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Hydrogen Mobility Europe

H2ME2 Work Package 6: Customer Readiness

Deliverable 6.8 Deliverable 6.16	Commercial advancements in hydrogen fuel retailing Recommendations for harmonising the hydrogen refuelling business in Europe (H2ME2)
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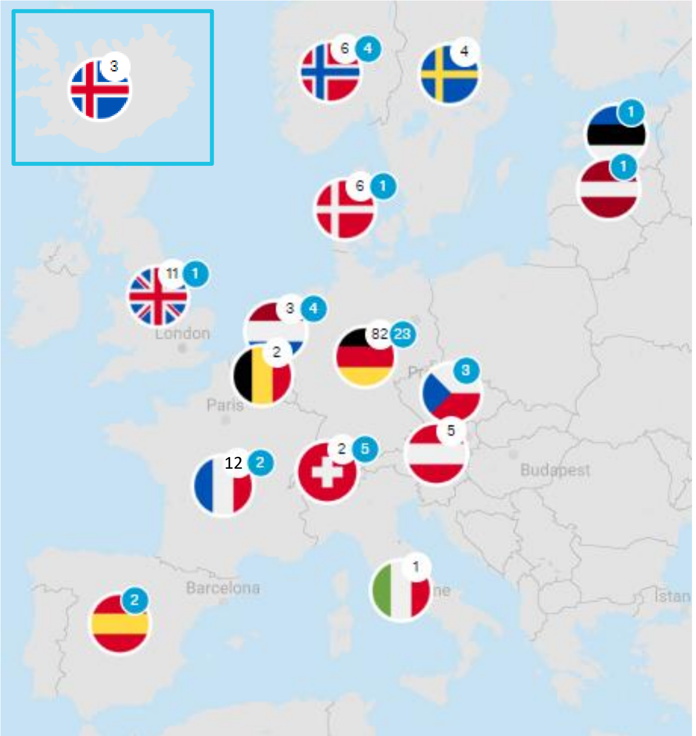
FCH FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

Introduction

To deliver the potential benefits of hydrogen transport, rapid progress is needed in the deployment and operation of hydrogen refuelling stations

Context of this report

- Numerous governments across Europe have committed to limiting the increases in global temperatures by achieving carbon neutrality by 2050. As part of this, rapid reductions in carbon emissions from the transport sector are needed.
- Part of the strategy to achieve this is a switch to **vehicles with zero harmful emissions at the tailpipe**, and very low emissions on a "well-to-wheel" basis – such as battery electric or **hydrogen fuel cell electric vehicles (FCEVs)**.
- FCEVs run solely on **hydrogen, which can be produced through various low carbon production methods**, including electrolysis with renewable electricity and (in the future) reformation of methane with carbon capture and storage.
- Thousands of hydrogen cars are now in use worldwide, and in Europe numerous fleet users are putting them to use in high mileage applications – evidencing the readiness and suitability of the technology for commercial applications. The network of hydrogen refueling stations in Europe is also growing steadily, with **over 130 refueling stations installed to date**.
- However, hydrogen mobility is not yet fully commercialized. **Challenges relating to the deployment and operation of refuelling infrastructure are amongst the main remaining barriers** to wider adoption of hydrogen transport technologies.



Map of operational (white) and planned (blue) hydrogen refuelling stations in Europe as of February 2020[1]. Source: H2Live

[1] Shows predominantly 700 bar stations; 350 bar fuelling points shown when near 700 bar stations, as well as 8 additional 350 bar stations in France

Previous H2ME reports have identified several key issues relating to HRS networks that present barriers to further adoption of FCEVs; these are summarised below:

H2ME partners and their customers have identified the following barriers to wider FCEV adoption:

- **Number of local HRS (i.e. in hydrogen demand "clusters")**
  - A minimum of two HRS per cluster is required to establish demand from light fleet applications; this provides redundancy (allowing HRS maintenance to take place) as well as additional geographic coverage.
  - Some high-mileage light duty fleets need more operational flexibility; to support a higher replacement rate in these fleets, more local HRS are required to provide a greater degree of city-wide coverage.
- **Wider HRS coverage (to enable long distance journeys)**
  - Many business customers (as well as private customers, and some fleets) rely on the ability to make long journeys. In addition, some fleets frequently operate in suburban or rural areas which are not covered by current HRS locations, which tend to be closer to urban centres.
- **Some HRS have limited capacity, performance or interoperability**
  - Some HRS deployed several years ago are not designed to meet the level of demand from recently deployed local fleets, and need to be replaced or upgraded; in addition some relatively recent HRS can only refuel at 350 bar.

Key issues to be addressed to accelerate HRS deployment include the following:

- **Siting and permitting challenges**
  - The time taken to identify sites for HRS and delays at the permitting stage are major factors that have contributed to the deployment of new HRS being slower than envisaged by national strategies.
- **High investment risk for HRS operators and green hydrogen producers**
  - Uncertainty around long-term hydrogen demand creates risk for investors in new HRS and green hydrogen production.
  - Uncertainty around the timings of centralised large-scale low carbon hydrogen production (e.g. at the scale envisaged for the use of hydrogen in heat and industrial applications) also creates a demand risk for short-term, smaller scale green hydrogen production routes.
  - For trucks, lack of certainty around refuelling technology choices (as well as demand) is also holding up progress.

This report assesses the status and progress of commercial issues for Hydrogen Refuelling Stations under the Hydrogen Mobility Europe initiative

Hydrogen Mobility Europe

- Hydrogen Mobility Europe (H2ME) is a **flagship European project**, deploying hundreds of fuel cell hydrogen cars and vans and the associated refuelling infrastructure, across 8 countries in Europe.
- As part of the project, **more than 1,400 vehicles and 49 hydrogen refuelling stations** will be deployed by 2022. More detail can be found on the following page.
- The project is being supported by the European Union through the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). This support is matched by **significant financial commitments from leading vehicle manufacturers and infrastructure developers**.

Overview of this report

- One of the key aims of the H2ME initiative is to analyse and summarise the findings and lessons learned as a result of the deployment activities during the project, in order to provide guidance for Member States and industry stakeholders in developing and implementing their own plans for hydrogen mobility.
- Ensuring customers' experiences match, if not exceed, that of the incumbent technology is critical for the success of new technologies. Despite improvements across a number of areas in HRS networks and hydrogen fuel retailing, **various challenges still remain before the convenience of petrol/diesel refuelling is matched**.
- This report forms an interim deliverable (2 of 5 across H2ME and H2ME2) performing a **critical assessment of the commercial issues relating to Hydrogen Refuelling Stations (HRS) and the sale of hydrogen as a fuel**. This document builds on the previous iteration of this report, published in late 2018, and covers numerous topics, from siting and permitting to business cases. For each of these topics, the report provides an overview of the current status, areas of progress and best practices identified, and priorities for further work. Several further updates will be provided before the end of Hydrogen Mobility Europe in 2022.

The findings of the report are based on the experiences of the H2ME project partners, which have been shared through interviews and workshops

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Hydrogen Mobility Europe

- **The contents of this report is drawn predominantly from bilateral interviews with vehicle manufacturer (OEM) and HRS stakeholders**, as well as workshop discussions held throughout the duration of the project.
- The project partners have contributed to the deployment of over 130 public HRS and over 1,000 cars and vans in Europe to date. This report draws on the lessons learned as a result of these activities.

HRS partners (suppliers and operators)

- Air Liquide
- CNR
- H2 MOBILITY (Germany)
- McPhy
- WaterstofNet
- CASC
- GNVERT/engie
- ITM Power
- Nel

OEM partners

- BMW
- Daimler
- Honda
- Symbio
- Toyota

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Several topics relating to different aspects of public refuelling network development are explored

This report explores the following topics:

1) Siting and permitting

While some progress has been made, challenges associated with siting and permitting can still lead to significant delays for new HRS deployment

2) Communication with customers

The public HRS network is still in early stages of development, and therefore making key information (e.g. HRS availability) easily available to customers is important to make the customer experience as positive as possible

3) Technical performance

Good HRS performance (including availability and the ability to fully refuel FCEVs consistently) is vital to maximise the customer proposition of hydrogen mobility

4) Safety

Best practices on HRS safety must be widely disseminated to minimise the risks associated with hydrogen as a transport technology

5) Business cases

The wider rollout of hydrogen mobility will rely on the development of sustainable business cases for HRS operators; challenges to be addressed include demand risks and supply chain immaturity

Each section of the report will focus on a specific topic, broadly following the overall structure below:

1. Overview of issues
2. Examples of recent progress and ongoing work
3. Lessons learnt
4. Best practices and further work required

Siting and permitting

Identifying and securing suitable sites for HRS can be challenging due to land availability constraints

Overview of siting issues

- According to end user survey results, the low number of refuelling stations is the most commonly cited barrier to adoption of FCEVs.
- The time taken to **identify sites** for HRS and **delays at the permitting stage** are major factors that have contributed to the deployment of new HRS being slower than envisaged.
- **Identifying and securing suitable sites can be very challenging due to limited availability of land.** This is particularly the case for sites in urban hubs and high-traffic locations.
- **Whilst the co-location of HRS on existing forecourts can help address this challenge**, it relies on partnerships with existing fuel providers. There are active efforts to establish relationships with fuel providers in several countries across Europe. In the UK, the process for forecourt co-location has been made easier by the addition of hydrogen to the Blue Book (a guidance document for petrol forecourts). This has also helped to normalise hydrogen as a fuel.
- Forecourt integration nevertheless comes with its own challenges – generally there is **more competition for space on-site and negotiations are needed** between the fuel provider and the HRS operator, and in some cases there are **more complex administrative processes associated with integrated stations**.
- **Reduction in the time taken to find suitable sites is not guaranteed in the future –** many early stations are at relatively straightforward sites that could be considered as 'low hanging fruit'. Conversely, **as familiarity with the technology grows**, and partnerships with conventional fuel retailers develop, this should bring improvements to **siting times and locations.**

The vast majority of Germany's stations are located on existing petrol forecourts, which brings both challenges and opportunities

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Case Study: siting approach in Germany

- **H2 MOBILITY is a joint venture** responsible for establishing a **nationwide hydrogen refuelling infrastructure** to supply FCEVs in Germany. Due to shareholder obligations, **H2MOBIITY must build 90% of its HRS on existing petrol stations** from Shell, Total, and OMV. In return, H2 MOBILITY will be **offered potentially suitable locations** by its shareholders.
- The advantage of this approach is a **broad selection of possible sites in attractive locations** at traffic hubs and city centres.
- Challenges however arise for HRS concepts with large space requirements e.g. for bus/truck refuelling. The **limited available space at existing refuelling stations can lead to conflicts of interest** between the station operator and the HRS provider (reduction of parking spaces and other service facilities).
- The selection and evaluation of a potential site is done according to a **Scoping Protocol** developed by H2MOBILITY. This protocol considers site parameters that may prevent the implementation or affect the cost and timeline of the HRS project. The scoping is carried out on-site.

PARAMETER	DESCRIPTION
ENTRANCES AND EXITS	
USE OF CONVENTIONAL PETROL STATION	Installations, opening hours, customers, etc.
USE OF THE NEIGHBOURHOOD	Apartments, commercial
CLASSIFICATION IN ACCORDANCE WITH THE FEDERAL BUILDING UTILISATION ORDINANCE	Residential area / mixed area / commercial area / industrial area
BUILDING GROUND	Soil structure, potential contamination
ENERGY SUPPLY	Transformer capacity /distance to energy supply
FIRE WATER SUPPLY	
BUILDING CHARGES / EASEMENTS / OWNERSHIP	
SPECIAL FEATURES	Power poles, manhole covers, etc. in the possible area of the HRS
HRS LAYOUT PROPOSAL	Description/quick ckeck of possible HRS layouts
PROPERTY BOUNDARIES	Compliance with distances (5m) to the property line for HRS layouts
SPACE REQUIREMENT	Usable space (parking spaces etc.)
COLLISION PROTECTION	Requirements per HRS layout proposal
FIRE PROTECTION	Requirements per HRS layout proposal
DISPENSER INTEGRATION	Integration/Stand Alone, Distance between container and dispenser
H2-SUPPLY	Accessibility; Reverse driving required?

The table above shows the parameters considered in the H2 MOBILITY Scoping Protocol.

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Once potential sites have been identified, the process of gaining planning permission can lead to significant delays to HRS deployment

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Overview of permitting issues

- Once a potential site has been identified, **HRS operators must apply for planning permission from relevant bodies – in most countries this involves engaging with local authorities, though regulations can exist at the national or regional level depending on the country.**
- **Significant variability exists across regions and countries with regards to permitting times**. For example, in Denmark there are cases of approval being granted within a week, whilst in France sites have in some extreme cases taken more than 24 months to gain approval. Generally, **countries where regulations relating to permitting exist at the national level have been able to reduce approval times to a much greater extent than those with regulations and processes that differ at the regional level.**
- **Gaining permits for the first HRS in an area generally takes longer than anticipated**. Early stations establish a precedent which makes gaining approvals for future stations in the same area easier. This is especially the case in countries which implement relevant regulations at the national, rather than regional, level.
- **Where national legislations exist, it is easier to replicate application processes as well as use demonstrated precedent to reassure and familiarise newcomers to hydrogen stations**. In contrast, countries where regulations relating to permitting vary by region require engagement with a new municipality and their own specific set of regulations and processes for each new HRS. Even changes of personnel within organisations can lead to having to work with a new set of key stakeholders, hindering progress.
- **As familiarity with the technology grows**, particularly within organisations in charge of granting permits, **it may be that permitting times improve.**

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The requirements for permitting vary by country (and in some cases by region)

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Examples of regional differences in permitting processes

- A number of **factors influence the time taken for approvals to be granted** for permits including:
  - **Existing planning processes** (variation between municipalities and countries);
  - **Level of knowledge and experience** in planning and safety bodies with regards to hydrogen;
  - **Cooperation** of local authorities and landlords;
  - **Type of site** e.g. urban / suburban / rural; forecourt integrated / standalone;
  - **Hydrogen supply and production factors** e.g. on-site electrolyser / amount of on-site hydrogen storage / space required for hydrogen deliveries.

- <u>**Denmark**</u>
  - In Denmark, **national planning processes are implemented at the local level i.e. by local authorities**. Using existing stations as established precedent has allowed for vast improvements in the time taken for permitting approvals to be received (e.g. 6 months in 2012 down to less than a week in 2019).
- <u>**Germany**</u>
  - In Germany it is necessary to apply for a building permit and an operation permit. Whilst the latter is governed by clear national regulations, the former is managed by regional regulations. This means that **repeated engagement with local authorities is required for every station in a new municipality**.
- <u>**France**</u>
  - **In October 2018, the permitting process** for stations with under 1 ton of on-site storage **came under one standardised online process**. However for stations with on-site electrolysers and on-site storage > 1 ton, **variation at the regional level is still a challenge.**
- <u>**UK**</u>
  - In the UK, **local authorities grant planning approval** and so engagement to understand the requirements of different authorities is needed for **every station in a new area.** Even in areas with existing HRS, turnover in key personnel can result in the need for **repeated engagement with the same local authority.**

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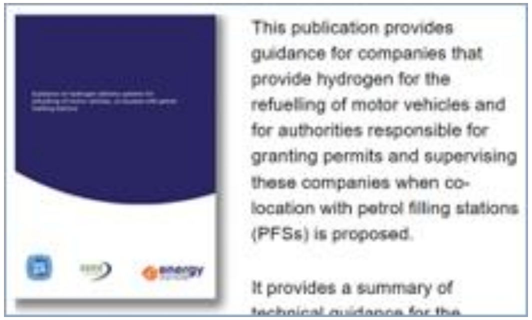
Progress has been made in several aspects of siting and permitting, but permitting times are still variable

Recent progress and on-going work for siting and permitting

- **On-going work across many regions in Europe has led to progress in the siting and permitting progress**:
  - **<u>UK</u>**: **Hydrogen addendum to Blue Book** (UK guidance for petrol station design and construction) to allow forecourt integration. This was a major step in the normalisation and integration of hydrogen as a fuel type in the UK. Work is on-going with the Office for Low Emission Vehicles (OLEV) **to relax parameters on noise restrictions in residential areas.** If successful, this could make available some sites in more central locations, again helping to normalise hydrogen as a fuel type.
  - **<u>France</u>:** Prior to October 2018, the permitting approval process was split between two authorities (DGPR – national and DREAL – regional). **Since October 2018, a new single ICPE online process was established** for stations with less than 1 ton of on-site storage. Uncertainty however remains with regards to how the new process applies to stations with on-site electrolysers.
  - **<u>Germany:</u>** H2MOBILITY, the joint venture leading on the rollout of HRS in Germany, has a partnership with the major petrol fuel retailers in Germany – Shell, Total, OMV, meaning that **90% of their stations will be built on existing petrol forecourts**. Since 2016, there has been a reduction in average HRS delivery time from 24 down to 12 months.
  - **<u>Benelux</u>**: Efforts are being made to **inform permitting agencies of hydrogen mobility, even in advance of its rollout** so that familiarity with the technology can be established.
  - **<u>The Netherlands</u>**: the Dutch Ministry is setting up a **trouble-shooting initiative (H2 Platform)** in order to speed up the development of HRS and share learnings regarding a number of HRS issues. **The platform aims to offer information and assurances to local authorities to speed up the permitting process,** which is taking more time than expected.


This publication provides guidance for companies that provide hydrogen for the refuelling of motor vehicles and for authorities responsible for granting permits and supervising these companies when co-location with petrol filling stations (PFSs) is proposed.

It provides a summary of

UK H2 addendum to Blue Book

Choice of site can have critical implications for speed of permitting and future 'success' of HRS

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Lessons learnt for siting

- **Choice of site is critical and can greatly impact speed of permitting.**
- **Developing planning applications with a siting partner** (and other local specialists) improves the chances of obtaining planning permission for new HRS.
- **Working with existing gas (petrol/diesel) stations can be more challenging** due to additional requirements and considerations.
- Whilst station locations near to main roads or important city hubs (such as airports) provide convenience and visibility, **access can be difficult** due to traffic or parked cars obscuring the station entrance.
- Some landlords may also put parking enforcements in place for sites in busy areas, which can impose restrictions for HRS maintenance staff accessing the site.

Best practices for siting

- **Define a clear set of criteria before identifying sites and ensure that these inform selected sites.**
- **Engage with vehicle deployment stakeholders to determine preferred site locations and ensure accessibility is considered.**
- **Identify at least two back-up sites** as this helps adaptability if permission for one site falls through.
- **Future-proof HRS during the initial site assessment** to reduce the time needed to increase capacity at future dates when demand is likely to require it e.g. ensure there is sufficient space on-site for anticipated upgrades.

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Lessons learnt and best practices for HRS permitting should be disseminated to all stakeholders involved in the implementation of hydrogen mobility

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Lessons learnt for permitting

- **Involvement of local authorities/regulatory bodies during early project stages reduces the risk of delays** due to planning and environmental issues.
- **Permitting for the first hydrogen station within an area can take significantly longer than anticipated.**
- **On-site generation (electrolysis) generally makes the permitting process more complex** and can lead to variable timelines.
- **Working with existing gas (petrol/diesel) stations can be more challenging** due to additional requirements and considerations.
- **Unexpected/unforeseen challenges often lead to delays:** e.g. unknown sewage pipes, local elections delaying permit approval, landowners changing their minds.
- In some residential areas, **noise constraints** can be impossible to meet due to compressor noise.

Best practices for permitting

- **Engage in early and continuous communication with relevant bodies and authorities**, including: fire fighters/marshalls, local municipalities, regulatory bodies, landowners, utilities operators, civil sub-contractors.
- **Where possible, gather support (and evidence of support) from hydrogen associations and national government.**
- **Hydrogen mobility stakeholders should contact local municipalities as a collective** to demonstrate cooperation and that the HRS is widely supported by different actors.
- **Obtain legal advice** to review leases and highlight constraints/issues at an early stage.
- **Prepare detailed safety and educational information** to provide to permitting bodies in advance.
- **Use established precedent of previous stations to reassure stakeholders** new to hydrogen and to speed up process of permitting in new areas.
- **Encourage standardisation of regulations and procedures** – regions where building and permitting are centrally regulated are better able to reduce times for siting and permitting e.g. Denmark 6 months (2012) down to less than a week (2019).

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Further work is required to ensure continued improvements to HRS siting and permitting processes

Further areas to be explored

- Opportunities for **standardisation of regulations and procedures relating to permitting**, e.g.:
    - In Germany for building permitting (controlled by local authorities);
    - In France for stations with >1 ton of on-site storage and stations with on-site electrolysers (these cases do not fall under the centralised ICPE permitting system).
- Further **engagement with existing diesel and petrol fuel suppliers** to open up siting options**.**
- Further efforts to gain more **national and regional government support** during siting and permitting processes.
    - This is already happening in some countries; for example, in the UK, ITM Power are working with the government to review noise requirements for planning approvals.
- HRS equipment providers could explore **methods to reduce noise from compressors**.
- Effective approaches for **wider dissemination and adoption of best practices**.

Communication with customers

While hydrogen refuelling infrastructure is still in the early stages of development, communication with customers is important to deliver positive experiences of hydrogen

Overview of communication with customers

- This report explores several aspects of customer communication:
  - **Planned HRS installations**
    - It is important that potential customers are provided with as much visibility as possible on the timing and location of planned HRS, so that they are able to make well-informed decisions on the adoption of FCEVs.
  - **Mapping and availability data**
    - The public HRS network is still in early stages of development, and therefore ensuring that customers have access to key information about refuelling stations (such as locations & availability) is important to minimise inconvenience to customers.
  - **Access & billing**
    - Access and payment at refuelling stations are important issues for achieving an interoperable European HRS network.
  - **Customer support systems**
    - Experiences of HRS operators to date have shown that, in addition to maps and apps, provision of other customer services such as training for new users and hotlines at refuelling stations can improve the overall customer experience and satisfaction with the hydrogen refuelling network.

Communication with customers: Access & billing

Transparency with potential customers is needed on the level of certainty for planned HRS locations and deployment timings

Overview of issues for communication on planned HRS installations

- It is important that potential customers are provided with **as much visibility as possible on the timing and location of planned HRS**, so that they can make well-informed decisions on the adoption of FCEVs. This helps to ensure that, for those customers choosing to adopt FCEVs, expectations on HRS locations are met, thus helping to avoid low customer satisfaction with the technology due to the insufficient number of HRS in convenient locations.
- There have been some cases where customers have purchased FCEVs at least partly on the basis of planned public HRS locations that have then not materialized due to various issues at the planning stage.
  - While consulting potential customers on preferred locations for new HRS is recommended (especially for fleet customers), **if an HRS is still in the planning stages and subject to possible cancellation, HRS operators and vehicle manufacturers should be very careful when communicating to potential customers regarding this HRS**. Communication on specific sites before planning permission has been finalised and construction has started should be limited where possible.
  - Similarly, where planned sites are discussed, it is important that the possibility of significant delays at the planning or construction stage is communicated clearly to potential customers.

Best practices for communication on planned HRS installations

- HRS operators and vehicle manufacturers should:
  - **Avoid making commitments to potential customers regarding sites in specific locations**, unless the HRS is already under construction and there is no risk that the HRS will not be opened.
  - Ensure that communications with potential customers about upcoming HRS are **focused on HRS which have passed the planning and permitting stage**; for example, those where construction has started and the HRS is “committed” to opening.
  - Once a site is committed, **ensure that potential customers are aware of possible delays** to planned HRS opening dates.

Communication with customers: Mapping and availability data

Maps and apps showing live HRS status can be an invaluable resource for early hydrogen vehicle users

Overview of issues relating to maps and apps

- Despite the continuing rollout of stations, Europe's HRS network will remain relatively sparse relative to the existing petrol/diesel station network in the coming years. Providing **reliable and up-to-date information** on the locations and real-time availability of HRS is therefore critical in the short-term (e.g. 2020-2025) to **avoid inconveniencing users** who may travel to an HRS to find that it is not open, and to allow users to **plan their routes**. Feedback from early customers suggests that customers are more understanding of station downtime if they are made aware of this in advance.
- Numerous websites and apps have been developed that show the locations and status of refuelling stations across Europe with **varying degrees of completeness;** these are useful resources for new and existing customers.
- However, **further progress and harmonization of maps and apps is still needed** to ensure that hydrogen vehicle users across Europe can easily find out the status of any HRS.
- In addition, given that HRS operators need to minimize the costs associated with network operation, systems to provide centralised availability data should be **as simple and low-cost as possible** to encourage widespread use of such systems.

Example concept for communicating HRS status online

Source: Spilett (2017) 'Presentation on project process and results, FCH 2 JU Programme Review Days 2017 - Concept for a common European HRS availability system' [PowerPoint presentation] Available here.

Information on HRS in Europe in online maps and apps has increased significantly over the past two years

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Recent progress on maps and apps

- There are numerous websites and apps now providing information on the location of hydrogen refuelling stations in Europe. The table below summarises the provision of some of the public resources that have recently become available:

Resource	App?	Web-site?	Coverage	Location data	Availability status
H2.LIVE	✓	✓	Europe - focuses on 700 bar stations but shows 350 bar fuelling points when located near 700 bar stations	✓ App links to navigation	✓ Data provided by H2 MOBILITY's HRS Connect system (data for HRS outside Germany collected directly from HRS operators or via H2-map.eu)
H2-map.eu (see next slide)	-	✓	Europe	✓ Website links to navigation	✓ Defined by an agreed common definition; updated every 1-4 minutes
FillnDrive	✓	-	Selected HRS in France	✓ App links to navigation	✓ Also includes information on available capacity
PitPoint	✓	✓	Netherlands (+ Europe)	✓	-
VIG'HY	-	✓	France	✓	-

- The table shows publicly available resources; other apps and maps are also available to users of specific HRS networks (e.g. captive fleet users who operate in specific areas).
- As well as data related to live availability status, several of these apps provide additional information e.g. regarding station pressure; opening hours; customer support numbers; and in many cases provide access to and payment options for stations.

The FCH 2 JU funded the development and business case assessment of a real-time HRS availability system

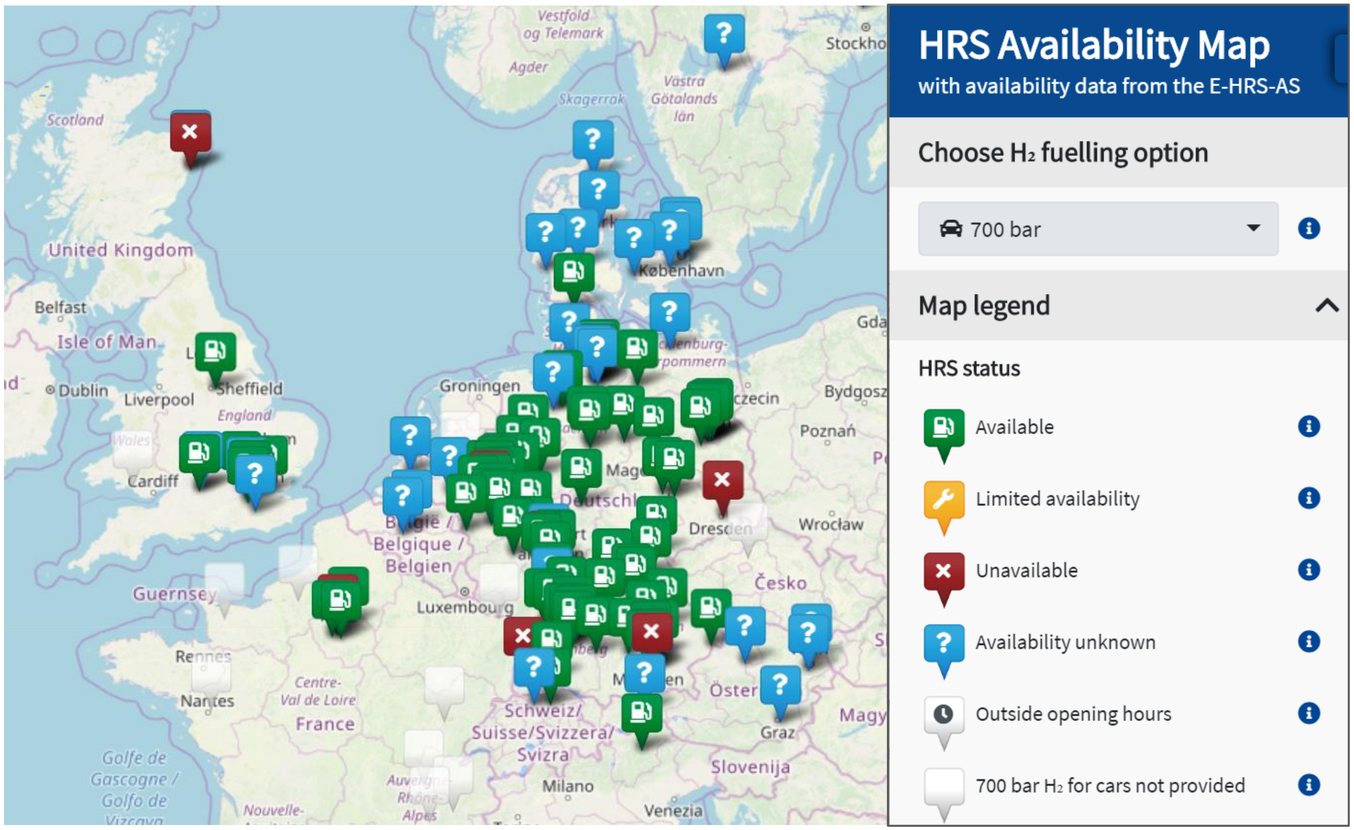
Recent progress on maps and apps

- In 2019, the FCH 2 JU launched the **European Hydrogen Refuelling Stations Availability System (E-HRS-AS)** to provide real-time information on the availability status of publicly accessible HRS across Europe, following the design, testing and trial of this system in 2017-2018. The information is provided via an online map: https://h2-map.eu/.
- Consultation with a range of sector experts led to a proposed common definition of an ‘available’ HRS as one where **users are able to refuel vehicles in line with their refuelling protocol**; as such the map can be filtered according to the type of refuelling available at each HRS, as well as indicating the availability status (screenshots are provided on the following slides).
- In parallel, the FCH 2 JU also funded a business case assessment for the ongoing operation of the E-HRS-AS. Related costs include:
  - Set-up costs for the system (covered as part of the study)
  - Set-up costs for new participating HRS
  - Operating costs for the system (user support and costs of online platform)
  - Software maintenance costs for participating HRS
- Several possible business models were assessed for the ongoing operation of this system and the inclusion of further new and existing HRS; the FCH 2 JU is now considering financing options. One of the key aims of the system is to **provide access to data that can be exported to third party applications (possibly via a subscription fee)**.

- **The following slides provide screenshots of the website.**

Overview of FCH JU-funded HRS availability website (1/2)

https://h2-map.eu/ (February 2020)

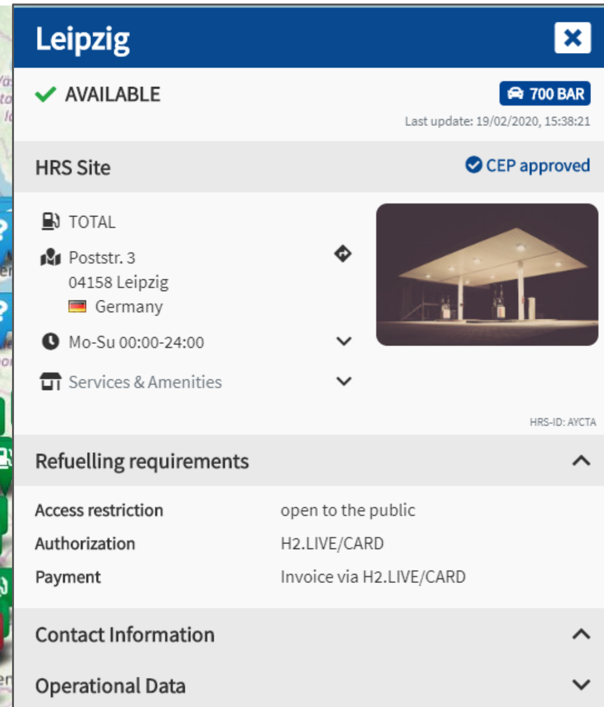


Users can select their required refuelling option so that the map shows only the suitable HRS.

The map shows the HRS status (for the stations which are providing data to the system) according to the legend shown.

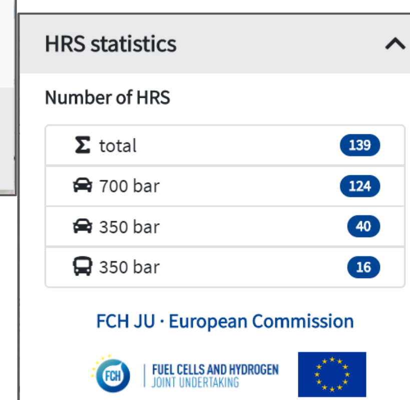
Overview of FCH JU-funded HRS availability website (2/2)

https://h2-map.eu/ (February 2020)



Clicking on an individual HRS brings up detailed information about the station, including status, contact information, and requirements to enable refuelling.

The website also shows the total number of HRS of each type included in the map.



Further progress is needed to ensure that map resources provide fully comprehensive information

Best practices for maps and apps

- For hydrogen vehicle sales teams and fleets: customers and drivers should be made aware of the map resources available.
- Participation in availability data systems should be straightforward and at a low cost to HRS operators.
- Maps should aim to cover all publicly accessible HRS in Europe, including the following information for each HRS:
  - Type of refuelling available; note that maps designed for specific end-users (e.g. car drivers) should show only 700-bar refuelling stations as default
  - HRS availability status (updated every few minutes) in line with commonly agreed definitions (see above)
    - This can include providing a distinction for HRS that have recently opened and are still in the teething period; e.g. H2.LIVE does not mark new HRS as fully Live until after the optimization phase.
  - Up-to-date contact number for HRS operator
  - Information on how to register to use the HRS (if applicable)
  - Link to navigation

Further progress needed for maps and apps

- Not all HRS in Europe currently provide consistent availability data; further harmonization is needed to ensure a smooth customer experience. This will include the continued rollout of remote HRS monitoring, enabling data on HRS status to be shared automatically.
- All stations funded with public money should be mandated to provide data to open mapping apps and all private stations should be expected to do the same (by mandating where possible within national laws).
- There is a need to ensure that, where HRS locations and data are displayed alongside other infrastructure (e.g. in the European Alternative Fuels Observatory map), only the most accurate information (consistent with dedicated HRS maps) is shown. In the longer term, data could also be made available through popular web mapping and navigation services.
- Industry stakeholders should continue to build on existing work to identify common frameworks (definitions, symbols, signage, etc.) across the EU.

Communication with customers: Access & billing

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Access and billing are important issues for achieving an interoperable European HRS network

Overview of HRS access & billing issues

- Once HRS networks are sufficiently developed, one of the advantages of hydrogen vehicles over other zero-emission technologies will be **the ability to easily carry out long-distance journeys**. As such, HRS networks should aim to deliver a customer refuelling experience that is comparable (or improves on) the petrol and diesel experience.
- Access and billing are important aspects of this. The long-term objective is to give customers **the ability to refuel and pay at any given station** without having had prior engagement with the station operator. This would also entail a **universal and widely used payment system** (e.g. credit and debit card payment, PayPal etc.) **at all stations across Europe,** to bring interoperability in preparation for mass-market rollout.
- However, there are several issues to be overcome to achieve this, and to improve interoperability in the near term. These issues are explored in the following slides:
  1. **Registration is currently needed to ensure compatibility between vehicles & HRS.**
  2. **HRS registration and access requirements are not always clear, especially for FCEV users seeking to travel across several different European countries.**
  3. **Access requirements and payment processes currently vary between different HRS operators and countries.**

1

Registration with the HRS operator in advance of refuelling is currently required for most stations across Europe

Current status: HRS registration processes

- **Most stations currently require customer registration with the HRS operator prior to use, so that hydrogen can be dispensed safely. Once registered, users will be granted 'access' to the site,** most commonly via a pin, tag, or card, specific to the station operator.
- The need for registration is largely to **mitigate damage caused by potential incompatibility between certain types of vehicles and HRS**.
    - Some 350 bar refuelling stations do not have pre-cooling, which means that they are not specified for use by vehicles with Type IV tanks (use could compromise the safety and longevity of the tanks). Restricting access to hydrogen at stations via a registration process thereby ensures that **only vehicles approved by the operator can use their stations** and mitigates any potential damage.
    - In the near term, it is highly likely that HRS will continue to be designed to a variety of different specifications, and that vehicles will use a range of different fuel tanks. As such, **access to stations not meeting the standards mentioned in the EU directive 2014/94/EU should prohibit access to all vehicles that are not registered** at that station.

Long-term ambition

- In the longer term, the need for registration could be removed by **designing and advertising stations so that they can either refuel all vehicle types**, regardless of tank type, **or for use by one vehicle type** (which would rely on the HRS design being compatible with tanks across that vehicle category).

2

More transparency and standardisation of access and payment is needed between HRS operators

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Current status of HRS access & billing interoperability

- **Methods for accessing and paying for hydrogen fuel currently vary by HRS operator.**
  - The process for registering to use an HRS for the first time currently varies by operator, and information on access requirements can be difficult to find for some HRS.
  - Payment options also differ between regions and even between HRS run by different operators within the same city. Whilst some stations provide the option of credit and debit card payment, fuel cards with monthly invoice and mobile apps are commonly used. This reflects the fact that a large proportion of current FCEV users are fleet or business users.
  - Where payment options are specific to an individual operator, **users who refuel at multiple stations with different operators require multiple fuel cards and apps**. Along with differences to registration processes, this has implications for ease of use from a customer perspective and interoperability of stations.

Best practices for HRS access & billing interoperability

- As a minimum, operators of public HRS should **provide information on their registration and payment process through online resources such as H2-map.eu and H2.LIVE**.
- Public HRS operators who are active in the same region should aim to **align their access and payment processes** where possible. This can be facilitated by regional hydrogen initiatives, government initiatives, or other third parties acting to coordinate HRS deployment.

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3

The extent to which access and payment options are standardised within regions varies by region

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HRS access & billing methods: examples of regional progress

- **Denmark** – customers register for station access, with approval taking up to three days to be granted. Access to stations is gained via tokens.
- **France** – access to stations and payment options vary by operator; access and payment via FillnDrive app is currently available for 8 HRS (as of April 2020).
- **Germany** – **most stations across the German network use a standardised access and payment system** (a H2.LIVE card), established and managed by H2 MOBILITY. Note that Germany is one of the countries in Europe where restrictions around station payment are required due to the legal framework for sale of hydrogen as a fuel which requires a certain level of metering accuracy beyond what is currently feasible. Customers in Germany therefore currently agree in advance to use a lower metering accuracy to purchase hydrogen.
- **UK** – access to stations and payment options vary by operator. The main HRS operator in the UK, ITM Power, is in the process of installing credit/debit card payment systems at a number of their sites.

General trends and outlook

- Increasingly, **HRS operators are looking to digitalised access and payment options, e.g. via mobile app and credit/debit card payment systems**. Whilst some regions have relatively standardised payment options, **site access still varies by station operator in most regions**. Options for universal access must be explored to ensure that drivers can refuel at any HRS in a network.
- **Single payment and access system should be targeted within countries, with a universal system in Europe the long-term goal.**

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Communication with customers: Customer support systems

As uptake of FCEVs increases, there is a growing need for well-defined HRS user support services

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Overview of customer support systems

- Experiences of HRS operators to date have shown that, in addition to providing information on HRS availability status through maps and apps (which are the resource most heavily utilized by customers), provision of the following support services can improve the overall customer experience and satisfaction with the hydrogen refuelling network:
  - **User training and guidance** for use of the HRS
  - **Technical hotline** for customers at the HRS to call in the event of a problem
  - **General customer support and contact system** (to address ongoing questions and comments from customers)
- The need for these systems arises from the fact that HRS are currently at an early stage of commercialisation; the supply chains for several components are immature and therefore design improvements are still needed to make the refuelling process as straightforward and intuitive as possible. The expectation is that as the technology matures and familiarity with the technology increases, HRS design will improve, and the need for some types of customer support (e.g. training and technical hotline) will diminish. However, during the commercialization phase, providing this support has several positive effects:
  - **Training minimizes the frequency of issues caused by 'user error'** at the HRS.
  - **A technical hotline enables HRS operators to be made aware of any issues quickly**, so that they can be addressed.
  - The **overall customer experience and confidence in the network** is improved.
- Nevertheless, the implementation of these systems can come at a cost to HRS operators, and their value (relative to their cost) depends on the total number of HRS in operation in a given country or region. In general, these systems become more cost-effective to implement (and therefore more viable for HRS operators) when one operator has several HRS in a given country or region, and when each HRS is used by multiple customers on a daily basis.

Best practices for HRS operators with increasing numbers of customers include the provision of user training and a technical hotline

Best practices for customer support systems

- The table below summarises the best practices for HRS operators implementing customer support systems, during the very early stages of deployment (i.e. few HRS; low numbers of users), and during wider rollout. Overall, it is essential that HRS operators establish **clear avenues of communication** for customers; fleet managers can also play a role in disseminating key information to drivers.

Customer support system	Best practices during early deployment (Operator has few HRS and customers)	Best practices during wider rollout (>3 HRS and/or many regular customers per HRS operator)
User training and guidance	▪ Instructions at the HRS ▪ Training provided to new users	▪ Instructions at the HRS ▪ Training provided to new users ▪ 'Train the trainer' approach for fleets
Technical hotline	▪ Hotline available during peak times ▪ Phone number easy to find at the HRS ▪ Start to identify common user issues and develop a script ▪ Engineers available to address technical issues	▪ 24/7 hotline ▪ Phone number easy to find at the HRS ▪ Script for triage and to address common user issues (e.g. can outsource to a call centre) ▪ Engineers / technical staff available to address any technical issues
General customer support and contact system	▪ Up to date phone number or email address available online	▪ Up to date phone number or email address available online ▪ FAQs available online ▪ Consultation and regular updates on new HRS locations and timelines provided to customers seeking to expand their FCEV fleets

The provision of these services has increased in recent years, particularly from HRS operators who have seen significant expansion of their customer base

Examples of recent progress for customer support systems

- The table below provides some examples of cases where these best practices have been implemented; these HRS operators are supporting amongst the highest numbers of FCEV users in Europe (either at individual HRS or across their overall networks), and therefore are generally more likely to require customer support systems, compared to operators who currently have lower numbers of users.

HRS operator	HRS in operation (Q1 2020)	Key customer support systems in place
H2 MOBILITY	>80 in Germany (serving ~650 FCEVs)	▪ 24/7 technical hotline number at HRS ▪ Video training available on website (H2 LIVE) ▪ Clear instructions at HRS ▪ General support and FAQs via website and app
ITM Power	8 in the UK (serving ~200 FCEVs)	▪ 24/7 technical helpline ▪ In-person user training & video guide ▪ Clear instructions at HRS ▪ Dedicated fuel sales manager: implementation of feedback loops via key fleet contacts
Air Liquide	4 in Paris (serving >100 FCEVs)	▪ Technicians on site ▪ Support available through FillnDrive app

Key recommendations for customer support systems

- Best practices should be **implemented in advance of anticipated growth in demand**.
- In the longer term, **HRS usability issues need to be addressed at the design stage**, to reduce the need for training and troubleshooting. This may require specific **R&D funding** to encourage the supply chain to provide solutions.

Technical performance

Good HRS performance is essential to maximise the customer proposition of hydrogen mobility

Overview of technical performance

- This report explores two aspects of technical performance:
  - **Availability**
    - Particularly for areas with low numbers of HRS, ensuring that customers can refuel at HRS when required is critical if hydrogen vehicles are to provide an attractive customer proposition. Numerous H2ME partners have made progress in this area, and best practices have been identified - as well as recommendations to enable further advancement.
  - **State of Charge**
    - The state of charge that can be delivered by an HRS describes how full the hydrogen tank is after refuelling, compared to its maximum capacity. Early customers have reported refuelling events where the maximum state of charge that can be achieved is below 95%; this has implications for how far vehicles can drive before needing to refuel again and needs to be addressed to maximise the FCEV customer proposition. This report describes the ongoing work and findings of the H2ME partners in this area.

Technical performance: Availability

HRS availability is generally improving over time, but continued efforts are needed to ensure that this continues as more new suppliers enter the market

Overview of availability issues

- To ensure that customers can fully utilise the capabilities of FCEVs, the amount of time that each HRS is fully operational and available for customers to refuel (i.e. the **availability**) should be maximised; the H2ME initiative **aims to achieve an average HRS availability of over 98% by 2022** across all the HRS in the project.
- The availability of the public HRS deployed to date varies, and not all stations currently meet this target. It is **common for HRS to experience a 'teething period'**, when various technical issues need to be addressed, during the initial period after opening, and in some cases after significant upgrades have taken place. After this, availability tends to improve.
- Some HRS operators with experience of operating multiple HRS for several years have started to observe improvements in station availability for new stations (compared to previous models from the same supplier), suggesting that design and operational improvements are being implemented as a result of the experiences of early stations. Best practices should be shared widely wherever possible to ensure that HRS from new suppliers and operators also have high availability.
- **Some components (compressors and dispensers) are particularly unreliable or prone to damage** (including damage by mishandling by users), and further development of the supply chain is needed to produce more reliable and robust components.
- Vehicle manufacturers have identified **improvements to station availability as a high priority** and critical to the commercialisation of hydrogen mobility. Problems with isolated stations could cause disruption to customers and reputational risks, particularly as in the early stages of HRS network development there may be limited alternative locations for customers to refuel nearby should issues arise.

Substantial improvements in the time taken to address technical issues at HRS have been achieved and the supply chain is maturing in response to increased demand

Recent progress on availability issues

- HRS operators with significant numbers of HRS on their network are seeing **improvements to overall availability** on the network over time.
- **Improved response times** to HRS technical issues have been achieved, as a result of:
  - **Increased monitoring and remote maintenance**
  - **Presence of local maintenance staff** (due to increased numbers of hydrogen-trained personnel) and **formalised maintenance contracts**
  - **Storage of spare parts at or near refuelling stations**
  - Increase in HRS operators providing **customer helplines;** this means that any issues not detected remotely can be flagged to HRS operators as they arise
- **The HRS supply chain is maturing** as a result of significant scale-up in HRS demand. For example:
  - Nel Hydrogen's large-scale production facility (with an annual capacity of 300 hydrogen stations per year) opened in 2018
  - New user-friendly nozzle designs are in development (e.g. this concept from WEH, which has features such as a start button on the nozzle itself, a swivel joint, and anti-freeze technology)
  - ITM Power is due to open an electrolyser manufacturing plant with a capacity of 1GW/year in late 2020
- **Improvements are being made to station designs** (e.g. choice of materials used, placement of sensors, etc.) as a result of data monitoring and analysis; alongside efforts to improve availability via **redundancy of parts** (e.g. presence of more than one dispenser at some new stations).
- Suppliers are contributing to the **development of performance standards and test procedures** for particular station components. For example, ITM Power has provided feedback regarding nozzle test specifications which may lead to standardised nozzles.

Detailed remote monitoring of HRS and the presence of local maintenance staff are two of the recommended best practices to improve availability

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Best practices for availability issues

- Conduct **rigorous testing of stations** off-site (this reduces commissioning time) and on-site (this can include using FCEVs to test HRS performance before opening).
- Ensure **robust, centralised, and constant, data monitoring systems** are in place with **dedicated employees for analysis of data**.
  - **Allows early detection of problems**, resulting in quick response times, often before customers become aware of any issues.
  - **Identifies trends** in any problems which may occur, informing existing and future station development e.g. problems related to user error, frequency at which key components break down, thus allowing the **preventative replacement of parts.**
  - Allows for **remote maintenance**, often resulting in quicker response times.
- Provide training to ensure that common technical issues can be addressed remotely or by local **maintenance staff.**
- Establish **formalised maintenance procedures and contracts** with clearly defined responsibilities and timescales which reflect targeted availability (>98%).
- **Use data (cross-checking downtime with video surveillance) and/or customer feedback to improve user-friendliness of stations** to help decrease user error as a cause of downtime.
- Ensure that **24/7 customer helplines** are available at HRS (this can help ensure that any technical issues are identified quickly).
- Ensure that **spare parts are available locally** to enable quick replacements to be made as required.
- As far as possible, **plan for environmental factors such as low temperatures affecting station equipment** e.g. freezing nozzles.

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HRS availability remains a high priority, and further work is required to ensure continued improvement

Further work needed for availability issues

- HRS network operators must continue to ensure **local (in-country) availability of:**
  - Stock of replacement parts;
  - Sufficiently large teams of technicians (directly employed by the HRS operator, rather than subcontracted) with appropriate training to address a range of issues.
- **The supply chain needs to bring improvements** (in terms of reliability and cost) **for components with high rates of failure.** Funding is needed for R&D as well as to support the further development of standards for components.
- Safety processes such as alarm systems and sensors need to be configured correctly to avoid unnecessary downtime (i.e. as a result of station shut down mechanisms being triggered by events that do not impose risks at the HRS)**.**
- **Causes of poorer availability** in first months of operation and at older stations should continue to be explored.
- The costs and benefits of **retrofitting older stations with data monitoring and new component parts** should be explored, to ensure improvements in availability are seen across HRS networks.
- **Third party testing of HRS (before commissioning)** should be established in each country to ensure that stations from different suppliers perform to a consistent standard across the network. This has been set up in Germany and car manufacturers are keen to see wider implementation across Europe. The possibility of including certification of measures to maximise availability could be explored.

Technical performance: State of charge

1. Introduction

2. Siting and permitting

3. Communication with customers

    - Planned HRS installations

    - Mapping and availability data

    - Access & billing

    - Customer support systems

4. Technical performance

    - Availability

    - State of charge

5. Safety: recommended best practices

6. Business cases

7. Conclusions

HRS suppliers and operators need to minimise the frequency of refuelling events where the maximum state of charge that can be achieved is below 95%

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Overview of State of Charge issues (1/2)

- A major selling point of FCEVs is the ability to provide **long distance zero-emission driving.** When state of charge (SOC, i.e. how full the tank is as a percentage of its design capacity or pressure) at the end of refuelling is significantly less than 100%, the **maximum range of the vehicle is reduced.** This reduces the long distance benefits offered by FCEVs, particularly in the early stages of HRS network development when the number of nearby alternative HRS will be limited.

- At present, OEMs have identified that there are **too many partial fills by stations**, and customer feedback has highlighted that as a result of this **users often feel vehicles are not meeting their advertised range.** As such, achieving a consistently high SOC is a priority for HRS operators and suppliers.

- In some cases the HRS detects that vehicles have not been fully refuelled. In others, there are discrepancies between HRS and FCEV readings. A number of OEMs and station suppliers and operators are working together, and **within H2ME a dedicated taskforce was established, to create a methodical monitoring of SOCs to inform further understanding and improvement**.

- This report looks at causes of partial fills, examining the various factors contributing to lower than desired SOC.

Stations do not currently display information on the SOC achieved, which increases the need for a reliably high SOC

Overview of State of Charge issues (2/2)

- At present, **customers must switch on their vehicle to determine SOC** as this is not displayed by the HRS**;** however the accuracy provided by the vehicle electronic display may not differentiate between e.g. 95% and 100% SOC (see examples of vehicle display panels below).
- Vehicle manufacturers have suggested that it would be beneficial for HRS to display information to customers on the SOC achieved after refuelling, and (in the event of the maximum SOC being significantly below 100%) further information briefly stating the cause and recommended actions (if appropriate). For example, in some cases, a more complete SOC could be achieved by waiting a few minutes for the quantity of high pressure hydrogen available to increase.
- This could:
  - allow customers to gauge the **volume of H2 refuelled** without having to turn on their vehicles (thus aligning with the current customer experience with regards to petrol and diesel refuelling);
  - enable customers to choose to **take measures to achieve a more complete refuel**, where this is applicable (e.g. wait or contact the HRS operator);
  - ensure that **range expectations** following refuelling are appropriately aligned with the SOC achieved.
- Efforts should be made to ensure that **different HRS operators across Europe follow a consistent approach** to providing this information.

Examples of FCEV display panels showing SOC and estimated range

Small differences between vehicle and HRS SOC measurements do not significantly contribute to lower than desired SOC

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Discrepancies between HRS and vehicle readings

- **Different definitions of SOC can exist** (e.g. see below) – SAE protocols dictate that different methods of calculation can be used, so long as they are generally accurate to within 0.5-1%.

Toyota Mirai	SAE J2601
$SOC\ [\%] = \frac{m\ [p,T,V]}{m\ [NWP,15°C]}\ x\ 100$	$SOC\ [\%] = \frac{\rho\ [p,T]}{\rho\ [NWP,15°C]}\ x\ 100$

- **Tank temperature varies in different parts of the tank** – depending on where sensors are located, this can influence the measured SOC. Though tank pressure is consistent in different parts of the tank, **pressure can vary slightly between the tank and the place where it is measured** (e.g. the Mirai does not have a pressure sensor inside the tank, but rather at the intake manifold outside the tank). **These variances will result in very small SOC variances.**
- Analysis conducted to date between Nel and Toyota demonstrates that **differences in SoC measurements between station and vehicle is <1% in communicative refuelling.**

Whilst efforts should be made to reduce discrepancies between HRS and FCEV readings of SOC, analysis to date suggests this is not a major cause of lower than desired SOC. Further work should however be carried out to ensure this is the case for multiple vehicle types and HRS manufactured by multiple suppliers.

Several factors can contribute to lower than desired SOC, but more work is required to better understand and address these causes

Causes of lower than desired SOC (unrelated to protocols or station hardware):

- **User error** can lead to **failed refuelling attempts** e.g. through not connecting the nozzle correctly. New users tend to make a lot of mistakes in the first month of use, but failure rates drop as users become increasingly familiar with the system (note the importance of customer support systems, as mentioned previously in this report).
- **Availability of hydrogen –** different HRS have various capacities for refuelling, which can be related to the total quantity of hydrogen stored on site, the amount of hydrogen stored at high pressure, or the capacity of the compression system. As such, these factors may limit the number of 100% SOC refuelling events that can take place within a given time period, and some HRS may deliver a partial refuel following several complete refuelling events.

Causes of lower than desired SOC (protocols or station hardware related):

- **Start pressure and ambient temperature** – if pressures and temperatures are outside of a certain threshold, the fueling process will not begin. Failure of temperature sensors can also lead to aborted refuelling events.
- **Pressure ratings** of dispensing system components and vehicles using the station – some stations have the capacity to refuel at 875 bar which would increase the likelihood of SOC >95% but if, for example, the nozzle is not certified above 750 bar, fuelling is terminated once this threshold is reached.
- **Communicative vs non-communicative refuelling.** Non-communicative refuelling generally restricts SOC to 80-90% as target pressures are used to determine a 'complete' fill. Some dispenser manufacturers have safety restrictions which significantly lower SOCs during non-communicative refuelling, in case a vehicle's compressed hydrogen storage system (CHSS) is not adequately rated.
- **Differences in the specifications that stations have been designed to meet.** Stations designed to comply with different protocols may achieve differences in SOC in both communicative and non-communicative refuelling, perhaps as a result of the protocols themselves, or due to different interpretations of the protocols.

The impact, if any, that different refuelling protocols have on SOC is expected to be minor

Summary of potential impact of protocols on SOC

- A key aim of the SAE J2601: 2016 protocols is to provide a **high density fuelling as fast as possible, whilst staying within the operating limits of internal tank temperature and pressure**.
- **Within some regional HRS networks,** stations are split between those that comply with the 2016, 2014, 2010 version of SAE J2601, or other protocols, for instance protocols based on the SAE protocols.
- There may be **some minor differences in SOC achieved for stations designed to comply with different protocols in both communicative and non-communicative refuelling** (see following slides).
- **Differences in how protocols are implemented**, rather than the protocols themselves, **may also explain differences in SOC achieved**.
- Even within a regional HRS network, **the same vehicle may therefore achieve different SOC depending on the station at which it refuels**.
- Project partners are exploring options to **improve the ability of stations installed with older protocols, where SOC issues are more prevalent, to achieve higher SOC**.

The maximum SOC that can be achieved by non-communicative refuelling is lower than the maximum that can be achieved via communicative refuelling

Non-communicative refuelling

- The latest HRS protocols are designed to enable communicative refuelling (for 700 bar refuelling). However if the method for communication at the dispenser breaks, the HRS will use non-communicative (non-comms) fuelling.
- In non-communicative refuelling, in line with SAE protocols, **HRSs determine a 'successful' refill once pre-defined pressure values are reached (as read by the *dispenser* pressure sensor).**
- These values are calculated using the **initial gas pressure from the FCEV, the ambient temperature, and the dispenser's T-rating** to determine the fuelling rate and target pressure at which the dispenser stops fuelling.
- **This generally restricts SOC to 80-90%.** Though according to existing protocols, a successful and complete refill has been conducted, in reality customers face a reduced range relative to that advertised.
- Further reductions in SOC may occur in cases where **the safety case for non-communicative refuelling includes a greater degree of conservatism than the non-communicative refueling table** (right).

H70-T40 4-7kg non-comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]											
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	40	50	60	70	> 70
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	5,1	77,8	77,6	77,3	76,9	76,6	76,2	75,7	75,3	74,7	73,9	72,8	no fueling
45	8,1	76,3	77,2	76,9	76,5	76,4	76,2	75,6	75,3	74,7	73,9	72,7	no fueling
40	11,5	73,2	75,6	76,8	76,3	76,4	76,2	75,6	75,3	74,6	73,9	72,7	no fueling
35	12,4	72,9	75,3	76,4	76,0	76,1	75,9	75,3	75,1	74,5	73,8	72,7	no fueling
30	15,3	70,6	73,9	75,8	75,2	75,4	75,1	74,3	74,1	73,3	72,4	71,3	no fueling
25	18,5	69,0	72,8	75,1	74,5	74,7	74,3	73,3	73,0	72,0	71,1	no fueling	no fueling
20	21,8	67,9	72,1	74,5	73,7	74,0	73,4	72,2	71,9	70,7	69,7	no fueling	no fueling
10	28,0	66,3	71,1	74,1	73,2	72,4	71,6	70,9	69,6	68,4	66,9	no fueling	no fueling
0	28,5	74,0	73,4	72,4	70,6	70,7	69,6	68,6	67,1	65,7	64,0	no fueling	no fueling
-10	28,5	73,4	72,9	71,9	70,0	70,0	68,4	66,5	64,4	62,9	61,2	no fueling	no fueling
-20	28,5	72,9	72,3	71,3	71,0	69,5	68,0	65,7	62,4	60,0	no fueling	no fueling	no fueling
-30	28,5	72,1	71,6	70,6	70,4	69,0	67,4	65,2	61,8	58,7	no fueling	no fueling	no fueling
-40	28,5	71,6	71,1	70,2	70,0	68,5	66,9	64,8	61,5	58,5	no fueling	no fueling	no fueling
< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Example table of target pressures for non-communicative refuelling

Communicative refuelling increases the maximum SoC that can be achieved, but SOCs of 95% or above are not always reached by HRS using this approach

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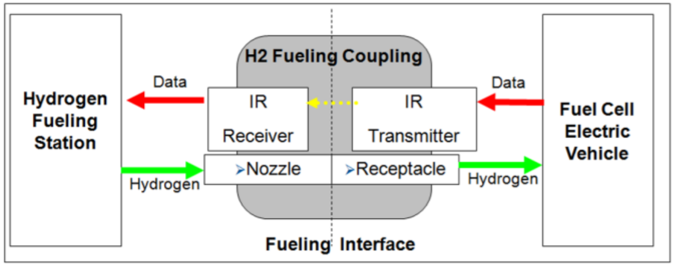
Communicative refuelling

- **The SOC target when fuelling with communications is 95-100%** under all operating conditions, according to the latest station refuelling protocols (SAE J2601: 2016).
- Typically, **stations that supply hydrogen at 700 bar tend to have communicative refuelling capabilities** (non-communicative refuelling is still possible); and **stations (and vehicles) that refuel at 350 bar typically use non-communicative refuelling**.



- **Pressure at the dispensing nozzle, as well as vehicle data parameters, are continuously monitored in communicative fuelling.** Fuelling is typically terminated when the calculated SOC = 95-100%, or one of the fuelling limits is reached, for instance: P station + ΔP station = 125% Nominal Working Pressure (NWP); or the vehicle tank temperature limit is reached.
- Where SOC is greater than or equal to 100%, fuelling must terminate as soon as possible and within 5 seconds. The station may use SOC vehicle or SOC station (a more conservative value) based on the station dispenser fuelling methodology (see 6.4.1 State of Charge in protocols).

Potential impact of protocols on communicative refuelling

- The **first protocols to provide communicative refuelling with specified pressure limits via the inclusion of look-up tables was SAE J2601: 2014**. Earlier versions of protocols allow communicative refuelling but do not include look-up tables and so it may be that **stations complying to earlier protocols achieve higher SOC in communicative refuelling due to the absence of pressure limits**. It is not however clear if any of these limits are typically reached for a fuelling to 100% SOC. Conversely, **different interpretations when using older protocols without look-up tables may have led to lower SOCs for communicative fuelling** in such stations, compared to the 95-100% SOC that would otherwise be expected.

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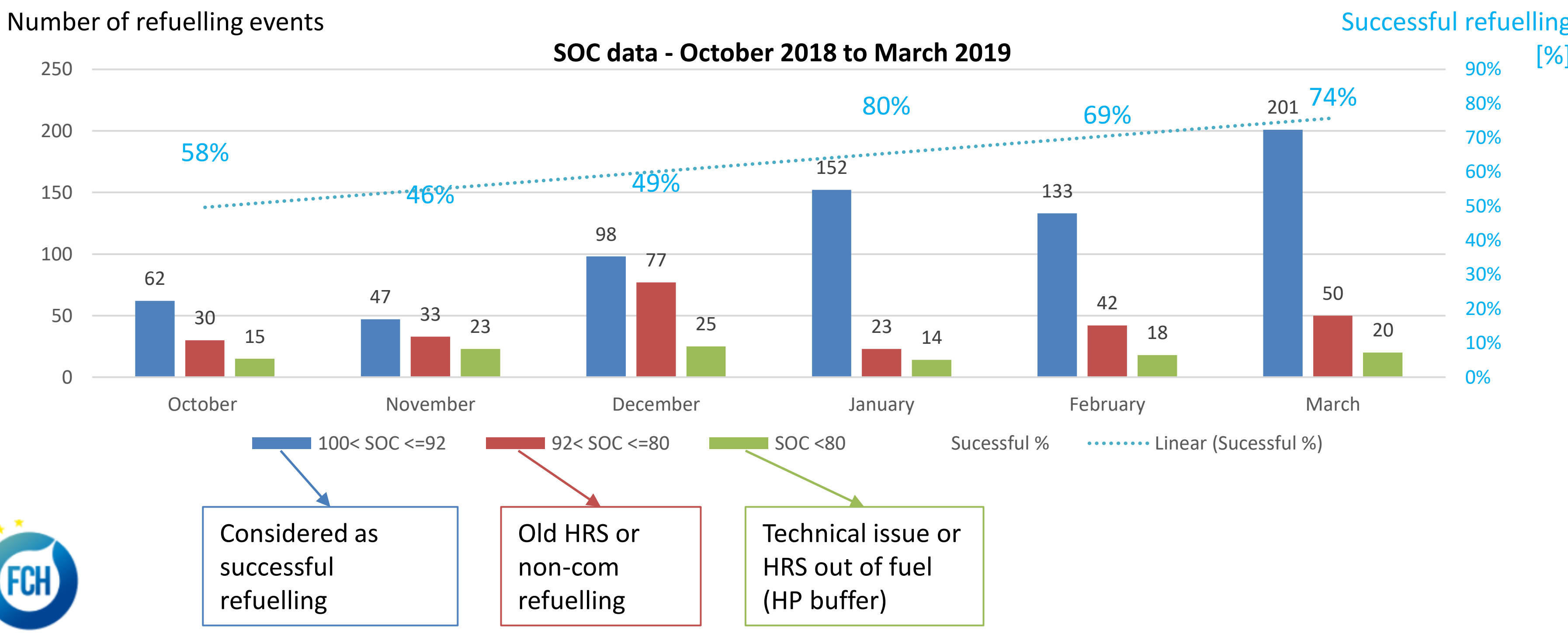
H2ME project partners are working collaboratively to monitor the causes of low SOC refuelling events; results show that the frequency of low SOC events is decreasing

Ongoing work on SOC issues

- **Within H2ME, a taskforce has been established to carry out systematic testing** logging instances of low SOC refuelling events and creating a database of technical issues and user errors that lead to zero and <95% fills. This work expands on Toyota and Nel's pre-existing activities and aims to incorporate as many stations and vehicle providers as possible. Initial results are shown below, showing that:
  - Overall, the percentage of successful refuelling events (>92% SOC) is increasing over time
  - Refuelling events with SOC between 80% and 92% are more common than those with <80% SOC; the latter may be caused be various technical issues or by limited hydrogen at the required pressure onsite.



Various technical issues may contribute to low SOCs; continued work is needed to fully understand the causes and potential solutions

Further areas yet to be explored relating to SOC include:

- **Impact of station capacity** on achieving satisfactory SOC at high levels of utilisation.
- **Impact of metering** on achieving satisfactory SOC.
- Addressing the issue that **in non-communicative refuelling, stations measure 100% SOC if P target is met** (even though this is not the case).
- **Possibility of improving protocols such that they do not unnecessarily impose restrictions that limit SOC** e.g. ambient temperature and start pressure combinations that result in zero fills.
- **Potential for upgrades to soft/hardware to** improve SOC for some stations.
- **Impact** (if any) **of protocols on communicative and non-communicative refuelling,** or whether low SOC can be attributed predominately to interpretation of protocols
- **Impact of different vehicles and tank types** on SOC.
- **Impact of precooling** on SOC.
- Potential demand for the provision of greater SOC granularity to customers via **FCEV display panels.**

Safety

Minimising the frequency and impact of safety incidents at HRS is vital for the successful commercialisation of hydrogen mobility

Overview of HRS safety

- The successful commercialisation of hydrogen mobility will rely on achieving a certain level of **public confidence** in the technology, including safety aspects.
- As such, the **frequency of incidents should be minimised**, and when they do occur (however rare this may be) it is important that HRS operators and suppliers are prepared, both in terms of taking all necessary steps to contain and address issues, and also in terms of how incident (and the measures taken) are **communicated externally**.

- Currently, at the European regulatory level, only sites with over 5 tonnes of hydrogen are required to report safety incidents. Incidents (including ‘near misses’ and cases where no hydrogen is released) can also be reported to the Hydrogen Incidents and Accidents Database (HIAD) on a voluntary basis.
  - According to the European Hydrogen Safety Panel (EHSP), the total number of events reported in HIAD in 2018 was 272 (155 of which were in Europe). Of these, 7 incidents related to hydrogen refuelling stations.
- The EHSP extracted the following findings based on incidents reported to HIAD:
  - Overall, the overarching lesson learnt is that accidents might consist of several causal events that, if occurring separately, might have little consequences; but if these minor events occurred simultaneously, they could still result in extremely serious consequences.
  - **Accidents are often initiated under special conditions**, like maintenance, revision or restart after changing the system.
  - Most cases are attributed to the human factor (wrong design, wrong operation).

Implementation of rigorous safety processes and checks is an essential part of HRS installation and operation

Summary of recommended best practices on HRS safety

HRS and component design

- Avoid 'overdesign'. Equipment should be designed so that any **failures can be detected at the testing stage**.
- One cause of leakages in Japan and the USA is **poorly planned fatigue**. Considering the incidents in EU, Japan and the USA, it is very important to adequately consider operational conditions in the design; compressor induced vibrations are a key example that should be accounted for.
- Some leakage events are caused by **screw joints and inappropriate sealings**. If welded joints are to be used instead, do careful statistical checks of weldings and control certificates and capabilities of suppliers. Obtain data on the strength of welded parts and develop technology and techniques for improving quality of welding of hydrogen compatible material and reducing the pipe thickness.
- Be aware of differences between specifications and standards between different markets (e.g. North America / Europe) – this can cause issues if not identified early.

HRS installation and operation

- Insist on fully documented quality control, appropriate checks and prompt documentation of installation (and upgrade) procedures.
- Develop and implement thorough quality control processes and checks (e.g. regular leak tests). Training procedures should include appropriate testing to ensure capability.
- Implement a Safety Alarm Plan in response to sensor conditions and ensure that this is kept up to date following any changes.
- Carry out Emergency Response training for first responders (both internally and with local Emergency Services).
- Ensure that contingency plans are in place setting out clear actions in the event of an incident.

Business cases

To create sustainable hydrogen refuelling networks, network growth and performance criteria must be balanced with the need to operate cost-effectively

Overview of issues for HRS business cases

- To support the continued commercialization of hydrogen mobility in Europe, HRS operators need to balance the following key objectives for refuelling stations:
  - Installing enough HRS to provide sufficient **coverage** of the operating area for their target market;
  - Providing a high quality service to customers: crucially, this means providing high HRS **availability** to ensure that customers have access to hydrogen when required, and communicating HRS availability to customers;
  - Ensuring that **fixed and variable operating costs are not prohibitive** to the long-term business case.
- The business case for public HRS operators can be challenging for several reasons:
  - **In the absence of demand commitments from customers, investment in new HRS is risky** due to the uncertainty of future demand growth and the high costs of current HRS capex and opex; this means that many HRS operators take a 'demand-led' approach to network growth. Uncertainty around the **future supply of vehicles, and value of hydrogen** (low carbon hydrogen in particular) also contributes to the risk; policy setting out **clearly defined cost support for low carbon hydrogen and vehicles** can help to address this.
  - **Overall utilisation of public refuelling networks is low** compared to installed capacity during the early years of deployment: even in areas of relatively high FCEV deployment (e.g. Paris, London, Hamburg) average levels of HRS utilisation only recently exceeded ~30% of capacity. As overall FCEV deployment starts to ramp up, the need for high availability and customer support increases, and so do the associated HRS operator costs. Initially these costs may be high relative to the overall revenue, but as the total number of customers and HRS increases, these processes become more efficient and the associated operating costs become less significant to the overall cashflow. However, the **costs of high HRS availability and customer support should be minimised** going forwards.
  - **Access to low cost, low carbon, fuel-cell quality hydrogen is currently limited**. Some HRS operators and suppliers focus on the provision of electrolytic hydrogen from renewable electricity; this is generally more costly than hydrogen produced as a by-product of chemical processes, or from reformation of methane, due to the relatively high cost of electricity compared to methane. However, new approaches to cost-effectively supply low carbon hydrogen are now starting to be demonstrated in Europe.

The following page sets out the emerging HRS business case approaches and remaining issues to be addressed.

Further public funding, combined with strategies that go beyond the current demand-led approaches to network growth, is needed to advance HRS business cases

Emerging approaches and further work required for HRS business cases

- The table below shows the emerging approaches that H2ME partners are taking to try to address the key challenges for the HRS business case (**note that these have been explored in detail in previous H2ME reports***) and some of the issues that require further work; some of these issues will be explored further in future iterations of this report.

Business case challenges	Emerging approaches	Remaining issues to be addressed
Investment in public HRS is risky due to lack of certainty around: a) Future demand (exacerbated by uncertainty around future vehicle production numbers) b) Future value of hydrogen;	• Demand aggregation and demand-led siting for new HRS; focus on higher capacity HRS (rather than small HRS) serving a greater total demand* • Joint ventures (at city-level and national level) to de-risk deployment • Lobbying for clearly defined policy support for low carbon hydrogen	• Very few commitments to FCEV production (and specific HRS network conditions needed) from OEMs • Access to two significant potential markets for hydrogen (large passenger cars and long-haul HGVs) will rely on the accelerated development of comprehensive national / pan European networks; significantly higher levels of commitment and coordination of both government and industry are likely to be needed here. • Further assessment of the feasibility and potential role of HRS serving heavy + light duty vehicles is needed.
Costs of high HRS availability and customer support need to be minimised	• Remote monitoring and maintenance • Call-centres used to deal with common issues • 'Train the trainer' approach for fleets	• Business cases for upgrading older HRS • Funding will be needed to deliver improvements across the supply chain: e.g. more reliable compressors; robust and user-friendly nozzles; more diversity of suppliers; cost reductions to key components.
Access to low cost, low carbon hydrogen	• Large scale electrolysis directly coupled to renewables, combined with tube-trailer distribution • Co-location of HRS with local sources of low-cost low carbon hydrogen	• Improvements to (and demonstration of) the cost and safety of higher-capacity hydrogen vessels, to enable more cost-effective hydrogen storage and distribution. • Demonstration and validation of off-shore hydrogen production.

*For example, further detail can be found in: H2ME deliverable 5.15 – Strategic recommendations for supporting the commercialisation of fuel cell electric vehicles in Europe (interim 2 of 3), 2020. Available at: https://cordis.europa.eu/project/id/671438/results

Conclusions

While progress has been made on HRS commercialisation, there is a clear need for further development of the supply chain and harmonisation across the network

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Initial conclusions on HRS issues

Based on the information in this report, initial high-level conclusions on HRS issues are summarised below. These conclusions will continue to be refined in future iterations of the report.

Siting and permitting

Continued efforts are needed to identify sites and gain planning approvals. Future HRS may require more space, to enable higher capacities, meaning that partnerships with existing fuel providers will have increasing strategic importance.

Communication with customers

Widespread provision of data to consistent maps and apps will be the key to providing network visibility; alongside this, harmonisation of access, billing and services such as 24/7 helplines at HRS help to optimise the customer experience.

Technical performance

Following significant efforts by HRS operators to optimise maintenance and functionality, further work is needed to ensure wider adoption of best practices and to ensure that components are reliable, user-friendly and cost-effective. Whilst the percentage of successful refuelling events (>92% SOC) is increasing over time, continued work is needed to fully understand the causes and potential solutions of lower SOCs.

Safety

Best practices on HRS safety (including quality assurance processes and contingency measures) must be widely disseminated and adopted to minimise the risks associated with hydrogen as a transport technology.

Business cases

Reducing the costs associated with HRS operation (with high technical performance) at low demand is likely to be critical to the continued roll-out (and operation) of public HRS networks. In addition, strategies are needed for the further development of national HRS networks across Europe, alongside the further refinement of local HRS deployments based on demand aggregation. However, the success of such strategies will rely on clear commitments from both policymakers and vehicle manufacturers.

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