Hydrogen Mobility in Europe: Overview of progress towards commercialisation

Part of the EC funded HyFIVE project

HyFIVE: Hydrogen for Innovative vehicles in Europe

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Contents

1 Introduction ........................................................................................................................................... 1
  1.1 Hydrogen mobility and the HyFIVE project ................................................................................. 1
  1.2 Report scope and structure ........................................................................................................... 2

2 Status of hydrogen mobility in Europe .......................................................................................... 4
  2.1 Hydrogen vehicles and refuelling stations in Europe and worldwide ...................................... 4
  2.2 Demonstrating the technical readiness of hydrogen vehicles ................................................. 7
  2.3 Barriers to commercialisation and the role of policy ................................................................. 9
    2.3.1 Purchase price ....................................................................................................................... 10
    2.3.2 Total cost of ownership ........................................................................................................ 11
    2.3.3 Refuelling infrastructure roll-out ......................................................................................... 15
    2.3.4 Other barriers ....................................................................................................................... 17
  2.4 Identifying early customer groups ............................................................................................. 19
    2.4.1 The BeeZero experience ...................................................................................................... 21
  2.5 Whole life emissions benefits of fuel cell cars ......................................................................... 21

3 Strategy for commercialisation of fuel cell cars ......................................................................... 26
  3.1 Overview of European market .................................................................................................. 26
  3.2 Retailing approach and aftermarket services .......................................................................... 28
    3.2.1 Retailing/sales strategy ......................................................................................................... 28
    3.2.2 Aftersales strategy ............................................................................................................... 29
  3.3 Next steps for global sales of hydrogen fuel cell cars ............................................................. 30

4 Delivering the European network of hydrogen refuelling stations .............................................. 32
  4.1 Experience of HRS network expansion in European countries ............................................. 33
    4.1.1 Strategies for planning HRS networks .................................................................................. 33
    4.1.2 Reducing delays to station delivery ..................................................................................... 34
    4.1.3 Improving HRS access and visibility ............................................................................... 35
    4.1.4 Branding and signage ......................................................................................................... 35
  4.2 Experience of HRS operation in European countries .............................................................. 36
    4.2.1 HRS reliability .................................................................................................................. 36
    4.2.2 Communicating station status ........................................................................................... 38
4.2.3 Usability and customer support ........................................... 38
4.2.4 Payment and metering ......................................................... 40
4.2.5 Completeness of refuelling ................................................... 41

5 Recommendations for further commercialisation ..................... 42
6 Annex ....................................................................................... 47
   6.1 Cost assumptions ............................................................... 47

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1 **Introduction**

1.1 **Hydrogen mobility and the HyFIVE project**

Transport accounts for 23% of global energy-related CO₂ emissions. In order to limit climate change to the 2°C targeted by the Paris Agreement, CO₂ emissions must be reduced by almost 60% by 2050 (compared with 2013)\(^1\). Since some sectors such as aviation and shipping are particularly difficult to decarbonise, road transport is expected to require almost an almost 100% reduction in emissions. Accelerated replacement of gasoline and diesel vehicles with zero-emission, low carbon alternatives will be essential to achieve this. In addition, air quality is a major concern in many European cities, with high levels of transport-related air pollution such as particulate matter and nitrogen oxides being linked to serious health risks. Increased adoption of vehicles with zero harmful emissions at the tailpipe can help to improve air quality as well as contributing to reduction of transport sector CO₂ emissions (provided that their fuel is generated via low carbon production routes).

Hydrogen fuel cell electric vehicles (FCEVs) have no harmful tailpipe emissions and run solely on hydrogen, which can be produced through various low carbon production methods, including electrolysis with renewable electricity and steam methane reformation with carbon capture and storage, and biomass gasification. In addition, they have comparable refuelling times and driving ranges to equivalent gasoline and diesel vehicles, making for a familiar driving and refuelling process for customers.

In the last five years, six of the twenty biggest car manufacturers in the world have begun to produce hydrogen vehicles, with series-produced models now available in Europe from Toyota and Hyundai, and expected to be available from Honda, Daimler and BMW by 2025. Thousands of hydrogen cars are now in use worldwide, and the readiness of the technology is evident in the fact that numerous taxi and ride-sharing companies have adopted fleets of these vehicles and are putting them to use in high mileage applications, where zero-emission driving can enhance the value of the service in congested and polluted cities. However, to enable widespread adoption of these vehicles in key global markets, networks of hydrogen refuelling stations must be in place. In addition, to capture a significant market share in the long term, from a customer perspective the cost of purchasing and operating the vehicles must become comparable to that of gasoline or diesel vehicles.

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\(^1\) [https://www.iea.org/etp/tracking2017/transport/](https://www.iea.org/etp/tracking2017/transport/)
Achieving successful station roll-out and attractive customer propositions (both in terms of costs and convenience) are critical if the potential benefits of hydrogen mobility are to be realised. Achieving these milestones, while addressing any other barriers to this technology (such as public acceptance and the development of the supply chain and supporting services), relies on the commitment of stakeholders across the transport and hydrogen sectors, and on collaboration between these stakeholders throughout the process of commercialisation.

The HyFIVE project, which began in 2014, represents one example of such collaboration. The project has brought together five major car manufacturers and five hydrogen station suppliers and operators to introduce vehicles in markets where their use is supported by an initial refuelling network, to demonstrate the performance of the vehicles on European roads and to test the options for identification of early adopters, for retailing of hydrogen, and for vehicle maintenance. The lessons learnt during this four-year project provide an insight into the overall progress towards commercialisation made by the hydrogen transport sector, and where the best opportunities for this technology lie in the short term, as well as indicating where further work is needed to allow commercialisation to continue.

1.2 Report scope and structure

The term “fuel cell electric vehicle” (FCEV) is often used as an umbrella term to describe cars, vans, trucks, buses and other types of vehicles which are powered by a hydrogen fuel cell drivetrain. However, the focus of HyFIVE project was the deployment of hydrogen fuel cell cars, and as such in this report the term FCEVs is used to refer specifically to passenger cars with a hydrogen fuel cell drivetrain.

This report consists of four main sections:

**Chapter 2** provides an overarching view of the status of hydrogen passenger cars in Europe, in terms of deployment, the national policy context and infrastructure strategies, and considers the implications of initial customer attitudes on the next steps in commercialisation and the need for long term national strategies.

**Chapter 3** explores the strategy for FCEV commercialisation from the perspective of vehicle manufacturers, including lessons learned for early dealerships and aftermarket services, and insights into the rationale behind early target markets for FCEVs.

**Chapter 4** describes the progress made and lessons learned by the developing hydrogen refuelling infrastructure network, in terms of planning
and installing stations, and operating the network, and highlights the priorities for improvement as adoption of FCEVs increases.

Finally, Chapter 0 draws out recommendations for vehicle manufacturers, for HRS suppliers and operators, and for policy-makers, for the further commercialisation of hydrogen mobility in Europe.
2 Status of hydrogen mobility in Europe

2.1 Hydrogen vehicles and refuelling stations in Europe and worldwide

In 2014, when the HyFIVE project began, about 200 hydrogen demonstration vehicles and 30 public hydrogen refuelling stations (HRS) were in use on European roads. Today, around 600 series-produced hydrogen cars have been deployed in Europe (around 14% of the global total), with an infrastructure of over 90 public hydrogen refuelling stations. Worldwide, over 5,000 hydrogen cars have been sold to date, with 48% of sales in California and 35% in Japan. Both Japan and California have well-developed localised HRS networks (shown in Figure 2-1) with around 90 and 32 public stations respectively, as well as strong incentives for the sale and purchase of FCEVs, and the impact of these factors is evident in their high market share.

Figure 2-1 HRS networks in California and Japan

Within Europe, Germany is the leading market, with over 40 public stations and around 300 hydrogen cars and vans. Considering its relative size and population, Denmark also has a high level of national coverage, with 10 stations and about 50 FCEVs. The HyFIVE project brought hydrogen cars and new stations to these markets, to Austria and to the UK. The vehicles deployed in the project also made use of existing HRS infrastructure in northern Italy. Figure 2-2 shows all the existing HRS in Europe.

3 Japan: https://www.netinform.net/H2/H2Stations/H2Stations.aspx; California: https://cafcp.org/
Figure 2-2 Hydrogen refuelling stations in Europe

The installation of initial HRS networks in each market is essential to enable adoption of FCEVs in that market. In allocating limited volumes of FCEVs over the past few years, to some extent car manufacturers have prioritised markets where HRS network development is more advanced. However, installing stations before FCEVs achieve a significant market share is not an attractive business proposition for HRS suppliers and operators. Various strategies have been developed in European countries (as well as in Japan and California) to address this challenge, in several cases involving joint ventures which bring multiple industry stakeholders together to support the national roll-out of hydrogen stations. In addition, governmental financial support for the installation of stations has been provided in some countries, alongside various financial incentives for the adoption of FCEVs.

4 https://www.netinform.net/H2/H2Stations/H2Stations.aspx
Table 2-1 provides a summary of hydrogen mobility strategies and national policy in some of the early hydrogen markets. Based on the level of vehicle sales and HRS deployment in each of these markets, the level of government engagement and support for hydrogen mobility is a strong determining factor of the success of deployment to date.

Table 2-1 Summary of hydrogen mobility strategies and national policy in early markets

<table>
<thead>
<tr>
<th>Market</th>
<th>Strategy for hydrogen mobility</th>
<th>Relevant national policy</th>
<th>Public HRS</th>
</tr>
</thead>
</table>
| Germany         | Joint venture between industry and government to deliver 100 stations independent of FCEV adoption (starting in 2002). In 2018, deployment of new stations is increasingly demand-led. | Grants for station installation  
Incentives covering up to 40% of the cost premium, and tax exemptions for FCEVs | 44         |
| Denmark         | Industrial joint venture to deliver 10-11 stations to enable nation-wide driving.              | Grants for station installation  
Exemptions from vehicle registration tax (up to 150%) for FCEVs | 10         |
| UK              | Initial deployment focusing on achieving good station coverage around London and in a limited number of other urban clusters (no specific government targets). | Grants for station installation  
Grants for FCEVs | 11         |
| California      | Strategy for HRS and vehicle roll-out developed through industry-government partnerships such as the California Fuel Cell Partnership, which estimated that a network of 68 stations would be required to achieve a basic level of network coverage. | State grants for installation (up to 85%) and operation of the first 100 stations; Low Carbon Fuel Standard provides incentives to sell low carbon intensity hydrogen  
FCEV purchase rebates and increasing quotas | 32         |
Government-led strategy for the first 100 stations to be focused in Tokyo, Aichi, Osaka and Fukuoka and on a corridor connecting them. Industrial partnership established in 2018 will foster continued HRS deployment, with guidance from the government.

Plans to transition all of Japan's energy sectors to hydrogen
Ministry of Economy, Trade and Industry
goals for FCEV sales:
1% of 2020 car sales, and 3% of 2030 car sales
FCEV grants

2.2 Demonstrating the technical readiness of hydrogen vehicles

The HyFIVE project has monitored some of the earliest deployments of FCEVs in Europe, and data from the project provides clear evidence of the technical readiness of hydrogen vehicles. A total of 154 hydrogen cars were placed with customers and monitored as part of the project, with a total mileage of over 2 million kilometres and an availability of 99.7% over the course of the project. The most heavily utilised vehicle in the project achieved a mileage of 67,800 km over 35 months (an average of 23,000 km per year). Over the four years, there were no hydrogen or fuel-cell related safety incidents with the vehicles or infrastructure, demonstrating the high level of safety of the technology\(^5\).

The reliability and durability of the vehicles on the market today has also been highlighted by several high intensity, long-distance trips made by FCEVs in recent years:

- Toyota led a 100,000-kilometre road test of a Mirai in Germany, involving 16 hours of driving every day for 107 days. During this time, the tyres were changed twice, and the brake pads were replaced, but there were no mechanical breakdowns. Even during a week when the outside temperature dropped to -20°C, the vehicle operated perfectly as expected.

\(^5\) The only recorded safety incidents were related to collisions at refuelling stations, typically involving HGVs not heeding height restrictions
- Jacob Krogsgaard of H2 Logic drove his Mirai from Denmark to Lake Garda, Italy and back: 1,800 km each way (equivalent to a 17-hour drive).
- As part of the parallel London Hydrogen Network Expansion project, a Hyundai ix35 completed around 50 laps of the M25 motorway (over 9,800 km) in six days.

The examples above clearly demonstrate the viability of FCEVs for high intensity duty cycles, which is reflected in the recent adoption of FCEVs across various fleet applications including taxis, car-sharing schemes and other applications which rely on a high level of vehicle utilisation.

Within the HyFIVE project, the vehicles were placed with a diverse range of customers, as summarised in Figure 2-3, which shows the different types of customers and the typical use case of the FCEVs used as part of the project.

![Figure 2-3](image)

**Figure 2-3 Range of customer categories and primary purposes of FCEVs used as part of the HyFIVE project**

While some hydrogen related companies (and their employees) were included amongst the list of customers, compared to previous European demonstration projects (where small numbers of FCEVs were used by project partners and organisations within or close to the hydrogen sector), the FCEVs deployed in the HyFIVE project were used by a much more diverse set of customers and applications, meaning that the data collected in the project is more representative of the overall potential FCEV market. Of the customers who completed a questionnaire after their time with the vehicle, there were 25 private customers, 20 representatives of private sector organisations, and 12 representatives of public sector organisations (as well as customers identifying themselves as “other”). 32% of respondents made trips exceeding 150km one way more than once a month, and 14% more
than once per week. Most respondents drove less than 100km on an average day, in line with European trip statistics for average drivers.

Questionnaires carried out before and after FCEV use and anecdotal evidence collected by the project partners revealed that customers had positive expectations and experiences, commenting on the following aspects in particular:

- High level of overall satisfaction with the vehicle
- Excellent driving experience
- No issues with cold starts in winter
- Safety rated as good or excellent
- Silent drive

Customers also had high expectations regarding the reliability, acceleration and noise levels of FCEVs relative to gasoline and diesel cars. After using the vehicles, on average, FCEVs were thought to be:

- About the same as gasoline as diesel cars in terms of reliability (76% of customers thought FCEVs were at least as reliable as gasoline or diesel cars);
- A marginal improvement in terms of acceleration.

However, a few customers experienced minor problems using their FCEV. Several of these were related to the 12V battery (such as those that could be expected with any car), but one FCEV experienced an issue relating to the purity of the hydrogen (leading to the customer being unable to start the vehicle). Some customers also experienced restrictions relating to hydrogen safety or perceived safety, such as not being able to use underground car parks or tunnels. These issues indicate that, although FCEVs are a proven technology which in many senses can directly replace gasoline or diesel vehicles, there is still progress to be made in terms of the interactions between the vehicles, the refuelling infrastructure and the wider transport ecosystem (including the development of regulations to ensure that safety measures allow FCEVs to be transported or parked underground) to enable further commercialisation.

2.3 Barriers to commercialisation and the role of policy

As well as seeking to understand customer attitudes and possible purchasing behaviours through questionnaires, many of the project partners in HyFIVE collected additional feedback from customers on their experiences in using FCEVs and hydrogen refuelling infrastructure, to identify the short-term and long-term priority areas for improvement to meet the needs of existing and future customers. Several aspects were consistently identified as being
significant barriers to future uptake of FCEVs (by the questionnaires and other feedback processes), with two of these being a) the price of FCEVs and b) the number of refuelling stations, particularly on major roads for long distance travels. This section of the report explores the details of these important barriers, as well as considering additional barriers and possible approaches to address them, including the role of policy and how this has been used in different countries.

2.3.1 Purchase price

For many of the vehicles deployed within the project, the customer proposition was improved due to the vehicle price being subsidised by the project’s European funding, but despite this many potential customers decided not to purchase (or lease) an FCEV, with 76% stating that the price was a barrier. For customers who used the FCEVs (either having purchased or leased the vehicles themselves as part of the project, or trialling them on loan from a project partner), 90% of those who responded to post-operation questionnaires considered the purchase or lease price of hydrogen vehicles to be too high to consider purchasing them in the next five years.

Retail prices (including VAT) for the FCEVs which were available to purchase during the project (namely the Hyundai ix35 fuel cell, the Toyota Mirai, and the Honda Clarity) are around €40,000 – €50,000 more than those of equivalent gasoline or gasoline vehicles, meaning that FCEVs are well over double the price of fossil fuel vehicles, and as such, this customer response is to be expected. As outlined in forecasts such as those set out by the Hydrogen Council in their Scaling up report\(^6\), these premiums will reduce over time as production and sales volumes increase, and manufacturers identify ways to reduce the cost of production: already the Hyundai Nexo is expected to be available from early 2018 at a price 20% below that of the ix35 (which is a smaller vehicle with less advanced features than the Nexo)\(^7\).

“On-the-road” costs to customers currently vary significantly between countries, due to the variation in subsidies and tax exemptions. Figure 2-4 shows the variation in purchase premiums across different European markets, after applying the various incentives available in these markets. Values shown are based on average premiums for the three models mentioned above, compared to equivalent diesel and gasoline vehicles.

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\(^7\) Based on information in the H2 International e-journal, October 2017 issue.
In Denmark, FCEVs are currently exempt from the high registration tax that applies to gasoline and diesel vehicles (exceeding 100% tax rate), and as a result the cost to the customer can be close to, or, for commercial customers who can reclaim VAT, even lower than that for the equivalent gasoline or diesel vehicle. In other European countries, including the UK and Germany, grants are available through the national government, covering up to 40% of the price difference in Germany and up to 35% in the UK, although only vehicles used in commercial applications are eligible for the highest funding levels. This reduces the purchase premium, but even after such grants, FCEVs would be at least €12,000 more expensive than the fossil fuel equivalent. Some regional governments also provide subsidies for vehicles in commercial applications.

### 2.3.2 Total cost of ownership

While the upfront cost is usually a major factor informing purchase or lease decisions, many potential customers will consider the economic case in terms of total cost of ownership (TCO); 83% of post-operation survey respondents said that in order to consider purchasing an FCEV, the TCO

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8 Error bars show the range on the purchase premium before incentives due to different levels of VAT in each country. Assumed prices for individual FCEVs and fossil fuel equivalents are shown in the Annex (under Cost assumptions).


10 Note that this is before any additional purchase subsidies from the HyFIVE project or other European funded projects are applied, and before any regional incentives.
premium would need to be within 10% or less of that of a gasoline or diesel vehicle. As well as vehicle price, TCO components include fuel, maintenance, insurance, and increasingly, taxes or charges for operation in city centres which suffer from congestion and high levels of air pollution.

Many of these components vary between different customer groups (due to differences in mileage, and whether zero-emission driving improves the business case for that customer), and between different markets (due to the different economic incentives supporting FCEVs and zero-emission vehicles in these markets). Figure 2-5 shows the TCO of gasoline, diesel and hydrogen passenger cars for a private customer buying a new car in Germany, Denmark and the UK, under the following assumptions:

- **Vehicle price**: based on average of available FCEVs and fossil fuel equivalents; includes VAT; available FCEV subsidies in each country are applied
- **Ownership period**: 15 years (i.e. total vehicle lifetime)
- **Annual mileage**: 12,000 km (equivalent to 230km every week; on the high side of expected mileage for private customers)
- **Fuel price**: 5-year average fuel price in each market (July 2012- July 2017) for gasoline and diesel; fixed price of 10.1 EUR/kg for hydrogen
- **Fuel consumption**: based on NEDC data for relevant vehicles
- No discounting of future costs
- No replacement of vehicle components is necessary
- Other assumptions (including vehicle tax, maintenance and insurance costs) can be found in the Annex, under Cost assumptions.
Figure 2-5 Total cost of private passenger car ownership over 15-year lifetime (12,000 km annual mileage) – including subsidies for hydrogen vehicles

Figure 2-5 shows that for the case of private customers (who tend to have relatively low mileages), the vehicle purchase cost (including related taxes) is likely to be by far the largest component of the TCO for FCEVs, and as a result even after applying the current incentive schemes in the UK and Germany (included in Figure 2-5), FCEVs are likely to be far more costly than gasoline and diesel vehicles on a TCO basis, with premiums at around 70%. The fact that fuel, maintenance and insurance costs are currently the same or higher for FCEVs as for gasoline and diesel vehicles also affects this. In Denmark, the TCO differential is currently much smaller, particularly for diesel vehicles, where the €6,300 premium represents 6% of the total TCO. As such, reduced hydrogen costs and improved vehicle efficiencies could bring the TCO to equivalency with gasoline and diesel vehicles for private customers (assuming that FCEVs still benefit from the registration tax exemption).

Figure 2-6 shows the TCO of gasoline, diesel and hydrogen passenger cars for commercial customers in these three markets. Vehicle price and fuel costs exclude VAT for commercial applications. Commercial customers typically have shorter ownership periods and higher annual mileages than private customers; the case shown below assumes a mileage of 40,000 km per year (equivalent to 770 km per week) and a 7-year ownership period. Other assumptions are the same as for Figure 2-5.
Figure 2-6 Total cost of commercial passenger car ownership over 7-year lifetime (40,000 km annual mileage) – including subsidies for hydrogen vehicles

For a commercial customer in Denmark, under current registration tax exemption, the TCO for an FCEV would be very similar as for a diesel vehicle, and only 14% higher than for a gasoline vehicle. Due to the reduced share of the vehicle price for commercial customers (in the absence of VAT), and the high vehicle mileage, fuel and maintenance costs make a significant difference to the TCO gaps for these customers, and at current vehicle efficiencies (and without VAT) the fuel cost for diesel vehicles is significantly lower than for FCEVs.

National policy that subsidises the sale of hydrogen as a renewable fuel could bridge part of the gap between FCEVs and fossil fuel vehicles, although the effective price of hydrogen would need to be reduced to a fraction of the current price in order for make up for the remaining purchase premiums outside of Denmark. Recent revisions to The Renewable Transport Fuel Obligation in the UK will effectively subsidise hydrogen from renewable sources by between £2 and £7 per kg, which would make it considerably more attractive to customers with high mileages, as well as encouraging increases to the share of hydrogen from renewable sources at UK refuelling stations.

The TCO gap for commercial and private FCEV customers operating in congested cities (such as London) could also benefit from exemption from the congestion and pollution charges that apply to diesel and gasoline vehicles. For example, in the commercial case, if the customer operates in a charge zone with a daily charge of €10-15, 200 days per year, they could
avoid charges of €15,000-20,000 over a 7-year vehicle lifetime, which would significantly reduce the TCO gap.

For European markets, FCEVs are still strongly reliant on supportive policies to achieve near-parity with either gasoline or diesel vehicles; only Denmark’s registration tax exemption provides a sufficient incentive for the majority of potential customers. In order to maximise the early benefits of FCEV adoption, policy-makers should consider where FCEVs could be used effectively in the short term, and aim to make purchase as achievable as possible for these early customers through a combination of mechanisms, such as those described above, which encourage the use of FCEVs in high mileage applications, and particularly in polluted areas. In designing policy, policy-makers should also consider refuelling network coverage; customer willingness to pay a premium for FCEVs is likely to be lower if there is insufficient coverage for refuelling.

While high costs are to be expected in this first generation of FCEVs, the initial market can be sustained by policy incentives and early adopter customers paying a premium for the CO₂ emissions savings and operational flexibility offered by these vehicles. However, in the long term, purchase prices and TCO will need to fall to levels close to those of gasoline and diesel cars, as well as other zero emission vehicles such as BEVs. Numerous studies have examined the likely long-term costs for FCEVs. The recent Hydrogen Council roadmap suggested that by 2030, the purchase price premium for an FCEV would fall to the equivalent of €5,000, similar to that of a battery electric vehicle. This confirms that future customers will be able to buy highly cost-competitive FCEVs, and this justifies support for the technology in the short term to enable the increase in production volumes essential to unlock these future costs.

2.3.3 Refuelling infrastructure roll-out

The extent of refuelling infrastructure network coverage in the HyFIVE countries varies significantly, as summarised in Table 2-2. Denmark has achieved a basic national network of hydrogen refuelling stations (HRSs) and some areas of Germany and the UK have developed clusters of several stations to support FCEV uptake in these areas, whereas the networks in Austria and Italy have yet to develop beyond a small number of initial stations.

Table 2-2 Status of HRS coverage in HyFIVE countries

<table>
<thead>
<tr>
<th>Market</th>
<th>Public HRS</th>
<th>National capabilities driving</th>
<th>Density of stations</th>
</tr>
</thead>
</table>

15
<table>
<thead>
<tr>
<th>Country</th>
<th>No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>44</td>
<td>Basic network connecting the South and West of Germany in place</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multiple cities have at least two stations</td>
</tr>
<tr>
<td>Denmark</td>
<td>10</td>
<td>Basic national network in place</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Copenhagen has three stations</td>
</tr>
<tr>
<td>UK</td>
<td>11</td>
<td>National driving not yet possible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most stations concentrated in London and the South East</td>
</tr>
<tr>
<td>Austria</td>
<td>4</td>
<td>Extension of the network in Southern Germany</td>
</tr>
<tr>
<td>Italy</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Given the number of HRS installed (which was lower at the start of HyFIVE), it is not surprising that the lack of infrastructure was a critical barrier for many potential customers at the point of purchase, and that for those who did use the vehicle, the majority of customers agreed that the refuelling infrastructure did not completely meet their driving needs\(^\text{11}\). Many early adopters of FCEVs are motivated by the potential for emissions reductions (either in terms of CO\(_2\) or air pollution) and the main advantages of FCEVs over other zero-emission alternatives such as battery electric vehicles are the longer range and shorter refuelling time. Both of these factors are somewhat limited for many potential customers in countries with incomplete HRS networks, or those who are not based within a reasonable proximity to existing stations. In the long term, attracting private customers in particular will rely on both national driving capabilities, and multiple stations within a city (to provide convenience for dispersed customers).

Although countries such as Germany and Denmark are on their way to achieving this, network development takes time and is very costly for HRS operators, especially given that the initial number of FCEVs (and hence station utilisation) is very low, making for a challenging business case. This means that network growth is heavily reliant on the presence of government funding for new stations. In addition, active partnerships between industry and government stakeholders have been instrumental in planning, delivering and maintaining the momentum for HRS network development in Europe and elsewhere, as was previously highlighted in Section 2.1 (see p4). In several countries (including Germany, the UK and France) such partnerships have

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\(^{11}\) For details see HyFIVE D5.1, Attitudes of early hydrogen fuel cell car users in Europe, Element Energy, 2018.
started focusing on identifying clusters of potential FCEV customers near existing stations, in order to increase demand and support the installation of additional stations within the operating zones of these customers.

2.3.4 Other barriers

Figure 2-7 shows the responses of HyFIVE customers to a question regarding improvements required for future adoption of FCEVs (responses are shown before and after FCEV utilisation).

![Question: “Which of the following would need to improve before you would consider buying an FCEV?”

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Pre-operation</th>
<th>Post-operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase/lease price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorway hydrogen stations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle driving range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of vehicle models offered</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen station reliability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of local hydrogen stations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle reliability</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2-7 HyFIVE customer attitudes to future FCEV purchase

Aside from the main factors already identified, the most common areas where improvement was required were vehicle driving range, model choice, and station reliability.

On vehicle range, in addition to the results shown in Figure 2-7, the customer surveys revealed that customers perceive the FCEV range to be slightly shorter than that of gasoline or diesel vehicles, and slightly longer than that of battery electric vehicles (BEVs). However, the perceived range relative to the other vehicle types reduced slightly after using the FCEVs, compared to before using them. Given that driving range is commonly cited as one of the advantages of FCEVs over shorter-range BEVs, it is worth considering the various factors which could explain this apparent shift in perceptions. One is that the BEV market has developed rapidly in recent years over the duration of the HyFIVE project: a wide range of different BEVs are now available with ranges of 350km and above according to New European Driving Cycle (NEDC) testing. For comparison, the NEDC ranges of the FCEVs sold under HyFIVE are between 550km and 650km, which still represents a significant improvement. Another factor is that these advertised ranges are not always achieved in the real world, which could lead to a
mismatch between customer expectations and FCEV performance. Several Danish users reported real world driving ranges of approximately 400km, while this is significantly more than the real-world range of most battery electric, it is shorter than typical diesel cars which often have ranges of 800-1000km in real world conditions. Hyundai’s second-generation FCEV, the Nexo, has been described as having an NEDC range of 800km, which indicates that FCEVs are continuing to improve in this aspect and that this barrier will be addressed as the market develops\textsuperscript{12}. In the meantime, it is important that marketing efforts do not overstate the range equivalence of FCEVs and diesel vehicles, as this could lead to unrealistic expectations among customers, even though the real-world range is still easily sufficient for even demanding duty cycles.

**Model choice** is likely to have a significant impact on the market share of FCEVs in the long term, as brand and vehicle size are primary factors in the purchase decisions of many new car buyers, with a wide range of preferences for different customers. In the short term, it will be important that the limited number of models available are aligned with the needs of the early FCEV customers. This will be discussed in detail in Chapter 3. In particular, the fact that several FCEV models only have 4 seats creates a potential disadvantage for taxi operation, and the focus on large sedans or SUV models can reduce the appeal of FCEVs for public sector fleets, who may be concerned about the public perception of operating large ‘luxury’ cars.

A high level of **station reliability** (i.e. minimal unscheduled downtime or problems with HRS) is vital to ensure that customer driving capabilities are not restricted, particularly in a developing HRS network. Many of the existing stations in Europe have been subject to various problems during their initial months of operation, but addressing these problems has generated valuable lessons learned for HRS operators and suppliers, who have been working hard to improve reliability.

Feedback from vehicle manufacturers has suggested that hydrogen **payment methods** also require improvement. While a variety of access and payment systems are currently in place across the different HRS operators, a universal payment method such as credit card payment would facilitate pan-European driving (a relatively common driving requirement for FCEV customers).

These factors and other infrastructure-related barriers will be discussed in more detail in Chapter 4, which explores the progress made to address the

\textsuperscript{12} H2 International e-journal, October 2017 edition (ISSN 2367-3931)
Barriers to date and sets out short-term and long-term priorities for HRS network improvement.

2.4 Identifying early customer groups

The strongest barriers to FCEV uptake (costs and limited refuelling infrastructure) are mutually dependent and addressing them is likely to be a gradual process that will continue over the next decade and beyond. Many of the earliest adopters of FCEVs (such as the HyFIVE customers) had an interest in the technology itself as well as benefitting from generous cost subsidies (including HyFIVE’s European funding), and therefore have been relatively accepting of the still-developing infrastructure network and other barriers to FCEV use. However, beyond the scope of demonstration projects, FCEVs will only be an attractive alternative to other zero-emission powertrains for customers who see their key advantages (long driving range and short refuelling time) as both achievable and valuable.

As such, one strategy to increase FCEV uptake in the short term (thus supporting the growth of HRS networks) while cost and infrastructure barriers are still evident is to focus on customers who require rapid refuelling as well as placing value on zero-emission driving, and whose refuelling needs can be met by a relatively small number of strategically placed stations.

These are likely to be fleet customers with high mileage applications and for which zero-emission capabilities directly add value to the business case (for example, taxis operating in areas with congestion and air-quality related restrictions). Localised fleets are less likely to rely on full nationwide HRS coverage, and tend to be more compatible with the business-to-business payment model currently in place for some European refuelling stations, compared to private customers who see the capability for long-distance journeys as a higher priority and are likely to prefer credit card payment. One example is Green Tomato cars in London, a taxi company who adopted two FCEVs under HyFIVE and, following the successful use of the vehicles, plans to add 50 new FCEVs to their fleet as part of the FCH JU-funded ZEFER project.

Figure 2-8 provides a summary of different FCEV customer groups and their respective places in ongoing process of commercialisation, in accordance with their priorities and requirements and when these could reasonably be met by the developing HRS and FCEV markets, showing that although there is likely to be some overlap between fleet customers and mass market customers, fleet customer needs are more aligned with the current status of the market.
While fleet customers will have high standards in terms of FCEV and HRS reliability, due to the predictable and localised nature of their operations compared to mass market business and private customers, they are likely to be more tolerant of a less-developed nationwide or Europe-wide HRS networks than mass-market customers would be. In addition, they will be less reliant on a wide range of FCEV model availability, provided that the available models are suitable for their operations, and are more likely to make purchase decisions on a TCO basis. Overall, given the current status of European HRS and FCEV markets, the requirements of fleet customers are likely to be more achievable in the short term.

This customer strategy is recognised by all of the car manufacturers selling FCEVs in Europe, who have a strong or exclusive focus on fleet sales for first generation vehicles. In particular, taxi/car sharing schemes have been a particular success (notably Green Tomato Cars and the Hype taxis in Paris), since current BEVs are unable to provide the same operational flexibility in these high mileage applications. An important aspect of this fleet focus is to ensure that HRS deployed to service short term fleet needs are also convenient for future private customers. In other words, stations should be in highly visible, convenient locations where private customers are likely to want to refuel, rather than in industrial areas that may be acceptable to taxi drivers only. Recent HRS deployments are consistent with this approach and are increasingly located on or near conventional service stations on major routes into or out of cities. Through this approach, stations can be built with a high utilisation rate from a ‘base load’ of local fleets, while also having spare capacity to service the gradually increasing number of private cars in future.
In parallel with HRS in cities built to service current and future fleet users, several countries such as Germany and Denmark are also already deploying HRS between major cities on motorways. This will maximise the perceived convenience for prospective FCEV buyers, as well as providing refuelling to existing fleet users during long trips. This approach must be balanced with the risk of station underutilisation until significantly higher vehicle numbers are sold in Europe. Several strategies can be used to minimise this underutilisation risk, such as siting stations on major roads where they can also service local fleets, building smaller but expandable stations, or supplying other vehicle types such as trucks which could contribute significant hydrogen demand.

2.4.1 The BeeZero experience

In April 2016, BeeZero (a Linde subsidiary) launched an FCEV-only carsharing service in Munich. The service, which is comparable in price to conventional carsharing schemes, will run until June 2018, and was established by Linde in order to raise the visibility of FCEV technology and hydrogen mobility, in response to a lack of awareness in the general public, particularly compared to the high visibility of battery electric vehicles. Over 2 years of operation, the cars achieved a total mileage of 500,000 km, translating to an average annual mileage of 5,000 km per vehicle. Although the utilization rate of BeeZero was comparable with many other carsharing schemes, a higher utilization rate would need to be achieved for the service to be profitable, and it would take further time and investment for the service to gain an increased market share. Combined with the fact that for Linde the business-to-customer mobility market is not part of the core business, Linde has taken the decision to end the service after 2 years and sell the majority of the vehicles on to new customers.

However, BeeZero was a successful demonstration activity, with useful lessons for future FCEV customers and for commercialisation in general:

- Over 5,000 customers signed up to the FCEV carsharing scheme in Munich, considerably raising the profile of the technology
- A large percentage of customers were unaware that hydrogen fuel cell vehicles are zero-emission, electric powertrains
- Of those that were engaged with over the 2 years of operation, the majority of customers think that the technology should be more widely available
- BeeZero was intended and designed to meet requirements of customers with longer rental periods and/or journeys, and customer driving patterns suggest that this was successful, with typical rental distances / journeys of 50-60km, compared to typical distances of
10km for most carsharing services. This demonstrates that FCEVs are well-suited to meeting mid-to-long-distance applications.

The FCEVs were trialled by various fleet and commercial customers, including taxi and ridesharing companies such as CleverShuttle, as well as private customers; following positive experiences with the vehicles, many of these customers are now making enquiries about purchasing them when BeeZero ends. In allocating the vehicles to customers, Linde will take account of the potential suitability and visibility of the customers and the planned application of the FCEVs, in order to maximise the potential to showcase the benefits of the technology.

2.5 Whole life emissions benefits of fuel cell cars

One of the most important motivations for transitioning from petrol and diesel vehicles to hydrogen mobility is to reduce CO₂ emissions and improve urban air quality. Fuel cell electric vehicles produce no CO₂ or local pollutants (such as oxides of nitrogen and particulates) at the tailpipe, since their only emissions are water vapour. However, it is important to consider emissions across the whole lifetime, from production to end of life, to demonstrate that overall emissions are indeed lower than conventional vehicles. Demonstrating strong emissions savings is a key part of securing support for the technology from policymakers, but it is also a key selling point for early adopters. In the consumer research conducted during the HyFIVE project (set out in Deliverable 5.1), reducing CO₂ emissions was the most commonly reported motivation of drivers and fleets using the vehicles in the project.

A detailed life cycle analysis (LCA) for fuel cell vehicles was conducted by Thinkstep as part of the HyFIVE project, and the findings and underlying assumptions are set out in detail in a separate report (Deliverable 4.7). In this section, a brief summary is provided, along with implications for policymakers and the hydrogen sector.

The LCA conducted for HyFIVE considered the whole life emissions (i.e. production, use and end of life phases) for fuel cell vehicles and comparative gasoline and diesel models. In addition, the analysis was conducted for a range of hydrogen production methods, covering electrolysis using renewable electricity, centralised steam methane reforming and the ‘average’ hydrogen mix dispensed by HyFIVE stations during the project. In addition, the analysis was conducted for a 2017 case and again in 2020, with the latter accounting for design and manufacturing changes such as the platinum content of the fuel cell systems and the mass of the hydrogen tank.
Figure 2-9 - Well to wheels emissions for fuel cell electric vehicles

Considering the in-use phase first, Figure 2-9 shows the well to wheel emissions (in tonnes of CO₂ equivalent) of FCEVs and comparable gasoline and diesel vehicles. Emissions for gasoline and diesel vehicles are primarily from combustion of the fuel in their engines, with additional ‘upstream’ emissions during fuel production. For FCEVs, 100% of the well to wheel emissions are from the hydrogen production phase, since the driving emissions are zero. On this well to wheels comparison, FCEVs based on the average hydrogen supply mix in HyFIVE reduce emissions by c. 75% relatively to a gasoline car and c. 69% relative to a diesel vehicle powered by a diesel and low blend (7% by weight) biodiesel mix. In the case of hydrogen produced using electrolysis and renewable electricity, the lifetime well to wheel emissions saving is at least 95% relative to the petrol and diesel comparison vehicles. Conversely, if hydrogen is supplied through reforming of natural gas, FCEVs offer a 25% or 40% saving relative to diesel and gasoline vehicles respectively. These results show the strong emissions reductions available from FCEVs even under the conventional hydrogen production routes, which are in addition to the zero tailpipe emissions of local pollutants.

13 The comparison vehicles were selected as the petrol and diesel variants of the same model (in the case of the Hyundai IX-35 and Mercedes B-Class) or the nearest models of a similar size where the fuel cell model did not have a petrol or diesel variant (for Honda and Toyota)
Figure 2-10 - Global warming potential for an FCEV

Figure 2-10 show the results of the full lifecycle emissions of an FCEV, taking into account production, use and end of life emissions. The inclusion of production emissions reduces the overall emissions savings of FCEVs since these are higher than the production emissions of a gasoline or diesel car. However, these emissions savings remain positive for all hydrogen sources. Overall lifecycle emissions for the HyFIVE hydrogen mix are 43-50% relative to a gasoline car, with the higher value expected to be achieved in 2020 through changes in the design and manufacturer of FCEVs (primarily changes in the primary platinum content of the fuel cell stack). For FCEVs powered by hydrogen from methane reforming, the savings are lower but still positive at 17-24%.

This analysis confirms the strong environmental benefits of FCEVs even using current production methods for the vehicles and conventional fossil fuel-derived hydrogen. This is an important finding, as it shows there is no risk of simply displacing rather than reducing emissions through a transition to FCEVs. In the longer term, savings of FCEVs are likely to grow, as the proportion of hydrogen produced from green electricity grows, in addition to the use of biomethane in SMR instead of conventional natural gas. Recent work has been undertaken through the FCH2JU-funded CertifHy project\(^\text{14}\) to create a ‘guarantee of origin’ certificate for green hydrogen, providing certainty for fleet operators that they are sourcing fuel that maximises the environmental benefits of their vehicles, and helping to create market pull for low carbon hydrogen. The CertifHy project developed common Europe-wide definitions of green and low carbon hydrogen as well as a framework for implementation of Guarantees of Origin (GOs) The first GOs for hydrogen

\(^{14}\) [http://www.certifhy.eu](http://www.certifhy.eu)
will be issued and traded between in the summer of 2018 in pilot schemes for different production routes (including SMR with carbon capture and storage, chlor-alkali process and water electrolysis with renewables). In addition, the project has created a stakeholder platform with 82 participating organisations, as a channel through which hydrogen mobility stakeholders can discuss GOs and to support the implementation of the GO scheme in Europe. According to the project website, it is expected that by 2030, 50-60% of all hydrogen for the mobility sector could originate from renewable or low-carbon sources.

In parallel with the increased use of low carbon and green hydrogen in Europe, improvements in the carbon intensity of electricity production in international markets (for example in FCEV production centres such as South Korea and Japan) will lead to reductions in production emissions, further improving the lifetime emissions savings.
3 Strategy for commercialisation of fuel cell cars

This section of the report explores the strategy for FCEV commercialisation from the perspective of vehicle manufacturers, including lessons learned for early dealingships and aftermarket services, and insights into the rationale informing the selection of early target markets for FCEVs.

3.1 Overview of European market

Although FCEVs have been proven as a reliable and safe zero-emission technology, the FCEV passenger car market is in the early stages of development in the context of full commercialisation: in Europe, only the Hyundai ix35 fuel cell and the Toyota Mirai have been made commercially available to date. Hyundai also recently announced the release of their next fuel cell model, the Nexo, which is expected to be available in Europe, and Daimler’s GLC F-Cell hydrogen plug-in hybrid is also expected to be available in 2018. Table 3-1 shows all the fuel cell passenger cars announced to date, and their estimated future production capacities.

Table 3-1 Current and planned FCEV model availability in Europe

<table>
<thead>
<tr>
<th>OEM</th>
<th>Model</th>
<th>Specifications</th>
<th>Availability in Europe</th>
<th>Annual global sales</th>
<th>Future annual global production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyundai</td>
<td>ix35 Fuel Cell</td>
<td>Range 594 km 4 seater 5,63kg tank</td>
<td>Available</td>
<td>c.200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NEKO</td>
<td>600km – 800 km 5 seater 5-6kg tank</td>
<td>Expected in 2018</td>
<td>1,400 target</td>
<td>Up to 3,600 capacity</td>
</tr>
<tr>
<td></td>
<td>Genesis GV80</td>
<td>Fuel cell / battery powertrain</td>
<td>Concept</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KIA</td>
<td>KIA FCV</td>
<td></td>
<td>Planned for 2020-2021</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Toyota</td>
<td>Mirai</td>
<td>Range 550 km 4 seater 5 kg tank</td>
<td>Available</td>
<td>c.3,000</td>
<td>30,000 in 2020</td>
</tr>
<tr>
<td></td>
<td>Fine-Comfort Ride</td>
<td>Fuel stack should deliver 50% efficiency gains and cost-savings</td>
<td>Planned for 2025-2030</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Honda</td>
<td>Clarity</td>
<td>Range 650 km 5 seater 5kg tank</td>
<td>Only for “small fleets in interested markets”</td>
<td>c.400</td>
<td>1,500 in 2020 (start of mass-production)</td>
</tr>
<tr>
<td>Daimler –</td>
<td>GLC F-Cell</td>
<td>Fuel cell / battery powertrain (Plug-In hybrid)</td>
<td>Expected in 2018</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Mercedes-Benz</td>
<td></td>
<td>Range 437 km 449 km on battery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMW</td>
<td>FF vehicle prototype</td>
<td>Expecting fuel cells to only be viable for model 5 or higher</td>
<td>Operational for demonstration and testing since 2015</td>
<td>Early 2020s: low-volume production Second half 2020s: Wider availability</td>
<td></td>
</tr>
</tbody>
</table>
Globally, the total annual production volume of fuel cell passenger cars to date has not exceeded 4,000, and 83% of sales have been in Japan and California, where refuelling infrastructure networks are more advanced (the Honda Clarity, for example, is not commercially available in Europe at all despite being produced in the low 100s). As such, availability of FCEVs from major vehicle manufacturers in Europe has been limited, meaning that in parts of Europe with relatively well-developed infrastructure (notably Denmark and parts of Germany), the demand for FCEVs exceeds supply, which presents a challenge for the business case of HRS operators and thus for the further expansion of the network. Section 3.3 will explore some of the criteria for selection of FCEV markets from the perspective of manufacturers, providing insight into how European markets might attract a more significant share of FCEV production for future models.

There have been significant developments to overall global FCEV market in recent years, with increases in driving range and reductions to purchase premiums with each successive model release (for example, the Hyundai Nexo retails at 54,000, compared to the 65,450 of the ix35 Fuel Cell\textsuperscript{15}). Global production is set to reach tens of thousands of vehicles each year by the early 2020s, and by 2025, FCEVs will be in series-production from at least six global brands (see Table 3-1).

Sales of FCEVs are currently only a fraction of the sales of battery electric vehicles, with over 1 million BEVs sold in 2017, and media coverage of FCEVs often suggests that using this technology for passenger cars is a gamble that is unlikely to pay off long-term, in the face of competition from BEVs. However, although interest in FCEV manufacturing currently seems to be limited to a few key players, in a 2017 global survey of over 900 automotive executives, 78% agreed or partly agreed that FCEVs would be the real breakthrough for electric mobility\textsuperscript{16}. This suggests that internal attitudes and long-term strategies towards FCEVs may differ from what is apparent based on public announcements.

As well as the broader cost and infrastructure challenges, the pathway to commercialisation of FCEVs will involve short-term challenges relating to the implementation of retailing and aftermarket services. Section 3.2 focuses on the development of these services for FCEVs within the HyFIVE project.

\textsuperscript{15}http://europe.autonews.com/article/20170308/ANE/170309801/hyundai-wants-new-fuel-cell-suv-to-have-own-identity
3.2 Retailing approach and aftermarket services

The deployment of FCEVs in the HyFIVE project has allowed the car manufacturer partners to refine their strategies for selling and maintaining the vehicles, to ensure they are prepared for more large-scale deployments in the coming years. Ensuring a smooth sales process and convenient, timely access to servicing and repairs is critical if early users are to have a positive ownership experience. Since many of these users are fleets who could deploy more FCEVs in future or influence other people’s perception of the technology, significant early ownership problems could have strong impacts on the short-term future for the technologies. The approach OEM and dealer strategies can be divided into retailing/sales and aftersales.

3.2.1 Retailing/sales strategy

The early sales strategy for FCEVs in Europe recognises that the relatively high prices of first generation vehicles and the limited hydrogen refuelling network will limit the appeal to private customers. Therefore, a strong focus has been placed on private and sector fleet owners, particularly in areas with strong financial incentives or other zero emission policies (such as urban access restrictions). This sales focus means that little marketing is currently aimed at private users, and for some manufacturers a ‘qualification questionnaire’ is provided to people registering their interest in the vehicle, to ensure that they live somewhere close to an HRS and so can conveniently refuel the vehicle. A sales strategy targeting fleets has several other benefits, since often multiple vehicles can be sold through one customer relationship, and the defined location of the vehicles (for example in or around a large city) avoids the need to train nationwide dealerships in this early stage of the rollout. For example, Toyota has focused its UK sales of the Mirai in London and South-east England, where sales and aftersales support can be given through a few selected dealerships, and where the UK’s hydrogen infrastructure is currently the most developed.

This strategy of targeting fleets in specific cities has yielded sufficient customers for the relatively low numbers of first generation FCEVs available in Europe. It has also minimised the cost and time to train large numbers of dealers who will have no or few FCEV customers in the short term. However, even at this early stage of the rollout, conventional dealers have been the ongoing point of contact with the customer, replicating the current sales process for conventional vehicles. This ensures that several large dealerships in big cities have experienced the product and the types of questions raised by prospective customers, and are ready to act as the main sales channel for increasing volumes in the future.
3.2.2 Aftersales strategy

The aftersales strategy for FCEVs is specific to each car manufacturer, but there has been close collaboration during HyFIVE on the specific approach to the safe servicing and maintenance of FCEVs. This approach is based on the division of servicing facilities into two types (alpha and beta), which differ in the type of work carried out, the staff training procedures and the safety equipment. The aim of this approach was to minimise the financial, training and regulatory burden on existing dealerships who are likely to encounter relatively few FCEVs in the next few years, while avoiding the need to send FCEVs to specialist repair centres for minor procedures. The alpha and beta workshops are described fully in Deliverable 3.4 of the HyFIVE project and are summarised here:

**Alpha workshops** are permitted to carry out all maintenance and repair activities on FCEVs, including on the fuel cell and hydrogen storage systems and defueling hydrogen from the car where needed. A high level of personnel training and safety equipment is required at the workshop given the possible presence of hydrogen escaping from the vehicle.

**Beta workshops** are permitted to carry out general maintenance and repairs on FCEVs that do not involve the fuel cell and hydrogen systems. This includes interventions on the bodywork, electrical systems, suspension etc. Since the FCEV is considered a leak-proof system (i.e. no hydrogen should be vented in normal operations), a lower level of training and specialist equipment can be used at beta workshops will still ensuring safety for technicians.

Each of the vehicle manufacturers in the HyFIVE project has created at least one alpha workshop for hydrogen-related maintenance. To ensure a high quality experience for vehicle users, the local dealership remains the first point of contact for any technical issues with the car. This allows simple issues to be addressed quickly without needing to transport the car long distances. Where further work at an alpha workshop is needed, a courtesy car is provided to the customer while their FCEV is being repaired.

The alpha and beta workshop approach is scalable as the number of FCEVs on the roads increases. For example, if large numbers of FCEVs are deployed within a city or region, a single dealer’s workshop can be upgraded with the appropriate safety equipment to handle hydrogen system maintenance, while other dealers in the cities would perform sales activities and general (non-hydrogen maintenance).

Another important part of the aftersales process is rapid access to replacement parts. The HyFIVE project has allowed manufacturers to define their systems for spare parts, often integrating the new parts into their
existing spare parts ordering and delivery systems. This has created some useful learning, such as the handling of parts with limited shelf lives such as ion diffusers, which has allowed logistics to be optimised before sales volumes increase.

The aftersales approach defined in HyFIVE has worked successfully for the specific vehicle operated within the project, as evidenced by the very high availability of 99.7%. The approach continues to be used for other vehicles deployed through the successor projects to HyFIVE (namely H2ME, H2ME2 and more recently the ZEPHYR project). This has avoided the creation of bespoke systems and training programmes for different project. In addition, it has laid the foundations for the future scale-up of FCEV deployments in other EU countries, as OEMs can leverage their large existing dealership networks, while creating a lower number of strategic workshops for fuel cell vehicles as a function of local demand.

3.3 Next steps for global sales of hydrogen fuel cell cars

In order to allow the commercialisation of hydrogen mobility in Europe to continue, European markets must attract an increasing share of the FCEVs being produced worldwide. This will help to justify the continued development of the HRS networks, as well as increasing the loading of existing stations, and gradually increasing the visibility of the technology.

First generation FCEVs are produced in relatively small quantities. For example, the first generation Hyundai IX-35 was limited to approximately 1,000 units while Toyota produces a total of 3,000 Mirais annually. The main early markets for these vehicles are South Korea and Japan (home markets for Hyundai and Toyota respectively), California (which has very strong zero emissions vehicles policies) and Europe. This creates an element of competition between the launch markets, with OEMs making decisions on the number of vehicles allocated to each region. The FCEV manufacturers under HyFIVE have provided some insights into the process that determines where FCEVs are allocated across the global markets. Criteria for market selection may include the following:

- Extent of HRS deployment in terms of a) capability for long-distance driving and b) level of local redundancy (i.e. the density of refuelling stations within a particular area).
- The reliability of the HRS network, as well as the level of provision of reliable live data on station status (to ensure that customers can easily see whether stations are available for use).
- Strength of the economic FCEV customer proposition in that market (dependent on the incentives for FCEVs and hydrogen relative to gasoline/diesel vehicles).
The presence or absence of zero emission vehicle mandates, which require a proportion of total sales to be zero emission vehicles. The ZEV mandate in California (in parallel with obligations to deploy HRS) creates a strong pull factor relative to other US states.

Size and accessibility of FCEV adopter markets for specific manufacturers (accessible markets being defined as within existing customer groups for that manufacturer). For example, even if fleet customers are identified as having a good business case for use of FCEVs in a particular country, if a manufacturer has not previously provided vehicles to fleet or commercial customers in that country, this would reduce the likelihood of that market being a priority target for early FCEV production, due to the costs involved in setting up the retailing avenues for a new market (this would also depend on the size of the market, and hence the potential gains for that manufacturer).

Extent to which FCEV adopter markets are complementary to (as opposed to in competition with) EV market share for that manufacturer. Using the example of fleets, if a particular manufacturer has a leading market share in the provision of EVs to particular fleet customers with moderate range applications, this market is unlikely to be suitable for FCEV sales.

The number of FCEVs brought to European markets will depend on how these markets measure against other global markets, such as Japan, California and Korea, in terms of the criteria above. To maximise the position of European markets against these criteria, and thereby secure a share of future FCEV sales, key players within European hydrogen mobility need to continue to collaborate to identify the largest potential markets for localised FCEV customers (and where these overlap with existing offers from relevant manufacturers) and use demand-led strategies to increase the density of HRS networks. In addition, national and regional governments can play a role to ensure that policy environment relevant to potential FCEV customer groups allows the customer proposition to be sufficiently competitive with that outside Europe. Existing partnerships between industry and government should be used to initiate communication with key decision-makers for international OEMs, to ensure that any demand-led strategies are aligned with OEM plans regarding particular markets and/or customer groups.
4 Delivering the European network of hydrogen refuelling stations

This section reflects on the experiences and role of HRS suppliers and operators in delivering HRS networks in Europe. The HyFIVE project partners include many of the major European HRS suppliers as well as FCEV manufacturers, and throughout the project these partners shared experiences and feedback on the deployment of refuelling stations, capturing both short-term and long-term priorities for improvement to ensure positive customer experiences and a sustainable network of refuelling stations.

Figure 4-1 summarises the infrastructure priorities for early markets (i.e. mainly fleet or business users) and for the transition to mass markets (where the number of vehicles in each city starts to exceed 100 vehicles, and the customer base becomes increasingly diversified), and indicates the areas where progress has been made against these priorities, and where significant further work is required.

As the initial HRS networks have developed, considerable progress has been made against many of the early priorities. However, each of these have been achieved to varying extents in different European markets, and continued efforts across the sector will be essential to ensure that the needs of early customers are met.
4.1 Experience of HRS network expansion in European countries

This section explores the challenges and lessons learned in planning and delivering HRS networks to date in terms of addressing the priorities outlined in Figure 4-1.

4.1.1 Strategies for planning HRS networks

In each of the key European hydrogen mobility markets, various working groups and partnerships including HRS operators, government stakeholders and (in most cases) vehicle manufacturers have been established with a view to developing strategies for coordinating the development of HRS networks. These groups broadly share a common long-term objective, i.e. to achieve national HRS coverage to enable adoption of FCEVs by mass market customers, and the work of most of these groups has included strategic planning of how (and where) the network should be initiated and developed over time. However, there is significant variation between markets in terms of commitment to delivering these strategies and the roles adopted by government and industry stakeholders. For example, the organisation H₂ Mobility Germany is a formal joint venture between six industrial actors (Air Liquide, Daimler, Linde, OMV, Shell and TOTAL), which is jointly investing in up to 400 HRS to be deployed by 2023. In other countries such as Denmark, France or the UK, there are national hydrogen mobility initiatives that are a looser association of partners. These act as discussion forums to co-ordinate the ongoing rollout of HRS and vehicles, while investments are done individually rather than through a formal legal entity.

The extent of deployment of FCEVs and HRSs to date (outside Europe as well as within the European markets) suggests that the initial success of hydrogen mobility for passenger cars is linked to the extent of government and industry commitment to support the development of the early HRS network. As discussed earlier in this report, fleet customers have the potential to provide a significant proportion of early demand for FCEVs due to their demand for higher driving distances and short refuelling times. The gradual rollout of FCEVs between now and 2020 beyond small-scale demonstration activities provides a strong incentive for HRS operators to closely match early station locations to likely demand hotspots from such customers, as opposed to locations which are seen as contributing to a strategic national network. For example, in Denmark, a potential station location was moved based on a higher number of firm commitments for FCEV purchases at a second site. Siting stations on the basis of firm commitments from local customers guarantees a minimum baseload for the HRS, which can help to avoid underutilisation and improve station performance, as well as improving the business case for operation of public HRSs (which is a key challenge in the early stages of FCEV deployment).
This approach has been formally adopted in successor projects to HyFIVE. For example, H₂ Mobility Germany has recently decided the locations of the next wave of HRS by inviting letters of interest from cities and businesses to ensure that there is sufficient baseload demand before the final sites are decided. In France, station locations are strongly influenced by the presence of local fleets, with letters of intent and commitments being used to reduce the underutilisation risk.

4.1.2 Reducing delays to station delivery

As HRS networks develop, the timescales for station opening can be a critical factor determining FCEV market success, as potential customers rely on the existence of conveniently located stations to enable them to purchase and use FCEVs. In Europe and worldwide, station openings have been subject to delays throughout the deployment process, but as experience of national planning processes grows, the timescales have considerably decreased.

The following lessons for reducing the time required for installation of future stations are drawn from the experience of the HyFIVE partners:

1. Permitting for the first hydrogen station in a country or even within an area can be significantly longer than in places with existing HRSs, due to the unfamiliarity of the technology to the relevant authorities. In countries with devolved (i.e. local) planning authorities such as the UK, obtaining permissions and safety approvals for subsequent stations is likely to involve a greater administrative burden (and hence a longer delivery timescale) than in those where more planning decisions are made at a national level (such as Denmark).

2. Time required for station delivery can be reduced by:

   a. Identifying at least two back-up sites;
   
   b. Gaining an understanding of local and national permitting processes, and the parties involved;
   
   c. Engaging with the relevant authorities early in the process to familiarise them with the technology and its benefits;
   
   d. Pre-preparation of detailed safety and educational information;
   
   e. Thoroughly testing equipment offsite to reduce the time for onsite testing.
   
   f. Use of containerised station solutions can reduce installation times and provides more flexibility to enable re-siting. However,
containerised solutions are unlikely to be appropriate for forecourt-integrated stations.

In order to facilitate planning processes and reduce the burden on HRS suppliers to produce comprehensive information packs for health and safety and planning authorities, various national industry and policy working groups have been established to create guidance documents and/or update the planning and construction environment for hydrogen. Work to date has included a hydrogen addendum to the Blue Book (UK guidance for petrol station design and construction) to allow forecourt integration, and the collection of evidence for the permission of 700 bar refuelling and reduced safety distances in Italy.

4.1.3 Improving HRS access and visibility

Although many of the early HRSs in Europe were installed on sites without the visibility or convenience of access of conventional filling stations, an increasing number of stations are now being co-located with or integrated on gasoline and diesel forecourts, thus bringing greater visibility to the technology. For example, two of the five new HyFIVE stations are at service stations, giving high visibility to the technology (on the M25 motorway near London, and on the 304 road into Munich). HRS suppliers have now developed relationships with traditional fuel retailers and new forecourt-integrated stations are planned. For the case of the UK, now that a precedent has been set for forecourt-integrated stations, it is likely that this will facilitate approvals for future forecourt-integrated stations. Furthermore, station suppliers are actively exploring options for modular equipment designed to be more easily integrated in forecourts, as tighter space constraints mean that reducing the footprint of refuelling equipment will be a priority for future stations.

4.1.4 Branding and signage

As with conventional fuels, hydrogen is and will be supplied by number of different HRS operators through a competitive market. Hence it is not desirable or feasible to completely standardise the station branding across all sites. Nevertheless, it is desirable to consider a consistent ‘look and feel’ as users currently experience when they visit petrol forecourts of different operators. This includes things like the colour of the nozzle, the information displayed on the dispenser and meter, the way hydrogen is priced (for example per kg or per 100g as this varies between stations in the three HyFIVE clusters). A further element to this ‘look and feel’ is whether the refuelling station equipment is hidden from the user versus highly visible and surrounded by protective fences and giving the look of an industrial installation. Recently deployed stations have made good progress in this
aspect, with facades and a customer friendly industrial design used to give the impression of a ‘polished’ product rather than early demonstration equipment (shown in Figure 4-2 for the recently opened station at Cobham, London).

Figure 4-2 Shell & ITM Power hydrogen station at Cobham services, London

A final element is the use of a common logo to indicate the availability of hydrogen fuel on HRS signs or road signs (for example highlighting availability of fuels at a nearby service station). This is especially important where there are stations offering 350 bar and 700 bar hydrogen (possibly at different prices). A logo design has been agreed in principle by a number of industry and national government stakeholders, and the HyFIVE project partners and the national hydrogen mobility initiatives are exploring the process and cost which would be involved in implementing this in signage.

4.2 Experience of HRS operation in European countries

This section explores the priorities for improvement of HRS operation, and the progress made and lessons learned by HRS operators to date in their work towards addressing these priorities.

4.2.1 HRS reliability

A high level of station reliability (i.e. minimal unscheduled downtime or problems with the HRS) is vital to ensure that customer journeys are not restricted. This is particularly important in a developing HRS network, since there may not be alternative stations nearby in the event of a technical
problem. Many of the existing stations in Europe have been subject to various problems during their initial months of operation, but improvements in station availability (up to levels of 98% and above) have been observed for most new stations after the first few months of operation. Several suppliers and operators are making a transition to increased remote maintenance, and more detailed station data is being collected to allow common issues to be identified. In addition, suppliers are contributing to the development of performance standards (and test procedures) for particular station components.

However, further improvement to average availability of stations is required to give consistent quality of service and across network, to fully match the current petrol/diesel experience. Care should be taken that older stations also achieve high availability, as problems with isolated stations could disrupt to customers and reputational risks even if newer stations are highly reliable. Station operators and suppliers need to continue to work to reduce the period after a new station opening before 98% availability is achieved.

From the experience of the HyFIVE partners, high reliability can be achieved through a combination of:

1. Provision of reliable, high quality components
   - Station suppliers have identified reliable options for key components, but the supply chain is still maturing.

2. Identification of preventative maintenance needs
   - Collecting and understanding data generated by the station (especially remotely) is essential to enable this and to understand how to quickly address any issues
   - Having an FCEV which can be used by the operator for live refuelling tests can assist in understanding issues

3. Swift delivery of both preventative and reactive maintenance as required
   - Where the station supplier is not the station operator, detailed contracts for operation and maintenance responsibilities should be clearly defined prior to construction, and should specify required timescales for maintenance which reflect the targeted levels of availability (98% and above)
   - New station operators are recommended to provide 24/7 availability of local technicians to maintain high availability
Some minor issues can be addressed remotely (e.g. resets of certain systems)

Several HRS operators have observed that training of HRS users helps maximise the chance of successful refuelling events, since it reduces problems due to user errors or lack of understanding. However, it is important to focus on improving HRS ease of use to avoid the need for training in the future, since individual training of new FCEV drivers may be feasible for small fleets but does not scale to large numbers of sales.

### 4.2.2 Communicating station status

As the numbers of FCEV users and hydrogen refuelling stations in Europe have increased, demand has emerged for maps and apps communicating live data on station availability, to allow drivers to plan their routes and ensure that they do not make plans to refuel at a particular station when it is undergoing maintenance. A variety of maps and apps are currently available, but reliability of availability data is currently uncertain due to varying sources and methods of data collection. Suppliers are in discussions around inclusion of live availability data provision as part of the requirements for new stations, and data loggers collecting live availability data have been installed on some stations across Europe to test the concept for a common European availability system (a feasibility study funded by the FCHJU). However:

- Lack of connectivity of some older stations is a potential challenge in creating a complete picture of the live availability of the European refuelling network
- Funding options and responsibility for a complete availability system have yet to be agreed, but are being explored as part of the FCHJU funded project on this topic.

### 4.2.3 Usability and customer support

Currently, FCEV customers may require guidance the first few times they refuel at an HRS, and at the majority of HRSs in Europe this is provided through a combination of training (leaflet, video or in person) on first use, simple instructions on the station itself, and 24/7 assistance hotlines. In general, once customers become familiar with the process of refuelling, feedback on usability is very positive, and the frequency of hotline calls is low.
In the long term, user training will need to be phased out to avoid any implications that the process is unsafe, and to reduce costs to HRS operators, but a higher level of usability combined with a greater public awareness of hydrogen technology is needed to enable this. European station suppliers are working on revising station designs to make them more user-centric, on the basis of detailed feedback about stations from initial customers. This includes the refuelling equipment itself, and consideration of options to enhance the experience (such as screens displaying information about the refuelling process). Outside of Europe, in California, BMW subsidiary Designworks has been working with Shell to develop a new dispenser design, which includes a light guidance system and a more ergonomic nozzle which is easier to hold than existing options.
4.2.4 Payment and metering

Most refuelling station operators currently monitor dispensed hydrogen and arrange payment via the use of access cards or RFID tags which are specific to the stations of that operator. While many commercial, locally-based users are satisfied with using this system combined with monthly billing, the agreed long-term goal is a transition towards more consistent, widely used payment systems, particularly when the target markets start to shift towards private motorists and business users with the demand for pan-European driving, as well as fleet users.

Credit card payment systems have now been installed at a number of stations across the European network, and several operators are exploring options for payment via fuel cards, reflecting the fact that a large proportion of FCEV adopters in the next few years are expected to be fleet or business users. In addition, the process for transition to mobile / app payment is being explored by some operators. As these options progress, operators will need to take measures to manage multiple payment methods (e.g. for fleet and

Figure 4-4 Design for improved HRS dispenser from Designworks and Shell

individual customers with different preferences) and to enable smooth transitions between approaches.

One barrier to universal payment is that in several countries, the legal framework for the sale of hydrogen as a transport fuel requires a level of metering accuracy beyond that which is currently feasible; in Germany, this means that customers currently agree in advance to use a lower metering accuracy in order to purchase hydrogen. Currently, access/payment cards to refuelling stations on the German H2 Mobility network are provided on this basis, and suppliers are exploring technical options for more accurate and cost-effective metering calibration.

4.2.5 Completeness of refuelling

In 2014, refuelling standards (SAE J2601/J2799) were introduced which described the process for communication between a station and a vehicle during refuelling, enabling a more complete refuel compared to some previous stations. Under HyFIVE, the capability of new stations to refuel multiple vehicles to 100% in quick succession has been demonstrated via back-to-back testing. However, older stations without refuelling communication capabilities, and those following certain older refuelling protocols, may not deliver complete refuelling, which reduces the maximum range of a vehicle.

Addressing this should be a priority to ensure that the long distance, zero emission driving capabilities of hydrogen vehicles are maximised. Suppliers and operators need to identify cost-effective ways to update older stations to come closer to the latest standards e.g. through software updates and/or replacement of particular components. In addition, displaying information on the state of charge (completeness of refuelling) achieved would be a useful addition to stations, for customers to gauge the distance possible before the next refuelling event.
5 Recommendations for further commercialisation

The HyFIVE project has successfully demonstrated series-produced FCEVs on European roads in demanding operations and has proved the technical readiness of both vehicles and stations for a more widespread rollout. In order to allow the commercialisation of hydrogen mobility in Europe to continue, stakeholders in European hydrogen mobility must continue to collaborate to attract an increasing share of the FCEVs being produced worldwide and continue to expand and improve HRS networks. The following recommendations set out how these objectives could be achieved, based on the lessons learnt through the experiences of the HyFIVE project partners. Specific recommendations are also provided in HyFIVE deliverables 5.1 (Attitudes of early hydrogen fuel cell car users in Europe) and 5.4 (Progress and lessons learnt from early Hydrogen Refuelling Station networks in Europe).

Identify (and locate) the largest potential markets for localised FCEV customers and where these overlap with existing offers from relevant manufacturers

- Vehicle manufacturers should use the feedback on early sales operations to define the customer types likely to take up FCEVs in the short term, and to use this to inform their strategy for early model availability. Based on the HyFIVE results, naturally suitable customer groups include fleet vehicles in cities with current or future restrictions on gasoline and diesel vehicles, or in countries with strong financial incentives that reduce the TCO gap even for relatively high cost first generation vehicles. This is already happening with the highly successful recent FCEV deployments in taxi fleets in Paris and London (through Hype and Green Tomato Cars respectively).

- Existing hydrogen mobility strategy groupings and partnerships between industry and government should be used to maintain communication with key decision-makers for international vehicle manufacturers, to ensure that strategies based on meeting the refuelling requirements of particular customer groups are aligned with vehicle manufacturer plans regarding vehicle availability or model choice for those customer groups.

Once target markets have been identified, ensure that policy and infrastructure provision support adoption by these customer groups

- Policy-makers can help ensure that the policy environment relevant to potential FCEV customer groups allows the customer proposition to be sufficiently competitive with that outside Europe. This could include policy that incentivises zero-emission driving in polluted areas, or subsidises the sale of renewable hydrogen. In particular, care is needed where
incentives are applied both to battery electric vehicles and FCEVs. Where these incentives are to be phased out due to falling prices and increasing sales of BEVs, to avoid negatively affecting early FCEV sales it may be necessary to preserve incentives for FCEVs for a longer period, reflecting their different levels of commercialisation and the different roles that the technology may play in decarbonising road transport.

- HRS operators should work with vehicle manufacturers to ensure that highly visible and convenient HRS are built close to FCEV customers, and that the priority needs of these customers are met.

**Use demand-led strategies to increase the density of HRS networks by reducing the utilisation risk in the early years**

- Fleets seeking to adopt multiple FCEVs should signal this demand both to vehicle manufacturers and HRS suppliers. This allows them to secure favourable prices for large vehicle orders, as well as influencing the locations of stations since they can offer a significant ‘base load’ of hydrogen demand for a new station.

- Government can facilitate this through funding competitions to identify clusters of FCEV demand in fleets. In the UK, this alignment between HRS deployments and fleet purchases is encouraged by the ongoing funding competitions run by the Office for Low Emission Vehicles.

- HRS operators should also explore whether stations can serve several vehicle types, allowing for a higher utilisation level compared to refuelling only passenger cars. Other vehicle types include light commercial vehicles (i.e. vans) as well as heavier vehicles such as trucks and buses. For heavy vehicles, fleet operators are likely to prefer separate depot-based stations in the long term, but in the short term when fleet sizes are low there may be opportunities to share stations to reduce the initial infrastructure costs. In addition, where there is significant hydrogen consumption by trucks or buses, this could allow decreases in the prices of delivered hydrogen within the same city/region even if light and heavy vehicles use different stations.

- Overall, HRS should aim to show that high levels of station utilisation can be reached where a high concentration of hydrogen demand can be found in the local area. Reaching fully utilised stations will provide additional technical learning (for example confirming that high station reliability can be maintained with high hydrogen throughputs), as well as confirming to potential investors that hydrogen stations can be operated profitably. This is critical in unlocking the significant investments that will be required to continue the build-out of the network in the 2020s.
Continue to reduce the timescales for deployment of new stations

- In planning new stations, suppliers and/or operators should engage with planning and safety authorities at the earliest possible stage and refer to successful cases of initial stations elsewhere in Europe to minimise delays due to lack of experience of the technology.
- Policy-makers can assist in this process by highlighting the growing experience of hydrogen mobility worldwide. The formation of industrial or industry-government partnerships can be a powerful tool in achieving higher levels of engagement within the relevant authorities.
- These efforts are already starting to simplify permitting procedures through the creation of national guidelines that can be used when approving planning applications. This includes the creation of an annex for hydrogen stations in the UK’s guidance document for the construction of petrol/diesel refuelling stations, and the proposed law currently in the French parliament which will standardise safety distances for future HRS deployments.

Continue to improve the reliability of new and existing stations

- Suppliers should draw on experiences of existing stations to ensure that components for future stations are reliable and of high quality, and ensure that compliance with the latest standards can be demonstrated.
- Operators should work with suppliers to explore cost-effective options to bring reliability and performance of all stations to a consistently high level. This should include enabling collection of detailed operational data to allow specific issues to be identified remotely.
- Operators should ensure that detailed maintenance contracts with suppliers are set out prior to construction, including required timescales for maintenance which are aligned with availability targets.
- Operators and suppliers should work together to provide more accessible, reliable information on availability of refuelling stations, both to support existing customers and to inform potential FCEV adopters.

Ensure that regulations facilitate the use of FCEVs across different environments

- Vehicle manufacturers and other stakeholders should communicate evidence on the safety of hydrogen in mobility applications to ensure that regulations are updated or created to enable more widespread use of FCEVs (including in environments such as car parks).
All stakeholders should continue to communicate the short and long term strategy for FCEVs to the general public, including:

- Clearly articulating the benefits of FCEVs and their readiness for real world use, and correcting any misconceptions about safety or reliability, or the idea that FCEVs are not yet ‘ready’.
- The types of customers expected to be the main users of fuel cell vehicles in the short term, and the rationale behind this in terms of the need for fast refuelling and the benefit of clusters of demand in the early stages of HRS roll-out.
- The strategy for the rollout of the hydrogen refuelling station network, both to meet the needs of users in the short term (for example fleets in major cities) and the national/cross-border mobility of private customers in the longer term.
- The expected market size for fuel cell vehicles in the long term in different vehicle segments and customer types, making clear the complementarity with battery electric mobility for long-range, demanding duty cycles.
- The long-term role of hydrogen in the decarbonisation of transport alongside other technologies such as battery electric vehicles. Existing industry initiatives such as the Hydrogen Council and Hydrogen Europe are playing and will continue to play a key role in this.

Many of these recommendations are already being implemented in the EU-funded projects that have succeeded HyFIVE, such as the H2ME and H2M2 projects. In particular, these projects have seen the emergence of promising business cases for taxi fleets in Paris and London, and significantly improved HRS utilisation levels for stations due to the presence of base load from these local fleets. A further FCH JU-funded project named ZEPHYR, which began in January 2018, focuses specifically on taxis and government fleets in London, Paris and Brussels, with the aim of demonstrating near 100% utilisation of HRS in those cities. This will be an important milestone, and by proving that stations can see high hydrogen demands even in the early years of the rollout, the project will help attract further investment and new actors into the sector.

In parallel with the ongoing work on refining the consumer experience (such as live availability maps and improvements in metering and payment methods), these ongoing projects will ensure that the groundwork is laid for the introduction of second generation FCEVs in the early 2020s. These lower cost vehicles will be available in more models from a wider range of manufacturers, and will facilitate the transition from FCEVs being a vehicle for local fleet use to one that can offer unrestricted national mobility for fleets and private customers alike. In turn, this second generation of vehicles and
the associated HRS network expansion will need to demonstrate that HRS can operate profitably while offering low cost, low carbon hydrogen. This will be key to creating a self-sustaining expansion of the network towards 2030 and beyond, and ensure that FCEVs can play a substantial role in decarbonising road transport.
6 Annex

6.1 Cost assumptions

Table 6-1 Sales prices (EUR)

<table>
<thead>
<tr>
<th>Configuration vehicle</th>
<th>Sales price incl. VAT (December 2017 values)</th>
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<tbody>
<tr>
<td>Toyota Mirai</td>
<td>78,540</td>
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<tr>
<td>Hyundai ix35 Fuel Cell</td>
<td>65,450</td>
</tr>
<tr>
<td>Hyundai Nexo</td>
<td>54,000</td>
</tr>
<tr>
<td>Toyota Avensis 2,0-l-D-4D</td>
<td>24,790</td>
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<tr>
<td>Hyundai Tucson 2,0 CRDi</td>
<td>22,740</td>
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<tr>
<td>Toyota Avensis 1,8-l</td>
<td>23,555</td>
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<tr>
<td>Tucson blue 1,6 GDI</td>
<td>17,164</td>
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Table 6-2 Assumptions for consumption-based fuel cost used in TCO calculations

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<thead>
<tr>
<th>Consumption per 100km</th>
<th>Gasoline</th>
<th>Diesel</th>
<th>Hydrogen</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>current</td>
<td>5 year average</td>
<td>current</td>
</tr>
<tr>
<td>EU28 [EUR/100km]</td>
<td>8.34</td>
<td>9.24</td>
<td>5.71</td>
</tr>
<tr>
<td>DE [EUR/100km]</td>
<td>8.55</td>
<td>9.34</td>
<td>5.56</td>
</tr>
<tr>
<td>DK [EUR/100km]</td>
<td>9.33</td>
<td>9.96</td>
<td>5.97</td>
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<tr>
<td>UK [EUR/100km]</td>
<td>8.10</td>
<td>8.64</td>
<td>6.39</td>
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Table 6-3 Assumptions for vehicle tax on ownership, maintenance costs and insurance

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel</th>
<th>FCEV</th>
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</thead>
<tbody>
<tr>
<td><strong>Tax on ownership</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany [EUR/year]</td>
<td>132</td>
<td>246</td>
<td>56 (tax exemption first 5 years)</td>
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<tr>
<td>Denmark [DKK/year]</td>
<td>2220</td>
<td>3560</td>
<td>Tax exemption</td>
</tr>
<tr>
<td>United Kingdom [GBP/year]</td>
<td>1st year rate: 145</td>
<td>1st year rate: 0</td>
<td>Tax exemption</td>
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<tr>
<td></td>
<td>Standard rate: 145</td>
<td>Standard rate: 30</td>
<td></td>
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<tr>
<td><strong>Maintenance</strong></td>
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<tr>
<td>Inspection &amp; Maintenance [EUR/month]</td>
<td>23</td>
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<td>17</td>
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<tr>
<td>Repair [EUR/month]</td>
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<tr>
<td>Tyre replacement [EUR/month]</td>
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<tr>
<td><strong>Insurance premiums</strong></td>
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