the development of this design.

[1]H2 Truck™, H2 PowerUnit™, H2 FillingStation™ and H2 Canister™ are registered trademarks.

Table 4: Technical Specifications of H2 Truck Version 2

Power System	PEM Fuel Cell hybrid system
Fuel Type	99,999% hydrogen
Exhaust	Water
Operating time	4 hours continuously, 12-16 hours normal operation
Tractive power / Load limit	2000kg / 750kg
Max. speed	15 km/h (9.3 mph)
Power	2 kW DC motor
Control System	Microprocessor with LCD touch screen operation of H2 truck & H2 PowerUnit
Dimensions (LxWxH)	205x90x120 cm (790”x 35”x47”)
Weight	450 kg

Basic model with an installed H2 PowerUnit

H2 FillingStation, disperser unit for refueling of H2 Canisters

H2 Canisters, metal hydride storage of hydrogen.

Easy to use Touch screen display and control system

Figure 1: Components of H2 Truck Version 2

An integrated control system surveys the fuel cell system operation, and a touch screen displays the operation status for the driver. The display shows the fuel cell temperature, power, hydrogen pressure and usage. It is possible to program the control of the fuel cell depending on the application environment. Depending on the operation conditions of the vehicle, the fuel cell operation can be optimized with respect to start/stop cycles and hybridization strategy.

3.2.2 The H2 PowerUnit

The H2 PowerUnit is the power-producing unit on the H2 Truck. It is a low noise generator consisting of a metal hydride hydrogen storage system and a PEM fuel cell that converts the hydrogen into electricity. The unit can replace batteries or gas/gasoline combustion engines in non-road vehicles. It produces 24 V_{DC} with 1200 W for the electrical propulsion engine or 230 V_{AC} with 1000 W for delivering mobile power in off-grid applications. The technical specifications of the unit are summarized in Table 5, and pictures are shown in Figure 2.

Hydrogen is stored inside the H2 PowerUnit in two H2 Canisters. With the aid of the H2 Logic "Easy replace and fill system™", the H2 Canisters can be replaced quickly and easily. The H2 PowerUnit is controlled via a LCD touch display on the H2 Truck. Safety has top priority in the H2 PowerUnit, which has two independent safety systems.

The H2 PowerUnit contains a fuel cell hybrid system with fuel cell and small buffer batteries. The hybrid system enables to supply peaks of up to 2 kW power for immediate startup, fast acceleration and driving on slopes.

Table 5: Technical Specifications of the H2 Power Unit

Power Range	0-1.2 kW 24 V_{DC} (peak 2kW), 0-1.0 kW 110/230V 50/60Hz AC outlet (peak 2kW)
Fuel supply	2 H2 Canisters™, ~4Nm^3 H2, weight 14.5 kg per H2 Canister
Operating time	4 hours continuously at 1.2 kW
Safety system	2 separated safety systems, hydrogen sensors, automatic shutdown
Dimensions (LxWxH)	60x55x40 cm (24”x22”x16”)
Weight	90 kg (excluding H2 Canister™)

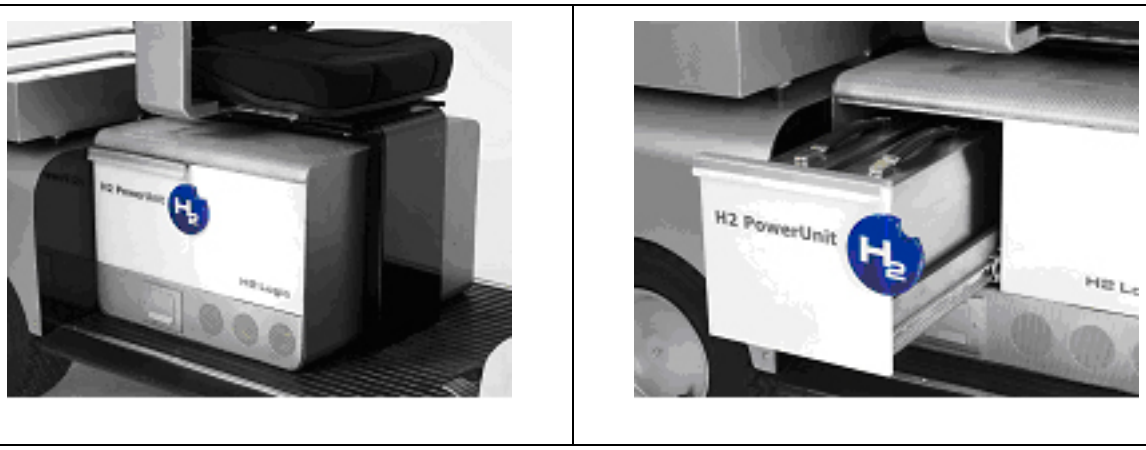

Figure 2: H2 PowerUnit installed on the H2 Truck with H2 Logic easy replace and fill system

While the H2 PowerUnit is installed on the truck in this example, it may also be used in other applications or as a mobile generator since it already delivers 24 V_{DC} and 230 V_{AC}.

3.2.3 The H2 Filling Station

The H2 Filling Station™, a hydrogen filling station to refill the H2 Canisters™ inside the H2 PowerUnit, completes the H2 Truck concept. The station is supplied with hydrogen from a bulk magazine, in order to keep the operation cost at a minimum.

The refill is performed quickly and easily with the H2 Logic "Easy replace and fill system™". The H2 Filling Station™ has a capacity of two H2 Canisters, which are refilled in 30-60 minutes. It can supply hydrogen for 10-15 H2 Trucks operating at normal daily cycles.

The H2 FillingStation must be installed outdoor to ensure optimal ventilation and safety. Its technical specifications are given in Table 6, and pictures in Figure 3.

Table 6: Technical Specifications H2 Filling Station

Net storage rate	Average 65 l H2/min
Inlet pressure	15-200 bar (218-2900 PSIG)
Purity	99,999+%
Refilling time	30-60 min (3800 l in 2 unit H2 canister)
Sitting location	Outdoor level with 230/110 V_{AC} outlet
Dimensions (LxWxH)	80x46x90 cm (32”x19”x35”)
Weight	85 kg (dry weight without H2 canisters™)

Figure 3: H2 FillingStation with bulk magazine of hydrogen and light in LCD control display

3.2.4 Special developments

In the development of the H2 Truck v2 the concept of metal hydride storage was chosen in the interest of long drive time and safe refueling. From the combination of this concept with the wishes for design and user interface, the requirements for the chosen system and components were determined. Standard components were used whenever this was possible, but some components had to be specially developed for the H2 Truck concept.

These special developments described below included:

- Quick couplings
- Manifold and cooling/heating system
- LCD Control and display system

In order to make simple and easy refueling of the H2 Canisters it was necessary to develop special quick couplings with tolerances of 2mm (x, y and z). Also the quick couplings should be made without a release button on the side of the coupling. These quick couplings were developed in cooperation with a supplier.

The exhaust heat from the air-cooled fuel cell is used to heat up the metal hydride canisters in order to ensure a stable desorption of hydrogen. The manifolds are specially designed to fit into the H2 PowerUnit, where the exhaust water from the fuel cell is collected, integrated in the manifold and stored in the H2 Canister.

H2 Logic developed a new control system for the H2 Truck and H2 FillingStation. This system allows the user to display the operation mode of the H2 Truck, hydrogen capacity in the hydrogen storage and all drive information from the H2 Truck if this is required. The system is very comprehensive, but it was a high priority requirement that the user interface and control be made simple, since the end users are not required to know anything about fuel cells.

4. INTEGRATION OF COMPONENTS

4.1 Hybrid system

The H2 Power units include a fuel cell, DC/DC converter and batteries. The batteries are connected to the vehicle drive system, and the power regulation of the fuel cell is made from the DC/DC converter that charges the batteries when the battery voltage reaches a specified level. The fuel cell is sized so that the fuel cell nominal power of 1.2 kW is a little more than the power usage from the H2 Truck when transporting 2000 kg at maximum speed. Two lead acid batteries (12 V/20 Ah) can supply power for the vehicle for 10-15 minutes. The batteries can handle micro-charges. A deep discharge will only cause slight damage to the batteries.

4.2 Control strategy

From end user conversations it was found that fast start-up of the vehicle was a critical point. Therefore the control strategy of the system should make this possible. From when the driver turns the ignition key, the control system makes a system test, and within less than 5 seconds the relay turns on, and the driver uses battery power for the first 30 seconds, before the fuel cells are started up. The fuel cells are then in idle mode, which means that they are either running or ready to supply energy. In this mode the fuel cell system can supply energy instantly (within a few milliseconds). The fuel cells deliver all energy to the drive train and the battery is only used for peaks and brake regeneration. If the vehicle is stopped, but the ignition key is not turned off, the fuel cell will charge the batteries (if necessary) and then go into stand-by mode for 20 minutes before the fuel cell is turned off. In stand-by mode the fuel cell is still kept warm and ready to supply energy right away. This is made to ensure less start/stops of the fuel cell, since this has more degrading effect on the stack than a total shut down.

4.3 Safety considerations

Safety is always a critical point in fuel cell systems, and it should always be addressed with special attention. In the H2 Truck v2 metal hydrides are used for hydrogen storage, since the maximum pressure in the hydrides is 20 bar. Inside the H2 PowerUnits all electronic parts and hydrogen components are kept in two different compartments, sealed of from each other. Valves in the H2 compartment are ex-certified (IECEx International Certification Scheme for hazardeous areas), and H2 detectors are installed in both compartments. If any hydrogen is detected in the electric compartment, the system is immediately shut off and the fan in this compartment is turned on. If hydrogen is detected in the H2 compartment at a low level the user display shows an alarm, but driving can continue. At leakages of 10% or more of the critical level (4% concentration in air) also a sound alarm starts, but the hydrogen supply is shut off. The driver is allowed to drive the vehicle for 60 seconds and then all systems are shut off and cannot be restarted before an H2 Logic technician has come to inspect the system.

If an accident should occur, the system is constructed so that there are weak points, where the side of the H2 PowerUnit will blow off. This will lead a potential explosion away from the driver and avoid injuring the driver. Due to the metal hydride storage, hydrogen leaks would be small even in this case, since the hydrides stop desorption of hydrogen if the flow is to high.

5. PERFORMANCE AND OPERATIONAL EXPERIENCE

5.1 Comparison of performance between H2Truck Versions 1 and 2.

As indicated in the general project description, significant improvements of the system have been achieved between Versions 1 and 2. The Fuel cell is the same in v1 and v2, while the control, hybrid and storage systems have been changed from v1 to v2. A summary of some of the key values representative for the performance in both versions is given in Table 7. It is compared with the expected performance values of the H2 Truck v3, and with the original battery vehicle (lead acid, 135 Ah).

From v1 to v2 the attention was concentrated mainly on extending the storage capacity of the H2 Truck and minimizing the refueling costs. A reduction of 25% in hydrogen price was achieved from v1 to v2 by using large bulks of hydrogen storage for supply of the H2 FillingStation. In the new v3 attention will be focused on developing a new fuel cell module based on a new stack with longer lifetime and higher efficiency.

The drive time was expected to double in the v2 compared to batteries. The experiences show that the use is actually extended to three-to-five times as long. This is mainly due to the fact that batteries almost never were completely discharged after one working day, but the vehicle was still parked for recharge and 1 cycle was used on the battery. The H2 Truck is as standard refueled in an interval of 3-5 working days, depending on the usage pattern.

The attention on the H2 Truck v3 will be price reduction and extending/validating long lifetimes.

Table 7: Performance of H2 Truck (all numbers at 1200W nominal power)

Parameter		Unit	H2 Truck v1	H2 Truck v2	H2 Truck v3	Battery vehicle
Efficiency	Stack	%	46	46	55	n/a
	BOP	W	300	300	<130	n/a
	Power unit	%	35-40	35-40	46-50	
Hydrogen consumption		W	1200	1200	1200	1200
		Nl/min	18	18	13-15	
Start-up time		sec	30-40	<5	<5	1
Refilling/recharge time		min	10	2	2-5	360-600
Refilling/refueling cost (H2 purchase cost only)		€ Nm^3 kWhe	~25 1	~6 4	<4 4	.5 3
Peak power of fuel cell		W	1200	1200	1500	
Peak power from battery		W	~500	~1000	~1500	3000
Fuel Cell System cost (complete system)		€/kW	~25.000	~21.000	~8-10.000	
Battery system cost		€/kW				~1000
Drive time at 1200 W		hours	1	4	4	2
System lifetime		hours	1500	2500	5000	6-8000

5.2 Operational experience

The H2 Truck is developed as a multipurpose vehicle where different trailers and accessories can be attached. Of the 6 H2 Trucks 4 are used at 3 different hospitals, where they are used to drag wagons with food, laundry etc. One vehicle is used as a maintenance vehicle at a waste plant and finally one vehicle is used as a city cleaner to clean the inner city and pedestrian walks. Some of these applications are shown in Figure 4.

After the delivery of the first 6 H2 Trucks in February 2006 the system has undergone a number of field trial tests and the vehicles show excellent results.

In the H2 Truck v1, hydrogen handling and refueling was a critical point, and due to a strict hydrogen detection policy, the vehicle quite often failed and had to be serviced by a technician. In the v2 the ventilation system was changed which took care of almost all failures. From February to December 2006 we have had 1 break down in the H2 Truck due to driver inexperience, since the driver emptied the hydrogen canisters and ignored the signal to refill. In addition, regenerative braking has caused quite some problems. During this procedure the voltage tended to exceed the critical level and at one point overheated and destroyed the DC/DC converter.

Since August 2006, all six H2 Truck v2 has been used without any trouble or failures. Service is made in 3-month intervals, where all logged drive data are stored. In total 1500 hours of drive

experience are gathered on the H2 Truck v1 and already ~2800 hours on the H2 Truck v2. One vehicle has been driving for more than 700 hours.

The low storage and filling pressure gives users a safe and reliable refueling. This is confirmed by the fact that not a single malfunction of the H2 Canister system has been measured or detected during 7 months of daily operation of 6 vehicles.

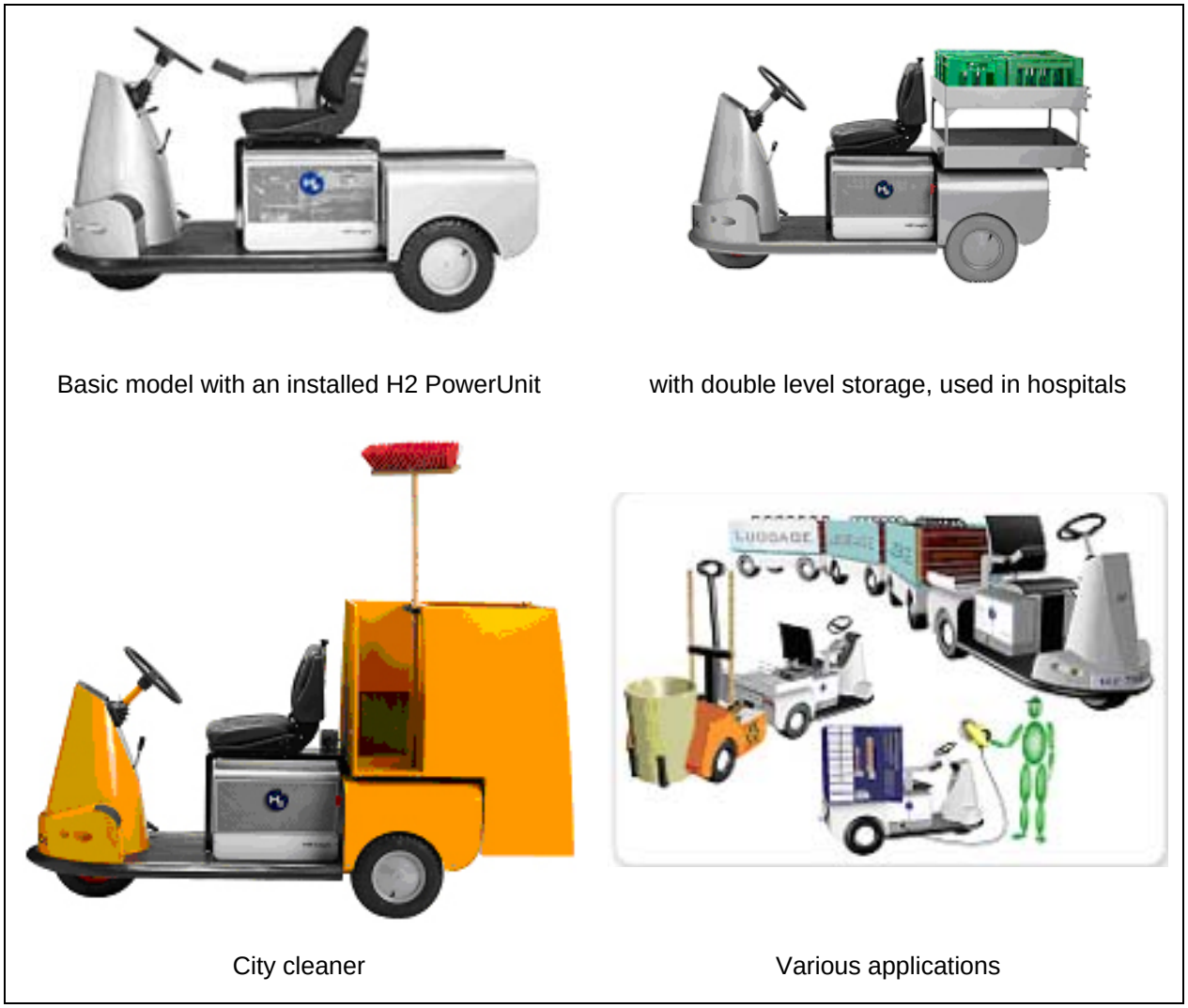

Figure 4: Examples of H2 Truck in operation

5.3 Drivers experience

It is very important to get as many different types of driving experiences as possible. The driving experience on such a vehicle is varying quite a bit from the day the vehicle starts in usage until after a few months. When the users become familiar with the H2 Truck they start to drive it more aggressively. However, the aggressive driving has not had any effect on the vehicles. All six are still in operation. The battery version of the H2 Truck is often used to bump into another vehicle and thereby move other vehicles that stand in the way, and due to this fact the front of the H2 Truck is made of 3 mm thick steel plates. The typical static load on this H2 Truck has doubled

since the first month of the field test. As a consequence, data acquired by usage in less than 3 months do not show the real usage behavior.

In November 2006 a workshop was held for all users/drivers of the 6 H2 Trucks with the aim of gathering and sharing experience. The drivers are especially pleased with the long drive time and the independence for planning long recharge times. Actually all concerns were related to the vehicles rather than to the H2 PowerUnit.

It turned out to be very important that all essential parameters are included in the touch screen display of the integrated control system, and that this system is easy to operate. Therefore each driver was able to compare his H2 Truck experience to other vehicles. This collected total experience is an important ingredient in the planning of the next version.

5.4 Data acquisition and modeling

On all six H2 Trucks in the field tests all data have been logged in a data logging system and afterwards the data have been analyzed in computer models and used to improve the control parameters of the H2 Truck. As an example the power consumption of the H2 Truck and the power output of the H2 PowerUnit is shown in Figure 5. The graph shows usage in a period of 2 minutes from one of the hospital towing tractor units. In the range from 500-1200W the fuel cell can supply all power usage, but at peak points the additional power is supplied from the battery pack. When the H2 Truck brakes, the negative power is regenerated to the battery pack.

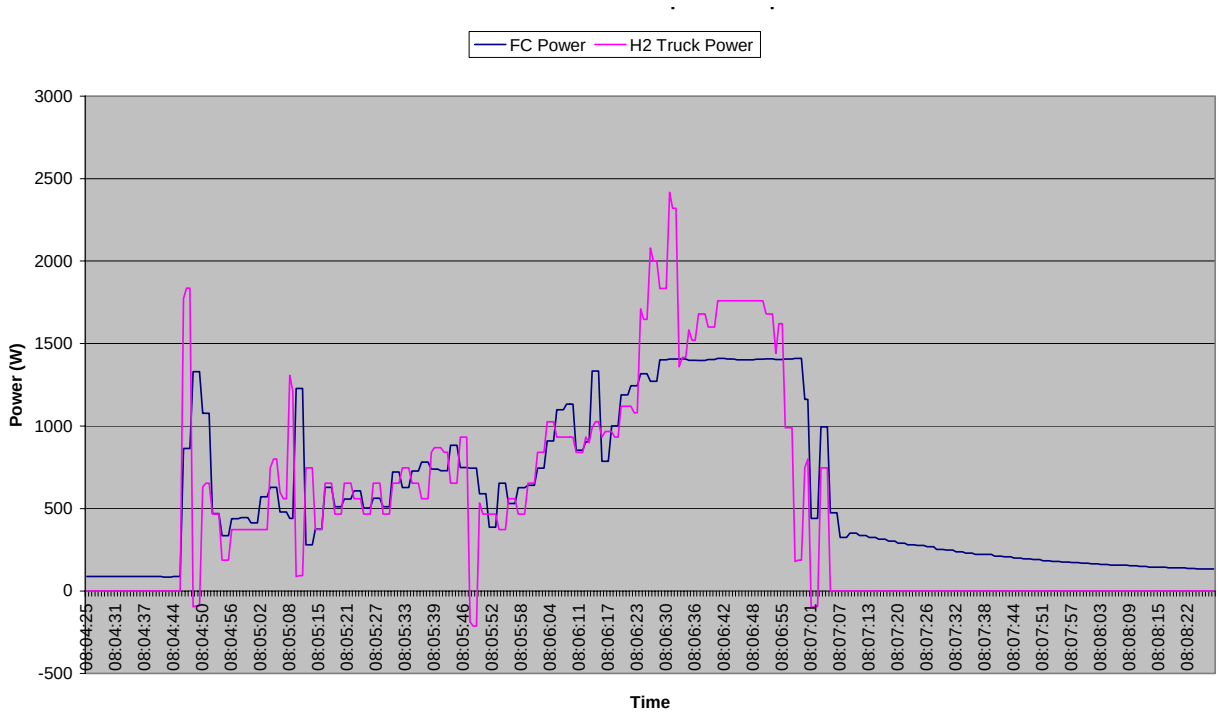

Figure 5: H2 Truck and H2 Power Unit power output

The H2 Truck has proven to have 3-5 times the drive time as standard battery vehicles. This exceeds the expected and calculated drive time of doubling the drive time. This is mainly explained by the fact that batteries in electric vehicles almost never are deeply discharged and therefore not all 135 Ah in the battery vehicle are used.

5.5 Summary

The complete system was used at various sites to give test results for the development of the next version. In parallel with the technical development, a comprehensive market analysis was performed to determine if a vehicle of this type would be suitable for further development towards commercialization. The results showed that small electrical vehicles as the H2 Truck would get additional drive time, which gives end users additional value and eventually makes them willing to pay the additional price in the pre-commercial market.

6. ENVIRONMENTAL ASPECTS AND SAFETY ISSUES

6.1 Environmental aspects

Regarding the environment the H2 Truck gives new usage possibilities in comparison to battery electric vehicles. As an example the City cleaner in Herning replaced a diesel service vehicle, since a hydrogen vehicle could now supply the needed drive time.

The only exhaust of the H2 Truck is pure water. It is not spilled on the floor but stored in the H2 Canisters and afterwards emptied in the H2 FillingStation. At full power the water production amounts to 0.8 l/h.

The Refilling Station uses maximum 150 W under refueling (this does not include active cooling), which makes the refueling at quite high efficiencies. A Danish gas supplier supplies the hydrogen. Electrolysis was considered but the capital cost of investment and lack of OEM modules was the deciding factor to use a bulk magazine of hydrogen.

6.2 Safety issues

Regarding safety the H2 Truck has two comprehensive safety systems to detect hydrogen leakage. If hydrogen is detected in only a small volume, a visual alarm is shown to the user. If the leakage reaches 10% of the critical level a sound alarm will alert the user. When the sound alarms starts all systems are shut down.

Besides hydrogen sensors all electronic and gas components are divided in two compartments, and all electronics in the hydrogen compartment are approved for use in gaseous compartments. Finally if everything else should fail, a weak spot is provided in the construction, so that an explosion will occur on the side away from the driver.

The H2 FillingStation should always be installed outside in a ventilated environment. The H2 Truck can be used both indoors and outdoors.

7. REGULATORY ASPECTS AND LICENSING PROCEDURES

The H2 Truck and H2 FillingStation are CE certified. This job has been extremely comprehensive, and from the start of the project external help has been used to help certify the systems. Due to lack of experience from Danish authorities on hydrogen safety, it took approximately 5 months to get the certificate. As a part of the CE certification an EMC test (electromagnetic compatibility) was made on the H2 Truck and H2 FillingStation, which both passed.

Due to the lack of standards and legislation for high pressure refueling, certification was easier to achieve with the method of refueling by the H2 Canisters used in the present project.

The local Fire Department was consulted regarding the installation of the FillingStation. It turned out to be very convenient that they were invited to hear about the project at an early stage, which allowed them to comment on the concept. Therefore it was easy to get their approval.

No special requirements, as compared with battery vehicles, were imposed by the authorities for using the vehicles indoors.

Standardization of the technical components and of the certification procedure is a subject that needs immediate attention, since this already today puts restraints on products coming out to the market.

All persons that were to use the H2 Truck had a ½ day training course at H2 Logic.

8. PUBLIC ACCEPTANCE

The H2 Truck has drawn great attention in Denmark and abroad, and resulted in a great number of newspaper and TV items about the truck. In 2004 the H2 Truck was also presented in the Fuel Cell Today's "Fuel Cell Market Survey: Niche Transport 2004".

The H2 Truck had been mentioned 15-20 times in national Danish television, ~50 times in local television and more than 100 times in national newspapers and science magazines. The public interest has been huge, due to the fact that this finally is a vehicle where the Danish public can see the hydrogen technologies in practice.

The product design of the H2 Truck has received as much emphasis as the technology. From the start it was clear that H2 Truck should appeal to users as a high-class product. Everyone should know in the matter of seconds that this is no ordinary vehicle but a hydrogen vehicle. The argument for the new design was: “you cannot sell a FIAT with a Ferrari engine, you need vehicle and power train to match each other to give prestige and performance”. It was essential to determine a design line which signals that the hydrogen technology is new, safe and pollution free. To make the message easy to understand, all colors, shapes and materials are held in a tight and simple style. For instance, the outside of the H2 FillingStation is completely white, only the H2 Logic logo and the touch screen have been added.

The H2 Truck moves away from the dull expression that characterizes most battery powered trucks used today. Instead inspiration for the H2 Truck has been found in the car industry. The H2 Truck has a clear face with round lights that symbolizes eyes and evokes associations to sports cars.

9. OTHER EXPERIENCES

Many general experiences have been gathered from the H2 Truck project. The close cooperation between systems integrator and vehicle constructor and the organization of local support on all levels are two of the most important examples:

The close cooperation between H2 Logic and AF Truck is for sure a factor that limits mistakes and limits the risk of failure. The vehicle constructor always has greater experience of how the vehicle is handled and these experiences should be included in the technical specification process of all projects to develop fuel cell systems for niche market vehicles.

Local support from municipalities, counties and industry is critical for this kind of project. One company cannot change the world; cooperation on both political and technical level has also been one of the key success factors of the H2 Truck project.

10. COSTS

The approximate project costs and the sales price for the basic H2 Truck and the filling station are given in Table 8. Various applications can be attached to the H2 Truck, see www.h2truck.dk for more information. Using hydrogen delivered by the local gas company and storing it in a large bulk magazine reduce the annual operation cost to a minimum of 1'200-1'600 EUR (1'500-2'000 USD) per H2 Truck, depending on its usage (calculated on the basis of the same daily usage as a similar battery truck on 6-8 hours/day).

Table 8: Project costs and sales price (at an exchange rate of 1.25USD/EUR)

Approximate project costs	EUR	USD
Development of the H2 Truck and H2 FillingStation	240'000	300'000
Deployment of 6 H2 Trucks and 3 H2 Filling Stations	320'000	400'000
Sales price		
Basic H2 Truck	46'000	57'500
H2 FillingStation	28'750	36'000

11. FUTURE PLANS

Is it expected that Fuel Cell Power Units for materials handling vehicles will be commercial at a price of 3'000 EUR/kW, and that this target should be achieved for production in small quantities in 2009. The H2 Truck and forklift trucks will be the first commercial vehicles, and H2 Logic has now signed with partners to make joint development of PowerUnits for these applications.

H2 Logic is starting 3 demonstration projects in 2007 for small niche transportation vehicles, which is directly related to the H2 Truck project.

The H2 Truck v3 will be a vehicle that can compete with batteries in special applications where long drive time is necessary. These markets/applications are identified and will be included in the next version of the H2 Truck.

Within the next five years the H2 Logic PowerUnits are expected to be a directly competitive alternative to batteries, and mass markets such as materials handling and leisure will be established.

11.1 Hydrogen Link

Hydrogen Link is a national network for research, development and demonstration of hydrogen and fuel cell technologies for transportation with the purpose of advancing a Danish infrastructure of hydrogen filling stations and a widespread use of fuel cell vehicles, beginning with niche transportation and in long term road transportation. Hydrogen Link is structured under the umbrella of the Danish Energy Authority’s Hydrogen & Fuel Cell Platform as the main activity within transportation.

The network approach in Hydrogen Link is based on creating so-called triple helix network constellations where authorities, companies and universities collaborate on solving research, development, demonstration (R/D/D) and market challenges of introducing hydrogen for transport fuel. The R/D activities are carried through in national and international projects with both technological and theoretical content. Pilot testing and demonstration activities and the

connection with companies and grounding of R/D/D activities are happening around selected hydrogen filling station locations, the so-called H2 “HUBs” placed strategically in Denmark. Each H2 HUB is unique in the sense that R/D/D activities focus on various technologies in the “Hydrogen Chain”, depending on the knowledge and industrial competences in the local H2 HUB areas and the local energy infrastructure. At the moment, eight H2 HUB locations have been identified in Jutland and more locations are under identification in both Jutland, Fyn and Zealand with a target of having 10-15 H2 HUBs identified by the year 2010 (see map in Figure 6).

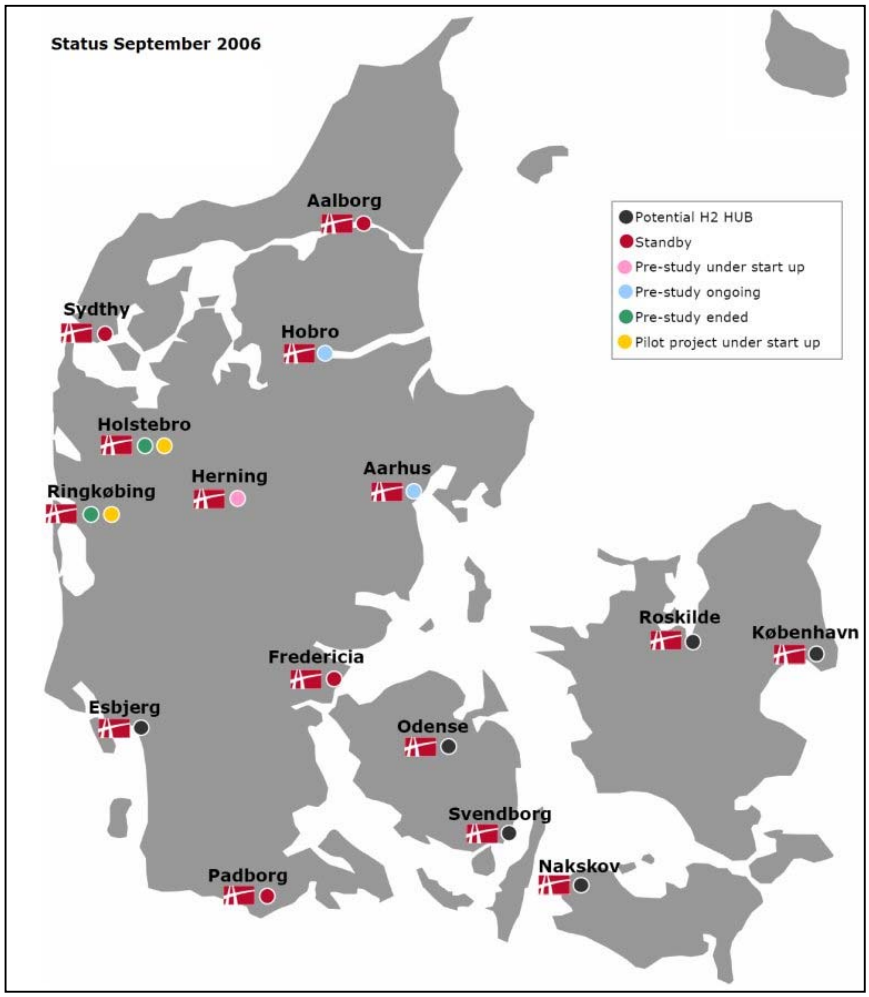

Figure 6: The Hydrogen Link

As national R/D projects are carried out, local pre-studies are done around each H2 HUB in order to plan the subsequent pilot testing and later demonstration projects. Pre-studies are ongoing in four H2 HUBs and the first pilot project is under startup. It is the target to start up 5-10 pilot projects in different H2 HUBs towards year 2010. The knowledge gathered from the pilot projects in the different H2 HUBs are to be pooled together in five large H2 HUB demonstration projects around year 2010, where the filling station size is increased as well as the numbers of hydrogen vehicles around it. Each demonstration H2 HUB is expected to cost $5 million and the total cost on $25 million for all demonstration H2 HUBs is planned to be funded through a combination of European, National, regional, local and company funding. The demonstration projects therefore are to be carried through as part of a large EU Lighthouse Demonstration

(LHP) project in Scandinavia in co-operation with other hydrogen infrastructure networks in Norway and Sweden. This Scandinavian co-operation goes under the name: ”Scandinavian Hydrogen Highway Partnership” (SHHP) and consists of the three national hydrogen infrastructure networks in Norway (HyNor), Sweden (Hyfuture) and Denmark (Hydrogen Link). SHHP it to gather and align the networks in the three countries in a joint Scandinavian application for an EU Lighthouse demonstration project for hydrogen transport around 2010. More information on these projects may be found on www.scandinavianhydrogen.org.

12. CONCLUSIONS

- The proof of concept of the H2 Truck has been successfully completed. Fuel cells can be used for battery replacement in systems for utility vehicles, providing significant improvements in operating life.
- The H2 Truck project has been an eye-opener for Danish governmental institutions that now also focus on system R/D and not only fuel cell R/D.
- A market potential has been determined which the project partners expect to follow up.

13. CONTACT INFORMATION

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