Concept for a common European HRS availability system

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Abstract

This study has successfully proven the concept of a Europe-wide system to report the real-time availability of hydrogen refueling stations (HRS). The HRS availability system helps to address current issues facing fuel cell electric vehicle (FCEV) owners on hydrogen refueling infrastructure anxiety, by providing information on the real-time status of publicly accessible refueling stations.

The proposed system includes a hardware-based solution (type A) and the option for HRS operators to send a signal from their refueling stations to update a web-based platform (type B). The import application programming interface (API) for type B HRS has been published in an open format on https://api.h2-map.eu/doc and allows easy integration of real-time signals from the operators' existing plant monitoring systems. All information (dynamic and static site information) of the HRS availability system is publicly available and visualized on a map to be found at https://h2-map.eu. For third parties who would like to integrate the information in their own applications, an open format export function including all real-time and static information has been realized that can be publicly accessed for free at https://h2-map.eu/data.

This study has successfully demonstrated the type A system, which was proven to be highly reliable and has received positive feedback from HRS operators who implemented the system during trials. The implementation of type B software-based solutions was more problematic, often with unexpected complications to implement this approach.

Consultations with stakeholders from the hydrogen and fuel cell sector were used as a basis to explore options to fully deploy this system across Europe. Cost estimates for the scale-up of the system with the growing HRS and FCEV market have been developed to understand the revenues required for this system to be commercially viable.

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1 Executive Summary

The study "Concept for a common European HRS availability system" ran from July 28th, 2017 to February 28th, 2018 with the aim to develop and demonstrate a real-time information system on HRS availability for the current and future hydrogen refueling stations in Europe. A consortium formed by Spilett n/t (study lead), ENDA from Germany and Element Energy from the UK used its expertise and networks to identify and prove a technical solution that is widely accepted by the HRS community and responds to the expectations of the FCH 2 JU to be uniform, open-source, compatible with all HRS station designs and with the flexibility to meet individual operators' needs.

The study succeeded in aligning definitions on HRS availability throughout Europe and finding a consensus on a methodology to gather and process real-time HRS availability information from the HRS data community for the first time.

The definition of "HRS availability" comprises three core availability states: available, not available, and limited availability. The dispenser readiness signal will be used to identify HRS availability states, as it comprises all prior availability signals of HRS components on site[1]. This approach has been confirmed as being the most appropriate solution for an automated real-time availability system by the HRS stakeholder community. Two additional availability states important to FCEV users will be generated by the HRS availability system: an "outside opening hours" state, as well as a state if no real-time information on the HRS site is available ("status unknown").

The definition of "real-time" is more complicated as it needs to be aligned to the expectations of FCEV customers on one side, and technical feasibility of signal transfer on the other. Thus, a two-step approach was agreed: whenever possible, signals from the stations should be updated every 60 seconds. If only signal changes are communicated, a heartbeat signal confirming the connectivity of the system needs to be sent at minimum, every 60 minutes. Any signal updates with a frequency greater than 60 minutes are not accepted as providing a real-time update.

The technical solutions developed and tested in this study have been confirmed to be compatible for all HRS in Europe by major HRS suppliers (including Linde, Air Liquide, Air Products, Hydrogenics, McPhy, ITM Power, NEL).

The HRS availability system consists of:

i. a hardware and a software solution to collect and import the real-time signal
ii. an HRS availability platform to process data and enable HRS operators to integrate and update static information relating to their sites
iii. a webpage to visualize information via OpenStreetMap
iv. a software solution to export the dataset of European HRS availability for visualization in third party applications (apps, website, car navigation systems).

All software used in this system is Open-source, the import and export interfaces have been designed in a standard programming language being compatible with existing systems, such as those used by HRS operators who remotely monitor their stations or third-party applications. Discussions with app

[1] If one of the relevant HRS plant components fails, the dispenser unit signal turns into "not available" to prevent customers from filling. This is not automatically true at European HRS if storage volume is low or (in Germany) the card reader unit fails. It therefore was decided to include a customer notification function into the software portal to enable HRS operators to manually set their station into "not / restricted availability mode".

developers including TomTom Custom Systems – Content & Services and YellowMap GeoSolutions, who closely cooperate with vehicle OEMs in navigation map services, as well as feedback from Toyota, Hyundai, AUDI and Daimler have confirmed the suitability and appropriateness of the export software.

The concept of the HRS availability system has been realized in a prototype and tested in proof-of-concept trials undertaken from October 30th, 2017 to February 28th, 2018. Seven HRS were equipped with the hardware to collect dispenser signals on site (type A HRS)[2], and two HRS suppliers/operators participated with a software solution (type B HRS)[3]. The trials successfully proved the concept, signals were received by the platform and accurately visualized on a web-based map. The experience from conducting the trial phase has been valuable for planning the future widespread deployment of an HRS availability system, with the main learnings from the trial phase including:

- The reliability of the type A hardware solution was 100% during the trial period. All signals were updated every 30 seconds as defined in the preferred option. The compliance of the signals to the common definition of availability is guaranteed by the system design.
- Feedback from the on-site installation of type A hardware (signal transmission unit) was positive overall, with technicians finding the process quick and easy. However, there were difficulties using the installation manual which was not always in the local language. A translation of the manuals or a web-based support portal would help to avoid future misconnection of the system.
- Challenges arose with the type B software solution, with many of the proof-of-concept sites remaining incomplete at the close of this study. The software programming of the standardized application programming interface (API) was found to be time consuming, as a result it was agreed to integrate a pre-existing individual API from one supplier. All HRS from this supplier have been successfully displayed on the web-based map. Nevertheless, the signals provided by this API do not (yet) comply to the availability definitions from the HRS community: signals are only updated on change (> 60 minutes, at many sites even > 48h) or on push basis (every 24h). The HRS supplier plans to improve the reliability of their monitoring system and the quality of the information exchange via their API to comply with the proposed European HRS availability system.
- The study has supported a second HRS supplier to program the standardized API, however a series of complications in developing the API prevented the connection of the HRS to the HRS availability platform. Issues arose in exporting the correct signals at the defined transfer rate from the plant monitoring system. A third HRS supplier/operator initially interested in the type B solution reverted to the type A system, which proved easier to install.

In summary, the signal collection via the hardware solution (type A HRS) proved to be easy to use and reliable in providing the required signals at the required frequency. Connecting HRS via the software solution (type B HRS) requires programming of the standardized API, which has not yet proven successful in the trials but is expected to be successfully realized after the end of the trials by at least one HRS operator. The quality of the signal (including the requirement for a heartbeat signal, at minimum, every 60 minutes) from the type B system has not yet been proven by the HRS availability system.

[2] Of which 2 could only connect after the end of the trials (Air Products, HyOP), one site could not connect to the local internet due to lack of space in the control cabinet that was occupied by other measuring devices.
[3] Of which 1 could not finalize the API programming within the trial period.

An analysis of costs and likely business models was undertaken to understand the sustainability of the technology solution and potential options for funding widespread uptake of the system.

The total number of publicly accessible HRS operational in Europe is expected to reach 140 by the end of 2018. This number is based on a review of all existing and planned HRS in Europe undertaken as part of this study, which included consultation with all the major HRS suppliers and operators. These stations need to be retrofitted with the HRS availability system, either by installing a transmitter unit (hardware, type A) or by connecting them via the standardized API (software, type B). Future stations may integrate the transmitter directly into the equipment during the construction / installation process, reducing costs for the organization and support during installation. Future stations are also less likely to be prototypes but commercial systems with standardized approaches to plant monitoring. This will significantly reduce the variation and complications (and thus the time and expense) associated with programming APIs that vary from station to station.

To accelerate the roll-out of the common European HRS availability system it is recommended to reduce the costs for the early adopters of the system by funding the retrofitting of existing stations with the type A transmitter unit as well as 6 months of operation for all HRS connected to the system.

The costs to deploy the HRS availability system throughout Europe have been estimated based on the costs from this proof-of-concept trial. There is a degree of uncertainty associated with the cost estimates for the scale-up of the system, particularly as a large portion of these costs are associated with the costs for technicians' time. As some of the expenditure is fixed (e.g. data storage, software maintenance), the forecast cost to deploy and operate the system per hydrogen refueling station is estimated to reduce with the scale-up and the number of stations participating in the HRS availability system. A summary of the estimated costs is as follows:

- The total costs of retrofitting existing stations with the type A HRS availability system is estimated to be around €1,380 per station.
- The deployment of type B systems requires the HRS operators/providers to invest in developing an application program interface (API) to send signals from the HRS sites to the HRS availability platform. This cost would vary significantly depending on the HRS operator and the configuration at their hydrogen refueling stations. The cost for the HRS availability system technician to support the integration of the standardized API into the European HRS system portal is estimated to be 300 € / HRS, although this is likely to be a fraction of the total cost to the HRS operator and the contractor of the HRS availability system.
- The costs to continually operate the system, including operation of the website, data storage, software maintenance (including security architecture), have also been estimated at €1,500 per HRS per year during the initial deployment phase (< 200 HRS), reducing to €400 per HRS per year at the mass market phase (> 500 HRS).

Consultations with the hydrogen refueling industry have highlighted the high level of interest in the HRS availability system, however many stakeholders have already heavily invested in hydrogen refueling infrastructure and fuel cell vehicles and have shown a limited appetite to invest in the HRS availability system while the market remains in a development phase. This restricts the opportunities to secure revenues to finance the deployment and initial operation of the HRS availability system at a time when the system will be most valuable to FCEV users.

A subsidy to support the first phase of deployment would help to overcome this financial barrier and help to prove the value of the system to HRS operators and vehicle OEMs who would be the potential future customers. This would also help to generate momentum to establish the HRS availability system for future commercial deployment throughout Europe.

Based on assumptions of 140 hydrogen refueling stations across Europe, with 50% adopting the type A system, a subsidy of approximately k€ 110 would cover the installation costs, and a subsidy of k€ 195 would cover these installation costs and the operation of the whole system for the first six months. This subsidy could also be designed with a deadline for participation in the first phase of deployment, which would help to accelerate the uptake of the HRS availability system and incentivize the early adoption of the system.

The HRS availability system will help to reinforce the confidence FCEV owners have in the refueling infrastructure and encourage further uptake of FCEVs, requiring further HRS and growing the market for the HRS availability system. The HRS availability system would therefore have a circular impact, by benefitting the HRS and FCEV community it would be benefitting itself by increasing the potential market for the system.

Revenue streams required for the economic viability of the HRS availability system after an initial subsidy-supported deployment phase have been calculated based on the estimated initial up-front costs of the system and the annual on-going costs. Various stakeholders have been identified who would benefit from the system and would be potential customers, provided the value of the HRS availability system can be demonstrated. Cash flow analyses from the perspective of an organization seeking to introduce the HRS availability system across Europe were used to calculate the revenue required per station or per FCEV for a sustainable roll-out under different scenarios of further HRS and FCEV uptake. The total revenue required for a positive cash flow of approximately €1,200 per HRS per year during the initial roll-out phase is expected to reduce significantly with the further expansion of the hydrogen refueling infrastructure and potential market size for the HRS availability system.

2 Introduction

The potential for hydrogen fuel cell electric vehicles (FCEVs) to reduce harmful emissions has been recognized at a European Union and global level. For example, the Directive on the deployment of alternative fuels infrastructure states that "*electricity and hydrogen are particularly attractive power sources for the deployment of electric / fuel cell vehicles and L-category vehicles in urban / suburban agglomerations and other densely populated areas, which can contribute to improving air quality and reducing noise. Electro-mobility is an important contributor to meeting the Union's ambitious climate and energy targets for 2020.*" [4]

Several automotive OEMs are now marketing fuel cell cars in Europe, and many others have stated publicly their intentions to bring similar products into series production from the early 2020s. The FCH 2 JU has played a central role in positioning Europe as a leading market for such vehicles by supporting a series of pre-commercial demonstration projects that allow real-world testing and validation of hydrogen and fuel cell technologies (the vehicles and associated refueling infrastructure).

Based on these activities, hydrogen refueling stations (HRS) in Europe are transitioning from being advanced technology demonstrators to semi-permanent assets that will allow further uptake of FCEVs.

In this context, several countries (notably Germany, Denmark, the UK, and France) have developed plans for coordinated roll-out of HRS to provide national coverage within the next few years. Despite the various on-going coordinated programmes, Europe's *HRS network* will remain relatively sparse (e.g. compared to petrol filling stations) for many years, which means that up-to-date information on stations (location, status, etc.) is and will remain valuable for FCEV users.

2.1 Context and aims of study

The core aim of this study was to develop and demonstrate a concept for a hydrogen refueling station availability system and investigate potential business cases for implementing the system.

While there is little demand for systems communicating the status of petrol stations (given the high level of coverage and very high availability levels), an HRS availability system is needed due to:

(i) the low density of HRS coverage,

(ii) the fact that HRS availability levels are not yet at the level of traditional fuel dispensers, and

(iii) a lower level of familiarity with the infrastructure amongst end users – i.e. an HRS availability system is a useful confidence-building measure for potential users of FCEVs.

While there have been various attempts to inform customers about the extent and status of HRS roll-out by country / across Europe, the hydrogen transport sector lacks a definitive source of reliable, up-to-date information on the real-time availability of HRS across Europe.

This report summarizes the work undertaken by a consultancy team comprising Spilett, ENDA, and Element Energy that was commissioned by the FCH 2 JU in summer 2017 to carry out this study.

[4] Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure.
http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32014L0094.

2.2 Overview on study team and activities

The study was implemented by an interdisciplinary team comprising expertise in hydrogen & fuel cell technologies, hydrogen mobility and data monitoring systems (see *Figure 1*).

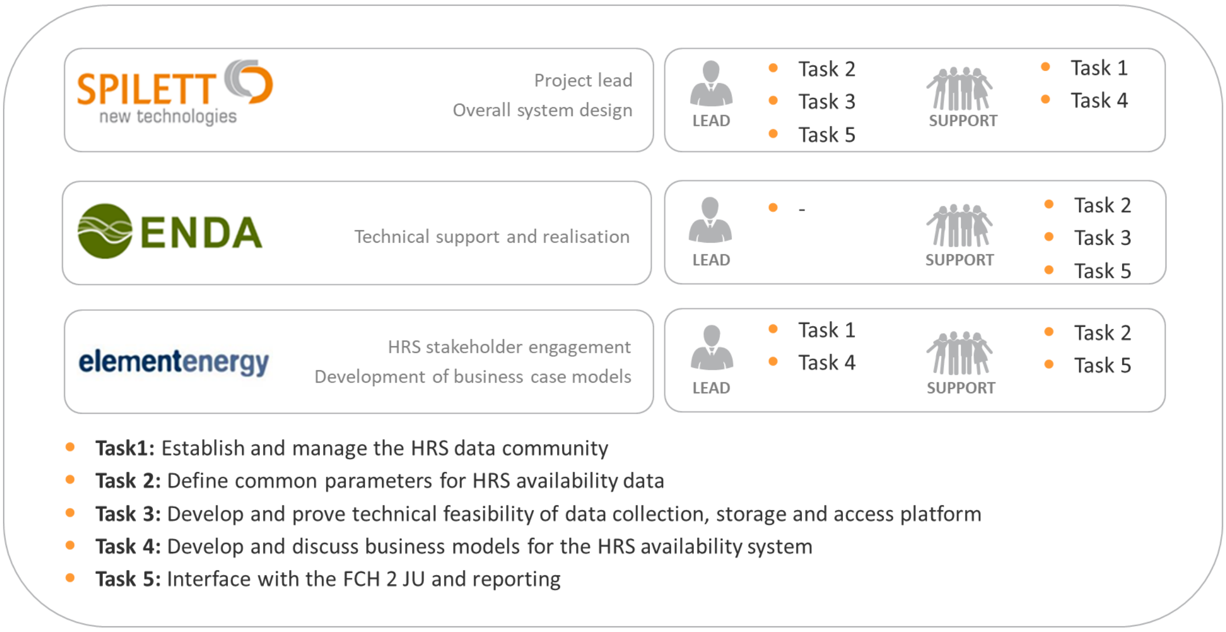

Figure 1: Study team and responsibilities

The six-month study to develop and prove the concept of a common European HRS availability system was divided into three parts (see *Figure 2*):

1. The *consultation with the HRS stakeholder community* to come to a consensus on a common definition of HRS availability states and discuss / evaluate the technical feasibility of different hardware and software solutions;
2. The *development of the HRS availability system, comprising*
    a. a suitable hardware solution for type A HRS (including configuration of 7 hardware transmitters to be tested in the proof-of-concept trial),
    b. a standardized API to integrate signals from type B HRS,
    c. a HRS software portal including operators' access area (to store, process and access data / information), and
    d. a standardized API to export availability signals to third parties (app developers, car navigation system providers, website developers etc.)
3. The *organization, implementation and evaluation of a "proof-of-concept"* from November 2017 including 6-8 sites in 4 different countries.

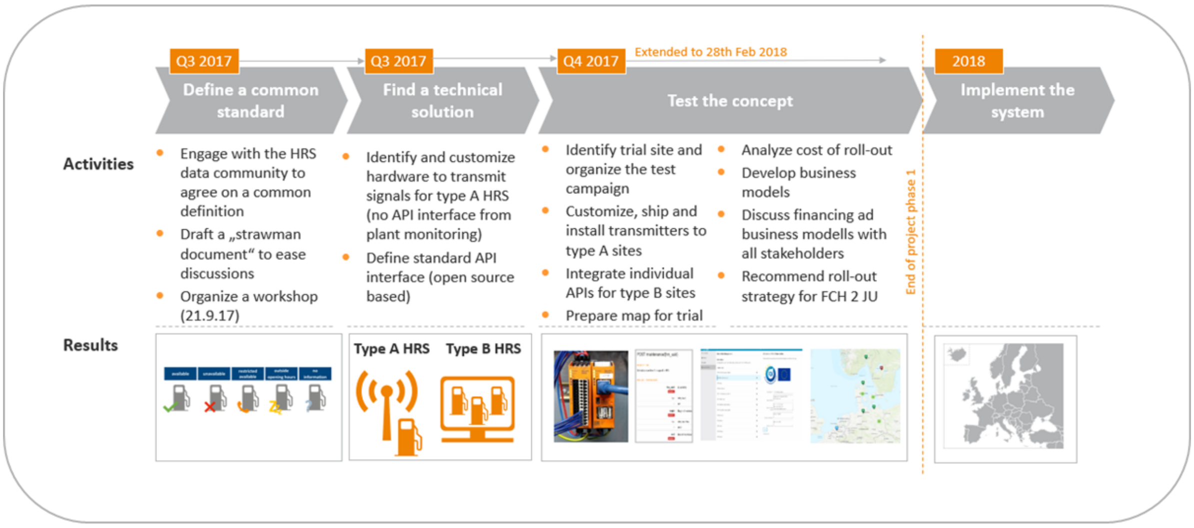

Figure 2: Study activities in phase 1 (July 28th, 2017 - February 28th, 2018)

3 HRS Availability System

3.1 System requirements

From the outset of the study, the study team identified the need for the common (Europe-wide) HRS availability system to meet various criteria, including:

- **Focus on end users' needs** – the system must provide information that is sufficiently comprehensive to meet the needs of all HRS users.
- **Acceptability to all major HRS operators** – the usefulness of an HRS availability system depends on accessing data from all accessible HRS, which in turn implies a need to secure buy-in from all HRS operators.
- **Acceptability to all major HRS station technology suppliers** – the HRS availability system needs to gather plant information, process this information and make them publicly available. Some operators might in addition use this data source to store information and calculate benchmarks. As HRS performance will be revealed, technology suppliers must buy-in not only to the hardware concept for transmitting the data but also to the definition of availability and the calculation processes. In addition, the hardware solution must be certified to not risk or complicate the certification of components and approval process of the HRS station.
- **Robustness** – the system needs to be capable of accepting and processing data from multiple sources and provide accurate, relevant information in a suitable format for a variety of uses. There is also a requirement to future-proof the system for longevity.
- **Commercial viability** – the benefits of this type of system will only be realised if it is implemented across the HRS network, hence there is a need to consider the commercial case for adopting the solution and develop an implementation plan.

The study's methodology was developed with these points in mind and a wide-ranging consultation with relevant stakeholders was undertaken during Q3 and Q4 2017.

3.2 Definition of real-time availability

The consultation of industry stakeholders has helped to **define up to five categories of real-time availability** which will be used to quickly show FCEV owners the status of each station: “available”, “unavailable”, “restricted availability”, “outside opening hours” and “no information”.

In order to increase transparency of the information it was decided to collect and communicate signal states for 700 bar and 350 bar dispensers separately.

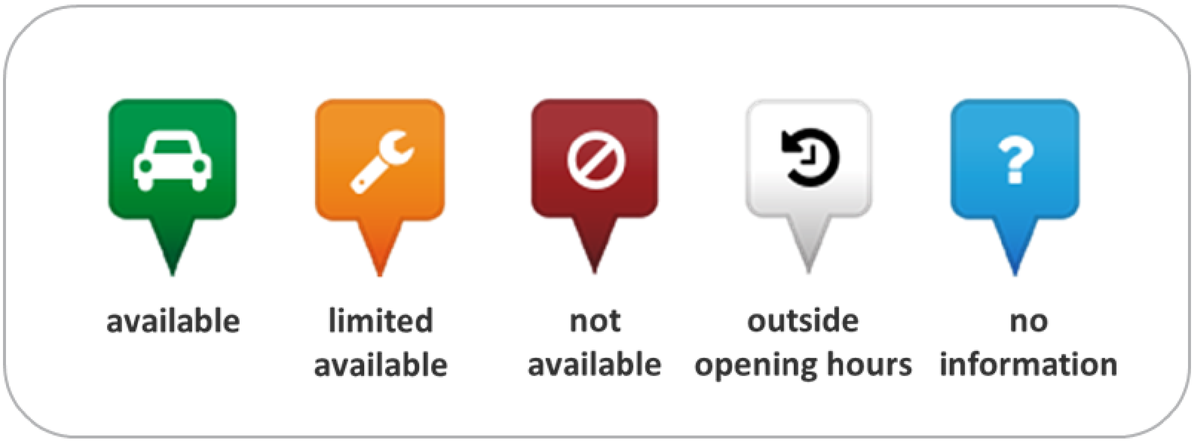

Figure 3: Discriminating-free icons used for illustrating HRS availability states

Category 1: Available

The HRS will be shown as being available provided at least one hydrogen dispenser of the pressure level of interest is available for use and ready to refuel a vehicle. Following consultation with a range of sector experts, the proposed common definition of an “available” HRS is one at which:

“Users are able to refuel vehicles in line with their refueling protocol”

The operator of each HRS in the system will be responsible for providing a single signal that refers to the availability state communicated to the customer at the station (when starting the refueling process). In most cases this might be the “dispenser availability”, at some stations the availability of the card reader may be included (if faults with the card reader / payment infrastructure prohibits refueling).

Category 2: Restricted available

In the event that it is still possible to refuel hydrogen vehicles on site, although the availability criteria shown above is not fulfilled a second status will be used “restricted availability”. This will then direct the FCEV owner to further information, either directly from the online portal, or from contact with the HRS operator. This category would include a range of scenarios, e.g. when refueling would take longer than normal, or where on-going maintenance at the site would cause disruption or require assistance for refueling.

Category 3: Not available

The “unavailable” status includes all scenarios where it is not possible for FCEV owners to access the site and refuel their vehicle with hydrogen. This includes a wide range of situations, e.g. technical faults with the HRS components and dispensing equipment or any other elements of the station required for refueling, including depleted hydrogen storage or no available access to the hydrogen dispenser.

Category 4: Outside opening hours

To distinguish between technical issues and normal closure periods for sites which are not open 24/7 information on the opening hours of the station will be included. The availability definition will be presented as “outside opening hours” in this case.

Category 5: No information

This status indicates that there is no signal from the HRS availability transmitter or the plant monitoring system, i.e. no live information on the availability of the station is available.

3.3 HRS Availability System design

3.3.1 Overview

The proposed HRS availability system designed at the beginning of this study proved to be technically feasible and reliable in operation during the 120 days of trial and was widely accepted by operators and suppliers throughout Europe. The system consists of three parts:

- **a signal input unit** (separate solutions for connecting the HRS via software interface or hardware transmitter)
- **a central software platform** to collect and update real-time HRS availability (allowing for site-specific update of static information or planned maintenance activities) and processing information
- **a standardized, open-source based API** to export signal and HRS site information to third party users (integrating the information in own web portals, apps and / or car navigation systems).

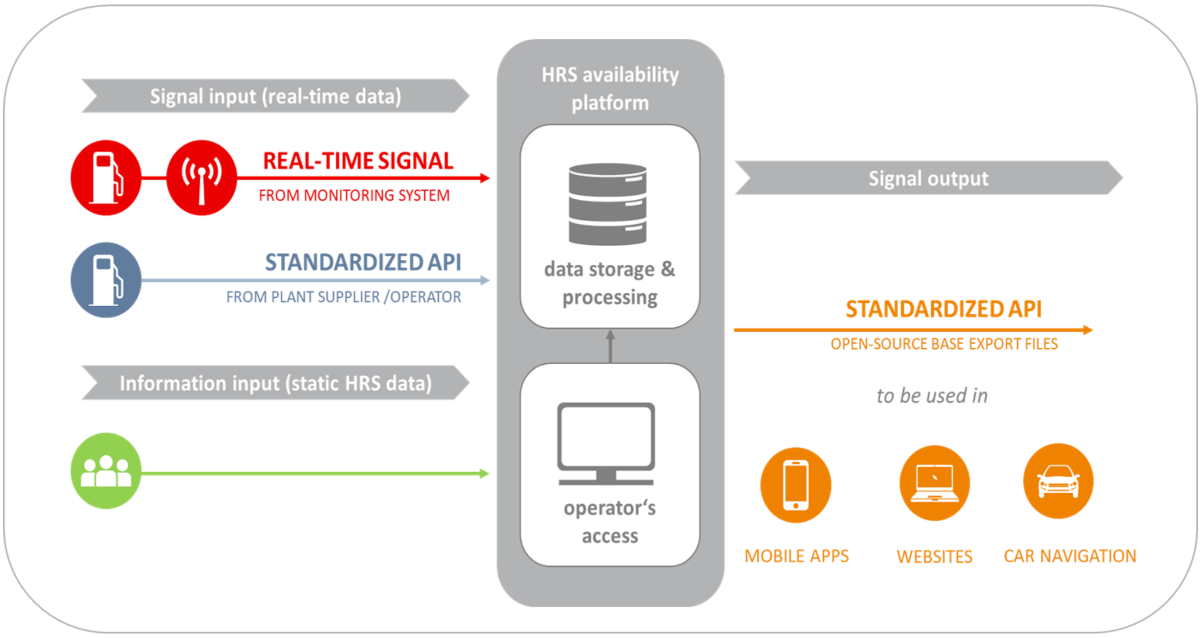

Figure 4: Schematic of the European HRS real-time availability system

3.3.2 How to generate and collect real time signals (system input)

From the consultations with the HRS community and based on experiences with two other automated HRS real-time availability systems (in Germany and California), it was decided to offer two types of signal input for HRS operators and suppliers to connect to the European system:

- **Type A HRS:** Provide a hardware solution to be installed on site (in a control cabinet) to collect and transfer signals as defined in chapter 3.2.

Type B HRS: Integrate signals provided by the HRS operator's plant monitoring via a standardized application programming interface (API). The standardized API ensures compatibility with the European HRS availability system and defines the type of signal and frequency of transmission. The API has been published at https://api.h2-map.eu/doc.

- **Hardware solution for the collection of real-time signals @ type A HRS**

Figure 5 illustrates the signal transfer via the transmitter unit for type A HRS. The transmitter unit identifies dispenser availability signals (e.g. available, unavailable) and is installed on site in the HRS control cabinet. The transmitter unit includes a maintenance switch which enables technicians to manually switch the availability state.

Signals are transferred via a local internet connection to the central HRS availability platform (WiFi or LAN). If no internet connection is available on site (e.g. stand-alone HRS sites) or if the internet connection is not able to be used by the HRS availability system (e.g. due to safety concerns from the HRS supplier) a separate router can be installed to connect the HRS transmitter unit to the software platform. During the trials suitable hardware for this purpose was identified.

The hardware transmitter collects and updates the HRS dispenser availability signal every 30 seconds. If the software portal does not receive a signal update for 5 minutes, the availability state of the HRS is changed to "unknown status".

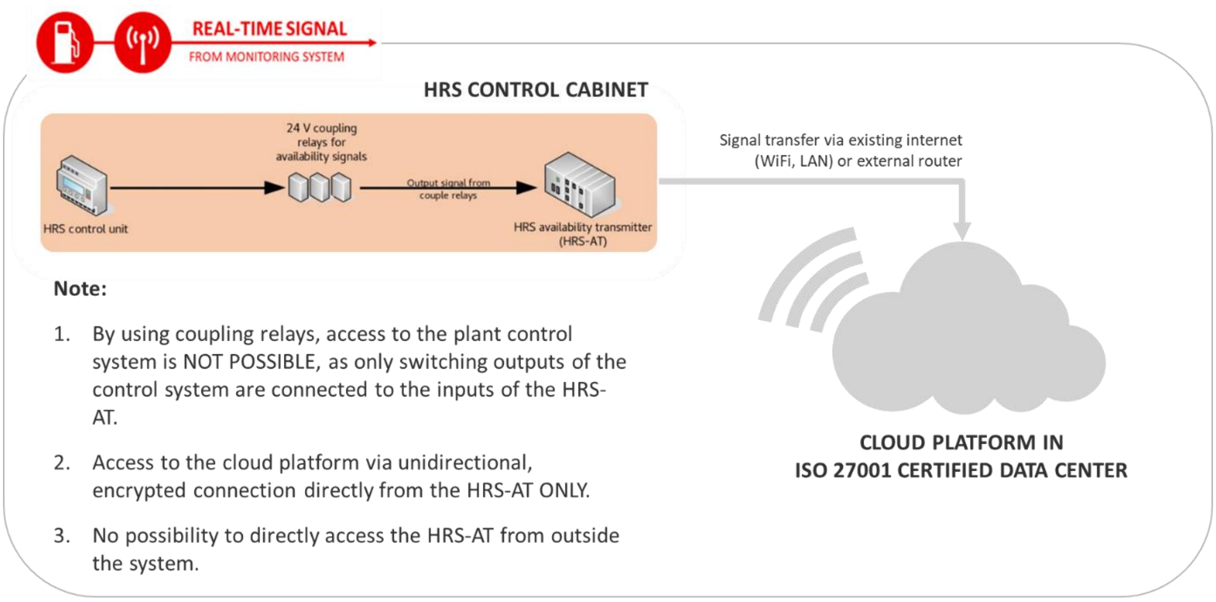

Figure 5: The concept of signal transfer via RevPI (type A HRS)

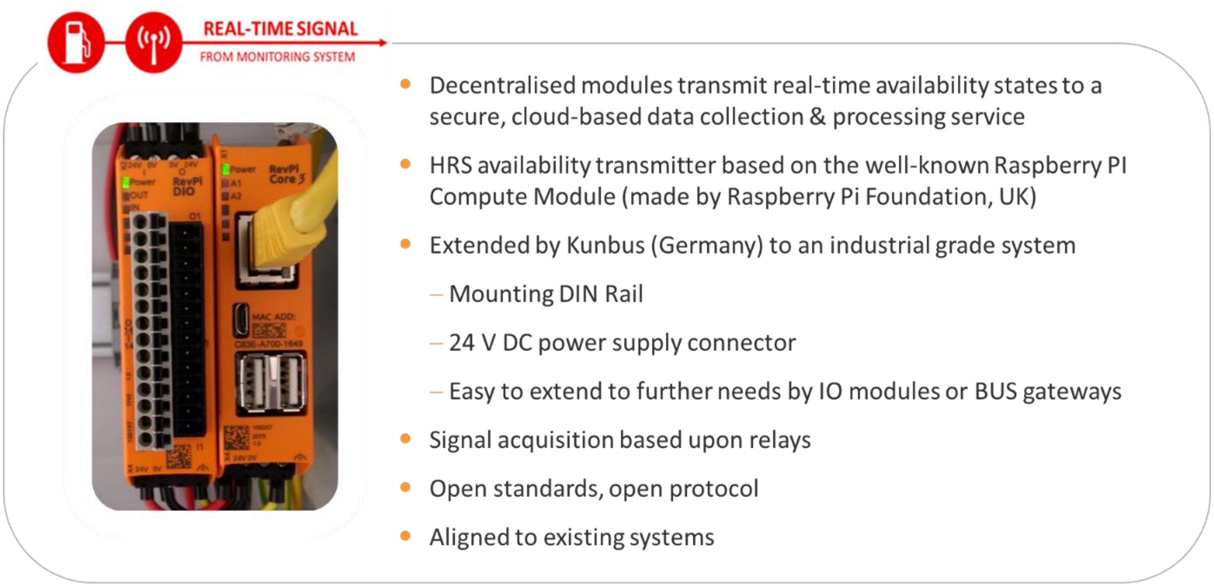

Figure 6: Overview of the RevPi hardware transmitter (type A HRS)

Figure 7: Manual switch to override type A HRS availability (restricted availability)

Software solution for the collection of real-time signals @ type B HRS

Signal transfer from type B HRS is realized with a standardized interface protocol: The plant monitoring system sends a set of predefined data in a specified format to the HRS availability portal, which processes and aggregates all signals to a uniform database source. The incoming information from type B HRS needs to be updated at least once an hour or with each signal change to ensure accuracy of information.

The standardized interface protocol has been published here: https://api.h2-map.eu/doc.

3.3.3 How to integrate and update static HRS information (operators' access area)

The operators' access area has been developed in the prototype platform with an individual, password-protected area summarizing static information of all sites registered by the HRS operator on the HRS availability system. During the trials, the operators' access sites have been serviced by ENDA who oversaw the integration and updated the static station information provided by the trial sites.

The HRS availability platform automatically generates two of the five availability signals:

1. **Outside opening hours** – the opening hours of the HRS[5] overwrites the real-time dispenser availability signals for HRS that are not open 24/ 7. The customer will see a “grey” (clock) symbol along with the information “outside opening hours” in the periods the HRS is not in operation.
2. **Unknown status (no information)** – if the HRS availability portal does not receive any signal update for more than 5 minutes (type A HRS) or 60 minutes (type B HRS) the availability signal changes to “unknown status” until the next signal update.

A third availability signal may be manually set from the operators’ access area (in addition to the switch on site or the API information):

3. **Restricted availability** – the customer notification functionality (see *Figure 9*) enables the operator to change the HRS availability to a restricted availability state which will act to notify customers of events or visits on site (e.g. inform on temporary availability due to storage tank fillings, training session, or other events at the site).

The operators’ access area provides an overview of all static information to be included in the API to be exported to the European HRS map and third parties (to be used in apps, navigation systems and or web portals). The portal has a password-restricted and personalized access and provides a template to update static information or insert customer notifications for all HRS sites registered to the operator (see *Figure 8*).

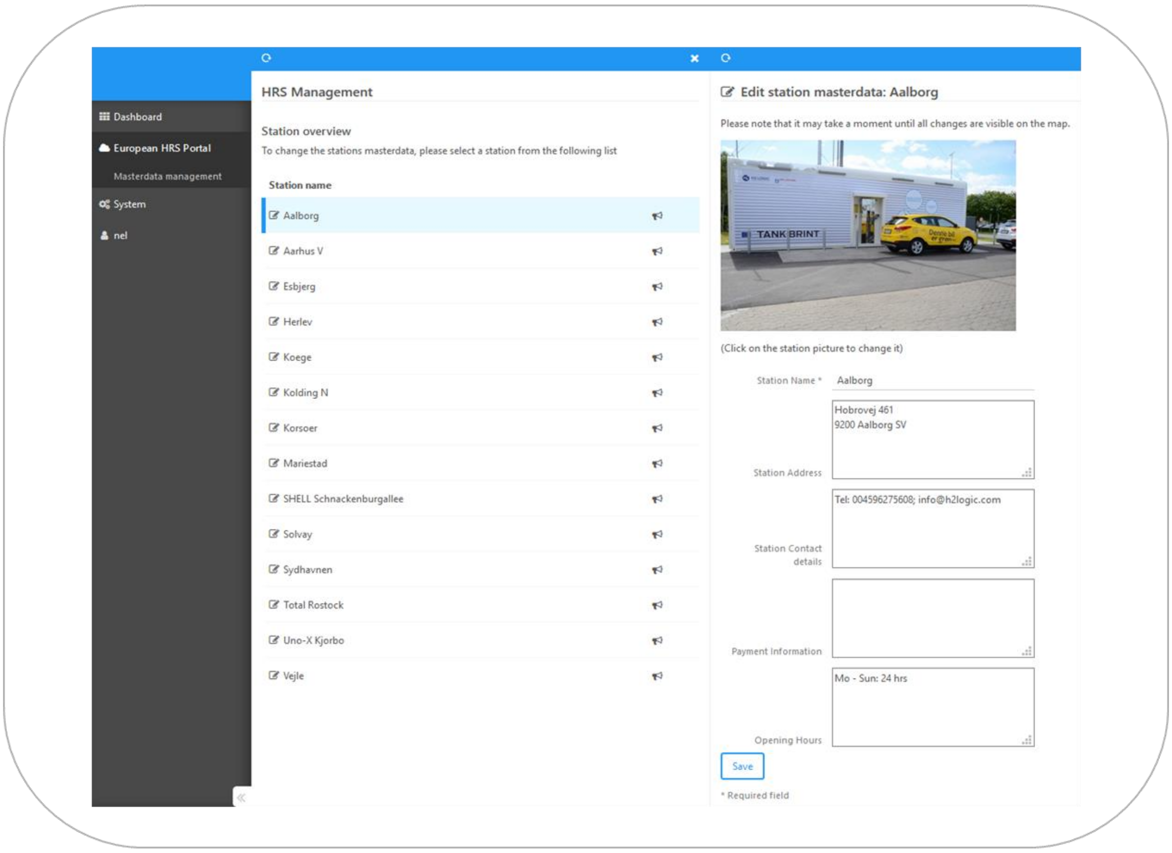

Figure 8: User interface of the operators' access (portal)

[5] Static information that the operator may define and adjust when necessary.

Figure 9: User interface and map display of the customer notification function

3.3.4 How to process and store information (HRS availability portal)

The HRS availability portal is the central database for storing and processing all data sent by the individual sites and operators. *Figure 10* provides an overview of the data processing logic and software tools used for developing the HRS availability system (portal) prototype.

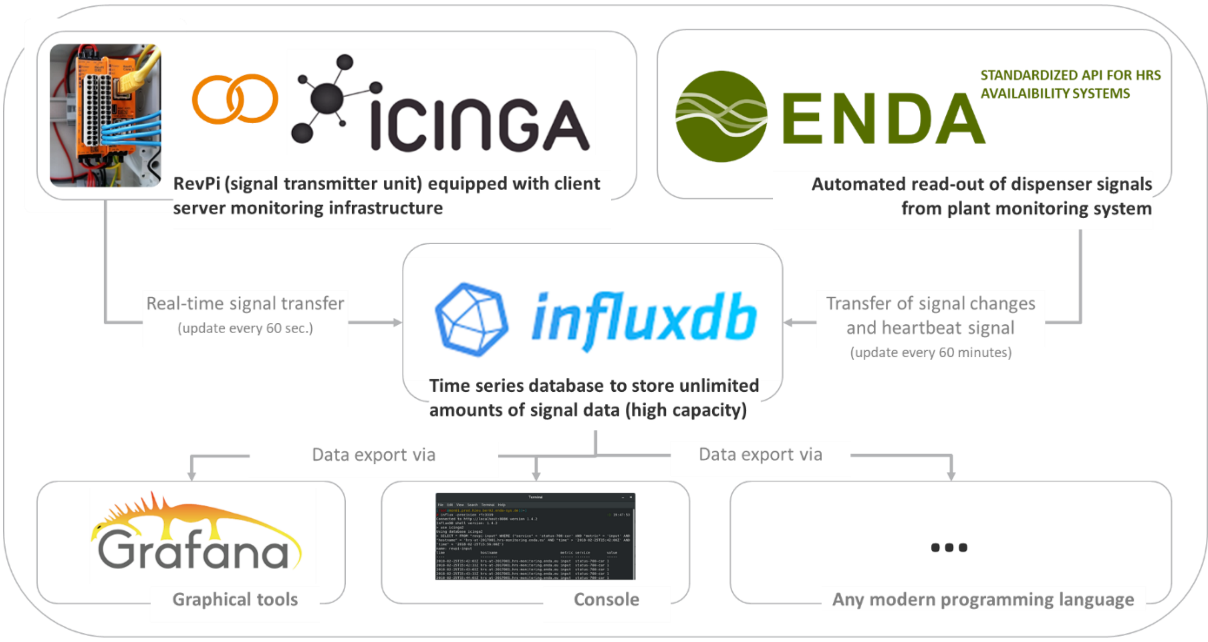

Figure 10: Scheme and structure of the HRS availability portal

All elements of the software portal are open source and compatible with a variety of business solutions that may be used by HRS stakeholders to internally evaluate data and integrate the exported data into their existing reporting tools.

The criteria for choosing *Icinga, Influxdb and Grafana* are:

1. Icinga is the most advanced and mature Open Source (OS) monitoring solution with a broad community and thus sustainable. It is scalable from small businesses to enterprises like Adobe and integrates with the OS time series database influxdb.

2. Icinga uses decentralised data collectors like the one developed for this study. Those satellite systems implement and use a standardized API to deliver monitoring data to the centralised Icinga instance, that in turn can be configured and extended to display the status information on the monitored system.
3. Icinga uses a time series database to store all HRS status information. Here influxdb was an obvious candidate, as it is also OpenSource, can cope with a very dense stream of continuously delivered data and integrates well with Icinga.
4. The time series database can be queried via console, via a comprehensively documented http interface, by direct database access drivers for a wealth of programming languages and by making use of the visualisation tool Grafana (also being OS). The latter allows options for a decentralised system(s), their signal(s) and a time range, within that the signal values are displayed. A CSV export can also be obtained from Grafana.
5. For quick overviews to more in-depth analysis Grafana is the first choice. For repetitive tasks and sophisticated calculations an individual program that uses the appropriate direct database access driver would be the way to go.

For the time being, basic reporting has been enabled by the standardized interface for data export via Grafana or the HRS operators' own software. **It is nevertheless suggested to include a work package on standardizing HRS (internal or external) reporting in phase 2 of this study to accompany system roll-out. If HRS operators could agree on common formats on how to internally and externally edit reports, add-ins can be developed that may increase the value of the tool by reducing the individual effort of data analysis.**

3.3.5 How to export and visualize data

A mandate of the study was to develop an HRS availability map showing all HRS trial sites being able to include all current and future HRS throughout Europe. This map was realized with OpenStreetMap to align with the Open Source strategy of the European Union. The prototype map has been published at https://h2-map.eu (see *Figure 11*).

The five availability states will be displayed *discrimination-free* on the map, both in colors and icons to allow color-blind people to easily navigate and identify HRS availabilities at first sight. To ease navigation, regional cluster information is provided to indicate whether at least one HRS is available for filling in the region. By clicking on the cluster icons, the map automatically zooms in to provide more information (see *Figure 12*). Full information on the individual HRS site is provided by clicking on the site. In addition, customers are informed on the time of the last signal update (see *Figure 13*).

Customers may use their mobile phones to access the European HRS availability mobile map via the short link function of their smartphones.

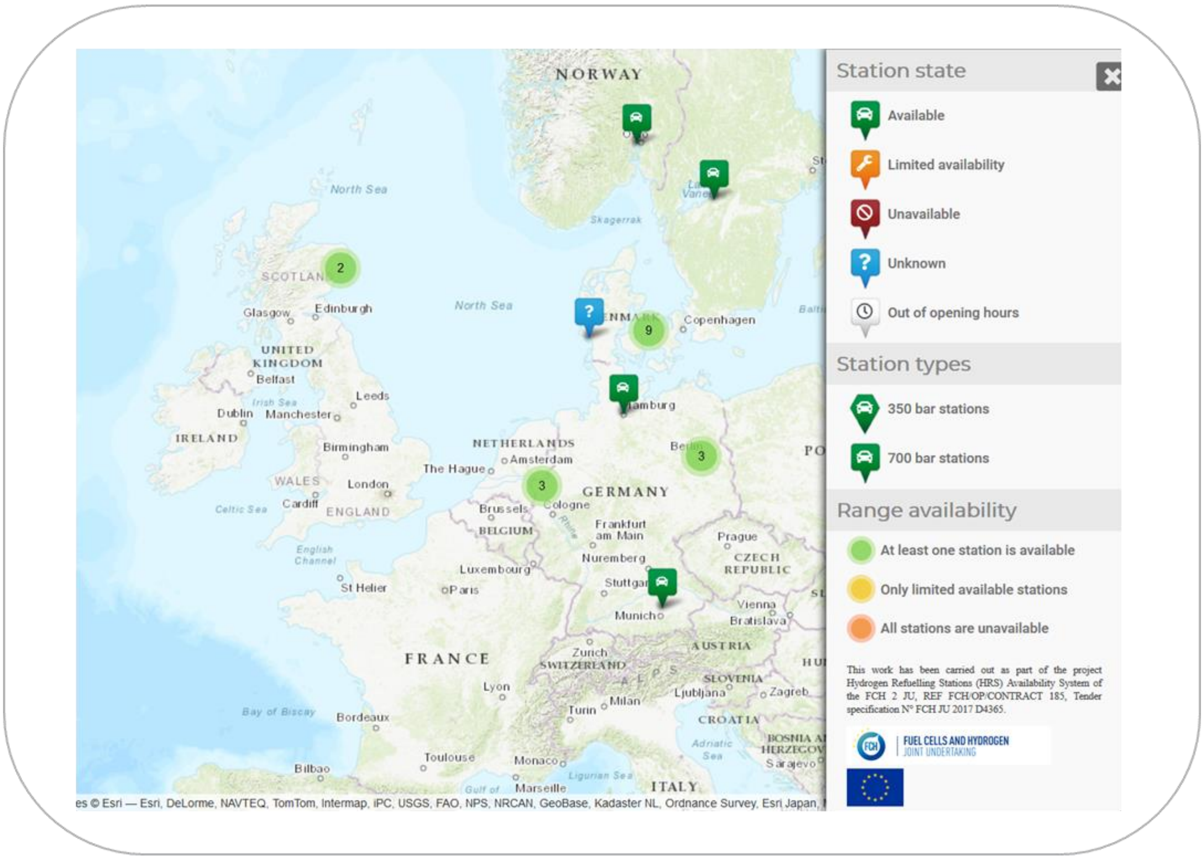

Figure 11: The European HRS availability map

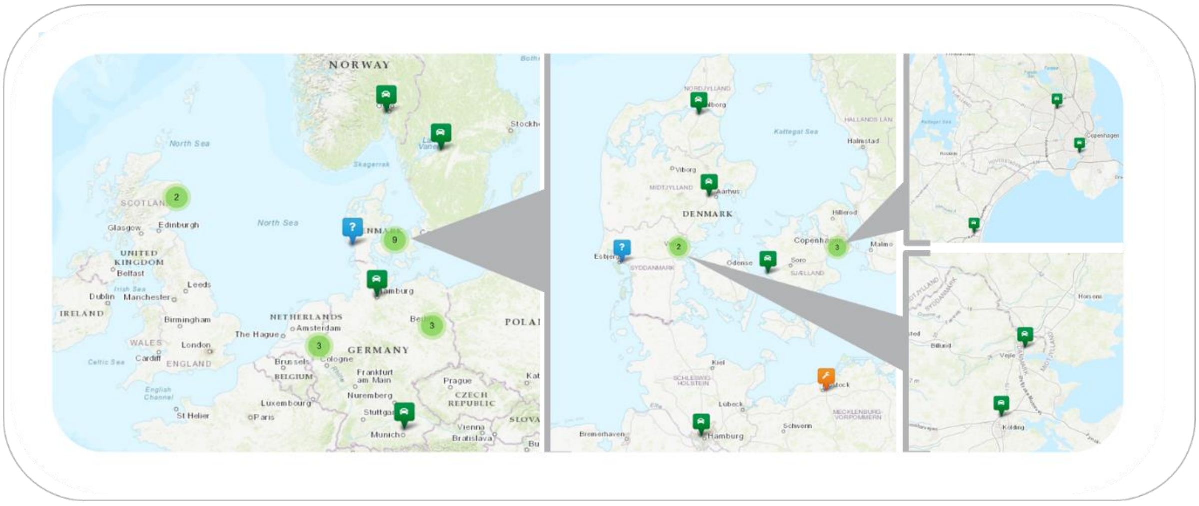

Figure 12: Regional availability clusters - zoom in

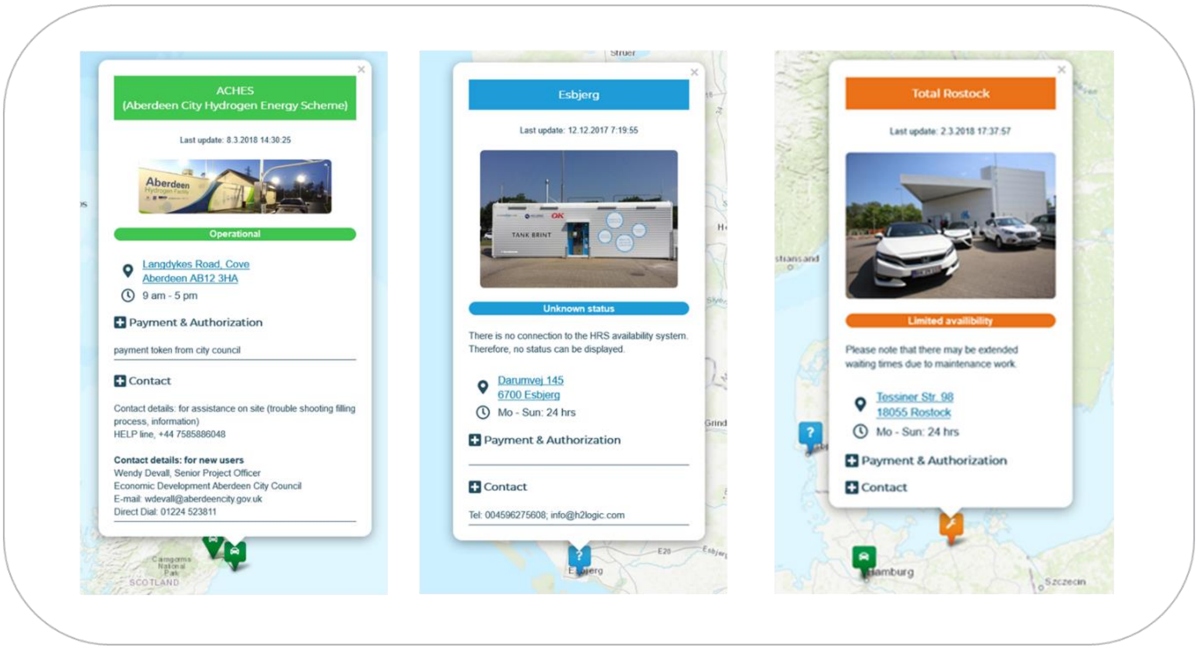

Figure 13: Detailed HRS site information

Third parties who intend to integrate the HRS availability information (dynamic and static data) into their own applications and websites may access all required information via an open protocol that has been published under https://h2-map.eu/data.

4 Proof-of-concept trial

4.1 Description of the trial

The mandate of the study included a real-life proof-of-concept trial across 6-8 sites in at least 4 countries throughout Europe. The aim of the trials was to prove the technical feasibility of the system for both the type A and type B HRS sites in various system designs, to investigate reliability of signal transfers and evaluate efforts associated with the integration and operation of the system. The learnings and results from the trial served as information for planning the implementation (roll-out) of a common European real-time HRS availability system in 2018.

The trials started on October 30th, 2017 and were extended to February 28th, 2018 as more HRS operators than originally envisaged showed interest to participate in the trials and experience the new system. To maximize learnings from the trials, the study partners agreed with the FCH 2 JU to include as many different HRS suppliers, operators and sites as possible. The organization of the trials was more time consuming than originally estimated, requiring greater personnel time and taking longer time from the initiation with the HRS operator to successfully connecting a site to the availability platform.

There were various reasons for the extended time and effort for implementation, including:

- a lack of technicians available for installation of type A HRS transmitter units at participating sites (due to pre-planned maintenance work at other sites by the end of 2017);
- the wish of HRS operators to reduce cost for technicians coming to the site, resulting in scheduling of the transmitter installation to planned site maintenance work;
- the identification and commissioning of a suitable router to replace the need for an internet connection on site (add-on) with support of ENDA;

- the implementation of the standardized type B API to connect to the EU system;
- the need for programming an individual API to integrate an existing API of one of the HRS suppliers;
- long response times for requests for information and coordination of system implementation from some HRS operators (reflecting a high work load, change in responsibilities etc.).

It is expected – and can be reasonably argued from the very constructive and positive cooperation with all trial sites and suppliers / operators – that a consolidated European roll-out of the real-time HRS availability system covering all sites can successfully be managed within shorter periods of time as the commercial roll-out phase may result in a higher priority with the HRS operators and suppliers.

The selection criteria for the trials were defined being

1. HRS in at least 4 different countries
2. as many HRS suppliers (designs) as possible
3. at least one HRS with a high number of daily fillings (frequencies)
4. Type A and B HRS, with at least 4 type A HRS

Operators who volunteered to become a trial site were Linde, HyOP, ITM Power, H2Mobility Germany, Air Liquide, NEL, Hydrogenics, Westfalen and Air Products. Although McPhy expressed a strong interest in the system and the trials, they could not join due to a very tight schedule at the end of the year 2017.

4.2 Results of the trials and lessons learned

The trials proved that the type A system works well and successfully provided the signal information as envisaged. Thus, the general success and suitability of the suggested system design can be stated. A total of 3 type A HRS system were successfully installed and operated in Germany and the UK with a total operation time of more than 6,491 hours. Experiences with daily operation of the system were gained from the trial period[6]:

- **HRS in Berlin Sachsendamm (operated by H2Mobility)** successfully connected on 19.11.2017 / 16:20 p.m. local time,
- **HRS Aberdeen (operated by Aberdeen city Council)** connected on 05.12.2017/ 12:55 p.m. local time,
- **HRS Fürholzen (operated by Tank & Rast)** connected on 18.12.2017 / 13:49 p.m. local time.

The **type B HRS** integrated to the HRS availability platform during the trial period included 14 HRS from NEL, located in Germany, Denmark, Sweden and Norway. No other HRS operators / suppliers were able to provide type B signals based on the study definitions of the standardized API within the trial period. The NEL type B stations were connected to the HRS availability platform with an individual API, rather than a standardized API to trial the automated transfer of signals from plant monitoring systems. The NEL API was integrated into the HRS availability system on 19.11.2017 (at 16:25 local time), with total operation of 2,591 hours.

[6] The type A HRS at Westfalen / Muenster started successfully operation on March 19th, 12 a.m. after re-wiring

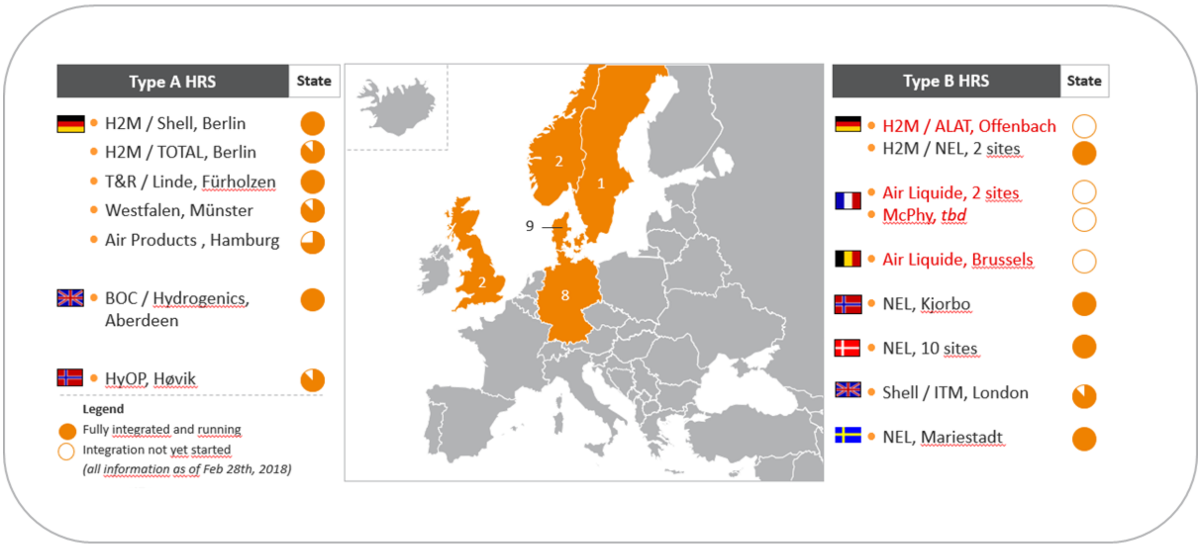

Figure 14: Participating sites and chosen technology in the trial (30.10.2017 – 28.02.2018)

The proposed HRS availability system proved to be a reliable and functional solution for a daily operation of a common European HRS availability system.

Although the integration of most of the trial sites took longer than originally expected, a European roll-out of the system is still achievable at up to 140 sites within 6-8 months. This is possible with a thorough and well-prepared organization of the roll-out, strategies to reduce personnel and organizational efforts per operator /region. The experience from the proof-of-concept trial found that the activities of installing the transmitter and (at some of the sites) trouble shooting to guarantee a high-quality signal transfer, were comparatively low compared to the efforts to organize the installation. This is partly explained by high workloads of the operators and technicians at the end of 2017, but this should also be expected for the roll-out of the system.

Similar experiences were found from the trial of type B systems, with very long and yet unsuccessful / unfinished activities to apply the standardized API. Each HRS supplier not only differs in plant monitoring systems but also with different HRS technology generations. It is expected that programming the API for future HRS can be replicated with scale-up and will therefore be cheaper per HRS unit. HRS operators and providers confirmed the feasibility and requirements of collecting dispenser signals to provide a heartbeat signal from a standardized API.

With ITM Power developing a standardized API and H2Mobility Germany informing about their commitment to become a future type B HRS participant of the European system, it is expected that the software integration of plant monitoring signals will shortly be successful proven. The HRS availability portal has already proven the reliability of the process and visualized data from API input, with future connection of new HRS via the standardized API possible.

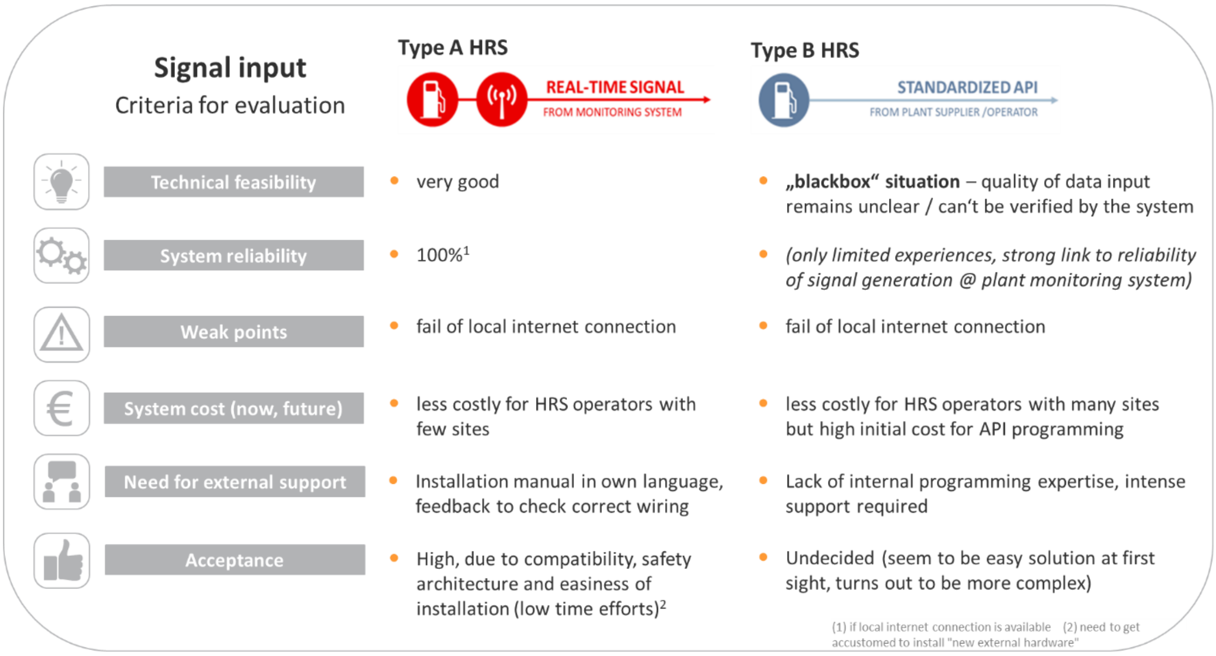

Figure 15: HRS availability system evaluation - comparative results from the trials

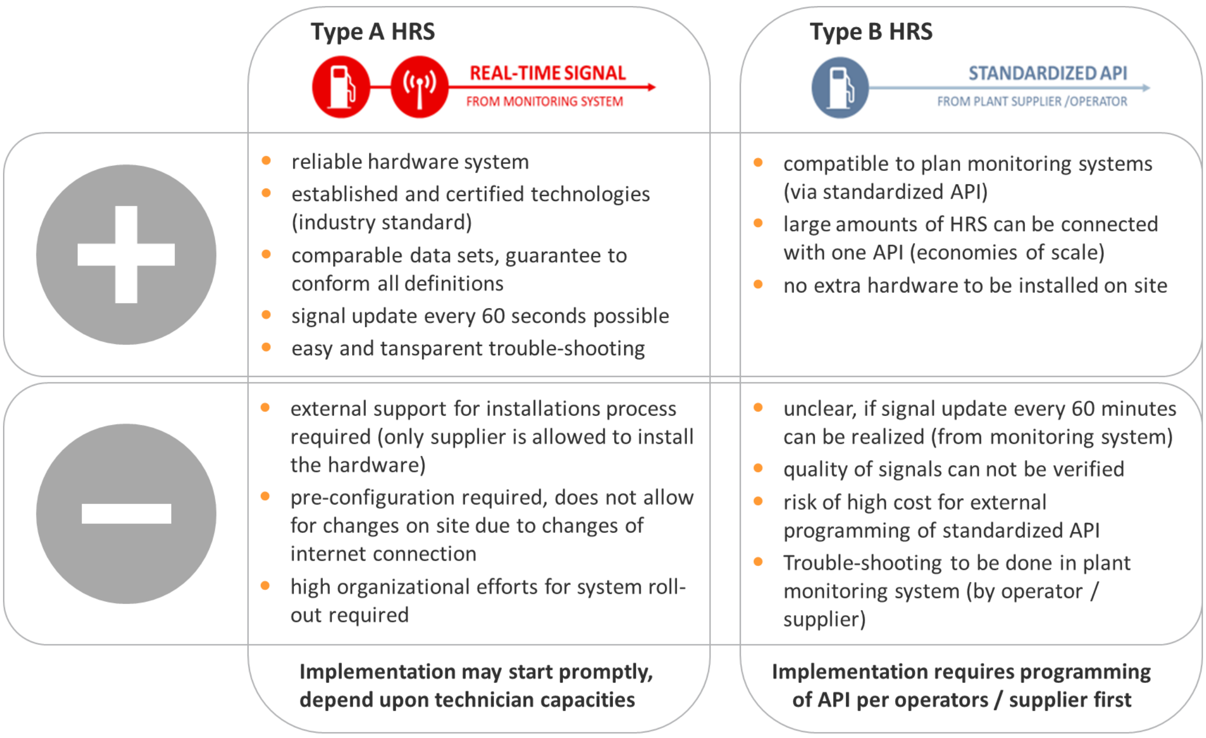

Figure 16: Pros and cons of the type A and type HRS systems

The trial phase has successfully demonstrated the feasibility of data transfer, processing and visualization from type A systems to the HRS availability platform. Type A systems can also provide a level of guarantee on the quality and frequency of the signal from the HRS. Type B solutions do not include a quality check of signals, other than a check on the frequency of signal updates. Therefore, further quality control may need to be incorporated into the standardized API for type B systems. The proposed type B system relies on the HRS operator to quality control the signals, so they comply with the definitions of availability as agreed during the consultation phase of this study with the HRS stakeholder community.

5 Costs and funding for a European-wide HRS availability system

5.1 Context

The market for the HRS availability system is driven by the move away from diesel and petrol towards battery electric and fuel cell electric vehicles. This is in combination with the emergence of the internet of things technologies, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, as well as in-vehicle 4G LTE technology, with companies such as Vodafone in Europe offering packages for in-car internet[7,8]. China has a fleet of almost 400,000 'internet cars' developed by Alibaba, which will incorporate their e-commerce platform to assist in tasks such as finding parking spaces and locating and using refueling stations, including Shell's fuel station of the future in Beijing[9,10] .

Hydrogen refueling infrastructure is in the early stages of roll-out (late stages of development) and the current sparse network in Europe causes potential issues for FCEV owners looking to refuel their vehicles. The HRS availability scheme proposes to address this problem, and this is the value proposition for the HRS availability system business case.

With approximately 1,000 FCEVs currently on the road in Europe[11] the small size of the market limits the options for covering the costs of implementing and running an HRS availability system.[12] There is, however, a great potential for strong growth in FCEVs with the backing of major industry players, as indicated by the Hydrogen Council's aim for 1 in 12 cars sold in Germany to be a FCEV by 2030[13].

The initial development of the HRS availability system is key to encouraging the uptake of FCEVs, which will in turn improve the utilization of hydrogen refueling stations (HRS). This will increase their revenue streams and the overall economic viability of HRS. The contradiction with this business case is that the value proposition is highest when there are few FCEVs and hydrogen refueling stations, and the HRS availability system may become superfluous to requirements with the full establishment of a hydrogen station network with sufficient density to provide convenient back-up across Europe, as is the case today with filling stations for conventional fuels.

As stated above there are potential business opportunities for V2I developments, this could involve real-time reporting of hydrogen prices, connection to the fuel tank sensors or similar. Examples of systems into which the HRS availability system could be integrated include Hyundai's *LIVE* service and

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[7] 4G LTE is the fourth generation of broadband cellular network. Long-term evolution (LTE) is the standard for high-speed wireless communication for wireless devices.

[8] Vodafone in car internet: https://internetinthecar.vodafone.com/

[9] Washington Post, The importance of Alibaba's new 'Internet car': https://www.washingtonpost.com/news/the-switch/wp/2016/07/12/the-importance-of-alibabas-new-internet-car/?utm_term=.e985f28f0add

[10] ERPEC News, Shell testing fuel station of the future in Beijing, http://www.erpecnewslive.com/article/1639/shell-testing-fuel-station-of-the-future-in-beijing

[11] Presentation of Bart Biebuyck, Executive Director of the FCH 2 JU, Hydrogen for Clean Transport, 2017, Available from: http://www.element-energy.co.uk/wordpress/wp-content/uploads/2017/10/HCT-22.09.2017-Bart-Biebuyck.pdf

[12] For example, one potential income stream would be from advertisers targeting users of the information provided by the system. However, with such a small pool of end users (at least in the short term), the potential revenues from advertising are very limited.

[13] Hydrogen Council, 2017, Hydrogen scaling up: a sustainable pathway for the global energy transition, available from: http://hydrogencouncil.com/

Toyota's *Touch 2*, which already include real-time information on weather reports, traffic and speed camera updates and fuel prices (see *Figure 17*)[14,15]. Although these types of V2I solutions are out of the scope of this study, the development of the HRS availability system could present other business opportunities after the widespread deployment of hydrogen refueling infrastructure.

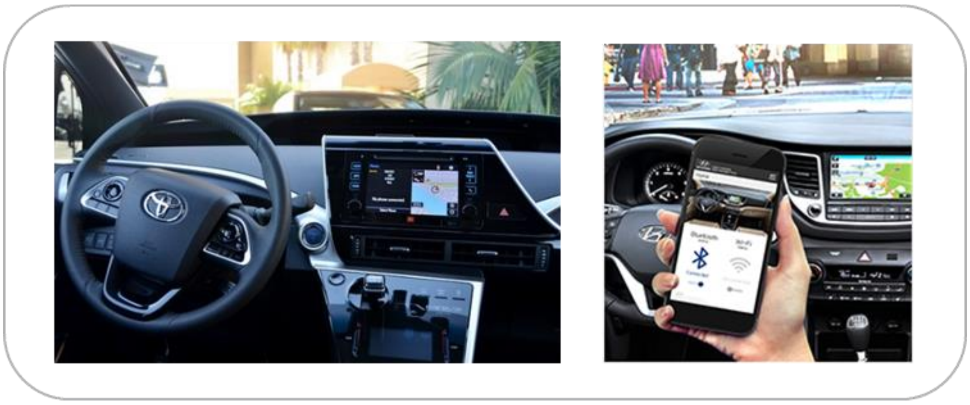

Figure 17: Toyota Touch 2 and Hyundai LIVE provide real time information to customers, such as information on weather reports, traffic conditions and fuel prices

This current proof-of-concept study has established a platform to promote and advertise the need for the HRS availability system and prove the technology via a real-world trial. Within the scope of this study, the team has sought to estimate the costs of wider scale roll-out of the system and identify sustainable models for implementing and running the system.

The value of the HRS availability system is enhanced by including the whole of Europe, this is crucial in providing the end user with complete information on all the HRS locations they can use to refuel their vehicles. This therefore requires cooperation between various companies across multiple countries to agree on a common system. The current study has looked to engage all relevant parties and to test the system on trial sites. This will help to ensure the system is tailored to the needs of the end use and increase the overall value of the system.

Different strategies to deploy this system across Europe most effectively have been considered, including multiple phases for roll-out, which aim to reduce the risk in deploying the system.

5.2 Scope of HRS availability system

Workshops and discussions with industry stakeholders were undertaken to develop the scope of the HRS availability system. At its most basic, the system will report live data on the status of each refueling station. Other features that could be offered include a diagnostic tool for equipment at each station, and a benchmarking system to assist HRS operators in reporting for European funded projects. Based on feedback from industry the proposed system and business model will focus on the core operation to provide real-time availability information for FCEV users. This will be the principal aim of this system, however additional services, such as key performance indicators for HRS, benchmarking etc. could be included, and perhaps developed by third parties, if the market demand exists.

To maximize the value of the HRS availability system to end users the HRS availability information will be made openly and freely available. This is consistent with the systems operated by Spilett and the

[14] Hyundai Connectivity, available from: http://www.hyundai.com/eu/en/Innovation/Connectivity/index.html
[15] Toyota, Touch 2 with Go Plus, available from: https://www.toyota.co.uk/download/cms/gben/Quick%20Reference%20Guide%20%2021042015_tcm-3060-405975.pdf

California Fuel Cell Partnership and the station status app[16]. The motivation for this is to promote FCEVs and the hydrogen refueling infrastructure to the widest possible audience and encourage the accelerated uptake of FCEVs across Europe.

5.3 Business model scenarios

5.3.1 Forecast system uptake

The uptake forecast for the number of HRS and FCEVs in Europe will influence the business model, as this will affect the number of potential customers. Scenarios for the future deployment of HRS and FCEVs are illustrated in Figure 18 and Figure 19 and shown in Table 1. The forecasts used here are only an indication of potential scenarios and there will be many factors which affect the uptake of FCEVs and HRS that are not considered in these cost calculations. These scenarios have been used to provide an indication of the total costs of the roll-out in the future, and to calculate the costs per station and per vehicle. *Note that costs are presented in this way (per HRS / per FCEV) to put the figures into context; no presumption on how the costs will be covered in practice should be made unless explicitly stated otherwise.* The high uptake scenario of hydrogen refueling stations has been assumed to follow the uptake from the Hydrogen Council, increasing from the current ca. 135[11] HRS in 2018 to 520 by 2020 and 2,000 by 2025[13]. This target reflects Germany's ambitious HRS target for 400 HRS by 2023[17]. The low uptake scenario assumes 500 stations in Europe by 2023, this is based on a 30% average annual increase, which is slightly higher than the current rate of deployment of approximately 25%[11].

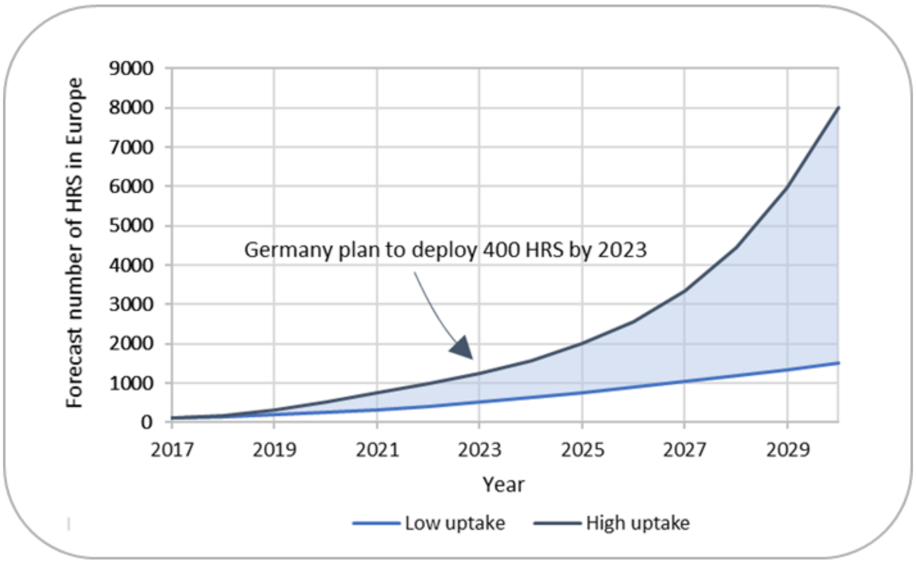

Figure 18: Low and high uptake forecasts for number of HRS in Europe

Table 1: Number of HRS in Europe under the low uptake and high uptake scenarios. All sites assumed to be enroll in the HRS availability scheme

Year	Low uptake (based on c.30% annual increase)	High uptake (based on Hydrogen Council scenario[13])
2018	140	170

[16] California Fuel Cell Partnership, Station Status, available from: https://m.cafcp.org/
[17] H2Mobility: https://h2me.eu/2016/05/05/germany-h2-mobility-targets-400-hydrogen-fueling-stations-by-2023/

2020	250	520
2022	410	990
2024	625	1,580

The vehicle uptake scenarios in Figure 19 are based on a similar method as the HRS uptake. The current number of FCEVs in Europe are estimated to be c.1,000[11], with the uptake of FCEVs increasing at an annual rate of approximately 50%[11]. The low uptake scenario has been based at a similar level with an average 40% increase per year, resulting in c. 2,700 FCEVs in Europe by 2020. The high uptake scenario is based on Europe adopting similar targets to the Hydrogen Council's ambitious target of 1 in 12 new cars in Germany being a fuel cell car by 2030[13], with the high uptake scenario assuming 7% of all new vehicles procured in Europe in 2030 a FCEV.

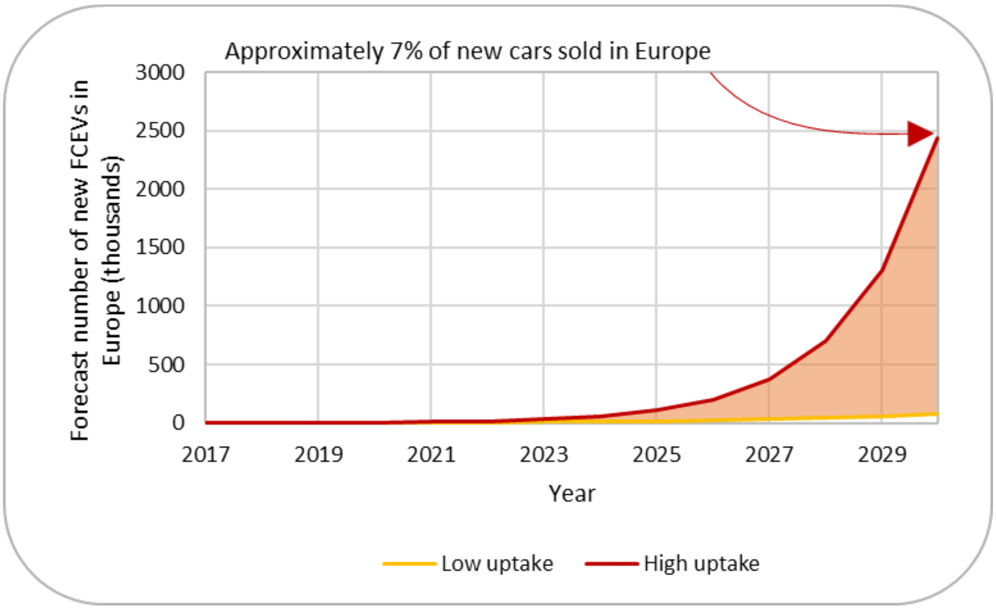

Figure 19: Low and high number of new FCEVs forecast in Europe

Taking a conservative approach based on the low uptake scenario, the estimated on-going costs (annual maintenance and running costs) of the HRS availability system are shown in Figure 20. These costs are represented as cost per HRS and FCEV, in the initial early phase and the mid-market phase of deployment. The initial cost per FCEV increases in the early phase, as there is an initial increase in the number of HRS, and therefore increase in the costs to deploy the system. This is based on the development of the hydrogen refueling network to encourage increased FCEV ownership, with increased uptake in FCEV ownership once this infrastructure is more established. As the scale-up of the FCEVs increases the costs per FCEV reduce. The reduction in costs follows the economies of scale as well as division of the fixed costs between the increasing number of customers during the scale-up. It is worth noting that alternative uptake scenarios for the number of HRS or FCEVs would lead to different estimates in costs per FCEV and HRS shown in Figure 20.

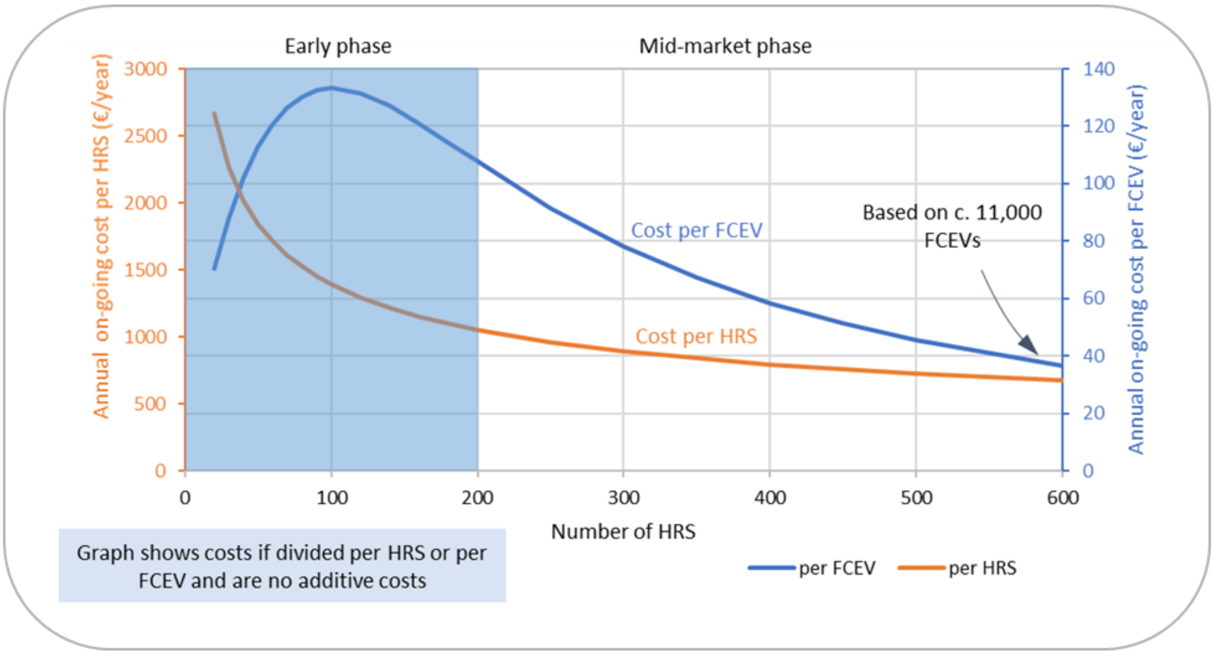

Figure 20: Estimated operating cost of HRS availability system spread across the number of hydrogen refueling station (HRS) or fuel cell electric vehicles (FCEVs) in the low uptake scenario.

5.3.2 HRS availability system costs

Based on the costs of installing the proof-of-concept trial, estimates have been made of the cost for deploying this system across Europe with growing HRS and FCEV numbers. Table 2 shows the cost estimates used in the following cash flow analysis scenarios, with an assumption that 50% of stations are type A and require hardware on site and 50% are type B. The assumption that 50% of the stations will be type A and 50% type B is based on the plans for H2Mobility Germany, who will support a network of 70–80 HRS by the end of 2018 and plan to develop a standardized API to connect to the European HRS availability system. The remaining stations in Europe are then assumed to opt for a type A system. The low uptake scenario represents a conservative approach to the forecast expansion of HRS across Europe, with lower number of customers and opportunities for income to cover the costs of the system.

Table 2: Estimated up-front costs for installation of HRS availability systems (assuming 50% Type A and 50% Type B) and on-going (annual) costs to run the system

Year	Low uptake			
	Number of HRS	Number of FCEVs	Up-front costs[18] (€)	On-going costs (€/year)
2018	140	1,350	€ 108,000	€ 175,000
2020	250	2,670	€ 44,000	€ 245,000

[18] Based on number of new HRS availability systems installed each year by type (type A / type B), and projected cost of each system (which is assumed to fall as the number of HRS per operator grows, reflecting potential economies of scale).

2022	410	5,690	€ 58,000	€ 325,000
2024	624	11,900	€ 72,000	€ 415,000

The costs to install the system at HRS across Europe and the annual operational costs of the system are illustrated in cash flows shown in the four scenarios below.

5.3.3 Scenario comparisons

The uptake scenarios will have a large effect on the simulated cash flows, as illustrated in Figure 21. For the purposes of this analysis the revenues are fixed at €1,250 per HRS per year, with an initial subsidy to support the installation costs and first six months of operation. Higher uptake scenarios in the number of HRS, and thus uptake of the HRS availability system result in larger revenues and higher returns on investment for the HRS availability system.

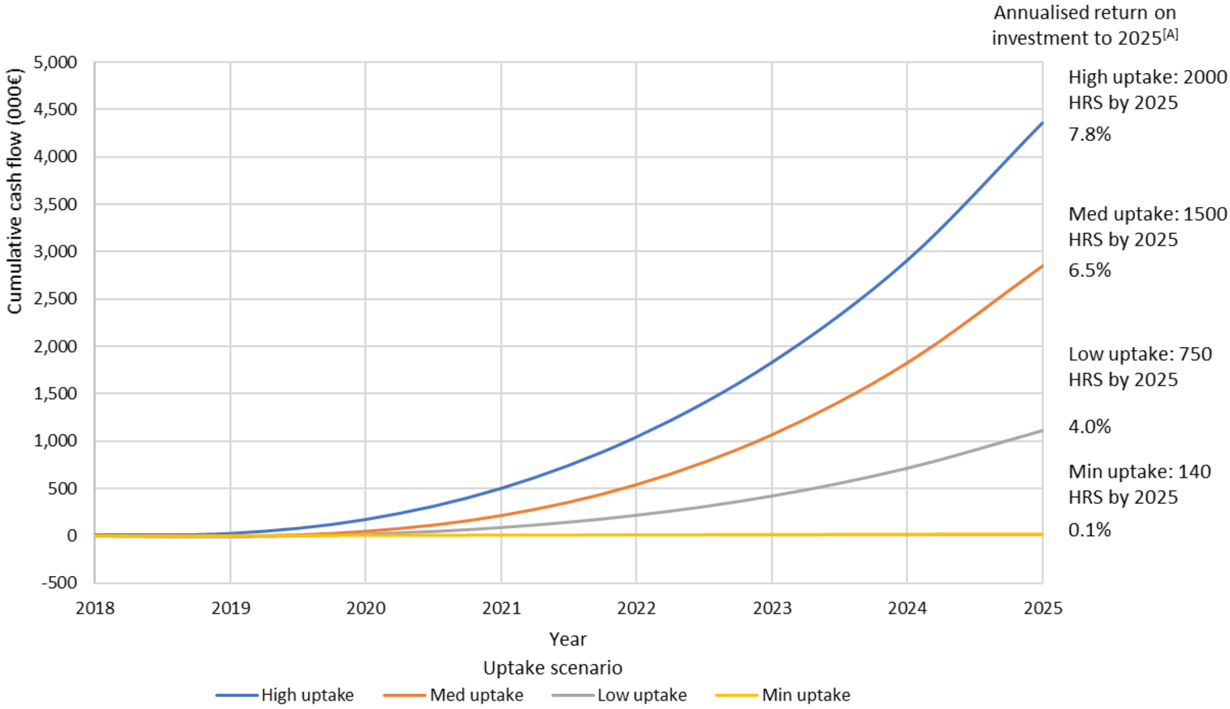

Figure 21: Effect on HRS uptake on the cumulative cash flow, with revenues of €1,250/HRS/year and initial public subsidy. (A: Annualized return on investment is based on (total return/total investment)^(1/years of investment))

The effect of different revenue models on the cash flow are shown in Figure 22. These different revenue models are based on the low uptake scenario and include subsidies to cover the initial deployment of the HRS availability system and the first six months of operation. A revenue equivalent of €83 per HRS per month (equivalent to c.€1,000 per HRS per year) would result in the system breaking even after five years. Higher revenues of €104 per HRS per month (equivalent to c.€1,250 per HRS per year) would maintain the positive cash flow throughout, with an annualized return on investment (calculated based on an initial investment) of 4.0% from 2018 to 2025.

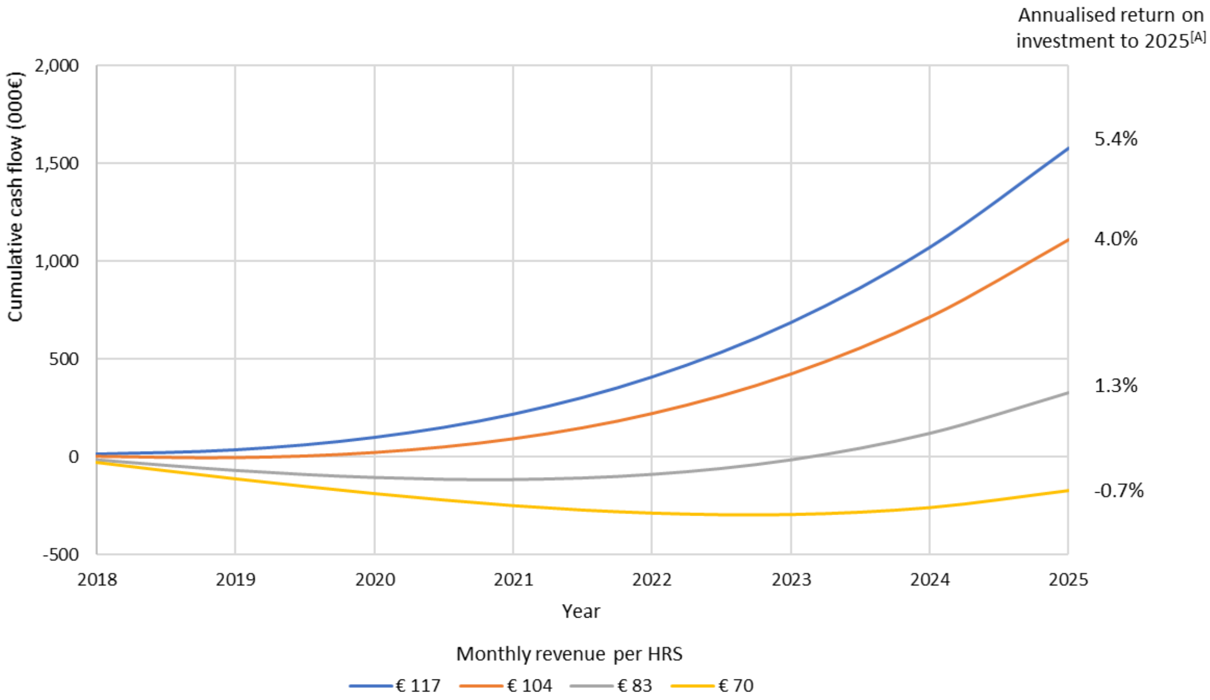

Figure 22: Effect of monthly revenue per HRS on the cumulative cash flow and annualized return on investment, under the low uptake scenario (A: Annualized return on investment is based on (total return/total investment)^(1/years of investment))

The scale-up of the HRS availability system results in cost savings from the transition to the early phase of deployment to the mid-market phase. Reduction in the revenue per HRS could be set from the mid-market phase (>200 HRS), with reduced costs estimated from integrating the HRS availability system into the hydrogen refueling equipment at the point of production, rather than retro-fitting at the refueling station. Figure 23 shows the effect of reducing the revenue per HRS by different rates from 2020. For the low uptake scenario, a reduction in costs by 5% per year from the mid-market phase onwards equates to an annual revenue of €920 required per HRS by 2025 and would return an annualized return on investment of 1.7% by 2025, based on the low uptake scenario and 50:50 split between type A and type B systems.

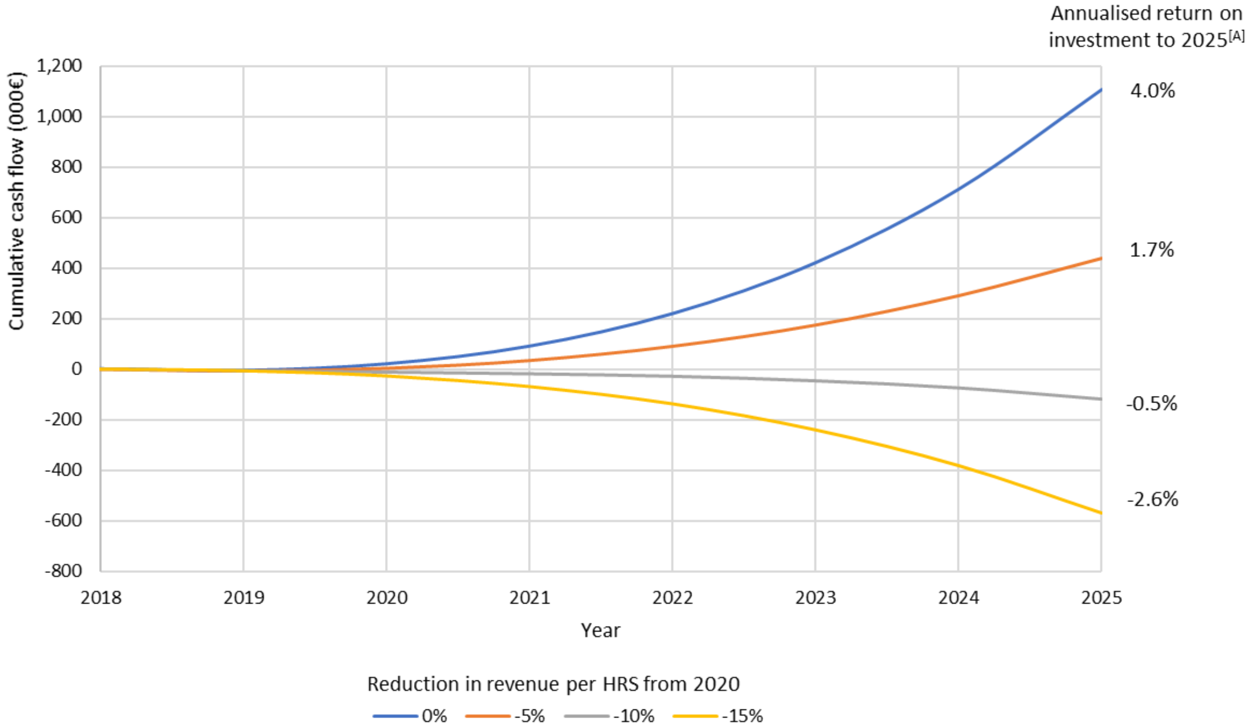

Figure 23: Effect of reducing the revenue per HRS on the cumulative cash flow of the HRS availability system, assuming low uptake scenario and initial revenue of €1,250/HRS/year for the first two years (A: Annualized return on investment is based on (total return/total investment)^(1/years of investment))

5.4 Funding conclusions

Consultations with stakeholders across the hydrogen refueling and fuel cell vehicle sectors have reinforced the importance of the HRS availability system. There is recognition of the value of this system and enthusiasm from HRS operators to communicate the availability and advertise the location of their refueling stations. Options to include additional functions along with the HRS availability system, such as on-site energy consumption or key performance indicators for FCH 2 JU projects received mixed feedback. Many HRS operators, and HRS technology providers already have systems in place to monitor the HRS equipment and would not require an additional system to do this. The HRS operators consulted in this study were keen to keep the system as simple as possible to minimize deployment costs and ensure it is simple to install and operate.

Discussions with vehicle OEMs on the HRS availability system were similarly positive, with an interest in integrating the real-time HRS availability information into in-vehicle media systems. Vehicle OEMs are keen to support the HRS availability system. They are currently investing in technology for vehicle communications, such as in-car internet connections, however, are not prepared to take on the responsibility to deploy the system. Many vehicle OEMs have contracts with satellite navigation providers for in-vehicle navigation systems, who are also interested in incorporating the HRS availability system into their platforms.

The costs to deploy the HRS availability system throughout Europe have been estimated based on the costs from this proof-of-concept trial. There is a degree of uncertainty associated with the cost estimates for the scale-up of the system, particularly as a large portion of these costs are associated with the costs for technicians' time. The forecast cost to deploy and operate the system per hydrogen refueling station are estimated to reduce with the scale-up and the number of stations participating in the HRS availability system.

A public subsidy to support the initial deployment of the system would incentivize HRS operators to implement this system. Based on 140 hydrogen refueling stations across Europe adopting the HRS availability system, a subsidy of approximately €108,000 would cover the installation costs of 140 stations (assuming 50:50 split between type A and type B), and a subsidy of €195,000 would cover the installation costs and operation of the system for the first six months. This subsidy would provide the initial support to finance the system and generate the momentum to establish the HRS availability system for future commercial deployment. **Without intervention to cover the initial costs of the system it is unlikely that a universal HRS availability system will be developed.** The alternative, as currently being developed, is a combination of platforms from individual HRS operators, FCEV OEMs or national bodies, which results in a dispersed system, with different technology platforms such as SMS, email and web-based apps. Multiple sources with differing detail of information would restrict the usability of the system and limit the accessibility of the hydrogen refueling network and appeal of FCEVs.

Once the HRS availability system is established, benefits will be felt across the FCEV and hydrogen refueling infrastructure value chain. A range of potential business models for continuing to operate and expand the system exists, with potential revenue sources including HRS operators, vehicle OEMs, FCEV users, and various third parties (advertisers, mobile phone app developers, satellite navigation system providers, etc.).

6 Study conclusions and recommendations for Phase 2 (roll-out)

There is a strong desire for a universal HRS availability system amongst vehicle OEMs, HRS operators, and FCEV users. However, all these parties are under financial pressures, particularly during the early phase of development of the hydrogen transport sector, which is the point at which such a system is most valuable. This implies that (a) the system should be kept as simple as possible to minimize implementation and operating costs, and (b) there is a case for public subsidies to be used to cover some of the initial set up costs as without such intervention there is a high probability that the HRS availability system will not be delivered.

Should the hydrogen transport sector continue to develop in line with the vision of many players in this area (e.g. as articulated by the Hydrogen Council), then a pan-European HRS availability system will include many hundreds of stations from the early 2020s. At this point, there will be a business case for the contractor of the system to maintain and expand the system if revenues equivalent to several hundred euros per year per HRS can be secured. This study has identified a wide range of potential revenue streams based on a number of value-adding services that the contractor of such a system could offer in the future, which implies that there should be limited need for on-going public subsidy to support operation of the system over the long term. An initial subsidy would incentivize HRS operators to adopt the HRS availability system and provide a single point of access for HRS updates to FCEV owners, improving the usability of the hydrogen refueling network across Europe.

A suitable funding strategy to subsidize the roll-out of the HRS availability system across Europe would enable existing HRS to be retrofitted with the required hardware (type A) or support HRS operators with the software development (type B) to transmit availability signals to the European HRS availability platform. An initial subsidy would ensure this roll-out occurs effectively and within a short time frame, this could be set to cover the installation costs, and potentially the first six

months of operation to support this system through the early market phase. This proof-of-concept study has confirmed the high reliability during the operation of type A systems at all sites installed. There were difficulties during some of the site installations, however it is thought these could be easily rectified with an instruction manual translated into local languages. The main barrier faced during this study was to organize and coordinate the installation of the type A system and support the development of the API for type B systems. Motivation for HRS operators to engage and install the system could be provided through a subsidy (potentially with an offer to HRS operators of no hardware costs provided the HRS availability system is installed and operational by a fixed date).

Based on the experience in this study, development of a website to give interactive instructions to guide technicians through the set-up of type A systems and provide feedback on the connection of the system is recommended. It is estimated that the costs of developing such a website would be quickly paid back from savings in the labour time of the HRS availability system technician supporting the installation process. This online tool would provide web-based instructions and visual feedback to support technicians connecting the system on-site.

It is expected that the retrofit and integration of all HRS in operation/planned in 2018 will take several months, however the platform itself needs to be set up and operating from day one. Because of this, the cost for operating the system during the first six months have been included in the proposed subsidy. This will benefit “early movers” who use the system and support the contractor of the HRS availability system despite low numbers of participants in the first months. This initial phase would also provide a chance for the system to demonstrate the value of the HRS availability system to HRS operators, vehicle OEMs and third parties. This could potentially be achieved by further exploring options to incorporate the HRS availability system into the media systems of FCEVs, and by collecting user feedback from FCEVs owners. The initial phase would also allow further discussions with HRS technology developers and the opportunities to integrate the system directly into hydrogen refueling equipment at the manufacturing facility. This would help to reduce the costs of the installation process, with specialist technicians installing the system at the manufacturing facilities of HRS technology providers. This initial financial support would establish the HRS availability system and reduce costs of the installation of this equipment for a larger market, with greater opportunities for increased revenues estimated from 2020.

Due to the high uncertainty around the costs involved in the development of a standardized API, and the technical risks with this option, it is advised against funding the programming cost required for the type B system from HRS operators. The complications from developing the API relate to extracting the signal information from the plant monitoring system, which can only be done by the HRS suppliers and their programming personnel.

As of February 2018, a total of 104 HRS are in operation in Europe, and it is expected that around 140 HRS will be in operation by the end of 2018 / early 2019. It has been shown this can sustain a business case for the HRS availability system provided that revenues equivalent to around €100 per month per HRS can be secured. Based on the assumptions taken in the cash flow analysis in this study, the cost to install the system would be €108,000 and to set up a website to support the installation of type A systems and operation of the platform for the first year would be an additional €183,000 (€291,000 in total). A subsidy of €195,000 would cover the installation costs and the operation through the first six months. This would provide the HRS availability system with an opportunity to prove the value of the system and establish the system for commercialization.

A proposed method to achieve this roll-out would be to provide funding to the contractor of the HRS availability system directly, with the requirement to install a set number of systems across Europe by a specific date (e.g. 100 stations by the end of 2018, or 140 by the end of Q1 2019). This could be combined with a requirement to operate the system for a set period, such as a minimum to operate to 2020. The contractor would then take the responsibility to find commercial revenue streams to operate the system after this initial subsidy-supported period. Should this scheme continue to be supported by the FCH 2 JU, additional funding could be provided with the requirement that all future HRS installations funded by the FCH 2 JU incorporate the HRS availability system.