



## FCEVs — Fuel Cell Electric Vehicles

19 FCEVs, 1 hydrogen station, 5 months:

Results and facts from the EU-Lighthouse project “H2moves Scandinavia“

September 2012

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# FCEVs and H2moves Scandinavia

## What are FCEVs?

Have you heard about FCEVs?

FCEV stands for **Fuel Cell Electric Vehicle**. These cars drive purely electrical, the fuel is gaseous hydrogen. It is only necessary to refuel once every 400-500 km, and it only takes four minutes to do so! The only emissions are droplets of pure water.

Have you driven a FCEV yet? It is the only way to get an accurate impression of the fascinating “silent car” with instantly available torque. Though they are still quite rare, you will soon be able to buy one of your own, as they will be available at dealers beginning in 2015.



## What is „H2moves Scandinavia“?

It is a demonstration project funded by the Fuel Cells and Hydrogen Joint Undertaking to accelerate the market introduction of FCEVs. The aim of the project is to demonstrate the readiness of these cars and the refuelling stations they require. From current daily operations, we collect real world data and publish the results to answer questions such as: How far do the cars drive? How reliable are they?

What H2moves Scandinavia did so far:

- ◆ We run a public hydrogen station in Oslo (Gaustad) / Norway
- ◆ We operate 19 FCEVs in Oslo/Norway, and Denmark
- ◆ We organise public events, such as a road tour through Europe in Autumn 2012 featuring public test drives

What can you expect from FCEVs? Find out yourself on the following pages and online at [www.scandinavianhydrogen.org/h2moves](http://www.scandinavianhydrogen.org/h2moves)

## FCEVs—Fuel Cell Electric Vehicles

### The sound of silence

The three types of cars that are part of the H2mS project look the same as their “regular” counterparts, but you will notice the difference as soon as you start their silent engines: These cars drive purely on electricity powered by hydrogen!



#### Hyundai ix35 FCEV: 4 Cars

The latest ix35 FCEV boasts levels of convenience and performance similar to those found in vehicles with conventional internal combustion engines. The ix35 FCEV combines the best of both worlds — the safety of an elegant and proven mass-production car with the benefits of hydrogen fuel cell technology — while providing personal mobility with zero compromise and zero emissions.

#### Mercedes-Benz B-Class F-CELL: 10 Cars

The Mercedes-Benz B-Class F-CELL, an electric vehicle with fuel cell offers everything that people expect from a Mercedes-Benz: High comfort and safety as well as no reduction in interior space and boot capacity. Customers will not have to sacrifice any driving pleasure either — the electric motor has a peak performance of 100 kW/136 hp and a maximum torque of 290 Nm, which is available from the first rotation.



#### Th!nk City Car with Fuel Cell Range extender: 5 Cars

The Th!nk — already well-known in Scandinavia — is a two-seater, battery-electric vehicle. The Danish company, H2 Logic, has retrofitted five of these vehicles with hydrogen tanks and fuel cells.

## FCEVs—Technical Data

FCEVs can drive up to 525 km on one refuelling.

	H2moves Scandinavia fleet
Fuel consumption (NEDC)	0.97 – 1.07 kg H <sub>2</sub> / 100 km
Maximum speed	160-170 km/h; Th!nk: 100 km/h
Acceleration 0-100 km/h	11.4 – 14.0 s Th!nk 0-50 km/h: 6.5 s
Tank capacity	3.7-5.6 kg; Th!nk: 1.5 kg
Driving range	250-525 km
Number of B-Class F-CELL	10
Number of ix35 FCEV	4
Number of Th!nk	5

**W**hat is your typical daily driving distance?

**L**et's say you drop your children off at school in the morning before driving to work. In the afternoon you go shopping quickly before picking your children up again. In the evening you meet friends

for dinner. This makes your daily travelling distance about 40 km. So, if your car has a range of about 400 km, you will need to refuel only every 10<sup>th</sup> working day or every second week. And this refuelling only takes three minutes.

Here is one of the Hyundai ix35 FCEVs on the highway. The long range of today's FCEVs, and the smooth driving experience make them perfectly suited for longer distance drives.

The labelling on the sides is the only thing that makes them look different from the conventional ix35.



## Cumulative Distance Travelled

In total, our cars drove around the world 1.7 times in 5.5 months.



On November 21<sup>st</sup>, 2011, the official opening ceremony for the H2mS hydrogen station took place, and our 19 cars started their mission — spreading the word about FCEVs, and collecting data. From that day until the end of April 2012, our cars drove more than 70,000 km — a distance greater than the circumference of the earth, which is about 40,000 km.

FCEVs are emission-free — all they leave behind are a few droplets of water. Conventional cars would have emitted 12.5 tons CO<sub>2</sub> (well-to-wheel) while driving these 71,788 km.

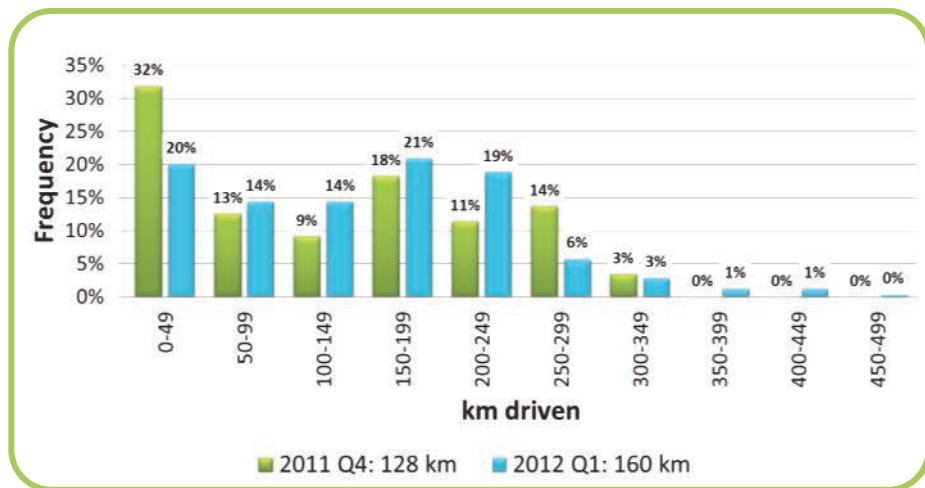
The cars are driven by normal, every-day customers, in company fleets, and for public outreach.



Opening ceremony of the H2mS refuelling station in Oslo in November of 2011, with Fabian Stand (Lord Mayor of Oslo), Jacob Krogsgaard (CEO of H2 Logic) and a Mercedes-Benz B-Class F-CELL refuelling.

## Distance Travelled between Refuellings

The more experienced the driver, the greater the trust in the FCEV.



Our customers refuel significantly more often than necessary. The Mercedes-Benz B-Class F-CELL has a range of 380 km, the Hyundai goes up to 525 km, and the Th!nk has a range of 250 km. Other fuel cell demonstration projects, such as NREL and CEP (see page 12) show similar results for the distance travelled between refuellings. The reason for this is known as “range anxiety”. As the hydro-

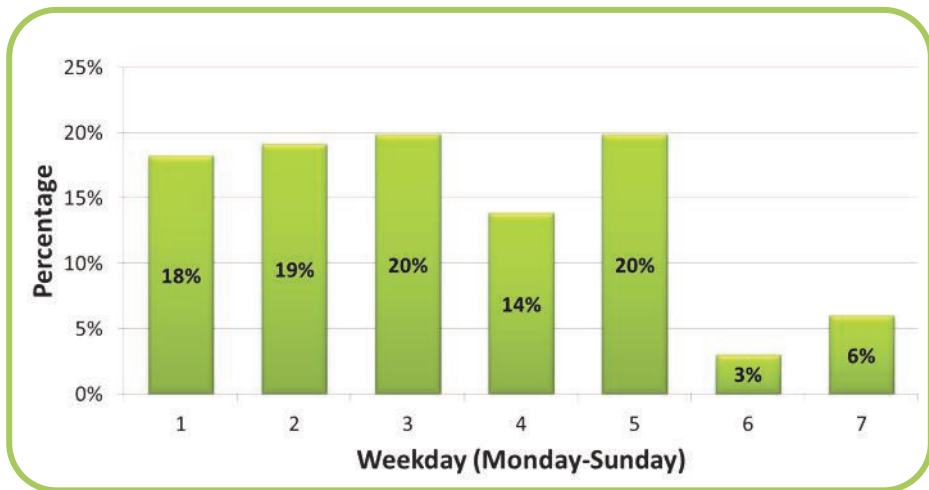
gen station network is rather thin, drivers tend to refuel each time they pass one. Over time, we have observed an increase in the average distance travelled before refuelling. The more familiar one gets with the car, the more one trusts the remaining range automatically predicted by the vehicle — and the reliability of the hydrogen stations (see page 21).

The predecessor of the Hyundai ix35 FCEV: a Hyundai Tucson FCEV. The tanks are in the back, the electric motor is under the hood.



## Refuelling by Weekday

Refuellings are evenly distributed throughout the work week.



One of the differences between conventional and hydrogen refuelling stations is the maximum number of cars that can refuel directly after one another. The number of these back-to-back (b2b) refuellings is limited, because of the limited quantity of hydrogen at high pressure. The official number of b2b refuellings for the H2mS Oslo Gaustad station is five.

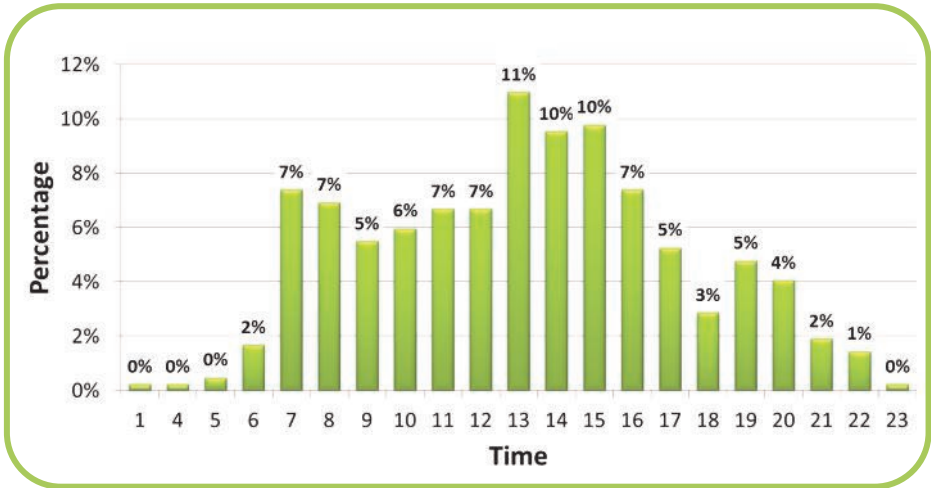
The graph above shows the rather homogeneous spread of individual refuelling events on working days. Only on weekends is the frequency significantly lower. We do not yet have an explanation for the lower number of refuellings on Thursdays.



This is the refuelling receptacle of a Hyundai ix35 FCEV. The nozzle gets imposed and high pressure is built up. In order to prevent people from driving away from the station without having detached the nozzle first, FCEVs can be refuelled only when the vehicle is shut down.

## Refuelling by Time of Day

Refuelling is evenly distributed during office hours.



**H**2mS stations are open 24/7. As the graph above shows, nearly all refuellings (95%) currently take place between 7 in the morning and 8 at night. Although there is a peak at 1 PM, with 11% of all refuellings, the distribution between 7 AM and 5 PM is otherwise generally even — between 5 and 11%.

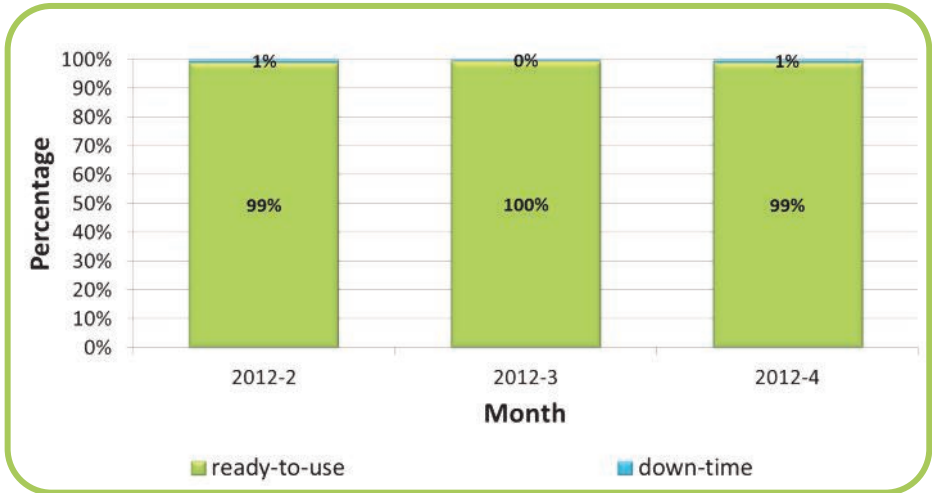
**C**onclusion: Although there is a limitation to the number of consecutive refuellings, this limitation will hardly be experienced in daily operation. See also page 20.

Refuelling a hydrogen powered car is just as simple as refuelling a gasoline powered car. Even the refuelling receptacle is at the usual location. One of the main differences is the infrared interface between the most advanced hydrogen cars and refuelling stations, where information is exchanged on the pressure level inside the tank and the termination of the refuelling process.



## FCEV Availability

Cars reached up to 100% availability.



Worldwide, there is no car manufacturer currently producing FCEVs on a large scale. All H2moves Scandinavia vehicles were produced in small batches. Reaching an availability of between 99 and 100% is an excellent result and demonstrates that some improvements still need to be made, but the technology is on its way to being

ready for large scale production and commercialization.

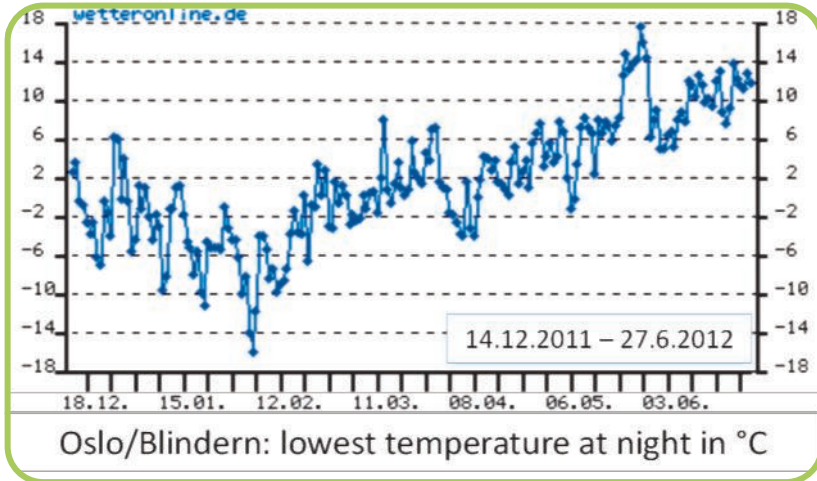
Availability times were calculated on the basis of minutes. We expect all our 19 vehicles to be ready-to-use 24/7 year-round, whether they are being used as part of a company fleet or for other purposes.



The 'heart' of this Mercedes-Benz B-Class F-CELL is hidden beneath the trunk. One can see one of the hydrogen tanks on the left side and the fuel cell stacks further to the right. In the individual fuel cells, hydrogen reacts with oxygen from the air to produce electricity and water vapour.

## FCEVs under Harsh Scandinavian Winter Conditions

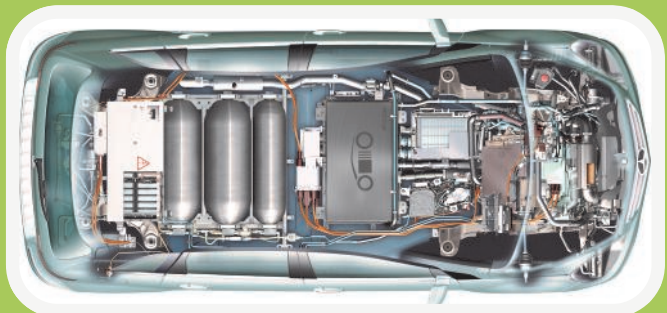
Today's FCEVs can be operated any time of the year.



Winter time in Scandinavia brings with it one of the coldest and most unfriendly climates in Europe — the perfect reason for us to test drive the FCEVs exactly there. As fuel cell cars leave behind only pure water which freezes below 0°C, low temperatures are an issue. Or should we say: used to be an issue.

Our customers reported no problems starting their cars — no matter how low the outside temperature. One customer even reported on a trip in Norway with temperatures of -27° C! The car started as normal, and brought them back home safely.

Mercedes-Benz B-Class F-CELL: this top-view illustration shows the location of all three hydrogen tanks and the entire fuel cell system.



## How do Other FCEV Demonstration Projects Perform?

Three demonstration projects yield comparable results.

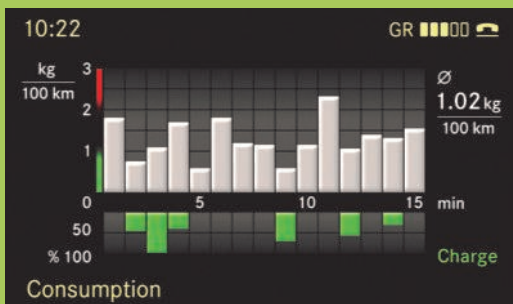
	H2mS (Norway, Denmark)	CEP (Germany)	NREL (USA)
Start of operational phase	2011	2005	2005
Total number of HRS incl. moveable refuellers	2	10	25
Total number of FCEVs since project begin	19	83	183
Km driven per FCEV per 12 months	8,702 km	2010: 6,351 km	-
Average tank capacity	3.52 kg Without ThInk: 4.24 kg	2011/2012: 3.93 kg	-
Average refuelling amount	2.11 kg	2012: 2.11 kg	2.13 kg <sup>A</sup> 2.64 kg <sup>B</sup>
Percentage refuelled of average tank capacity	47 % (without ThInk)	54 %	-
Median on-road distance between refuellings	163 km	-	158 km <sup>B</sup>
Percentage of fills between 6 AM and 6 PM	83 %	-	88 % <sup>B</sup>
Percentage of fills between 7 AM and 10 PM	94 %	-	-
Percentage of fills on weekends	11 %	-	6.5 % <sup>B</sup>

The NREL (National Renewable Energy Laboratory) runs the largest FCEV demonstration project in the world, which is financially supported by the U.S. Department of Energy (DoE). A total of 183 FCEVs and 25 hydrogen stations have been a part of the project since 2005.

CEP (Clean Energy Partnership), located in Berlin and Hamburg, is the most relevant German FCEV demonstration project.

Our Scandinavia-based project confirms several of the results of these other projects, such as the annual distance travelled and the low average refuelling quantity per refuelling which rises over time.

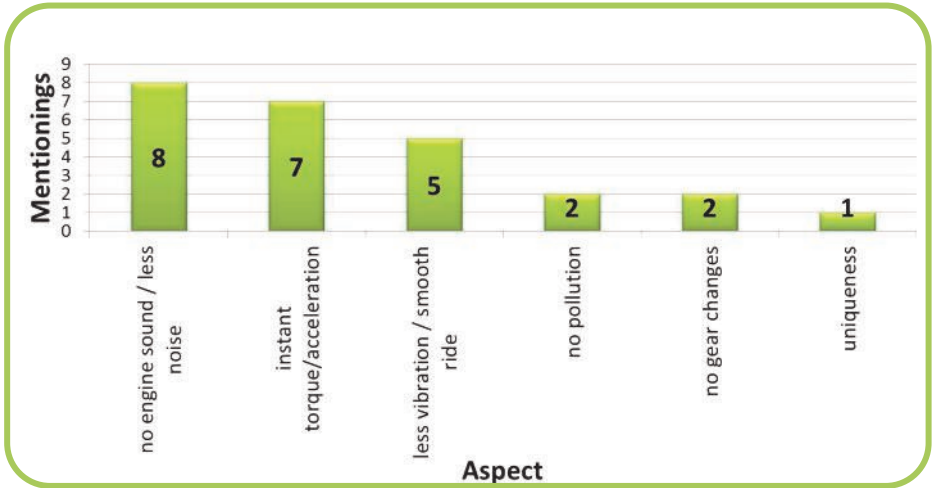
(<sup>A</sup>: through 2009 Q4, <sup>B</sup>: since 2009 Q4)



This screen in Mercedes-Benz B-Class F-CELL dashboard, illustrates the previous, present and average hydrogen consumption.

## What do Customers Appreciate about FCEVs?

The silence of these cars are their most impressive feature.



We conducted 11 interviews with our customers, and asked them which technical aspects they especially enjoy that are unique for FCEVs. Two representative responses were: “I am fascinated by the torque and the silence.” and “The FCEV exceeded my expectations — especially the instantly available torque.” Not just the drivers are fascinated. One told us: “My 13 year old kid

“forced” me to demonstrate the car at school to his class mates. The FCEV was clearly the most special and prestigious car around.”

Another customer, who unfortunately for him only has access to a company fleet car: “After driving a FCEV, you don’t want to get back to your old car.”

All 19 of our cars are in customer hands. Nevertheless, we sometimes organize public events where anyone can take a car for a 10-minute test drive. Try it and enjoy the silence in the city, the acceleration on the highway and the knowledge that all you are leaving behind is a fine trail of water droplets.



# Public Hydrogen S



The blue dots indicate those hydrogen refuelling stations currently being operated that provide public access and match the requirements of major car companies.

# Stations in Europe

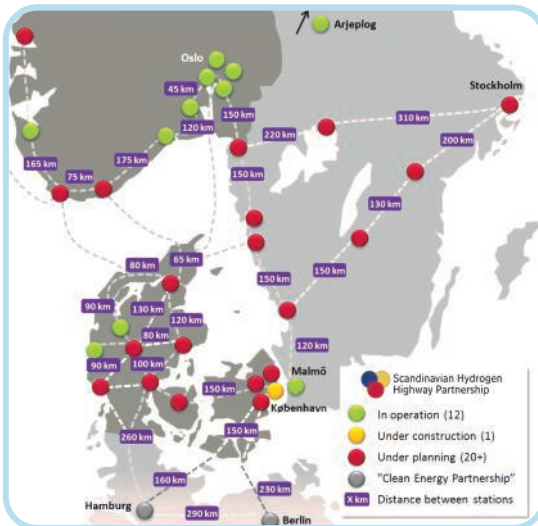


# HRS—Hydrogen Refuelling Station

Already 11 hydrogen stations in Scandinavia.



**H**2moves Scandinavia owns and operates one HRS. This state-of-the-art station, which opened in Oslo on November 21<sup>st</sup> 2011, operates in compliance with the latest international hydrogen refuelling standard — SAE J2601. This standard ensures safe and fast refuelling in under four minutes. The hydrogen is produced onsite, and is based on Norwegian electricity, of which more than 90% is obtained from renewable hydro and wind power sources.



**H**2 Logic has built the refuelling station in Oslo, as well as several more throughout Scandinavia.

**T**oday, the HRS network in Scandinavia is one of the densest in the world — additional stations are under construction or in the planning stages right now.

## Capacity of Oslo (Gaustad) HRS

Another 1,383 FCEVs can currently be supplied in Oslo.

	Per hour	Per day	Per week
kg of hydrogen that can be provided	20	200	1,400
Max number of FCEVs that can be fully refuelled	5	50	350

Our HRS can perform 350 refuellings per week. Assuming the same capacity for each of the 4 stations in Oslo, a total of 1,400 FCEVs can be supplied in

this area. At the moment, there are 17 FCEVs in Oslo. So, an additional 1,383 FCEVs could be operated in Oslo today.

This photo shows the user interface of the H2moves Scandinavia hydrogen refuelling station. Hydrogen is stocked at a pressure of 88 MPa (880 bar), which allows for long travelling distances between refuelling.

The station is certified according to the international standard SAE J2601 A-70. The tricky part when refuelling the hydrogen tank in the car is that the fast-flowing hydrogen gas gets hot in the vehicle tank. Therefore it is pre-cooled to enable you to refuel within a maximum of four minutes.



## Cumulative Hydrogen Dispensed at Oslo (Gaustad) HRS

342 kg emission-free hydrogen for 3,420 km emission-free driving.



Our station dispensed 342 kg purest hydrogen within the first five months. With each kg, a car can drive about 100 km. Just imagine if a gas fuelled car could drive 100 km on just one kilogram of fuel...

The cars within our project, H2moves Scandinavia, refuelled at 11 different

stations within the first 5 months, one of which is our Gaustad HRS.

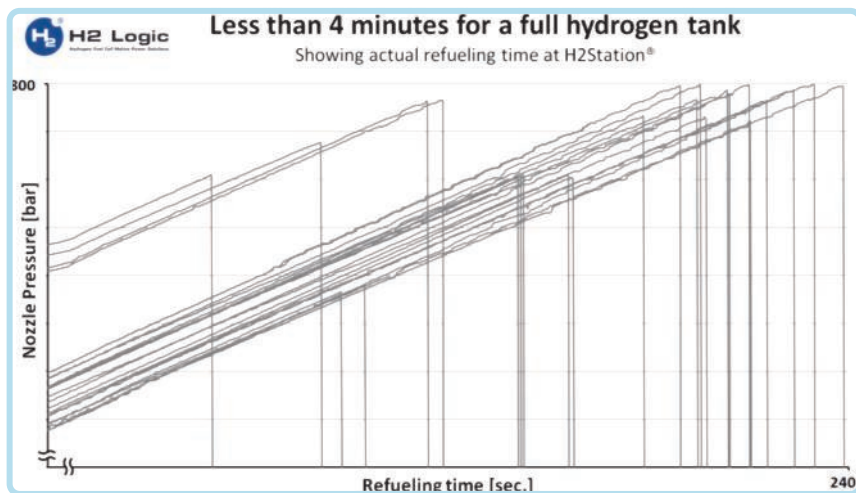
One of our customers says, "Refuelling hydrogen doesn't stink. Although I sometimes liked the smell of gasoline..."



In April 2012, these two Hyundai ix35 FCEV drove from Oslo to Monte Carlo, only accompanied by curious journalists. You can roughly follow their route on the map in the middle of this brochure. They refuelled at various stations throughout Europe.

## Duration of Individual Refuellings

Fully refuelling for purely electric driving in less than 4 minutes.

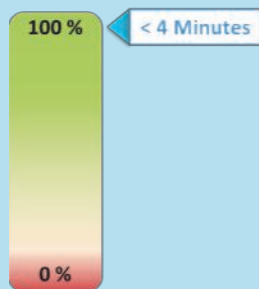


When refuelling a gasoline car, the liquid gasoline is pouring into the tank. The surplus air can freely leave the tank at the side of the nozzle. This is different for a hydrogen car, which doesn't refuel volume but pressure.

When a hydrogen tank is nearly empty, the residual pressure is around 2 MPa (20 bar). When the nozzle is attached to the car, the tank of the car

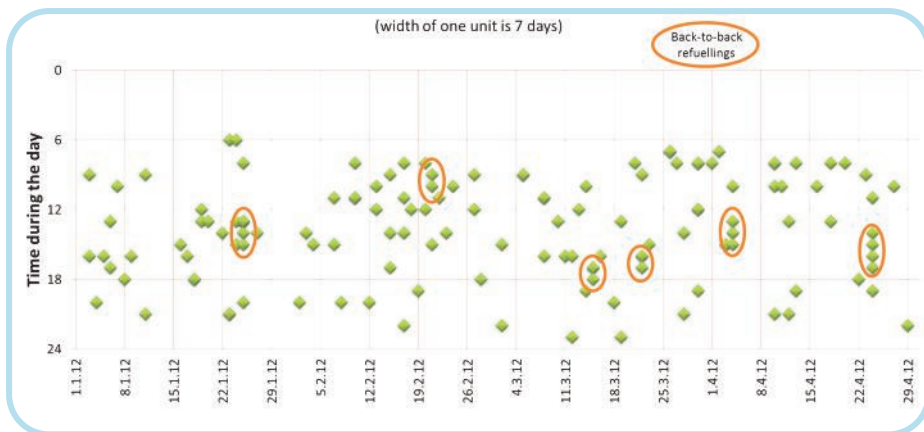
has a leak-proof connection to the hydrogen station. Not a single hydrogen molecule can escape into the air. At modern hydrogen stations, the hydrogen is pre-cooled down to  $-40^{\circ}\text{C}$  and is refuelled at a pressure of 88 MPa. These two parameters enable a fast refuelling to 70 MPa — within a maximum of four minutes, as the graph shows.

There is only one global standard for conducting hydrogen refuelling. This ensures that any type of fuel cell vehicle may fuel at any station, anywhere in the world. This standard also defines how to pre-cool hydrogen during refuelling, to avoid overheating of the tank, thus enabling very fast refuelling.



## Individual Refuellings over Time at Oslo (Gaustad) HRS

Refuelling is evenly distributed throughout the working week.



Our station can refuel up to 5 cars one after another. Our data show that this number of back-to-back refuellings is no limitation for every day driving.

The graph shows how often several cars refuelled in one or two hours

within 4 months. There is no clear tendency towards a specific time or day or combination thereof. So unless we say "Hydrogen is free on Monday mornings at 10 am" there won't be a shortage.



A Th!nk is being refuelled. Its tank capacity is 1,5 kg.

Hydrogen at the station in Oslo (Gaustad) is priced to ensure comparable fuel costs per driven kilometre as those incurred using a gasoline powered vehicle.

## Availability of Oslo (Gaustad) HRS

Excellent result: HRS was available 96% of the time.



**F**or customer convenience our station is open 24 hours a day, 7 days a week.

**T**he station is located on the premises of a research institute close to a major ring road. Special staff, consisting of employees from that institute, has been trained to do small repairs.

**W**e also established an SMS service. One of our customers states, "It is pretty convenient, I can text with my favourite hydrogen station. When I send an SMS to the station, I instantaneously get a response with the status of the station."

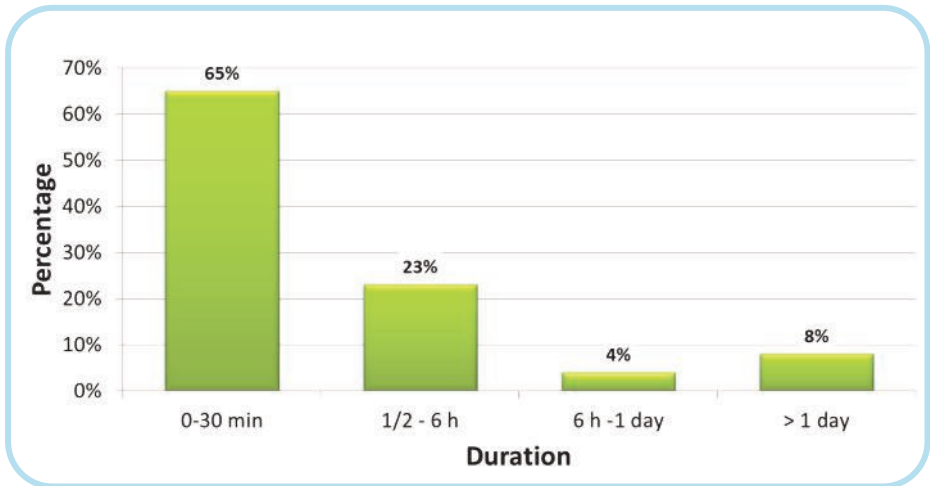
This is the highly visible, and completely accessible emergency button at the Oslo (Gaustad) Hydrogen refuelling station. With the exception of functional tests, it has yet to be used.

There are also hydrogen sensors inside the station that would trigger a safe emergency shut-down if a leak were to occur.



## Time to Repair Oslo (Gaustad) HRS

Mostly, station has been down for no longer than half an hour.



The station manufacturer and operator, H2 Logic, managed to solve 65% of down-time situations within less than half an hour. This is an excellent result given the present demonstration nature of the station. The ultimate goal however, is to ensure close to 100% availability of the hydrogen refuelling station network.

Also, the Danish manufacturer has online access to the station and can therefore modify settings remotely from their desks in Denmark which also helps shorten repair times.

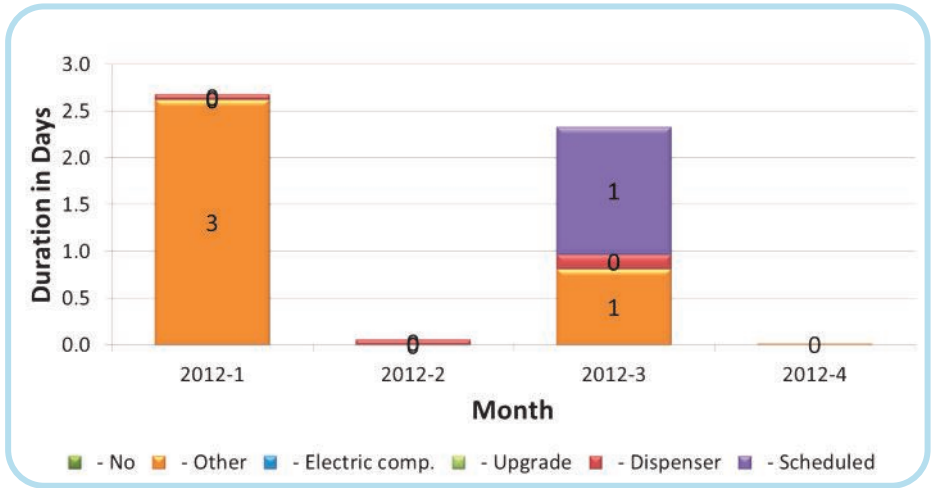


The safety precautions are the same as for conventional filling stations:

- ◆ The local fire brigade received a manual in case of emergencies
- ◆ Copies of this document are also located directly at the station and inside the next building
- ◆ There are signs that prohibit open flames

# Reasons for Temporary Downtime at Oslo (Gaustad) HRS

Electric components are reliable, time for upgrades negligible.



A record is kept when the station is out of operation for whatever reason. Most down-times have been very short. In 43 % of the records, the station has been running again within 10 minutes; in 66% of the reports it was fixed within an hour. In total, there were 26 records between January and April 2012.

Not a single safety-relevant incident has occurred so far. By safety-relevant we mean that a person was injured, the environment was polluted or damaged, or a hydrogen leak occurred. None of these things happened.

At the Oslo station a graphical wall briefly describes the project and lists the project partners. However, during a single refuelling you probably will not be able to read everything, as refuelling generally takes less than four minutes. So, we recommend you come back another time.



## Next-Generation Hydrogen Stations

Producing high quality hydrogen at lowest costs.



**H**ydrogen is produced in many ways, but must be very pure — nearly 100%, for use in fuel cell electric vehicles (FCEVs).

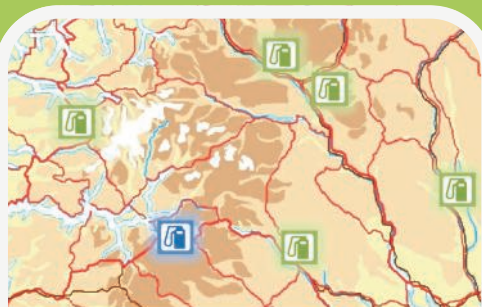
Small impurities in hydrogen fuel can damage fuel cells severely, and must therefore be reliably identified and removed.

We are developing new, more efficient methods to predict and develop strategies to mitigate impurities utilising experience from a wide range of applications and our international network.

**P**roducing hydrogen from water and renewable power is a zero-emission method, but an expensive one.

Electricity prices are variable e.g. because of fluctuating wind intensity; hydrogen can be produced when electricity is cheapest.

Our dynamic, on-line optimisation reduces the cost of hydrogen production from electricity.



 HRS in operation  Your nearest HRS

### Finding Hydrogen Stations

Initially, there will be few hydrogen refuelling stations. We are therefore developing applications for smartphones, the Web, and SMS, so customers can conveniently find the nearest HRS.

## Certification, Approval and Safety

Challenges for hydrogen can be handled.

Approval issues need to be considered for the upcoming market introduction of hydrogen as an energy carrier for FCEVs in Scandinavia. Required approvals for HRSs and FCEVs need to be achieved in an efficient and smooth way without jeopardizing safety, measurement accuracy or hydrogen quality.



### Safety and Emergency Plan

A safety and emergency plan is in place for all H2moves Scandinavia hardware, including the HRS in Oslo and the moveable HRS that accompanies the road tour.

### Expert Institutes

SP Technical Research Institute of Sweden and TÜV SÜD, Germany, have both been involved in the work on these issues.



### Early Measures

Involving permit and approval authorities early in the process has been a valuable tactic for facilitating permits/approvals.

Further suggested measures for HRSs approvals:

- ◆ Development of a European safety standard for HRSs, based on the coming new edition of ISO 20100
- ◆ implementation of harmonized procedures for establishing hydrogen refuelling stations (hydrogen quality, metering, refuelling process)
- ◆ support for regulatory and permit authorities



# Fuel Cells and Hydrogen Joint Undertaking

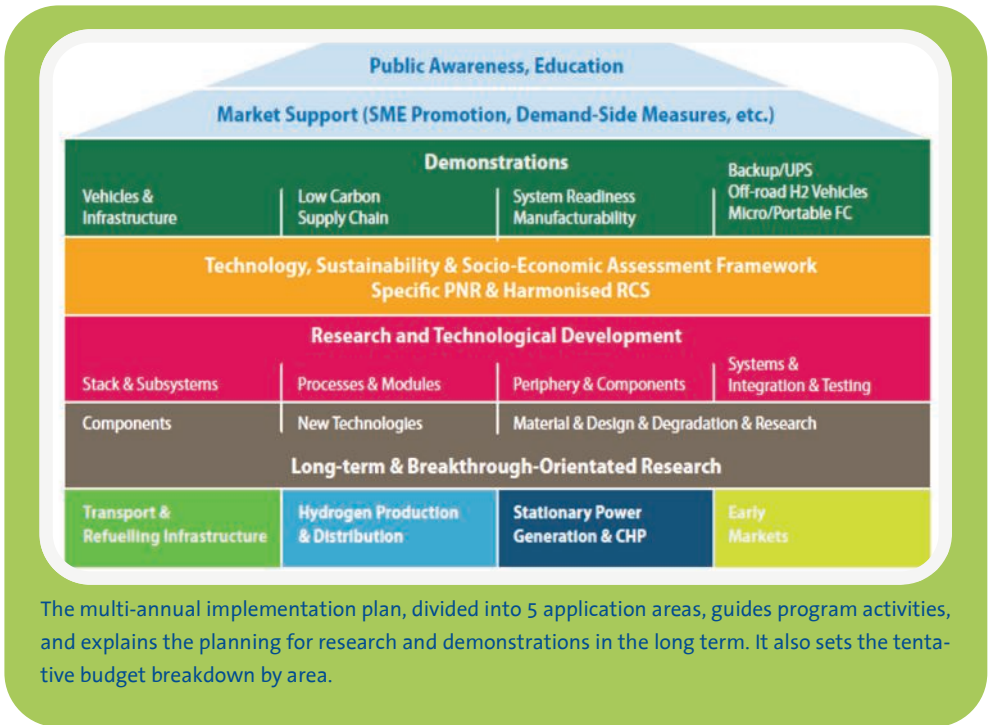
We accelerate market entry of fuel cells and hydrogen technologies.



With a ring-fenced budget of nearly one € billion between 2008 and 2013, this unique European public-private partnership is intended to accelerate the development of FCH technologies in order to enable their commercial deployment as of 2015.

The budget is operated to annually launch competitive and open calls for proposals.

Some 100 projects, among them H2moves Scandinavia, are currently supported and run in parallel by this joint undertaking.



# Glossary

b2b	back-to-back refuellings at a hydrogen station
FCEV	Fuel Cell Electric Vehicle
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
H2mS	H2 (Hydrogen) moves Scandinavia
HRS	Hydrogen Refuelling Station
MPa	Mega-Pascal (1 MPa = 10 bar, therefore: 70MPa = 700 bar)
NEDC	New European Driving Cycle

## Links and Further information

H2moves Scandinavia:	<a href="http://www.scandinavianhydrogen.org/h2moves">www.scandinavianhydrogen.org/h2moves</a>
Mercedes-Benz B-Class F-CELL:	<a href="http://www.fuel-cell-e-mobility.com">www.fuel-cell-e-mobility.com</a> , <a href="http://fuelcell@daimler.com">fuelcell@daimler.com</a>
Hyundai ix35 FCEV:	<a href="http://worldwide.hyundai.com/WW/Innovation/Eco/ZeroEmissionVehicle/index.html">http://worldwide.hyundai.com/WW/Innovation/Eco/ZeroEmissionVehicle/index.html</a> <a href="mailto:JayShim@Hyundai.com">JayShim@Hyundai.com</a> , <a href="mailto:SaeHoon@Hyundai.com">SaeHoon@Hyundai.com</a>
Th!nk:	These FCEVs are refurbished, regular, battery-electric Th!nks. There is no further development and manufacturing of them.
Hydrogen Stations:	<a href="http://www.h2logic.dk">www.h2logic.dk</a> , <a href="mailto:info@h2logic.com">info@h2logic.com</a>

Please be aware that if you want to do additional calculations, you should not mix data from different graphs. The data presented here are comparable within each graph, but not necessarily between graphs.

**Photos:** Daimler AG (pages 1,4,9,10,11,12,24,26), Hyundai Motor Europe (1,4,5,7,8), H2 Logic (6,16,20,23,24,25,26), Jöran Fagerlund/Hydrogen Sweden (1,3,4,13), LBST GmbH (17,21,22), Bjørnar Kruse/ZERO (18), SINTEF (24), Kartverket (24), Peter Bremer/SP (25), Thomas Maxe (25), Linde AG (26)

**Further references:** [www.wetteronline.de](http://www.wetteronline.de) (page 10), NREL [www.nrel.gov/hydrogen/pdfs/54860.pdf](http://www.nrel.gov/hydrogen/pdfs/54860.pdf) (page 12, accessed 20.7.2012), CEP [www.cleanenergypartnership.de](http://www.cleanenergypartnership.de) (page 12), Scandinavian Hydrogen Highway partnership SHHP (page 16)

## Partners

### Coordinator



ludwig bolkow  
systemtechnik

### Vehicles and infrastructure



HYUNDAI



SINTEF



H2 Logic  
Hydrogen Fuel Cell Mobile Power Solutions

DAIMLER

### Communication



### Safety



### CO-Funded by



Energteknologisk udvikling og demonstration



fuel cells & hydrogen for sustainability



European Commission

### Local partners

*Donald O'Shea*



Scandinavian Hydrogen  
Highway Partnership

H2moves.eu

SCANDINAVIA

Period covered in this report	11/2011 – 4/2012
Number of vehicles	19 (10 Daimler + 4 Hyundai + 5 Th!nk)
Location of FCEVs	17 in Oslo, Norway + 2 in Denmark
km driven	71,788 km
Hydrogen refuelled	882 kg
Number of refuellings of FCEVs	431
Number of HRS	1 (in Oslo, Norway)
Hydrogen dispensed at HRS	342 kg
Number of refuellings at HRS	155

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H2mS Coordination Office

LBST Ludwig-Bölkow-Systemtechnik GmbH

Daimlerstrasse 15

85521 Munich/Ottobrunn, Germany

### Press Contact

Dr. Ulrich Bünger

H2moves Scandinavia Coordinator

[info@h2moves.eu](mailto:info@h2moves.eu)

Tel +49 (0) 89 60 81 10-0

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