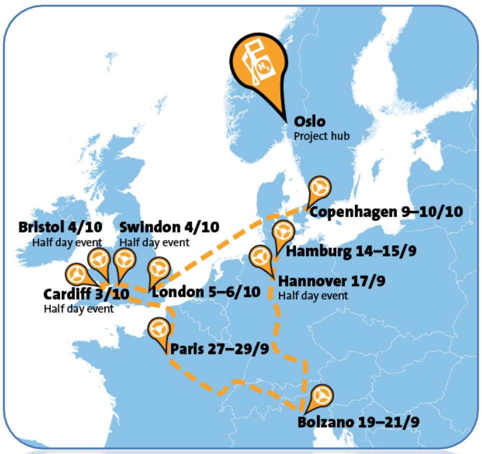

Lighthouse Project for the Demonstration of Hydrogen Fuel Cell Vehicles and Their Refuelling Infrastructure in Scandinavia

Final Report

Status: Draft

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This document is the result of the collaborative work of the H2moves Scandinavia partners. The results of the EU Hydrogen Road Tour were subsequently elaborated and are presented here in a coherent manner, which involved extensive stakeholder involvement.

The findings presented in this document were reviewed by the H2mS project partners to ensure broad general agreement with its principal findings and perspectives. However, while a commendable level of consensus has been achieved, this does not mean that every consulted stakeholder necessarily endorses or agrees with every finding in the document. The producer of this document is the sole responsible for its content and interpretations.

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Executive Summary

The H2moves Scandinavia project has been a unique opportunity to showcase the reliability and hence marked preparedness of hydrogen operated fuel cell cars under daily driving conditions, even in harsher climate conditions pertinent to Oslo and Copenhagen.

In its pioneering role it has suffered from a number of drawbacks specifically as a consequence of the aftermath of the 2008/09 economic crises; several key partners dropped out and others had to be convinced of this outstanding opportunity to participate in showcasing this technology.

Even though it has been the very first of a chain of Lighthouse Demonstration Projects (LHP), funded by the public private partnership Fuel Cell and Hydrogen Joint Undertaking (FCH JU), it has generated several valuable strategic insights which have been summarised in the table below.

Market preparation for Fuel Cell Electric Vehicles (FCEVs)	
1. Hardware demonstration is an essential preparation for commercialization, e.g. in H2mS testing hardware in harsh winter climate ☑	2. Without exception, our customers and passengers are enthusiastic about fuel cell cars ☑
3. Informal and trustful linkage between partners from industry has developed ☑	4. Regional orientation at this stage helps to focus measures (building infrastructure, developing interest in public and politics) ☑

The most outstanding result is that the hardware of fuel cell vehicles and the hydrogen refuelling stations (a stationary one in Oslo – Gaustad and a moveable one for use in the European Road Tour) have proven to be unexpectedly reliable. Except of a compressor failure which downed the Gaustad station for two months availabilities of 95-100% on a monthly basis could be reported and no single accident was encountered.

The other important result of the project has been the wide dissemination of the results, both by high level events, but specifically through the possibility for VIP and public ride&drives. All this has cumulated in the European Hydrogen Road Tour, posed as the major hydrogen and fuel cell event in 2012. During this tour H2mS could not only provide valuable insights into the learnings from everyday driving in the Nordic countries or offer free rides strategic, but also collect valuable feedback.

The echo from the regions visited was overwhelmingly positive and relevant people announced they would investigate into supporting the hydrogen infrastructure build up or start own demonstration activities. A firework of single events has made the EU Road Tour become a real success, among others by participation in the EcoDolomite electric vehicle race in Bolzano, a visit with own booth at the Paris Motor Show and of London's livingroom, the London's Mayor office, signing of an Memorandum of Understanding by the Nordic countries with several international automobile companies in Copenhagen to name but a few.

Also locally in the Nordic countries, the vehicle customers have used their FCEVs for promotional purposes, such as SINTEF for a Ride&Drive event in Trondheim in combination with an inner city rally (Daimler B-Class F-CELL), as ZERO for a trip to Monte Carlo of about 2,200 km refuelling at hydrogen stations along the route (Hyundai iX35 FCEV) or as H2 Logic as emission free support vehicle for the Denmark leg of the Giro d'Italia bicycle race. It goes without saying that all events had a very good media coverage, partially also at international level.

Another aspect which is typically forgotten in this context, but an important ingredient for a successful demonstration project is the building of stakeholder networks. On one side, the project partners have established a trustful cooperation, and here specifically the different approaches by stakeholders from the Nordic countries, from central Europe and from South Korea have contributed to a better understanding of the cultural differences but for the same technical and societal goal of introducing fuel cell vehicle technology.

On the other side, external stakeholders such as the technicians trained in the automotive workshops in Oslo and Copenhagen and certification or safety authorities in both countries got involved and learnt about the market readiness of fuel cell vehicles. As a good example, the rule banning gas fuelled cars from belowground parking garages, which had been established the very same moment when H2mS's demo phase commenced, was repealed after only few weeks of negotiation between the automobile manufacturer and authority.

The consortium is satisfied about the outcome of the project. The hardware lives on in Oslo and Copenhagen outside the framework of the H2mS project, the FCEVs collecting further miles on Norwegian and Danish roads and the refuelling station continuing to serve hydrogen to FCEVs in both growing hydrogen refuelling infrastructure networks. Strategies in both Norway and Denmark and in the other Nordic countries have been developed for a further deployment of the technology. H2mS has contributed an important and visible milestone along these developments.

1 Introduction

The H2moves Scandinavia project is the first European Lighthouse Project for hydrogen, funded by the European Fuel Cells and Hydrogen Joint Undertaking programme, launched by the European Commission and European industry. Main focus of the joint undertaking is to increase the impact of industrial level activities in Europe in this field and to address three major European policy targets:

- Energy diversity
- Mitigation of greenhouse gases
- Increase the share of renewable energies

Major car manufacturers have devoted a significant amount of resources towards developing hydrogen powered Fuel Cell Electric Vehicles (FCEVs) that will be mass produced from 2015. That is why we took cars from four companies – Daimler, Honda, Hyundai and Toyota – along the European Hydrogen Road Tour 2012.

In many of the cities we visited it was the first time the general public had an opportunity to test drive these cars with only water coming out of the exhaust. A fuel cell is a device which can be used to efficiently transform the hydrogen's chemical energy into electricity and heat. Even better, the only emission is pure water. The efficiency of a fuel cell car is twice as high as of a conventional gasoline vehicle, which compensates for loss of energy when producing hydrogen.

FCEVs are on a par with today's cars but emit much less noise and emissions. Provided the energy in the hydrogen production is renewable, the environmental impact is – compared to conventional internal combustion engine cars – near zero.

Our ambition is to prepare the European market for FCEVs so the FCEVs you can see here today, will be seen everywhere tomorrow.

2 Operation of Fuel Cell Vehicles

2.1 Daimler B-Class F-CELL

The Scandinavian market and especially Norway is an interesting pilot-market for electric vehicles with fuel cell for many reasons. Norway has the potential to produce green hydrogen (about 95% of the electricity is based on hydropower). The people are very open for new green technologies, the government is supporting green vehicles by exempting them from purchase tax and VAT, on top giving 90% discount on annual road tax. No toll or municipal parking fees are charged and you have free ferry passage and access to bus/taxi lanes. The cold climate is an additional point of interest to test freeze start capability of the vehicles. Furthermore, it seemed like Norway already had a fairly developed hydrogen infrastructure.

Having those benefits in mind, the decision was made to participate in the H2moves Scandinavia project with the main testing site Oslo, Norway. After the consortium was founded, Statoil, as the main fuelling station operator in Norway, dropped out of the hydrogen business. Later in the process it was discovered that the existing stations do have some problems with quality and reliability. This led to a delay in delivering vehicles to the Oslo market which had, at this point in time, no 700bar Daimler approved station (according to technical information report SAE J2601). One B-Class F-CELL vehicle was already delivered to Oslo at the end of 2010 in order to prepare the market for the vehicles to come. Many station tests were made at Oslo Økern to assure refueling for the coming fleet of ten B-Class F-CELL vehicles. In August 2011, the vehicles were shipped to the General Agent of Mercedes-Benz Bertel O. Steen. In 2011 it became apparent that the hydrogen dispensed at the Oslo Økern station was contaminated with particles.

Within Daimler every station at this point in time (not all stations are in accordance with SAE J2601) has to be accepted by Daimler through a special “recommendation process”. This process started in Oslo Økern at the end of October 2010 and was continued during 2011. The communication vehicle was very useful in this process to support the numerous tests at the Oslo Økern station.

To protect the fuel cell system from the particles, every single vehicle had to be upgraded with a 2 µm filter. Because of delivery problems of the filters, the process of exchanging the filters kept the aftersales department and also the workshop staff busy for months. With the opening of the well-functioning new project fuelling station Oslo Gaustad (H2Logic), the process of delivering vehicles to final customers started in November 2011.

A very high interest in the B-Class F-CELL was shown by the customers. The uncertain refuelling situation (it was not sure if Oslo Økern will stay in operation) led some customers to pull out.

Eight out of ten B-Class F-CELL vehicles went into customer hands. Two of them remained in the hands of Bertel O. Steen to use them for events and testing of fuelling stations. In addition they were used as “Mobility vehicles”, while servicing customer cars.

Customers, such as the research organizations SINTEF and IFE, were found. Also, automotive publishing houses are important customers since they write about the vehicles and inform the public about the technology. The vehicles were regularly operated. During the project phase the ten B-Class F-CELLs accumulated a mileage of 113.000 km.

The technical performance of the vehicles has exceeded the expectations, especially in the cold Norwegian climate. Not a single problem occurred because of the low temperatures. Freeze start capability was proven.

One of the projects aims was to have as many standard Mercedes-Benz processes as possible. The standard logistic process was successfully implemented. The vehicle repair took place in a normal Mercedes-Benz workshop with a fully trained technician. Nearly all repairs were handled on site at the workshop in Oslo.

Several obstacles, such as getting Norwegian license plates even though Daimler Germany was still the formal owner of the vehicles, were overcome.

A great joint achievement within the project was the revision of a statute in regards to parking below surfaces and driving through tunnels. The Fire Brigade officially stated that there are no more restrictions in this regard although it had been established just before the project had commenced.

The customer expectation study showed that the customers are very happy with the vehicles and only little technical challenges in regards to the vehicles are left.

The B-Class F-CELL vehicles will be operated well beyond the project duration.

Lessons learned:

- At least two operational hydrogen refuelling stations per demonstration site are required to guarantee customer satisfaction

- It is recommended to have additional Fuel Cell vehicles at the workshop for displaying to potential customers and as replacement vehicles for customers.
- The F-CELL functioned very well even in the cold climate of Norway, and most people were impressed with the smooth driving and comfort, and felt it was comparable to a conventional car.
- Even if the driving range is quite high, this is one of the major criticisms from the customers about the car - especially as there are quite few refuelling stations at this point in time.
- Although it is a relatively small market, Norway is an important pilot-market, with environmentally friendly people, who are very open for new technologies.

2.2 Hyundai ix35 FCEV

Hyundai Motor Company (HMC) has targeted the European market for demonstrating and deploying fuel cell electric vehicles (FCEV) at an introductory stage of the early FCEV market. Background is that the European countries strongly support sustainable and clean energy provision politically and already has a well developed hydrogen infrastructure. The Scandinavian market, especially Denmark and Norway, is attractive for demonstrating and deploying FCEVs as both countries have the potential to produce hydrogen from renewable electricity and develop a hydrogen infrastructure with strong governmental support, such as by tax exemptions and incentives. Bearing these benefits in mind and targeting the European market led HME to consider a participation in the H2moves Scandinavia project as to demonstrate ix35 FCEVs both in Denmark and Norway.

Hyundai Motor Europe (HME) has already started to participate in the H2moves Scandinavia project by demonstrating and deploying two ix35 FCEV in Herning and Copenhagen as early as by mid May 2011. The two customers of the two ix35 FCEV in Herning and Copenhagen are Hydrogen Link and the Danish Hydrogen and Fuel Cell Partnership, respectively. For the ix35 FCEVs deployed in Denmark a single type approval has been acquired from the Danish Transport Authority (DTA) for operating the FCEVs on public roads across Denmark. In addition to the deployment in Denmark, HME has also provided two ix35 FCEV to Oslo in Norway by mid November 2011. The customers for these ix35 FCEVs are HyNor and ZERO. Also for these ix35 FCEVs a single type approval has been acquired from the Norwegian Public Road Administration (NPRA) for operation on public roads in Norway.

For the maintenance of the four ix35 FCEVs operated for the H2mS project, HME has prepared a main workshop at the Offenbach headquarters in Germany as well as three local workshops in Herning (DK), Copenhagen (DK) and Oslo (NO). In all three local workshops hydrogen safety kits have been installed, including hydrogen detectors, a smart gas gateway and a portable defueling device. The hydrogen safety kit satisfies international hydrogen safety regulations.

In addition to the workshops, one of the FCEV development engineers from Hyundai Motor Corporation's (HMC) R&D center in South Korea has moved to Offenbach on permanent basis responsible for the European maintenance. This dedicated fuel cell engineer has managed and supported the Offenbach and local workshops.

The ix35 FCEVs operated for the H2mS project were equipped with a data monitoring system for collecting vehicle performance data. The data monitoring system was operated manually at an early stage of the project and in August 2012 been updated for automatic operation. All relevant vehicle performance data has automatically been transferred to a main server that monitors and manages the vehicle performance in-situ. The automatic data monitoring system has been developed for a simple handling of vehicle performance data offering the customer with convenient, safe and comfortable driving conditions.

The four H2mS ix35 FCEVs have been developed and manufactured as test-vehicles. As the ix35 FCEV use in H2mS was a pilot case for the European market, a service technician in the local workshop needed to be trained for handling the FCEVs. The FCEV engineer in HME Offenbach in turn has trained the service technicians in the local workshops. In case of serious malfunctions the local service technician could not repair her-/himself, the Offenbach based FCEV engineer supported the trained local technician by telephone. In cases when the FCEV engineer could not help the trained technician by telephone, the Offenbach based FCEV engineer needed to "fly to the workshop", i.e. dubbed the "flying doctor" concept. In case, the vehicle could not be repaired at the local workshop, the vehicle was planned be towed to the central HME workshop in Offenbach. However, this fortunately has never happened in the course of H2mS. In case where a "high level" upgrade plan or higher technical support were needed, engineers from HMC in South Korea need to visit the local workshops for further support.

The two ix35 FCEVs operated in Norway have been driven all the way from Oslo to Monaco without carrying an extra hydrogen tank on board. The total mileage of the trip was approximately 2,200 km for each vehicle. The drivers from Zero only used the existing hydrogen refuelling station during the journey, and each of them by manual operation. The reason was that the refuelling interface between the vehicle and station (nozzle) was standardized but the communication between the vehicle and station were not.

HME has also participated in the EU Hydrogen Road Tour organized by Hydrogen Sweden and LBST jointly with other automotive OEMs: Daimler, Toyota and Honda. During the tour, all partners have visited 5 countries and 9 cities in a period lasting about one month. During the city visits, all partners participated in VIP and public seminars and ride & drive events to promote the technical superiority of the FCEV technology and improve public awareness. In addition to visiting the cities, the partners have also participated in the Paris Motor Show, alongside a prominent Hyundai presentation of the FCEV at their own booth.

The official project duration of the H2mS project is three years. As HME has only entered the project partnership in mid 2011, HME will extend the operation of the four ix35 FCEV in Denmark and Norway until the end of 2013.

From the H2mS project, HME has taken home several strategic learnings for the future of operating FCEVs in Europe. First above all is the need to develop a tighter fuelling station network for customer satisfaction. More hydrogen refueling stations should be built to connect the major cities.

The second issue is that no serious performance difference has been encountered between the operation experience between (northern) Europe and South Korea, especially bearing degradation also in harsher and fluctuating climate in mind. The ix35 FCEVs now have spent two winters in Denmark and Norway. During winter time, no serious performance degradation could be observed and sub-zero start up problem have not occurred.

The third issue is that FCEV technology is still not well understood by the public. To overcome this weakness, it is therefore necessary to promote FCEV technology and improve public awareness.

Finally, HME found that it took less maintenance costs for the four ix35 FCEV compared to what had been initially planned. The overall availability of FCEVs during the project is approximately 98% even considering that some of the components needed to be delivered from Korea. This means that fewer malfunctions have occurred during the project. In conclusion, not much maintenance cost was necessary for the fuel cell vehicle.

2.3 BEV with fuel cell range extender

To supplement the "pure" FCEV's from Daimler and Hyundai the H2MOVES project also featured the demonstration of five standard TH!NK Battery Electric Vehicles (BEV) that have been retrofitted with a fuel cell system and hydrogen storage for range extension. The addition of the fuel cell helped increase the range from ~110 km by an additional 140 km, giving a total range of 250 km. Also excess heat from the fuel cell system was utilized for cabin heating which helped reduce range impact in cold weather.

Extensive results and lessons learned have been achieved during the entire process from manufacturing and homologation of the vehicles and during the operation.

The manufacturing and homologation benefitted from past efforts conducted in Denmark on a similar vehicle set-up. The five TH!NK vehicles were therefore already put in operation in May 2011 and have been operated until tzhe end of the project in December 2012.

The operation was however affected by the bankruptcy of the TH!NK company in June 2011, which made the provision of spare parts and servicing more challenging.

Further the base BEV platform proved not to have the same quality as conventional vehicles which also affected the operation. The five vehicles in total have clocked 28,014 km with an uptime of 91% on average. Approximately 2/3 of the kilometres were driven on battery, and 1/3 with fuel cell range extension.

The operation experience combined with further performance and price analyses however have shown that fuel cell plug-in hybrid vehicles or range extension may be a challenging concept. As the fuel cell has to be dimensioned to provide the peak power at high speed operation, the fuel cell cost will be similar to that of an FCEV. The only difference is the additional cost for the larger plug-in battery, which may be difficult to recover through savings in fuel cost when operating in battery mode.

3 Operation of Hydrogen Refuelling Stations

3.1 Stationary Refuelling Station Oslo – Gaustad from H2 Logic

As part of the project efforts H2 Logic constructed a large scale hydrogen refuelling station (HRS) in Oslo providing hydrogen for the FCEVs in the project. The effort provided extensive results and lessons learned across the entire process from site selection, HRS design and manufacturing to the final installation and operation.

An extensive site screening of more than 30 sites in Oslo was firstly conducted to identify the most optimal location for the HRS. A suitable site was identified at the research organisation SINTEF in Gaustad in the western part of Oslo. The location was strategically well located with regards to the other HRS's in the city ensuring good refuelling coverage in Oslo.

The HRS was manufactured, installed and operated by H2 Logic based on the company's H2Station® technology. The HRS provides 70 MPa refuelling in accordance with the SAE J2601, and operation results have confirmed refuelling times consistently below four minutes for a full tank. The HRS includes onsite electrolysis production providing a 20 kg/day base load supply, with potentially additional trucking-in of hydrogen up to a total capacity of 200 kg/day.

The installation of the HRS took 10 days in total, from arrival at site, until the first refuelling was conducted. This included local inspection by third parties and authorities as well as several days of hydrogen production and compression to reach the necessary refuelling pressure. Before opening a refuelling recommendation process was successfully conducted by Daimler. The HRS opened on 21st November 2011 and is now in daily operation. Besides the FCH JU the HRS is also co-funded by the Norwegian Transnova and the Danish EUDP program.

3.2 Moveable Refuelling Station from H2 Logic

To provide refuelling during the European hydrogen vehicle demonstration tour H2 Logic developed and operated a Moveable hydrogen refuelling station (HRS).

All the HRS equipment necessary for the refuelling is integrated into a compact station module allowing for easy transport and installation. The HRS is based on the H2Station® technology from H2 Logic and offers 70 MPa refuelling in accordance with the SAE J2601 and can provide up to 50 kg/day with back-to-back refuelling (2x4 kg).

In total the moveable HRS has been transported and installed at six different locations in four countries. During the H2mS European Road Tour the moveable refueller has been used at the Hannover and Copenhagen locations.

The many locations proved the feasibility of the moveable concept. Installation time of down to only two days was achieved from arrival of the HRS to the first refuelling.

The HRS worked flawless during the Road Tour with an uptime of 100% and conducting of several back-to-back refuellings.

3.3 Improvement Options for Future Hydrogen Infrastructure

3.3.1 Securing H_2 fuel gas quality at lower cost

There are very strict requirements on the purity of hydrogen fuel in fuel cell vehicles: in fact, the relevant technical standard SAE J2719 prescribes levels of purity so high they approach the current state of the art in quantitative measurement of impurities in hydrogen.

Certifying that a hydrogen sample from a HRS is compliant with this specification is therefore a complex, tedious and expensive endeavour, involving several cutting-edge measurement techniques.

SINTEF has tested the hydrogen quality of three HRSs in the Greater Oslo area, which provide hydrogen from different sources. The tests were performed both in-house, developing a long-path FTIR detector (see Figure 1), and for validation samples were sent to the only company in the world currently providing SAE J2719 certifications: Smart Chemistry Inc., of Sacramento, California.

Figure 1: SINTEF's long-path (35 m) Fourier- Transform InfraRed (FTIR) gas cell, developed in H2moves Scandinavia.

Whereas Smart Chemistry's approach is to use a full gamut of measurement techniques, SINTEF aimed at developing a simplified, cheaper and faster analytical protocol, which would make use of information on how the hydrogen is produced. This requires identifying *canary constituents*, i.e. compounds that are easily measured and can give a sufficiently precise estimate about other compounds that may be more difficult to quantify.

As for the actual hydrogen purity in the HRSs of the Greater Oslo area, each HRS failed the specification on at least one constituent; however, the violated parameters were related to inert gases (nitrogen and argon) and in one case to carbon dioxide; no catalyst poisons were detected above their prescribed levels.

3.3.2 Optimization of HRS operation with respect to electricity cost

Production of hydrogen by water electrolysis is of special interest in Norway, which has historically had access to cheap, renewable electricity. SINTEF studied the electricity prices in Norway, the Northern Countries and Germany, and calculated which dimensioning criteria are most appropriate for the different cases. In particular, electricity prices in Germany are much more variable than in Norway: this makes it economically sound to acquire a larger electrolyser that can satisfy the hydrogen demand by running only at night, when electricity prices are lower, for the German electricity market; in Norway, it is more advantageous to run a minimally sized electrolyser continuously.

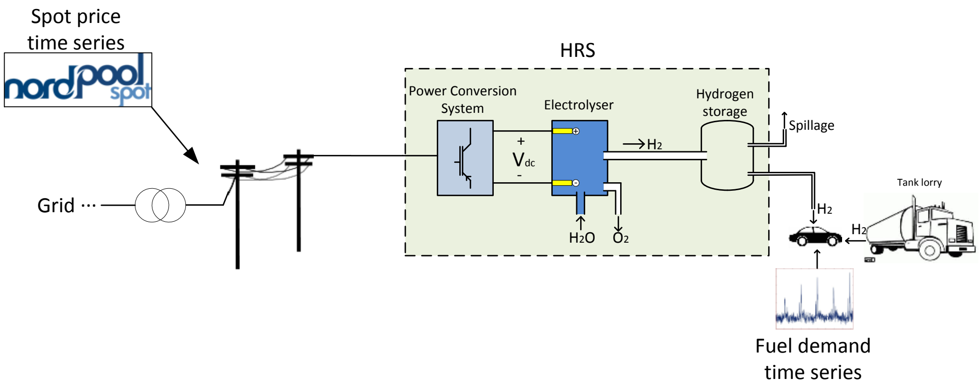


Figure 2: Integration of an HRS in the power grid.

The dimensioning of HRSs was investigated also with respect to the randomness of the demand: drivers do not necessarily refuel when their hydrogen tank is empty, but may decide to refuel a half-full tank before a planned long trip, or simply because they are driving by the refuelling station that particular day. Other vehicles, such as city buses, have a much more predictable refuelling pattern.

Several fleets of vehicles were simulated, and the results were used to determine how HRS should be dimensioned. In particular, it seems beneficial to dimension the electrolyser to be a bit (about 50%) oversized compared to its average production requirement, but not as much as to cover peak loads: it is economically sound to occasionally truck in hydrogen, even if it is much more expensive than producing it. The presence of buses in the fleet tends to require a more oversized system.

Finally, the possibility of using electrolysis-based HRSs as grid balancing units was investigated. The study identified immediate opportunities for frequency grid support (when there is too little or too much energy being produced compared to consumption), which may be expanded into fault support: in case of a major grid fault, HRSs can stop their hydrogen production immediately, thereby preventing a "domino effect". Voltage support (i.e. bringing voltage and current back in phase in the grid) is also possible, but requires retrofitting HRSs for this purpose.

3.3.3 Interaction between customers and HRSs in the Greater Oslo area

An issue among early adopters of hydrogen-fuelled FCEVs is the limited number of HRSs. Drivers of such vehicles need to know where HRSs are, and whether they are operational before they decide to drive there to refuel. HRSs are more complex and require more maintenance than charging stations for battery electric vehicles (BEVs), so it is reasonable that there will be relatively few HRSs in the foreseeable future; also, since FCEVs have a much wider range than BEVs, drivers would need to memorise where HRSs are in a much larger area.

The recent diffusion of smartphones equipped with GPS and internet connection allows solving this problem by storing information about HRSs in a central database, and then distributing it to users. Apps were developed for Android and iOS (iPhone), and are freely available from their respective App Stores under the keyword "H2where"; the apps offer the user a list of the nearest HRSs in operation, and can launch the GPS navigator to drive to an HRS selected by the user. The same information is available via the Web (h2where.info) and via SMS (only in Norway).

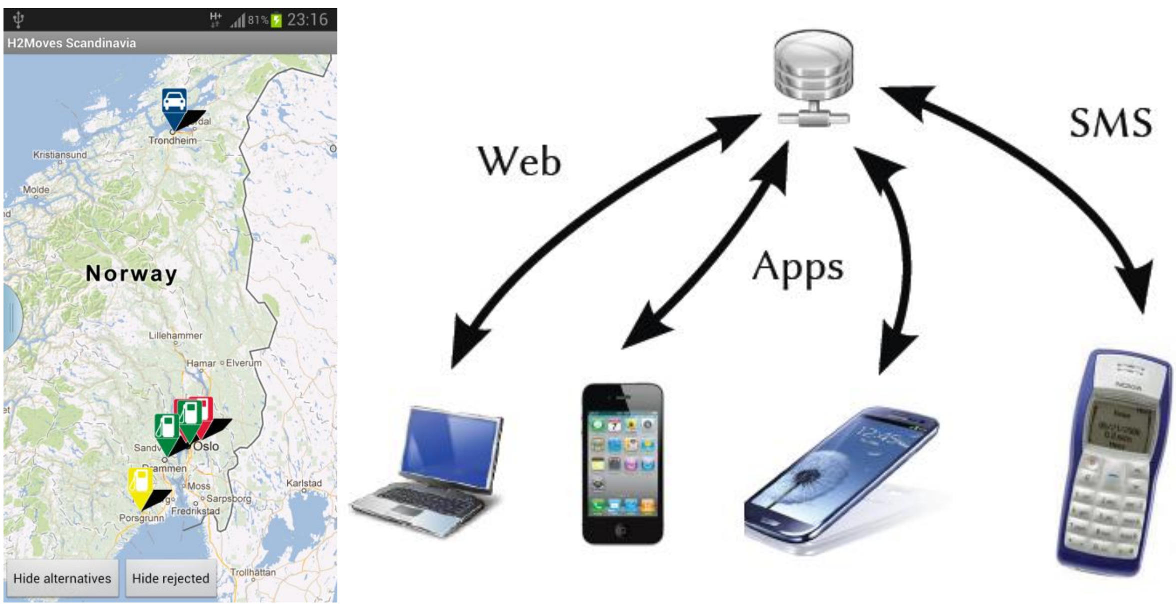


Figure 3: Screenshot of the Android application, and the information distribution model.

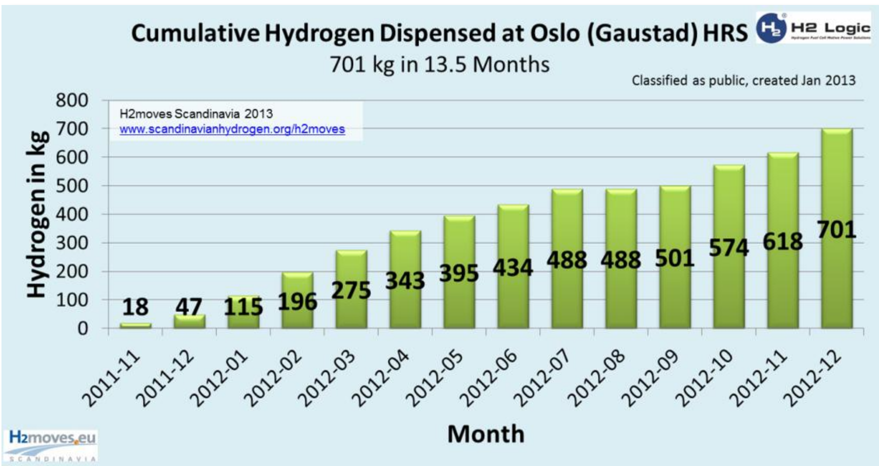
The system is currently limited to the five HRSs in the Greater Oslo area, but can easily be extended to cover any number of HRSs. An account system is implemented to allow HRS operators to edit information about their stations via the website.

The website and the smartphone app can also store user preferences such as the required hydrogen pressure (currently 700 or 350 bar), the maximum range to consider, the maximum price to pay for hydrogen fuel and the production method for hydrogen (electrolysis, reforming or industrial by-product).

4 Hardware Performance

The hydrogen refuelling station was officially opened on 21st November 2011 in Oslo, Gaustad. Since that day, data has been recorded by all FCEVs and the HRS. Each time a car refuelled – no matter at which station – this "event" was logged: date, time, refuelling amount and mileage was written on a vehicle internal memory. As there are four HRS in and around Oslo (named after the quarter they are built in: Gaustad, Økern, Drammen and Lillestrøm), the H2mS vehicles refuelled at many different stations. Also, two of the Hyundai FCEVs were located in Denmark and therefore of course did not refuel at Gaustad. Each time a FCEV refuelled at the H2moves Scandinavia Gaustad HRS, this refuelling event was logged by the station including date, time and refuelling amount.

In total, the 19 cars drove 213,641 km and the station dispensed 701 kg. For driving 100 km, a little more than 1 kg of hydrogen is needed.

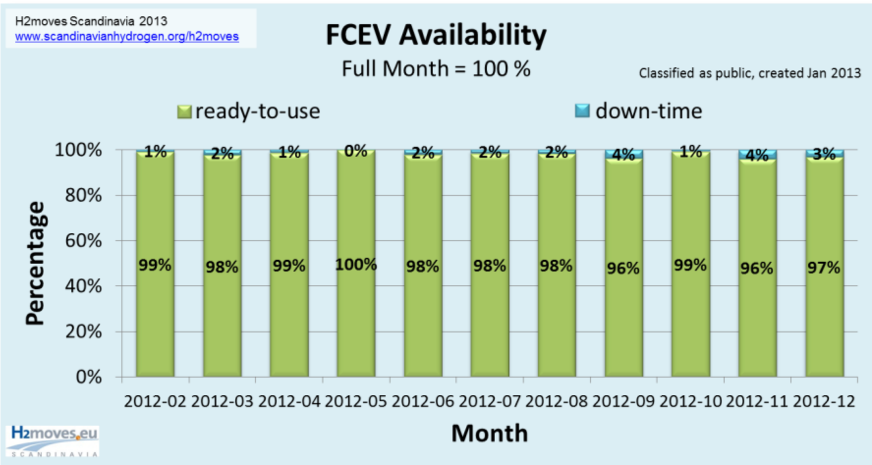


All in all, the performance of FCEVs and HRS in Oslo and Denmark has been so safe and reliable that a designated troubleshooting team to help the local stakeholders in case of any emergencies locally never had to travel to Oslo or Copenhagen.

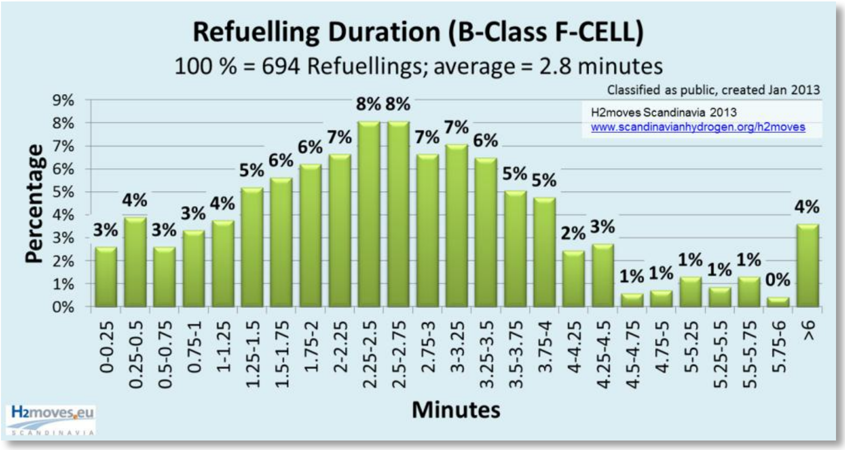
4.1 Fuel Cell Electric Vehicles

H2moves Scandinavia is a demonstration project with the aim to further improve the hardware and to demonstrate its performance. As part of this, the down-times of all hardware were recorded. Each time a car was in the workshop or could not be used by the customer for whichever reason on whichever day and time, this was logged. The graph “FCEV Availability” underneath shows the results.

The overall availability for all 19 FCEVs for the last 11 months of the project was 98%. This value exceeds all expectations, especially as these down-times include waiting times for delivery of spare parts. As it is known by now, which parts need to be in stock, repair times are expected to decrease further.



Latest HRS technology fulfils the SAE J2601 standard. Gaustad station does comply with this standard, it does fulfil the A-level which means that the hydrogen is pre-cooled to -40° C in order to allow fast filling. Also the other stations in Oslo can refuel FCEVs in shortest time as the next graph shows:

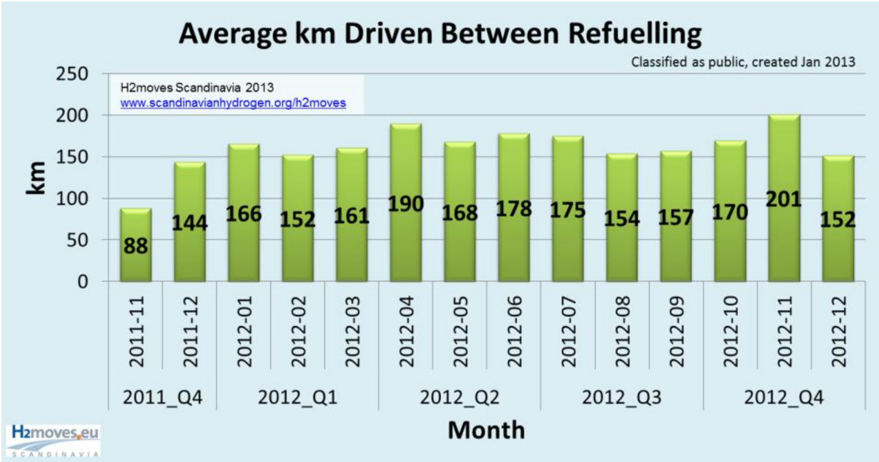


This data was taken from Daimler-Benz' B-Class F-CELL and shows the histogram over the filling duration of all 694 fillings recorded throughout the project duration. On average, fully refuelling took 2.8 minutes. This is representative for all FCEVs and HRS with latest technology. This average of 2.8 minutes is specifically spectacular when considering that only a few years ago, refuelling a hydrogen car easily took half an hour.

The NEDC (New European Driving Cycle) range of Daimler and Hyundai are 380 km and 525 km. As the data shows, these distances can be reached on single fillings. Nevertheless, people do refuel significantly more often. In the first month of operation, the FCEVs were refuelled on average after only 88 km of driving. This effect which is called range anxiety is a major issue for electric cars of all kinds. There are several reasons why the drivers only use a fraction of the full available range:

- drivers are not experienced with the cars (trustworthiness of displayed "remaining range", trust in technical reliability etc.),
- drivers do not know which factors decrease the cars' range to what extent (radiator / air conditioning, cold weather etc.) and
- clearly there is less hydrogen refuelling infrastructure than for conventional cars, resulting in refuelling each time driving past a HRS.

Throughout the duration of H2moves Scandinavia, a significant increase in km driven between refuelling can be detected. In the first month, the FCEVs refuelled on average after as few as 88 km. The highest value throughout the project was measured in November 2011 with an average of 201 km between refuelling. This is still significantly less than the NEDC values, but also does show a major improvement compared to the first months.



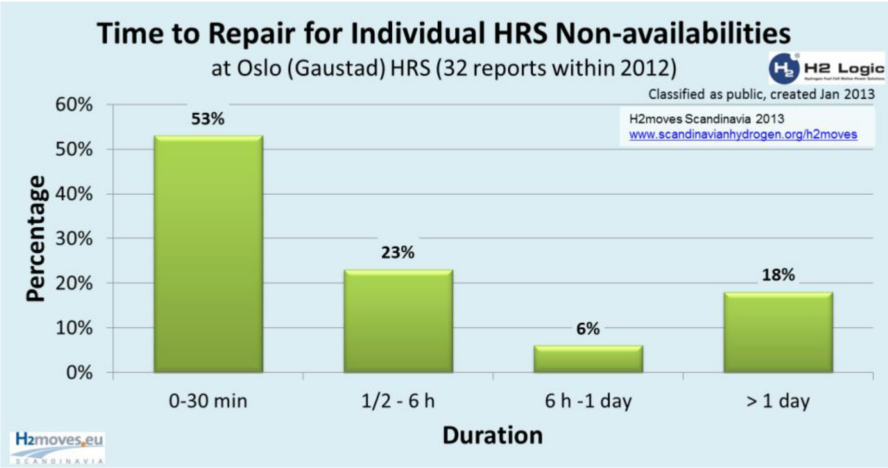
The following table compares results from H2moves Scandinavia with the largest European FCEV demonstration project (CEP) and the largest FCEV demonstration project worldwide (NREL). Most of the data is in the same range for all three projects:

	H2mS (Norway, Denmark)	CEP (Germany)	NREL (USA)
Start of operational phase	2011	2005	2005
Total number of HRS incl. moveable refuellers	2	11 (+2)	25
Total number of FCEVs since project begin	19	139	183
Km driven per FCEV per 12 months	9,995 km	2012: 5,568 km	-
Average tank capacity	3.52 kg Without Th!nk: 4.24 kg	2012: 3.98 kg	-
Average refuelling amount	2.0 kg	2012: 1,96 kg	2.13 kg[A] 2.64 kg[B]
Percentage refuelled of average tank capacity	45% (without Th!nk)	2012: 49 %	-
Median on-road distance between refuellings	166 km	-	158 km[B]
Percentage of fills between 6 AM and 6 PM	83 %	-	88 %[B]
Percentage of fills between 7 AM and 10 PM	94 %	-	-
Percentage of fills on weekends	13 %	-	6.5 %[B]

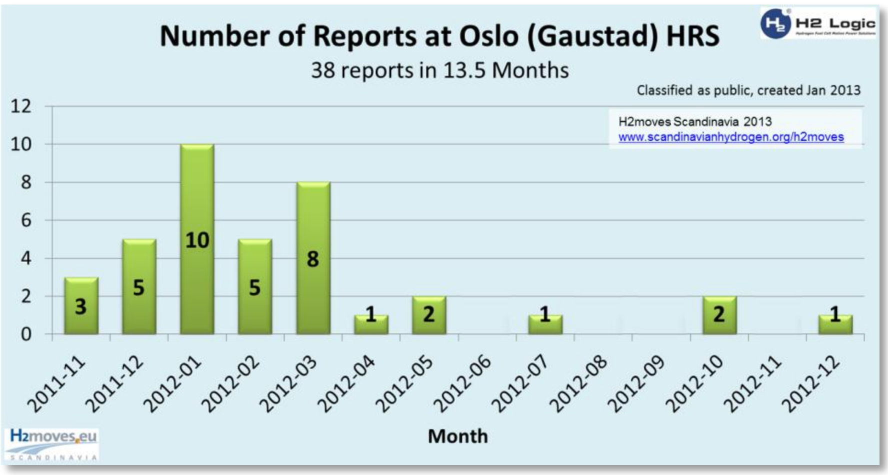
[A]: Through 2009 Q4, [B]: After 2009 Q4; Sources: NREL final report July 2012, CEP 01/2013

4.2 Hydrogen Refueling Stations

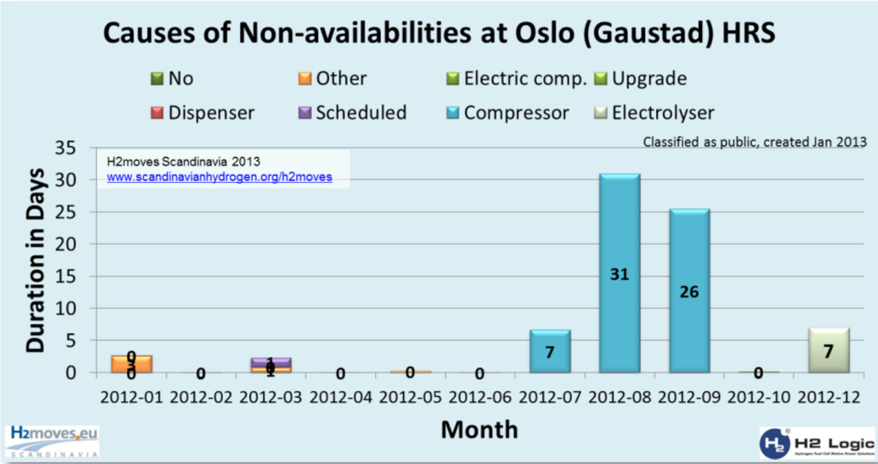
Refuelling Station Gaustad



As shown in the introduction of this chapter, 701 kg hydrogen were dispensed at Gaustad throughout the project duration. The station had an excellent availability throughout the first six months in 2012: 97.1 %. Unfortunately there was a problem with the compressor from a sub-supplier in July causing a down-time of two months. Overall, the repair times – except for major problems – was very short: 53 % of all necessary repairs and updates were finished within 30 minutes. 82 % of all incidents were fixed within one day.



The learning curve can be seen from the evolution of the number of reports, there were several reports per month in the first few months. This dropped significantly after March 2012, when there was either no report at all or a major component was malfunctioning.



5 Approval of Hydrogen Stations and Fuel Cell Cars in Scandinavia

SP Technical Research Institute of Sweden has investigated certification and approval procedures in Sweden, Norway and Denmark for hydrogen fuelling stations and hydrogen fuel cell electric cars. Legislative actors and provisions to regulate certification and approval procedures in Scandinavia have been identified. Emphasis has been on hydrogen fuelling stations being an important prerequisite for a successful market introduction of fuel cell electric cars.

Based on a number of case studies, possible obstacles for the commercialisation have been identified and recommendations are given to facilitate the commercialisation in Sweden, Norway and Denmark.

Harmonized EU provisions related to requirements and conformity procedures for hydrogen fuelling stations are not as well developed as hydrogen fuel cell electric cars. A number of different EU provisions and national provisions apply for hydrogen stations and parts thereof. The national provisions fall under the responsibility of different national authorities and the EU Directives are implemented in different ways in the actual Scandinavian countries. This together with procedures which are not harmonized by EU provisions, contributes to a non-transparent and complex situation for the establishment of an hydrogen station infrastructure.

For example, in Sweden and Denmark the operators need to apply for permit at the local authorities to handle and operate with flammable gas (hydrogen). The amount of gas which requires a permit varies between Sweden and Denmark. In Norway a permit is not required at all (however registration and providing certain information is required).

Recommendations for hydrogen fuelling stations

To facilitate the commercialisation of fuel cell cars in Scandinavia, a number of measures are recommended concerning hydrogen stations, including the following related to safety aspects:

- Guidelines should be developed by the Scandinavian stakeholders
- Support to the authorities for alignment of provisions in Scandinavia

- Include all Nordic countries in dedicated fora for the purpose, managed by the Nordic Council
- The EU Commission should consider provisions for 3rd party verification of fuelling protocols for hydrogen stations
- Operators should establish an early dialogue with permitting/approval authorities and an early involvement of professional local partners to facilitate achieving required approvals

On a European level, the EU Commission should support the establishment of a harmonized European standard for hydrogen stations, based on draft international standard ISO 20100. The stakeholders should consider a strong focus and involvement in the development of the international standard ISO 20100 for hydrogen fuelling stations, to ensure that appropriate requirements are included related to especially safety distances, risk assessment, fuelling protocols (according to SAE TIR J2601) and related test methods.

For the hydrogen quality, it is recommended to ensure an extreme care of cleanliness of all hydrogen carrying spaces (interior of pipes, tanks, hoses, connections etc.) and to locate particulate filters close to the delivery point (nozzle). The quality should be in accordance with ISO/TS 14687-2 and subject to regular analysis.

For metering accuracy on hydrogen fuelling stations, MID Directive 2004/22/EC (Annex MI-002) should be updated to apply for gas meters and volume conversion devices for hydrogen fuelling stations. OIML R139 should be amended with normative requirements (now stated as informative) for metering pressurized hydrogen.

The hydrogen quality and metering aspects should be adequately considered in the recommended European standard above for hydrogen stations (based on draft international standard ISO 20100) as well.

Note: After the study was completed in 2012, the European Commission has issued a proposal for a Directive on the deployment of alternative fuels infrastructure (COM(2013) 18 final – 2013/0012 (COD)), which includes also hydrogen fuelling station infrastructure.

Recommendations for fuel cell electric cars

Well harmonized requirements are currently in force in Sweden, Norway and Denmark based on the same European Regulations (EC No 79/2009 and No. 406/2010, used together with the Framework Directive 2007/46/EC for approval of road vehicles).

Easily available information for applicants, on the home pages of the national authorities for approval and registration, are recommended. To facilitate the approval and registration of cars, car manufacturers should seek detailed information from –

and dialogue with - the approval and registration authorities at an early stage. The owner of a car should be a company/person registered in the actual country.

National authorities responsible for rescue operations should make the car manufacturer's guidelines for rescue operations easily available for rescue personnel (first responders) through the internet. Such authorities should also ensure that rescue personnel receive education and guidelines concerning hydrogen and fuel cell electric cars.

6 Safety and Emergency Plan for Hydrogen Refuelling Stations


H2moves.eu SCANDINAVIA

Project in the 1st call of the European FCH JU

H2moves.eu SCANDINAVIA

Safety and Emergency Plan

Lighthouse Project for the Demonstration of Hydrogen Fuel Cell Vehicles and Refuelling Infrastructure in Scandinavia

Collaborative Project

Topic: SP1-JTI-FCH.1.1: Demonstration of hydrogen fuelled road vehicles and refuelling infrastructure

DELIVERABLE D2.5

06.12.2012

Classification: PU

Partners: Ludwig-Bölkow-Systemtechnik (coordinator), Daimler, Hyundai, H2 Logic, Hydrogen Link Denmark Association, Hydrogen Sweden, TÜV SÜD Industrie Service, SP Technical Research Institute of Sweden

Scandinavian Hydrogen Highway Partnership

TÜV SÜD has worked out a Safety and Emergency Plan, which can be used independently from the location of the filling station.

The aim of this Safety and Emergency Plan was to develop standard procedures which take into account alert mechanisms in case of a failure of technical components or systems. This plan could be adapted for both, the operation of stationary hydrogen refuelling stations, as e.g. the Oslo station of the H2movesScandinavia project, and for transportable or moveable hydrogen refuelling stations, as for example the one used for the European Hydrogen Road Tour.

It will be required to exchange on safety related issues with other European (or international) hydrogen and fuel cell demonstration projects to share insights and views. The plan has to be updated to reflect the learning and experiences gained during the demonstration phase of hydrogen vehicles and refuelling stations.

In future projects this emergency plan can be used as a practical and standard handbook for laying out similar hydrogen refuelling stations.

Recommended procedure to customise the Safety and Emergency Plan for a specific hydrogen refuelling station:

The Safety and Emergency Plan has to be developed by the operator of the refueling station. It shall be worked out in interaction with the manufacturer and the local authorities. The plan shall be updated frequently to reflect the learning and experiences gained during operation.

The Safety and Emergency Plan shall elaborate on the following topics:

- Details of the refuelling station
- Definition of emergency response teams and equipment
- Alarm procedures
- Warnings
- Emergency response
- Interfaces with external functions (fire department, local police, etc.)
- Procedures for information of the competent authorities

7 Communication and Dissemination Concept

The communication activities for the H2mS project can be simply split in two parts; the preparation and definition of processes and routines as well as the communication activities based on these.

Part of the preparation was the definition of communication tools, the central messages to be used guiding all communication and the decision on the responsibilities in the team. A communications and dissemination centre has been established with a group of 5 internal and 2 further external PR specialists, each one with a specific responsibility and role. An important part of this setup was a sound financial budget control as the available funding did not cover all partner costs. Separate funds were thus acquired to put in place the activities. Another important part was the facilitation of internal communication among the H2mS consortium in a chain of project meetings.

The planning was initiated by developing a communication and dissemination plan, establish the website (attached to H2moves Europe in the early project phase and later integrated into the Scandinavian Hydrogen Highway partnership (SHHP) own website at www.scandinavianhydrogen.org/h2moves. Decisions were taken which media should be addressed and with which core messages. The key slogan then became “fuel cell vehicles – here today – everywhere tomorrow”.

Also, communication channels such as a facebook location, a QR coding, a YouTube section for own videos, specifically from the EU Road Tour, and a flickr account were established, the later one to present relevant photos from events and the Road Tour.

The press was given much attention, the project own workbench extended by the PR channels of the project partners, FCH JU and HyER. Press releases and press kits were developed for the major events, such as the project launch in Oslo in 2011 or the public ride&drive in Oslo and Trondheim. Also, individual partners used their events, such as the Oslo-Monte Carlo tour, to communicate our success publically. Press conferences were scheduled, many interviews broadcasted on TV or radio within Scandinavia and beyond. Also the Clean Energy Partnership (CEP) project helped by providing a professional video and report about H2mS’s activities.

Much time was spent to carry out the major project events, such as the inauguration of the fuelling station in Oslo, the public ride&drives, the participation in regional, European or international conferences and the relevant documentation as well as a medium term and final project conference.

Local activities within Scandinavia such as a FCEV drivers club and local networking with relevant hydrogen and fuel cell strategy groups such as HyNor, SHHP, INE from Iceland, the Danish Hydrogen Association or Zero, as well as with the European regions within HyER have contributed to disseminate the success of the H2mS project widely.

Concluding, it should be pointed out that (a) given the challenging low funding rate the partnership has achieved a high quality of its communication/dissemination duties, but that (b) in future projects, this type of activity should be understood as necessary basic service to the demonstration core of the project, hence be funded by a rate of 100% of the total budget, to achieve the highest professional quality.

8 The European Hydrogen Road Tour

The European Hydrogen Road Tour has become the major international hydrogen and fuel cell event in the year 2012 with high regional and industrial involvement across Europe. Considered to be a number of up to five individual events in a number of European regions, it was later decided to organise the tour in one big event, based on the assumption of lowering the total costs and increasing the impact and public visibility at the same time.

A number of key lessons can be taken home from this four week event, which to our information, have contributed to provoke much regional interest in the commercial readiness of this technology and tell the story of the better E-Mobility:

- Even though Germany had a central role in the deployment strategy until now, Scandinavia is a preferred region not only because the vehicle sales taxation provide a cutting edge in early market financing, but also due to its strategic political commitment and ample renewable energy potential.
- In order to avoid the hen and egg dilemma of “cars or infrastructure first” the hydrogen infrastructure roll out needs to be coordinated with the one for the fuel cell vehicles. In the short term, three risks have to be overcome: an initial investment risk, a market risk and the first mover disadvantage. Initiatives such as H2 Mobility have shown that public private partnerships are a suitable instrument to address these risks with examples in the UK, France, Denmark and in Norway.
- Continuity of industry’s engagement and of political support is the most important ingredient to establish a solid regional commercialization strategy for fuel cell vehicles and hydrogen infrastructure. Another one is value creation in the relevant region in at least one element along the hydrogen and fuel cell vehicle supply chain. Another important aspect of value creation was seen in its shifting focus to avoid large scale fossil energy imports in the future.
- Further regions with specific industrial and political support were found to belong to the fast followers offering the relevant framework to participate in the early transition-phase of fuel cell vehicle and hydrogen refuelling infrastructure roll out,

such as the UK and northern Italy. To get further regions involved, demonstration projects will remain a key ingredient of commercialization also in the coming years, but can only be successful if followed by industrial implementation plans.

- Some key conditions to become eligible as demonstration regions were identified:
  - Existence of approval/admission/certification procedures/regulations,
  - Preparedness of the city/municipality to take up FCEVs in significant numbers (the first ‘commercial’ fuel cell electric vehicles are posed to arrive by 2015+ and need to find customers in the ten thousands) and
  - Visible trend of re-urbanisation region/municipality.

  Also, it would accelerate market introduction, if the financing sector would engage in the commercialisation of fuel cell vehicles and hydrogen infrastructure.
- Major ambitions in favour of fuel cell cars are fuel diversification, introduction of renewable energy into the transport sector and universality of fuel cell cars. In the future, also economic synergies for a wider use of hydrogen beyond that one of a transport fuel, i.e. for large scale electricity storage and for industry use, need to be explored further. Another option is the use of decentral energy storage for load levelling and powering cars and homes.
- Fuel cell electric vehicles need to be understood as the ‘better electric mobility’ without range anxiety and long recharging times. They can offer politics the much appreciated solution of non-inner city based e-mobility (additional comfort with reduced noise) at lower long-term infrastructure costs. Yet, its needs to be explained to the public that FCEVs are beneficial to the environment but will also be attractively priced for the markets.
- Concerning public perception it was felt that the fuel cell car market needs to be opened not only by rational arguments, but also by building on emotions, much like in today’s vehicle sales (“let’s not do FC technology ‘to’ them, but let’s do it ‘with and for’ them”). Even though vehicles and infrastructure are probably safer than gasoline vehicles safety needs to be addressed in the public. Most fuel cell vehicle test drivers forgot about it once they had experienced to drive one themselves.
- Using the example of electric vehicles using Oslo bus lanes or specifically designated parking lots at zero costs demonstrates how non-monetary incentives can be an important ingredient to kick-start electric vehicle cars sales. Yet, saturation is to be expected and then the vehicles should have been accepted and need to be competitively priced.

9 Project Coordination and Administration

The coordination of the H2moves Scandinavia demonstration tasks has turned out to be a challenging task in the beginning but a rewarding task in the one year demonstration phase.

The major challenge was that several key project partners have asked for their dismissal (an infrastructure provider, an automobile company, a certification expert and a power company), mainly caused by the aftermath of the 2008/2009 economic crises. All three earlier stakeholders had to be substituted as they had contributed a major part of the essential tasks which posed a major and unbudgeted administrative effort by the project coordination.

One of these cases, the substitution of one automobile partner dropping out by Hyundai Motor Europe (HME), eventually turned out to become one of the projects major assets. Not only could four instead of two fuel cell vehicles of latest design be demonstrated, two of which were now also demonstrated in Copenhagen, also several new aspects could be incorporated into the project. Even though the barrier to include Hyundai Motor Europe as partner had initially been high, as the fuel cell and system technology had been developed in Asia, the mutual learning from planning the demonstration part in real life, the EU Road Tour and the communication activities was intense. The two automobile partners harmonised well and the team was keen to support and learn from each other.

The extra administrative efforts by the coordinator were balanced out by the smooth demonstration phase, which required virtually no effort for local troubleshooting in Oslo or Copenhagen.

Also, the funding support by relevant national organisations in Norway (Transnova) and Denmark (EUDP) have helped significantly to reduce some of the financial burden on the small and medium enterprise project partners, i.e. the ones providing the fuelling station or project administrative services. This added value of national co-funding did not only improve the project’s economy, it actually fulfilled the original strategy of the European Commission for burden sharing the hydrogen and fuel cell development efforts between politics (EU, member states, regions) and industry and has intensified the stakeholder relations across Europe.

When the project turned into its smoother operation phase also the cooperation with the European funding agency Fuel Cell and Hydrogen Joint Undertaking (FCH JU) improved significantly, and the H2mS project has managed to establish close working relations to involve FCH JU in the PR activities e.g. during the Road Tour or the final project events.

10 Literature and Links

The following links provide relevant information on the project and some of its major activities:

- Project website: www.scandinavianhydrogen.org/h2moves
- http://www.h2euro.org/latest-news/events/let-hydrogen-move-you-2
- http://www.h2euro.org/latest-news/eha-in-action-home/did-hydrogen-move-you-june-21-2012-presentations
- http://eusew.eu/upload/events/3790_7213_eusew_let%20hydrogen%20move%20you_program_final.pdf
- http://www.h2euro.org/wp-content/uploads/2012/06/EUSEW2012_Let-Hydrogen_H2MovesScandinavia_210612.pdf
- http://www.flickr.com/photos/h2moves_scandinavia/sets/72157630299097244/
- http://www.flickr.com/photos/h2moves_scandinavia/sets/72157630297016336/
- http://www.youtube.com/watch?v=h4_SufOKwVU
- http://www.scandinavianhydrogen.org/h2moves/news/exhibition-in-the-eu-parliament
- http://www.fch-ju.eu/news/eu-sustainable-energy-week-events-fch-ju-exhibition-european-parliament-and-energy-day-fuel-cel
- http://www.h2euro.org/latest-news/eha-in-action-home/fuel-cell-and-battery-vehicles-in-eusew-clean-mob-kick-off-brussels-summer