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# Creating the European Vision for Hydrogen Transportation

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**Summary**

HyFIVE is an ambitious European project including 15 partners who will deploy 185 FCEVs manufactured by the five Global Automotive Companies leading the sector's commercialisation. H2ME is a flagship European project, deploying more than 1400 fuel cell hydrogen cars, vans and trucks and 49 HRS across 8 countries in Europe. It will create the first truly pan-European network, and the world's largest network, of hydrogen refuelling stations (HRS). In addition to their significant contributions to vehicle and station deployment across Europe, the projects also aim to provide analysis and recommendations on a number of other topics including commercialisation strategies, customer attitudes towards the technology, and the vital role that hydrogen transport can play in the integration of renewable energy into the energy system.

*Keywords: hydrogen mobility, transport, pan-European project, fuel cell electric vehicles (FCEVs), hydrogen refuelling stations (HRS)*

## 1 Introduction and Background

The European Commission[1] has identified Hydrogen Fuel Cell Electric Vehicles (FCEVs) as a key technology needed for Europe to meet its ambitious target of reducing GHG emissions from the transport sector by 60% by 2050[2]. Hydrogen refuelling technology has progressed significantly since the first demonstration and funding programmes began, but a number of market barriers persist preventing its widespread uptake within European markets [3].

HyFIVE and H2ME are both supported by the European Union through the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) but are driven by the continuous engagement of the industry. They seek to broaden hydrogen transportation infrastructure across Europe and solve social and technical issues which currently prevent its widespread commercial roll-out.

HyFIVE is a large-scale pan-European project seeking to deploy up to 185 FCEVs from the five global automotive companies leading the commercialisation of FCEVs. These new vehicles have different maturity levels, from prototype level up to commercial production, with performance characteristics and cost reduction targets which will lead to a plausible offer for early adopting customers.

H2ME significantly builds on HyFIVE, combining Europe's four leading initiatives on hydrogen mobility (in Germany, France, Scandinavia and the UK) to remove market barriers in order to create a truly pan-European hydrogen network and a united deployment strategy. The project is a unique opportunity for these major initiatives to harmonise their strategies for the first time and significantly expand Europe's hydrogen vehicle and station network whilst testing different strategies and the latest technology from leading car OEMs (Original Equipment Manufacturers) of the sector. The project will generate new insights for the hydrogen transport community and demonstrate hydrogen technology as the key to creating a green pan-European transport network.

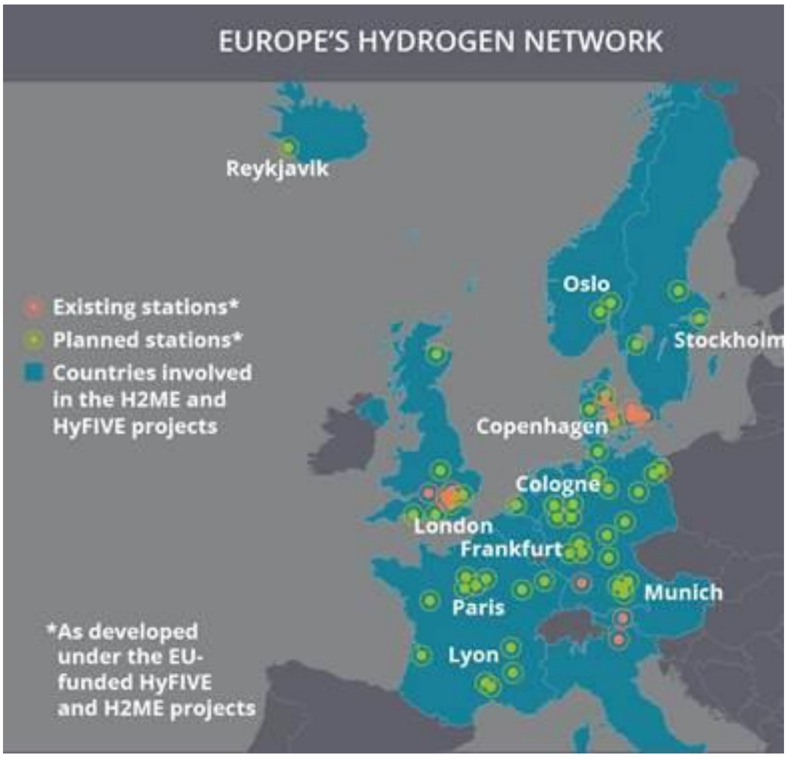


Fig. 1. Map of the HyFIVE and H2ME HRS

# 2 Expanding the Hydrogen Refuelling Station Network

HyFIVE has deployed 6 HRS over the course of the project in order to service the 185 vehicles that have been deployed. The project will create clusters of refuelling station networks in three parts of Europe, where there will be sufficient density of hydrogen stations to provide refuelling choice and convenience to early users of FCEVs.

H2ME will support the leading European operators and suppliers of hydrogen infrastructure (Air Liquide, AREVAH2GEN, BOC, Nel Hydrogen, AGA, HYOP, ITM Power, Linde, McPhy, H2 Mobility Deutschland GmbH & Co KG, and Danish Hydrogen Fuel) in deploying 49 new HRSs in eight countries (Denmark, France, Germany, Norway, Sweden, Iceland, the Netherlands and the UK). The newly funded stations will be sited to better connect and expand the existing local HRS networks and will be placed along the TEN-T corridors.

To date (August 2017), 4 HRS have been deployed as part of H2ME in Denmark, Sweden (x2) and in France. The next two years will see significant expansion of networks with the majority of H2ME HRS deployment to be completed by the end of 2018. Station sizes range from 30-200kg/day, with the majority over 100kg/day. Again, most will be 700 bar or dual pressure, with several stations offering 350 bar only refuelling where only range-extended vans will use the station.

## 2.1 Case Study: Nel Hydrogen H2 Station in Kolding, Denmark

The HRS in Kolding was the 1st H2ME station to be commissioned as part of the project, and was the ninth publicly accessible hydrogen station in 24/7 operation in Denmark. Data has been collected from the HRS since its opening in March 2016. In that time the station has dispensed 742kg of hydrogen (as of February 2017). The HRS in Kolding showed an average filling time of < 3 minutes with 1kg/minute dispensed, as dictated by the SAE (Society of Automotive Engineers) standards and overall availability of 98% (total average filling time = 4 minutes for 400km range). On average, users of the HRS in Kolding refuelled 2.8kg of hydrogen per re-fill event which mirrors patterns observed amongst conventional vehicle users whereby tanks are generally filled to a 2/3 capacity.



HRS in Kolding, Denmark

# 3 Trialling different FCEV solutions and understanding customer attitudes

A key goal of both projects is to create a self-sustaining market for FCEVs in Europe. To achieve this, it is important to understand customer attitudes to the technology in order to mitigate against barriers to its widespread uptake.

In each HyFIVE cluster the OEMs have placed vehicles in the hands of external end users (Daimler, Honda, Hyundai and Toyota). Working with the local facilitators, the OEMs have identified and approached customers via a number of different selling, leasing and rental strategies targeting different groups of potential adopters: large public fleet users (often considered the most likely early adopter market), large private fleets, small fleet users or car sharing schemes, and individual customers. HyFIVE is thus exceptionally well placed to produce new learning on appropriate strategies for the early commercial phase of the hydrogen roll-out, with respect to identifying and better targeting the earliest adopters, testing the most appropriate sales strategies, and better understanding the customers' practical business requirements.

Although the H2ME project is still in an early phase, key insights are already emerging from the customer outreach and sales activities as well as business cases analysis conducted alongside the deployment of vehicles and stations.

## 3.1 Customer Value Proposition Analysis

In both projects, online questionnaires have been developed in partnership with the vehicle suppliers and are structured to understand the end users' attitudes to hydrogen transport before, during and after operation of the vehicles, as well as the perceived customer value proposition for the vehicles in use.

The questions explore a number of areas, including:

- Rationale for the end user's interest in a FC vehicle, performance requirements and how well their vehicle meets them
- Attitudes to the economics of FCEVs, i.e. at which price points for vehicle and fuel would an FCEV purchase become attractive
- Experience of interacting with the HRS network (local and from other countries where possible), including feedback on aspects which could be improved, convenience and destination choice
- Experience of interactions at the fuelling stations themselves in terms of the aesthetics and ease of use of the customer interface

In both projects, a number of deliverables have been and will be published that analyse the responses received. Below, a brief summary of some of the emerging conclusions is presented.

In HyFIVE, refuelling infrastructure availability as a barrier to vehicle purchase has shown to be much stronger in the UK relative to Germany and Denmark. This may reflect the relatively low availability of infrastructure in the UK prior to the commissioning of HyFIVE, H2ME and other UK stations. Many customers in the London area had no local HRS, and access to only a single HRS such as the one at Heathrow Airport west of London was not convenient for customers using vehicles in other areas of the city. Positive implications from Germany results suggest that even with few HRS this is not perceived as a barrier for the majority of targeted customers.

Questionnaire results have shown that there is a demand for maps with live availability data to help customers refuel; this is likely to become more pressing when the number of private customers increases and as drivers begin to make use of fuel cell vehicles for long distance trips away from their local HRS. There are currently several initiatives at a national level which provide information on station locations, availability and contact information. Many HRS providers complement this service with text or email notifications. In addition, some OEMs have produced their own apps for customers. The FCH2 JU intends to publish an open procurement process (Q2 2017) for a 'HRS Operational Status System for FCEV users'.

Given the early stage of the project, data analysis in the H2ME project is still ongoing. Nevertheless, initial responses suggest good awareness of some of the benefits associated with FCEVs e.g. noise, emissions, and refuelling time. There is however concern in users before they have driven FCEVs with regards to vehicle performance (acceleration/top speed, reliability, range) and most strongly with regards to vehicle price and number of HRS in both the local area and on major roads. As additional responses are collected and the first round of during-operation questionnaires arrive, the project will look to determine the impact time spent with vehicles has had on all of these attributes, as well as considering whether responses vary by end-user type and country of deployment. Results from HyFIVE suggest that any negative expectations are overcome by time spend using vehicles in the real world. Future analysis under H2ME will include the responses of fleet drivers. This will provide insight into whether expectations differ significantly between those involved in the purchase/lease decision and those who are not, as well as whether time with the vehicle(s) leads to a convergence in attitudes.

Close collaboration between the two projects will allow H2ME to move forward with HyFIVE's initial findings, and analyse whether expanding infrastructure networks, greater FCEV deployment and improvements in other areas such as live information on station availability result in changed perceptions amongst customers.

## 3.2 H2 Mobility Strategies and Recommendations for Supporting Commercialisation of FCEVs in Europe

Due to the pan-European nature of the project, H2ME enables trials of a number of different strategies for the roll-out of FCEV technology in different regions, with a range of different policies, end users and geographical factors. A wide range of vehicles will be deployed including passenger cars, fuel cell range extended vans and fuel cell range trucks, for both private and commercial use, on a larger scale than has been attempted previously. H2ME will assess each of these strategies, identifying successes, challenges, and lessons learnt that can be used as models elsewhere. The different market introduction strategies tested in H2ME will be integrated into a coherent European blueprint for accelerating the commercialisation of the technology across Europe.

### 3.2.1 Brief overview of hydrogen mobility strategies

The German strategy looks to provide confidence to vehicle users by delivering a dense national network of stations. Germany is placing a bigger emphasis than some coalitions on network coverage on motorways, with 100 HRS planned by the end of 2018. These first 100 stations will be built independently of vehicle numbers. An additional 300 stations will be considered up to 2023, but these will be linked to the growth of vehicle numbers. The German strategy contrasts quite significantly from that of the French strategy, where the vehicle deployment is focused on captive fleet applications, allowing hydrogen stations to be deployed at the same time as a vehicle fleet, thereby securing demand and de-risking early HRS investments. In contrast to the Germany strategy, there is no explicit aim to populate motorway sites in the early years, with the mapped rollout showing a progressive linkage of cities that minimises the number of HRS on corridors, when low utilisation levels would make them more unprofitable than HRS placed in clusters. The UK strategy looks to deploy in a clustered approach, focusing on achieving good station coverage around London and in a limited number of other urban clusters (e.g. Aberdeen). This approach allows for the targeting of resources, and minimises dealer training costs. In Scandinavia, the strategy is based on the introduction of 700bar HRS to create a first network across Scandinavia. Vehicle deployment is supported by generous national tax regimes and other support mechanisms such as free public parking, access to bus lanes etc. Though the German strategy enables national mobility, it is vulnerable if FCEV rollout numbers are low; in contrast the French approach minimises risk but makes travelling across the country challenging for private users. The UK strategy also minimises risk, but seeks to provide customers with a sense of security by deploying several refuelling stations in each of the cluster regions. The Scandinavian strategy has invested significant resources into establishing a first plausible hydrogen refuelling network across the region, but roll-out of vehicles has not yet reached anticipated levels.

Due to the collaborative nature of these projects, lessons learnt from different regions are shared and increasingly being incorporated by different regions. An example of this can be seen in the deployment of HRS in HyFIVE. The station at Korsør was selected after an original plan to locate it 50km away at Odense. The relocation was due to higher interest from potential vehicle operators at Korsør, who could commit to adopting a larger number of vehicles. This approach of deciding station locations based on stated vehicle commitments is similar to the deployment strategy in H2Mobility France, which uses commitments from local 'captive fleets' to influence siting choices for stations. The benefit of this approach is it provides a minimum baseload of hydrogen demand, reducing operating losses of the station in the early years and supporting the highest number of FCEV sales for a given station investment. The approach is being increasingly adopted in other markets such as in the case of Korsør and in post-HyFIVEdeployments in the UK.

### 3.2.2 Business Case and Total Cost of Ownership Anaylsis

The rollout of OEM passenger cars will occur gradually, requiring 2-3 model generations to reach selling prices that are sufficiently attractive to mass market customers. This creates challenges both in securing early demand for relatively high priced vehicles, as well as reaching acceptable utilisation rates for refuelling stations and encouraging the continued expansion of the network. A working group has been established to find the best combinations of operations and markets where significant numbers of vehicles can be deployed in the short term, helping to sustain and expand the HRS infrastructure so that it is ready for the mass-market rollout of low cost FCEVs expected in c.2025. A number of potential ‘niches’ have so far been examined:

- Taxis
- City/captive fleets of cars and vans
- Deployments in ‘high tax’ regions such as Scandinavia, where exemptions from purchase and circulation taxes, similar to those used to support battery electric vehicles, can bridge the current TCO gap to petrol and diesel cars
- Buses
- Trucks

The working group has discussed the latest evidence on the economics and market opportunity for each niche, and discussed ways the group and the wider H2ME partners can support the deployment of vehicles and HRS in these niches.

Analysis conducted by the H2ME consortium has shown that even with first generation vehicle costs, attractive Total Cost of Ownership (TCO) models can be made, for example in high mileage taxi applications. In most cases, measures to restrict operations of diesel vehicles (such as city-level diesel bans) are likely to be required to allow FCEVs to be competitive. In other words, a policy framework providing a financial or operational advantage to using zero emission vehicles is required to encourage widespread uptake.

The graphs below show the average consumption of H2 by different vehicle types, and the corresponding number of vehicles therefore required to provide minimum loading of stations.

Our analysis has identified a required ‘baseload’ demand of c.50kg per station in order to achieve payback over a 10 year period. Due to low numbers of passenger cars expected before the mid-2020s, captive fleet approaches and mixed vehicle types may be required to sustain the early network (see Table 1 below).

Table 1: Illustrative hydrogen consumption for a range of vehicle types

| | Daily hydrogen consumption (kg) | Number of vehicles required to provide a 50kg ‘baseload demand’ |
|---|---|---|
| Passenger car (private use) | 0.5 | 100 |
| Passenger car (taxi) | 2 | 25 |
| Range-extended fuel cell van | 0.3-1 | 50-150 |
| Refuse truck | 10 | 5 |
| Bus (12 metre) | 20 | 2.5 |

### 3.22.1 Case Study: Taxis- a real life example of a successful captive fleet approach

The taxi market has often been an early adopter of new powertrains, since very high annual driving distances maximise the benefits of low running costs. In some cities, low emission taxis are granted additional benefits such as exemption from congestion charges or the ability to ‘queue-jump’ at airports. The demands of taxi duty cycles make them unsuitable for the majority of current BEV models, providing an advantage to fuel cells for zero emissions operations.

Due to their high daily driving distances, a single taxi FCEV consumes approximately 2kg H2/day. Thus, a relatively small fleet of vehicles can provide sufficient loading of a station to make it profitable. This then also benefits other customers using the same station for the refuelling of their vehicle(s). Just 25 vehicles provide 50kg of daily hydrogen demand, sufficient to ensure a viable business case for an HRS. This model is already being used in cities such as Paris (Hype taxis) and London (Green Tomato Cars).


FCEVs in operation with Green Tomato Cars in London and Hype Taxis in Paris

The analysis conducted as part of H2ME suggests a viable market for FCEVs in taxis and city fleets under the following conditions:

- Availability of $2^{nd}$ generation FCEVs at lower costs
- Appropriate vehicle sizes and configurations e.g. 5 seats, sufficient trunk space
- Restrictions on diesel (or preferably non-Zero Emission Capable) vehicles in cities
- Operational constraints on BEVs that make FCEVs a more attractive option (e.g. ability to double-shift vehicles over very high annual distances, limited access to home or en-route charging for EVs)
- Additional ‘sweeteners’ or privileges where possible, e.g. queue-jumping at airport taxi ranks
- Hydrogen at c. €7/kg from well-loaded local stations

The enhanced understanding of consumer characteristics and requirements produced by both projects will allow a major extension from the current state of the art (currently characterised by a limited number of next-generation FCEVs deployed across Europe) and will provide valuable insights to support the further deployment of hydrogen transport. This information will be captured to identify the likely earliest adopters of FCEVs and develop recommendations on successful strategies for the commercial roll-out of FCEVs in Europe.

# 4 Understanding the role of hydrogen technology as a key contributor to the unfolding new global energy system

Over the coming decades, dramatic changes must occur in the world’s energy production and distribution systems if ambitious emissions targets are to be met; both HyFIVE and H2ME provide an opportunity to encourage greater collaboration between major European initiatives and a real world test of the viability of creating a homogenous, green and pan-European energy network by investigating how electrolytic hydrogen production can support this transition.

To lower the overall $CO_2$ emissions of electricity generation, high penetration levels of wind, solar and other renewable generators are necessary. Although these have the potential to produce very substantial levels of green electricity[1], large scale renewables also present challenges for grid operation:

- The intermittency of wind and sunshine can lead to dramatic variations in the supply of electricity, making it difficult to match it to demand. In cases of very high production, this can lead to renewable generators being switched off, damaging their economic viability.
- 'Spinning reserve' in today's fossil fuel plants are used to maintain the frequency of electricity supply. As the proportion of renewable generation increases, new approaches will be needed to provide these grid services.

Electrolysers produce hydrogen by using electricity to split water molecules. As the amount of renewable generation increases, electrolysers can use this to produce low carbon hydrogen. In addition, electrolysers are capable of very flexible operation, and therefore, when deployed at scale they could absorb oversupply of renewable electricity or reduce their power demand in response to periods of shortfall. Furthermore, a series of innovations has led electrolysers to respond to frequency extremely quickly (e.g. sub-second), with groups of electrolysers operating in a co-ordinated way as 'virtual power plant'. At such speeds, electrolysers can be used to regulate system frequency. In this way, electrolysers have the potential to not only produce low carbon road fuel, but to directly support the integration of renewables and secure additional grid service revenues that can help to decrease hydrogen costs to end users.

Understanding the role and extent of the contribution of hydrogen to this green energy system has been projected but never proven in practice. HyFIVE has integrated hydrogen production into the overall energy system by equipping the majority of the new stations deployed (four out of five) with rapidly responsive water electrolysers, operated according to specific tariffs and utility requirements to ensure the electrolysers maximise the benefits to renewable generators and grid operators. A significant amount of the hydrogen dispensed (more than 50% across the project) is produced using renewable energy.

The H2ME project builds on this significantly and will integrate ten water electrolysers into hydrogen refuelling stations, and a dedicated work package will explore delocalised electrolytic hydrogen production units to demonstrate their ability to support the wider European energy system by providing grid balancing services. Operating protocols will be developed and implemented for the electrolysers to be used in this way. The project will use novel energy system modelling to quantify the role that electrolytic refuelling stations can play in the energy system and the associated benefits available in reducing the cost of electrolytic hydrogen for customers.

H2ME has so far commenced the deployment of four stations, analysed the state of today's electricity markets, and is currently developing detailed analyses of the technical potential of electrolysers today and in future. Taken together, these activities will set out the evidence base for the role of electrolysers as an attractive opportunity to support the inter-linkage of ultra-low carbon electricity and transport systems.

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[1] For example, by 2050, Germany aims to achieve over 80% electricity production share of renewables and today European countries such as Sweden report shares above 50% and countries beyond Europe such as Costa Rica reporting renewable energy shares of over 98%.

Horizon 2020 research and innovation programme, Hydrogen Europe and the New European Research Grouping on Fuel Cells and Hydrogen ("N.ERGHY")

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[4] Mobilité Hydrogène France, H2Mobility Germany, UK H2Mobility and the Scandinavian Hydrogen Highway Partnership

## Authors

Alex Stewart directs Element Energy's low carbon transport team, leading a broad range of projects from technology demonstration, strategy development for rolling out new technologies and providing policy advice to local and national governments. Alex led the analytical work during the first year of the H2M France coalition, and continues to co-ordinate the coalition and support the ongoing working group activities.