Hydrogen Refuelling Stations Safety, Regulations, Codes and Standards. Lessons Learned. Final Report

H2ME2 Deliverable 5.23

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Contents

Versions

Date	Version	Comment
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Apr 2019	D5.20	Added FR (Air Liquide, Roissy) and IS (Nel, Reykjavík)
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Apr 2023	D5.22	Revised format. Input received from H2ME-2 HRS in DK (Nel & Everfuel, Copenhagen) and NL (Kerkhof & Resato, The Hague), plus from H2MDE. Vehicle OEM input provided by Honda R&D Europe & Toyota Motor Europe
Jan 2024	D5.23	Final updated version. Input received from new H2ME-2 HRS deployed in FR (Air Liquide, Alma & Hype, Issy-Les-Moulineaux). Updated input received from H2ME-2 HRS in DK (Nel, Copenhagen) and NL (Kerkhof & Resato, The Hague), plus from H2MDE. Vehicle OEM input provided by Honda R&D Europe & Toyota Motor Europe

Abbreviations

AFID Alternative Fuels Infrastructure Directive

AFIR Alternative Fuels Infrastructure Regulations

AHJ Authority having jurisdiction

ATEX Explosive atmosphere

B2B Back to back (refuelling)

CE Conformité Européene

CEN Comité Européen de Normalisation

CEP Clean Energy Partnership

CHP Clean Hydrogen Partnership

CHSS Compressed hydrogen storage system

DEMA Danish Emergency Management Agency

DREAL Direction Régionale de l'Environnement, de l'Aménagement et du Logement

FAT Factory Acceptance Test

FC Fuel Cell

FCEV Fuel cell electric vehicle

FCHJU/FCH2JU Fuel Cells and Hydrogen Joint Undertaking

FC REEV Fuel cell range-extended electric vehicle

FSTM Fuelling station test module

H35, H70 Hydrogen dispensing at 35Mpa, 70 Mpa (350 bar and 700 bar)

HDV Heavy duty vehicle

H2M H2 MOBILITY Deutschland

H2ME Hydrogen Mobility Europe

HRS Hydrogen refuelling station

ICPE Installations Classées pour la Protection de l'Environnement

IED Industrial Emissions Directive

LDV Light duty vehicle

LH2 (storage) Cryogenic liquid hydrogen

MAP Minimum ambient precooling

NWP Nominal working pressure

OEM Original equipment manufacturer

PED Pressure Equipment Directive

RCS Regulations, codes, and standards

SAE Society of Automotive Engineers

SAT Site Acceptance Test

SOC State of charge

TIR Technical Information Release

Executive summary

Hydrogen Mobility Europe (H2ME, 2015-2023) is the largest passenger vehicle and hydrogen refuelling station demonstration initiative co-funded by the Clean Hydrogen Partnership (CHP). This report, the final in a series of five, provides four country case studies – Denmark, France, Germany, and the Netherlands – of hydrogen refuelling station (HRS) installations supported by H2ME-2 to understand how regulations, codes, and standards (RCS) are applied in each country to the station permitting and planning process, document lessons learned and record practical experience of the steps taken to ensure continued HRS safe operation. It also includes input from Honda R&D Europe and Toyota Motor Europe on the process of ensuring that HRS can refuel OEM vehicles safely and reproducibly according to accepted standards such as SAE J2601.

Denmark was cited in previous versions of this report as an exemplar of a country with a relatively centralised decision-making system which allowed established precedent and experience to apply to future installations, thereby speeding the HRS permitting process to as little as a week. However, from 2016 until the opening of the H2ME-2-supported Copenhagen Prags Boulevard HRS in 2021, few stations were installed in Denmark which meant that much of the experience and momentum built around hydrogen permitting and regulation had dissipated. The Prags Boulevard HRS took around two years to open from project inception. Station construction was slowed by equipment availability issues which were exacerbated by COVID-19. In contrast to the H2ME-2-supported Kolding HRS opened in 2016, the commissioning of the Prags Boulevard HRS also involved a Site Acceptance Test (SAT) using a fuel station test module (FSTM) with evaluation of the test results by vehicle OEMs. This is now a required part of the commissioning process for HRS under the AFID. The H2ME HRS in Denmark were closed in the summer of 2023 as they could not be operated economically. Attention in the country is now shifting to bus and HDV HRS.

H2ME HRS in **France** are small passenger HRS with low hydrogen vehicle flow rates (up to 60 g H_2/second) that can dispense around 200 kg/day of H_2. Nationally, ICPE rubric 1416 provides a comprehensive checklist whereby each HRS with under one tonne of on-site hydrogen storage can be ICPE declared via a single relatively simple process. HRS building permitting in France, however, remains the responsibility of local authorities. Once the authorities have received all the paperwork they require they have two months to approve the HRS; in practice, questions arising during the process means that it can take longer. In common with other countries, the focus in France is shifting to larger HRS capable of refuelling HDVS at higher vehicle flow rates (up to 300 g H_2/second). A regulatory framework for these high capacity stations is currently in development.

H2 MOBILITY Deutschland (H2M) has installed over 90 HRS in **Germany** to create a national network linking seven German metropolitan areas (Hamburg, Berlin, Rhine-Ruhr, Frankfurt, Nuremberg, Stuttgart and Munich) along the connecting arterial roads and motorways. Operational permitting for HRS in Germany is governed by clear centralised RCS such as the BetrSichV. However, building permitting is the responsibility of individual federal states, each one of which has its own building directive. In practical terms, the decentralised building permitting process in Germany requires repeated engagement to build know-how with the different authorities, which increases the permitting time and hinders standardised applications. H2M's strategy is evolving towards building

larger HRS located based on anchor demand from commercial vehicles and where a public filling station makes sense for a growing network of filling stations for cars. As such, it plans to upgrade many of its existing 700 bar HRS to add 350 bar fuelling to accomodate HDVs, and to provide 350 bar HDV refuelling at all its future HRS.In the medium term it is planning to offer up to 500 bar HDV which it believes can be provided by the current generation of compressors; 700 bar HDV refuelling will require a step change in compressor performance and reliability.

Opened in 2020 the H2ME-2-funded HRS in the Hague, the **Netherlands** operated by B. Kerkhof & Zn was the first public HRS constructed by Resato. permitting Anticipating the wider rollout of hydrogen fuelling, Netherlands national agencies such as the Ministry of Infrastructure and Water Management have been proactive in documenting the process for preparing, permitting, building, and commissioning at HRS. In common with the other country examples in this report, the key step is Environmental Permitting. This is controlled by the relevant municipality with is the authority having jurisdiction. In most cases the municipality delegates the permitting to the regional environmental agency; the appropriate safety region (veiligheidsregio) is also consulted on safety-relevant aspects. On average the permitting process takes around 18 months.

Major progressions in hydrogen fuelling during H2ME have included the wider rollout of vehicles leading to increased station loads and the introduction of vehicles with larger hydrogen tanks (for example, comparing the Hyundai Nexo at 6.3 kg capacity versus the Daimler B-Class FCELL at 3.7 kg). The SAE J2601 *Fueling Protocol for Light Duty Hydrogen Surface Vehicles* is now the standard used by HRS (including all H2ME-2 HRS) to ensure that the vehicle hydrogen storage system stays within operating temperature and pressure limits, and an acceptable refuelling speed and final state of charge (SOC) is achieved. To ensure HRS comply with the EN 17127 refuelling standard which incorporates J2601, vehicle OEMs have worked with HRS suppliers in the CEP OEM Group to devise a process to approve HRS for refuelling of their vehicles involving a Factory Acceptance test (FAT, provided by the HRS supplier), a hydrogen quality report, and the SAT (discussed above in the Denmark case study). The testing process is currently overseen by the vehicle OEMs, which is a relatively time-consuming process. Work is underway to transfer responsibility for HRS testing, evaluation, and approval on behalf of all CEP vehicle OEMs to an independent third party. This is scheduled to be completed in Germany by the end of 2023, and in France and the Netherlands by the end of 2024.

Comparing the individual case studies shows that, while there is commonality in terms of the overall EU directives that are followed in each country, there are differences in the processes and involved in HRS permitting and installation, despite the continued evolution of hydrogen refuelling RCS such as EN 17124, EN 17127, SAE J2601 and ISO 19880-1. The optimal situation for speed through the HRS permitting and planning process in each country appears to be a relatively centralised decision-making system which allows established precedent and experience to apply to each future installation (i.e., the situation which existed in Denmark, at least until 2016). Involvement of decentralised/regional agencies in the process requires repeated engagement for each individual HRS construction project to build know-how with different authorities. This increases the permitting time and hinders standardised applications. It is also clear that the regulations for stations that use on-site electrolysis are generally more onerous than for HRS that use delivered hydrogen.

Looking forward, increased standardisation of fuelling station components, the wider availability of testing equipment, and the growing momentum for HRS installation such as the plans for large-scale HRS deployment across the EU linked to the AFID are likely to mean that permitting and build times will start to fall. However, it is also clear that regulations and HRS technology will need to evolve and improve (and are evolving and improving) to accommodate the current surge of interest and activity in hydrogen HDV refuelling.

All HRS covered in this report, and all stations so far installed by the H2ME project, are operating safely. **As of December 2023, H2ME project refuelling stations have dispensed 791 000 kg of hydrogen in 318 000 refuelling events with no safety incidents that involved the release of hydrogen.**

1 Introduction to H2ME

Hydrogen Mobility Europe (H2ME, 2015-2023) is the largest light duty vehicle (LDV) and hydrogen refuelling station (HRS) demonstration initiative co-funded by the Clean Hydrogen Partnership (CHP). H2ME is formed of the two separate CHP-co-sponsored projects:

- H2ME-1 (2015-2020), which deployed 300 fuel cell electric vehicles (FCEVs) and fuel cell range-extended electric vehicles (FC REEVs) and 29 HRS.
- H2ME-2 (2016-2023), which aims to deploy over 1 000 FCEVs and FC REEVs and 20 HRS.

The aims and scope of H2ME are summarised below in Figure 1:

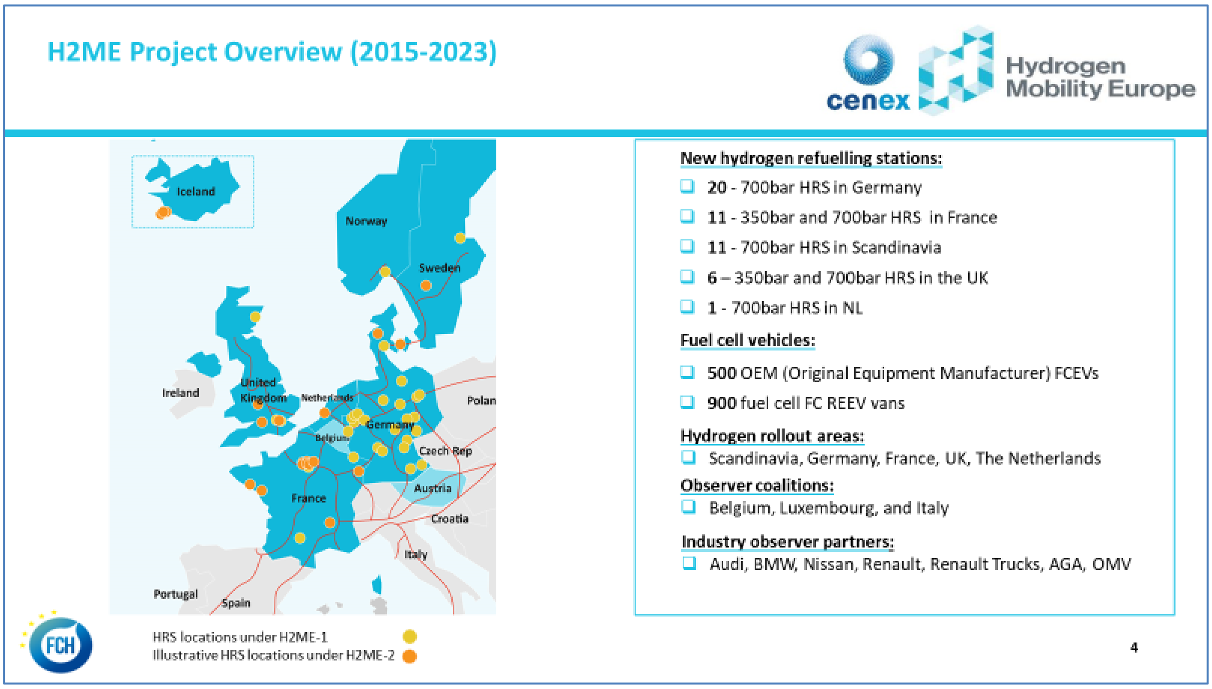

Figure 1. H2ME vehicle and HRS deployment summary[1]

2 Purpose of this document

The document is not intended to provide a comprehensive listing of regulations, codes and standards that are applicable to the installation of HRS in Europe, as that has been addressed by the HyLaw project (2017-18, https://www.hylaw.eu/) which provided a comprehensive database (https://www.hylaw.eu/database) and summary[2] of regulations, codes and standards (RCS) for

[1] *H2ME-2 Six Monthly Summary Technical Report Presenting Project Data to September 2022 – D5.13*. Cenex. Available from https://h2me.eu/wp-content/uploads/2022/12/H2ME2-D5.13-Public-FV-Public-summary-of-D5.7-for-the-%E2%80%A6.pdf (accessed 21th December 2023)

[2] *HyLaw Deliverable 4.4 EU regulations and directives which impact the deployment of FCH technologies.* Hydrogen Europe. *Available from https://www.hylaw.eu/files/2019-02/D4.4%20-%20EU%20regulations%20and%20directives%20which%20impact%20the%20deployment%20of%20FCH%20technologies_0.pdf* (accessed 21th December 2023)

applications of hydrogen. Currently, MultHyFuel (https://multhyfuel.eu/) is looking at strategies for implementing HRS in multi-fuel contexts and the harmonization of existing laws and standards.[3]

This report provides H2ME case studies of how RCS are applied in each country to the station permitting and planning process, documents lessons learned, and records practical experience of the steps taken by installers, operators, and vehicle manufacturers to ensure safe and efficient HRS operation.

3 Trends in hydrogen mobility and hydrogen refuelling

This report is the fifth in a series began in 2018.[4] During that time, the H2ME project, and hydrogen mobility in general, has made substantial progress. This section discusses some of the trends that have emerged since the start of H2ME, both within the project - which is primarily focused on light duty vehicle (LDV) refuelling - and in hydrogen mobility in general, and their implications for HRS design and performance requirements.

3.1 Trends in LDV deployment and refuelling within H2ME-2

- *The wider rollout of FCEVs and HRS:* as of December 2023, 534 FCEVs, 246 FC REEVs and 43 HRS in nine countries reported data to H2ME[5]; for comparison, the figures for May 2019 were 133 FCEVs, 178 FC REEVs and 23 HRS.[6] H2ME vehicles have reported almost 31 million km driven and the HRS (which fuel H2ME and non-H2ME vehicles) have dispensed 529 tonnes of hydrogen in 209 000 refuelling events.

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[3] *MultHyFuel Permitting requirements and risk assessment methodologies for HRS in the EU – D1.2*. Hydrogen Europe. Available from https://multhyfuel.eu/images/event-documents/deliverables/MHYF_WP1_D12_Permitting_requirements_and_risk_assessment_methodologies_20210930_03.pdf (accessed 21th December 2023)

[4] The previous (fourth) version of this report is available from https://h2me.eu/wp-content/uploads/2023/07/H2ME2-D5.22-Public-FV-Safety-and-RCS-lessons-learnt-%E2%80%A6.pdf (accessed 21th December 2023)

[5] *H2ME-2 Six Monthly Summary Technical Report Presenting Project Data to December 2022 – D5.41*. Cenex. Available from https://h2me.eu/wp-content/uploads/2023/07/H2ME-2-Six-monthly-reports-reviewing-the-technical-progress-for-vehicles-and-HRS-D5.41-PUBLIC-1.pdf (accessed 21th December 2023)

[6] *H2ME-2 Six Monthly Summary Technical Report Presenting Project Data to May 2019 – D5.9*. Cenex. Available from https://h2me.eu/wp-content/uploads/2021/11/H2ME2-D5.09-Public-FV-Public-summary-of-D5.3-for-the-%E2%80%A6.pdf (accessed 21th December 2023)

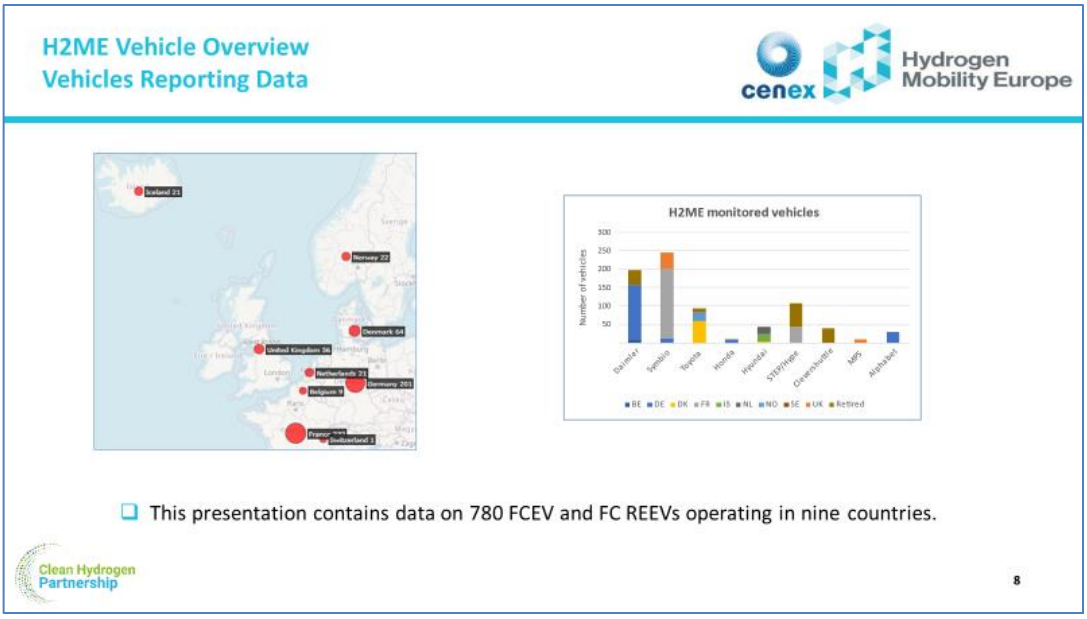

Figure 2. Locations of vehicles reporting data to H2ME as of December 2023

- *Urban deployments of FCEV taxis leading to increased HRS load:* in 2017, Hype began the rollout of Hyundai IX35 FCEVs and Toyota Mirais as taxis in Paris. To the end of March 2023, the H2ME-2 Hype fleet in Paris reported almost 6 million km driven (plus a further 4.2 m km for vehicles funded by the ZEFER project). The taxis in Paris drive an average of around 150 km per day with an average fuel consumption of ~1.1-1.2 kg H_2/100 km driven. As part of their operating patterns, they refuel at least once per day. Taxis therefore represent the highest intensity H2ME-2 vehicle and HRS use case.[7]

  In late 2023, Hype deployed the first zero-emission light commercial vehicles adapted for passenger transport with 50 Stellantis "HK0" plug-in hybrid fuel cell vehicles now completing Hype's fleet in the Paris region, including 2 vehicles deployed in the city of Brussels.

  Six HRS in locations where FCEV taxis are deployed have dispensed over 60% of the total hydrogen reported by the project. These HRS often have loads (measured by the daily amount dispensed as a proportion of the station's maximum daily capacity) of over 40%; in contrast the average H2ME station load in locations where taxis are not deployed is under 10%.
- *The addition of FCEVs with larger onboard hydrogen storage capacities:* As new FCEV models are released, in general the amount of hydrogen stored onboard has increased. Figure 3 below shows that the Daimler B-Class FCEVs deployed by H2ME in 2015 had a tank capacity of 3.7 kg. The next generation of FCEVs deployed by the project in 2017, such as the Generation 1 Mirai and the Honda Clarity, had tank capacities of around 5 kg of hydrogen.

  Since 2019, H2ME-2 has deployed Hyundai Nexos with a tank capacity of 6.3kg and is continuing the roll out the Generation 2 Toyota Mirai with an increased hydrogen tank capacity of 5.6 kg.

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[7] *H2ME-2 Vehicle and Infrastructure Performance Report 3*. Cenex. Available from https://h2me.eu/wp-content/uploads/2021/11/H2ME2-D5.16-Public-FV-Report-3-Interim-and-final-summary-%E2%80%A6.pdf (accessed 11th January 2024)

H2ME Vehicle Overview
Vehicles Reporting Data to H2ME

cenex Hydrogen Mobility Europe

	Daimler B-Class F-CELL FCEV	Daimler GLC F-CELL FCEV/PHEV	Honda Clarity FCEV	Hyundai ix35 FCEV	Hyundai Nexo FCEV	Toyota Mirai FCEV	Symbio ZE H2 FC REEV
Dates reporting data to H2ME	2015-2018 (retired)	2019-	2017-	2017-	2019-	2017-	2015-
H2ME use-cases	Passenger and fleet car	Passenger and fleet car	Passenger and fleet car	Passenger and fleet car, taxi	Passenger and fleet car	Passenger and fleet car, police car, taxi	Light van in company fleets
NEDC range	380 km	478 km	650 km	590 km	756 km	605 km Gen 1	300 km
H_2 tank capacity and pressure	3.7 kg (700 bar)	4.4 kg (700 bar)	5.5 kg (700 bar)	5.6 kg (700 bar)	6.3 kg (700 bar)	5.0 kg (Gen 1) 5.6 kg (Gen 2) (700 bar)	1.8 kg (350 bar version)
Battery capacity	1.4 kWh	13.5 kWh (9.3kWh usable)	1.7 kWh	0.95 kWh	1.6 kWh	1.6 kWh (Gen 1) 1.2 kWh (Gen 2)	22 kWh

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Figure 3. Vehicles deployed by H2ME

- *Development and adoption of the SAE J2601 vehicle refuelling standard*[8]*:* introduced in 2010, SAE J2601 establishes the fuelling protocol and process limits for hydrogen fuelling of vehicles with total volume capacities greater than or equal to 49.7 l.

3.2 Trends in hydrogen mobility outside of H2ME-2

- *The anticipated wider rollout of hydrogen heavy duty vehicles (HDVs)*: the main development in hydrogen mobility since the start of H2ME has been the growth in interest and associated investment in hydrogen HDVs. This interest is driven by the need to achieve net zero in this hard to decarbonise vehicle segment and the continued evolution of fuel cell technology. Limited deployments of fuel cell HDVs are beginning; for example, Daimler Truck recently announced its intention to trial five GenH2 40 t semi trailer trucks with customers in Germany in 2024[9] The vehicles have 88 kg of onboard liquid hydrogen (LH2) storage and can travel over 1,000 km on a single fuelling. The vehicles will be refuelled at designated public liquid hydrogen filling stations in Wörth am Rhein and in the Duisburg area using subcooled liquid hydrogen (sLH2). sLH2 is an onboard storage as well as a hydrogen refuelling technology that is currently being developed by Daimler Truck and Linde which potentially offers high flow rates (> 400 kg/h) with low TCO (up to 30 times lower energy demand per kg dispensed compared to CH2) and HDV fuelling times of 10-15 minutes.[10]

[8] *Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles J2601_202005*. SAE. Available from https://www.sae.org/standards/content/j2601_202005/ (accessed 11th January 2024)
[9] *Fuel-Cell Technology: Daimler Truck Builds First Mercedes-Benz GenH2 Truck Customer-Trial Fleet*. Daimler Truck. Available from https://www.daimlertruck.com/en/newsroom/pressrelease/fuel-cell-technology-daimler-truck-builds-first-mercedes-benz-genh2-truck-customer-trial-fleet-52552943 (accessed 22nd December 2023)
[10] Subcooled Liquid Hydrogen Technology for Heavy Duty Trucks. Available from https://evs36.com/wp-content/uploads/finalpapers/FinalPaper_Acher_Thomas_Will_Christian.pdf (accessed 22nd December 2023)

3.3 Implication of hydrogen mobility trends for H2ME-2 HRS

Amongst the implication of the developments in hydrogen mobility highlighted in Sections 3.1 and 3.2 are:

- *Future HRS are likely to dispense at 350 and 700 bar:* Many stations supported by H2ME-1, such as the stations in Kolding (Denmark) opened in 2016 and Potsdam (Germany) opened in 2018 discussed in previous versions of this report, were single 700 bar dispenser HRS aimed at refuelling relatively small fleets of LDVs. Many current FC buses and HDVs refuel at 350 bar. Therefore, stations that wish to fuel HDVs need to dispense at both pressures.[11]
- *HRS need higher daily dispensing capacities:* the rollout of increasing numbers of FCEVs and FC HDVs means that HRS will need higher capacities. The figure below shows that the capacities of HRS deployed by H2ME reflect this, with newer stations installed under H2ME-2 generally being capable of dispensing much more than the ~200 kg/day norm of H2ME-1 HRS.[12]

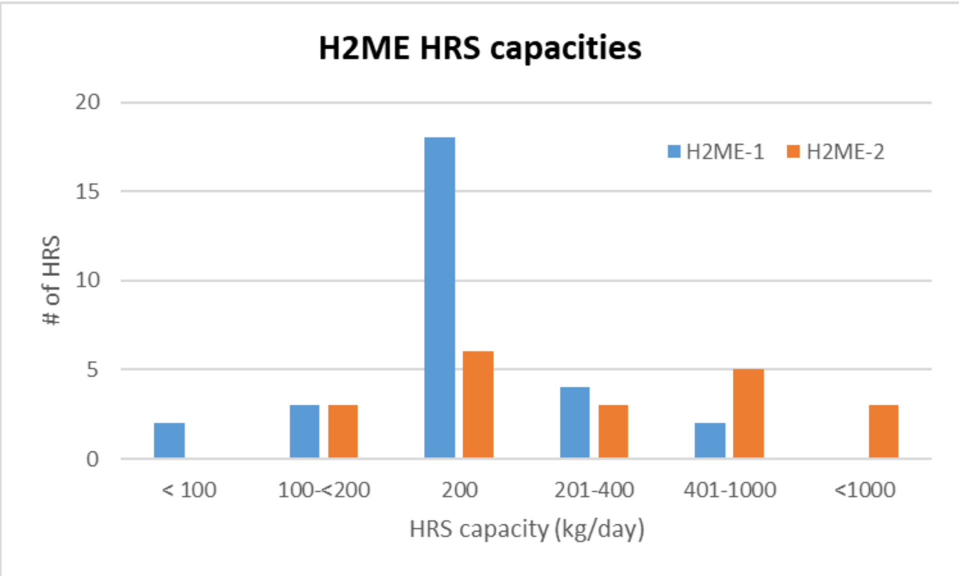

Figure 4. H2ME HRS daily capacities

- *HRS face the increasing probability of back-to-back (B2B) refuellings:* There are two principal limitations on HRS performance:
  - The first, as discussed above, is the *daily capacity* (how much hydrogen can the station dispense in a day?) In terms of station hardware, this is essentially dictated by the amount of low pressure onsite storage, and/or onsite generation.

[11] *Overview Hydrogen Refuelling for Heavy Duty Vehicles*. H2Mobility. Available from https://h2-mobility.de/wp-content/uploads/sites/2/2021/08/H2-MOBILITY_Overview-Hydrogen-Refuelling-For-Heavy-Duty-Vehicles_2021-08-10.pdf (accessed 11th January 2024)

[12] *H2ME Emerging Conclusions*. Element Energy. Available from https://h2me.eu/wp-content/uploads/2023/01/H2ME2-D7.19-Public-FV-Emerging-conclusions-document-%E2%80%A6.pdf (accessed 11th January 2024)

- The second is *back-to-back (B2B) refuelling capacity* (how many consecutive refuels within 10 minutes of a previous event can the station handle?). This is determined largely by the amount of high pressure storage and/or the HRS compressor capacity.

If B2B refuelling capability is exceeded regularly, it is likely that issues such a lack of sufficient hydrogen availability at the HRS for immediate refuelling, and therefore increased waiting time for vehicles to refuel, will emerge.[13]

- *HRS need to demonstrate that they support relevant refuelling protocols:* SAE J2601 has a performance target of a fuelling time of 3 minutes and SOC of 95% to 100% with communications, which can be achieved under reference temperature conditions with a 700 bar (H70) T40-rated dispenser.[14]

Incomplete compliance with J2601 in FCEV refuelling has three potential consequences:

- *Low state of charge:* The state of charge (SOC) of a FCEV measures the hydrogen in the tanks after a refuel as a percentage of their capacity. From a vehicle user's perspective, the most common manifestation of a non-J2601-compliant fill is an incomplete tank. The figure below shows H2ME data on post-fill SOC for Toyota Mirai Generation 1s operating in seven countries accumulated in 2017-2019. Only one country achieved an average fill of 95% or above; the average post-fill SOC for all H2ME Mirais in the period was 91.5%.[15]

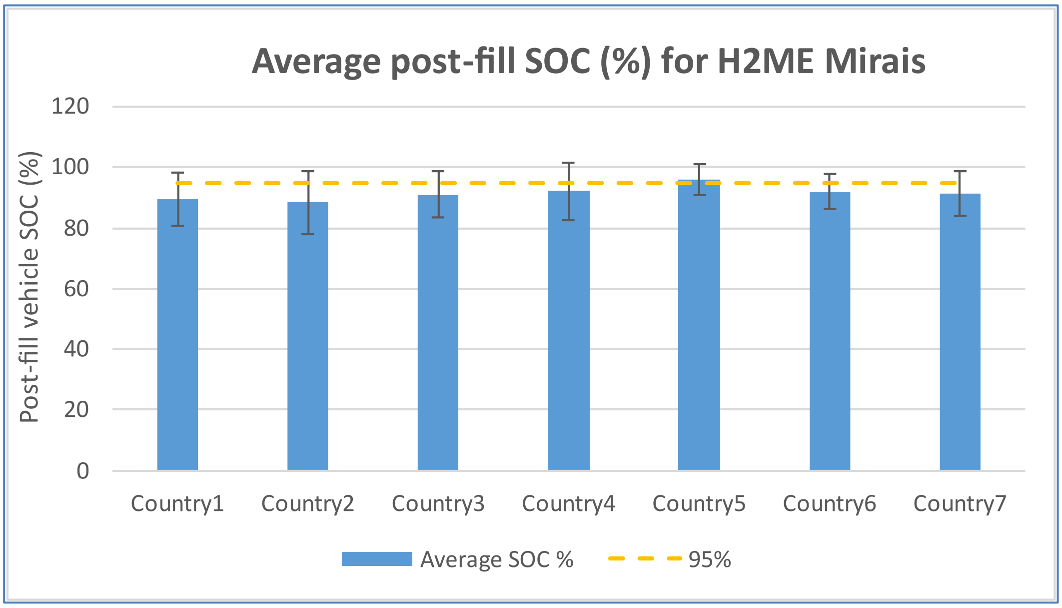

Figure 5. Post-fill SOC of H2ME Mirai Generation 1s from 2017-2019

- *Possible damage to vehicle tanks:* The operating temperature of Type IV composite on vehicle storage tanks must stay between -40°C and 85°C to prevent degradation of

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[13] For further discussion of B2B refuelling in H2ME, see *H2ME-2 Vehicle and Infrastructure Performance Report 4*. Cenex. Available from https://h2me.eu/wp-content/uploads/2021/11/H2ME2-D5.17-Public-FV-Report-4-Interim-and-final-summary-%E2%80%A6-1.pdf (accessed 11th January 2024)

[14] *Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles J2601_202005*. SAE. Available from https://www.sae.org/standards/content/j2601_202005/ (accessed 11th January 2024)

[15] For more details see *H2ME-1 Vehicle and Infrastructure Performance Report 5 (2015-2020)*. Cenex. Available from https://h2me.eu/wp-content/uploads/2021/10/H2ME-D4.16-Public-FV-Public-yearly-technical-reports-%E2%80%A6.pdf (accessed 11th January 2024)

the tank liner. As hydrogen exhibits a negative Joule-Thomson coefficient, and therefore the hydrogen inside the tank warms up as the fill proceeds, precooling (to -40°C in the case of T40 fuelling), and vehicle to dispenser communication where available, prevents the temperature in the tank from exceeding these safe limits.

- *Increased station wear:* In case of very low flow fuelling, neither the SOC nor the tank temperature is an issue. However, continuous chattering of the check valves can cause unintended wear over time with the risk of having leaking check valves. This is especially the case with non-SAE J2601 compliant stations such as ambient temperature fuelling that has fuelling ramp rates of below 1 MPa/min.

Efforts by HRS and vehicle OEMs to ensure safe refuelling and compliance with appropriate standards are discussed in more detail later in this report.

4 Scope of this document

This report covers the installation of selected H2ME-2 HRS that have been begun reporting data to the project since the last edition of this report as summarised below in Table 1. Although H2MOBILITY Deutschland does not have any stations supported by H2ME-2, it continues to upgrade its existing HRS network to support the developments in mobility, particularly the need for 350 bar refuelling of medium duty vehicles such as buses, discussed in Section 3. As such it has also provided input.

Table 1. H2ME HRS discussed in this report

Country	Location	Station description	Opened	Installer/ Operator
Denmark	Kolding	700 bar HRS integrated into conventional refuelling station	March 2016 Closed August 2023	Nel Hydrogen Fueling
Denmark	Copenhagen	Dual 350/700 bar HRS integrated into a conventional refuelling station	November 2021. Closed August 2023	Nel Hydrogen Fueling/ Everfuel
France	Orly	700 bar standalone HRS	December 2017	Air Liquide/ HysetCo
France	Pont de l'Alma	Dual 350/700 bar standalone HRS	December 2023 (*previous demonstration HRS opened in December 2015 for COP21 and closed in 2018*)	Air Liquide
France	Issy-les-Moulineaux	Dual 350/700 bar standalone HRS	April 2023	HRS/Hype
France	Le Mans	Dual 350/700 bar standalone HRS	June 2023	HRS/Hype
Germany	Potsdam	700 bar HRS integrated into conventional refuelling station	September 2018. Upgraded 2021 to handle larger vehicles	Linde/ H2MOBILITY Deutschland
Germany	Magdeburg	Dual 350/700 bar HRS integrated into a conventional refuelling station	December 2018 (700 bar). Upgraded November 2023 to offer 350 bar HDV fuelling	Air Liquide/ H2MOBILITY Deutschland
Germany	Erfurt	700 bar HRS integrated into conventional refuelling station incorporating cryogenic liquid H_2 storage	September 2020	Linde/ H2MOBILITY Deutschland
Netherlands	Den Haag	Dual 350/700 bar HRS integrated into a conventional refuelling station	April 2020	Resato/ J P Kerkhof

4.1 Safety

All stations covered in this report (and all stations so far installed by the H2ME project) are operating safely. **As of December 2023, project HRS have dispensed 791 000 kg of hydrogen in 318 000 refuelling events with no safety incidents that involved the release of hydrogen.**

5 Topics covered in the document

To ensure that answers could be compared across countries and regions, installers of HRS were asked to respond to a standard set of topics as presented below:

- A high-level overview of the process of station permitting and installation.
- The key RCS for installing stations in each country.
- How the process for installing stations in each country has evolved from the installation of early, pre-H2ME, HRS to the latest stations in H2ME (if applicable).
- Whether the presence of onsite hydrogen generation using electrolysers influences the RCS, and therefore the planning and installation process (if applicable).
- How the move in H2ME-2 to larger stations with increased amounts of HRS onsite storage and the possibility to refuel HDVs impacts RCS, planning and installation.
- Other significant issues that have arisen since the start of the H2ME project in 2015.

Honda and Toyota, vehicle OEMs participating in H2ME, also provided input on the evolution of RCS and best practice in ensuring safe and effective hydrogen vehicle refuelling.

6 Country and organisational experience of HRS installation and RCS

6.1 Denmark – Nel Hydrogen Fueling & Everfuel

Nel Hydrogen Fueling has extensive experience of installing hydrogen refuelling stations – with or without integrated electrolysers. The company has installed six HRS in Europe since the Copenhagen station.

The H2ME-2-supported HRS at Prags Boulevard, Copenhagen Denmark opened in November 2021 was built by Nel Hydrogen Fueling and operated by Everfuel. The HRS had two, essentially independent, 700 bar dispensers which primarily supported the DRIVR FCEV taxi fleet, plus a 350 bar dispenser designed for hydrogen bus refuelling.

Following a strategic review of its project portfolio, Everfuel is focusing on heavy duty vehicle fuelling. The Company's first-generation car fuelling stations in Denmark and Norway were discontinued in 2023 in line with the realigned strategy; as part of this process the Prags Boulevard HRS was closed in August 2023.[16]

Figure 6: Prags Boulevard HRS (source: Nel Hydrogen Fueling)[17]

The author would like to thank Lasse Dam of Nel Hydrogen Fueling for providing much of the content in this section.

[16] *Interim Report Q3 2023*. Everfuel. Available from https://www.everfuel.com/app/uploads/2023/11/22111023_EverfuelQ3_report.pdf (accessed 2nd January 2024)
[17] *Copenhagen gets a new Nel fueling station*. Nel Hydrogen Fueling. Available from https://nelhydrogen.com/articles/hydrogen-fueling/copenhagen-gets-a-new-nel-fueling-station/ (accessed 2nd January 2024)

6.1.1 Key RCS for station installation in Denmark

- The first H2ME HRS was opened by Nel in Kolding in 2016.
- Key documents/procedures for the installation of the Kolding HRS were:
  - ISO/TS20100:2008. This has since been superseded by ISO19880-1:2020, but at the time of Nel's first 700 bar installations in 2011 this was the key standard to work to.
  - The National Technical Guideline for Gases.[18]
  - Stations involving onsite generation and/or significant amounts of onsite storage need a permit from the Defence Ministry which has national responsibility for risks and operations that involve gas storage.
  - The Danish Building Code.
- Nel's track record of station installation also been crucial, as discussed further below.

6.1.2 The process for installing a HRS in Denmark

- Two processes are involved – building permitting and operation permitting.
- HRS building and permitting are controlled by centralised regulation, but are implemented by municipalities, as illustrated below:

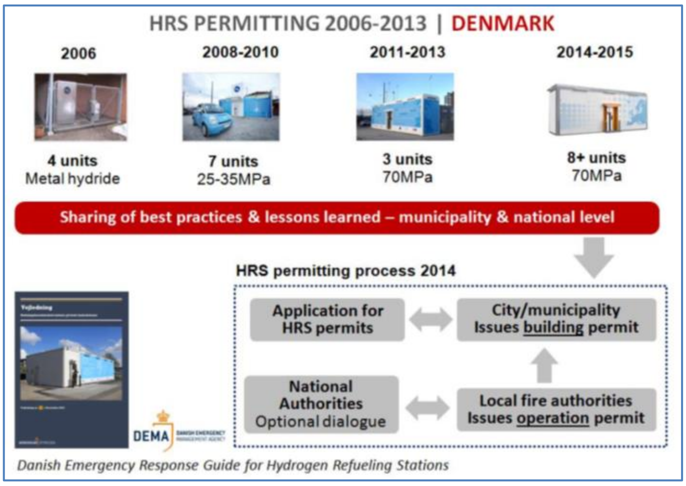

Figure 7. HRS permitting process in Denmark[19]

- Building permitting:
  - Nel has used its extensive experience in HRS installation to become skilled in preparing and submitting applications.
  - Early in the project Nel meets with all relevant municipality stakeholders (e.g., fire marshals, planning officers) to ensure that any concerns that they may have (e.g., interpretation of safety distances) are addressed.
  - Any concerns that stakeholders have (such as safety distances) can be mitigated in different ways – e.g., firewalls. The key point is that Nel tries to operate in a standard fashion in each installation which establishes precedent that can be followed and passed on to each municipality.
- Operational permitting:
  - The key sign-off point is the local fire marshal.

[18] *Guidance for technical regulations for gases*. Danish Emergency Management Agency.
[19] *Guidance: emergency service operations at hydrogen tank facilities*. Danish Emergency Management Agency

- As part of an effort to facilitate the process of operational permitting, Nel was instrumental in getting the fire marshals together at a national level to share best practice and knowledge of H_2. In addition, it helped author national regulations which were not well developed when Nel began installing stations.
- As part of the process of obtaining buy-in and establishing a relationship with fire marshals, Nel offers ongoing training and support once the stations are operational.
- The Danish Safety Technology Authority (https://www.sik.dk/) is the national agency controlling work and installations involving gas.
- The Copenhagen HRS has less than 5t of onsite storage (i.e., under the SEVESO limit), so that main steps in ensuring HRS compliance are:
  - That all equipment is CE marked
  - That the installation is signed off by a notified body (in the case of the Copenhagen station this was TUV).

6.1.3 The evolution of HRS installation in Denmark 1. Pre-2016

- In previous versions of this report, Denmark was cited as an exemplar of a country with a relatively centralised decision-making system which allowed established precedent and experience to apply to future installations, thereby speeding the HRS permitting and building process.
- The permitting process for the Copenhagen South station (opened in 2013 with FCH JU support during the HyTEC project) took around six months. Two examples illustrate how this evolved in subsequent stations in 2015-16:
  - The HRS deployed in Korsør under HyFive in 2015 took only 48 hours from submission of the application and appendixes to the granting of the permit.
  - In 2016 permitting for the Esbjerg HRS took four days: the application was sent in May 27th, 2016 and the permit was granted on May 31st 2016.

6.1.4 The evolution of HRS installation in Denmark 2. The Prags Boulevard HRS

- From 2016-2020 few stations were installed in Denmark. This meant that much of the experience and momentum built around hydrogen permitting and regulation discussed in the previous section has dispersed by the time the project to install the Copenhagen HRS was initiated in 2019. Therefore, effectively, the process had to start from scratch.
- A key further difference from previous HRS installs in Denmark was the introduction of Site Acceptance Tests (SATs) by the AFID (discussed in detail in Section 7) which are now mandatory and inevitably increase the HRS commissioning timeline.
- The COVID-19 pandemic in 2020 and 2021 also meant that key components for the HRS has long lead times and were delivered much later than anticipated.
- As a consequence of the points noted above, the permitting and construction time of the HRS was around two years.

6.1.5 Comments on and lessons learned from the Prags Boulevard HRS permitting, installation and commissioning

- *Deployment at scale is needed to make the HRS permitting and installation cheaper for all in the long term.* As noted above, developing the Prags Boulevard HRS after a relative lull in HRS deployment was a relatively inefficient process, with Everfuel and Nel Hydrogen Fueling suffering from first mover disadvantage in restarting this market. It is hoped that recent announcements for large-scale HRS deployment across the EU in the AFID and activities related to REPowerEU will mean that permitting times will again fall in Denmark and other countries.

- *The SAT process needs to be optimised.* Crucial steps in the SAT are the:
  - Testing of the HRS by a Fuel Station Test Module (FSTM) certified for CEP usage
  - Approval of the SAT results a vehicle OEM.

  As detailed in Section 7, steps are being taken by the CEP to increase the number of FSTMs, and SAT result approval is being transition to a third party. It is anticipated that these steps will speed SAT for new HRS.
- *Standardisation is required for hydrogen supply to the HRS as well as from the HRS to the vehicle.* Much like the standardisation that has been developed between the hydrogen dispenser and the vehicle that fuels at the dispenser, a standard must be developed for the interface between a hydrogen supply truck/trailer and the station. The lack of standardisation in this interface currently means that each station/trailer combination must undergo a risk assessment, and potentially engineering changes, to ensure safe operation. This increases the cost of ownership. A standardization of this interface would mean the following:
  - *Higher level of safety due to standardisation by removing the potential hazards of a case-by-case approach*. A standardised approach would be beneficial for all HRS and for safety.
  - *Lower TCO*. Lower CapEx due to off the shelf product being compatible with the H_2 supply trailer. During operation the operator would also see an increased flexibility in their supply chain as multiple suppliers would be able to provide/connect to their station, ensuring competition among suppliers, but also strengthening the supply of hydrogen to the sites. This would remove costs originating from having to perform interface risk assessment on new hydrogen suppliers/trailers.

6.2 France – Air Liquide

Since 2012 Air Liquide has designed and built over one hundred hydrogen stations world-wide. The Air Liquide-built H2ME station at Orly Airport in the south of Paris currently operates at 100% load and dispenses ~250kg of hydrogen per day, primarily to the STEP fleet of hydrogen fuel cell taxis. Opened in December 2015 for COP21, the H2ME station at Pont de l'Alma, a very high-profile location in central Paris, offers dual 350/700 bar dispensing up 80 kg H_2/day. The dispensing capability is governed by the limited onsite authorised hydrogen storage capacities in the urbanised location.

The author would like to thank Vincent Basset and Guillaume Gerin of Air Liquide for providing much of the content in this section.

6.2.1 Key RCS for station installation in France

Air Liquide's stations are compatible with the main following standards and regulations:

Standards

- SAE J2601, Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles. Version 2014 and its latest revision in 2016.
- SAE J2600, Compressed Hydrogen Surface Vehicle Fueling Connection Devices.
- SAE J2799, 70 MPa Compressed Hydrogen Surface Vehicle Fueling Connection Device and Optional Vehicle to Station Communications (and EN/ISO17268).
- ISO TC197 / ISO 19880-1, Gaseous Hydrogen - Fuelling Stations – General Requirements.
- ISO 14687, Hydrogen Fuel - product specification.

Regulations

- European Directive 2014/94/EU, Deployment of alternative fuels infrastructure.
- CE Directives such as electrical, PED or machinery for the compressors
- French Arrêté du 8 décembre 2017, Characteristics of hydrogen as a source of energy for transport.
- French nomenclature ICPE, (Installations Classified for the Protection of the Environment). This is discussed further in the next section.

6.2.2 How the regulatory frame for installing HRS in France is evolving: French Nomenclature ICPE rubrics 1416 and 4715 apply

- In France, industrial activities are governed by the *Installations Classées pour la Protection de l'Environnement* (ICPE).
- Historically, only one section, 4715, addressed hydrogen activities. It applies to industrial activity, and therefore is not directly adapted to a vehicle HRS.
- Through the efforts of a number of French organisations, including Air Liquide, a new ICPE rubric 1416 was issued on 22 October 2018, coming into force on 1 January 2019.
- Therefore, two ICPE rubrics apply today to HRS: 4715 and 1416.
- *Note: as discussed below, a new regulation upgrading the 22 October 2018 regulation is awaited by the summer 2024.*

Rubric 4715 applicable to the 'Technical Zone' of the HRS through the 12 February 1998 regulation[20]

- The technical zone (*aire de stockage et de production*) is not accessible to the public. It contains the hydrogen source, buffer storage and compression equipment.
- Rubric 4715 classifies the activities in different regimes according to the quantities of hydrogen stored on site:

Section 4715 of ICPE	Total quantity of Hydrogen stored on site (1)
Unclassified threshold	Less than 100 kg
Declaration threshold	Between 100 kg and 1 t
Authorisation threshold	From 1t and less than 5t
(1)Only thresholds applicable to HRS are mentioned	

- 'Unclassified' threshold: the rules of the art (*règles de l'art*) apply in connection with the European directives. No administrative action is required at the level of the authorities.
- 'Declaration' threshold: on-line declaration. Does not require a permit to operate, unless specifically requested by the DRIEE (*La Direction Régionale et Interdépartementale de l'Environnement*),
- 'Authorisation' threshold: an authorisation to operate order is required before starting the station.
- *Note: a working group of French H2 organisations is currently working on a new "Registration" level (plan to be at 3t or 4t), in order to reduce the authorisation delay to obtain an operating permit if the on-site H2 storage quantity is up to 1t. Results are awaited end of 2024.*

Rubric 1416 applicable to the 'Distribution Area' of the HRS through the 22 October 2018 regulation[21]

- The distribution area (*aire de distribution*) is accessible to the public and houses the hydrogen dispenser.
- This rubric classifies the distribution area under single report Declaration Under Control (DC) (*régime unique de Déclaration Sous Contrôle (DC)*). It means that a notified body has to check the conformity of the station to the applicable regulation at least six months after the station start-up.

[20] For more detail see *Fiche pratique sur la règlementation applicable à la filière hydrogène*. France Hydrogène. Available from https://s3.production.france-hydrogene.org/uploads/sites/5/2023/02/Fiche-ICPE-4715-Arrete-du-12.02.1998.pdf (accessed 12th January 2024)
[21] For more detail see *Fiche pratique sur la règlementation applicable à la filière hydrogène La règlementation ICPE N°1416*. France Hydrogène. Available from https://s3.production.france-hydrogene.org/uploads/sites/5/2023/02/Fiche-ICPE-1416-Distribution-dhydrogene.pdf (accessed 12th January 2024)

6.2.3 Air Liquide's HRS in H2ME under the ICPE regulations

- The stations built by Air Liquide at Orly, Roissy and Versailles had on-site storage of about 900 kg of hydrogen. The station near Versailles has since September 2022 on-site storage authorization of 2000 kg of hydrogen (the stations at Orly and Roissy are now operated by HysetCo).
- For Orly, Roissy stations and Versailles station before retrofit, these stations were declared on-line. This process is no longer difficult, neither in technical terms nor in terms of planning.
- Versailles station is today in authorization level, the delay to obtain the operational permit was about 1 year.

6.2.4 The process for installing a HRS in France[22]

- In France, two processes must be followed in parallel:
  - Follow the ICPE regulatory framework, as discussed above.
  - Obtain a building permit.
- The process is outlined in Figure 8 below:

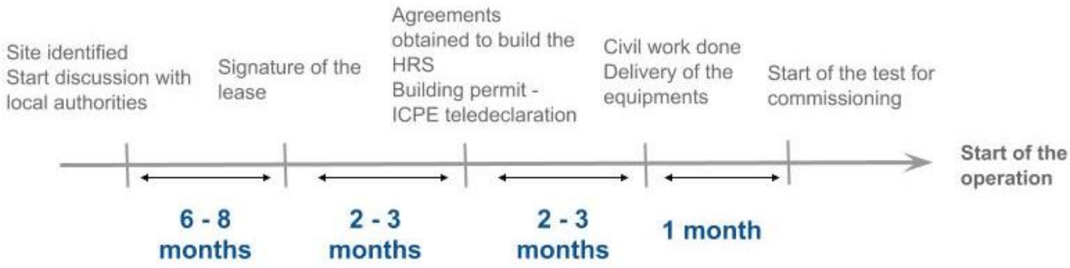

Figure 8 HRS installation process in France (source: Air Liquide)

- For stations with under 1t of on-site storage, ICPE declaration is straightforward and is not a constraint on the process.
- However, building permitting is controlled by the local authorities for each site.
- The process for submitting and obtaining a building permit is the following:
  - Gather all the required documents depending on the site. This typically includes the station layout and the look of the station in the environment.
  - Submit the documents to the local authorities, they then have two months to approve it in the standard procedure.
  - In case of any questions during the process of approval, or for example if the location is inside an historical monument perimeter, the legal lead time for approval increases by one month.
- A typical station design and implementation under ICPE rubrics 1416 (distribution) and 4715 (storage) showing recommended safety distances is shown below.

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[22] For more detail see *Fiche pratique sur la règlementation applicable à la filière hydrogène. Code l'environnement et code de l'urbanisme*. France Hydrogène. Available from https://s3.production.france-hydrogene.org/uploads/sites/5/2023/02/Fiche-Code-de-lEnvironnement-et-de-lUrbanisme.pdf (accessed 12th January 2024)

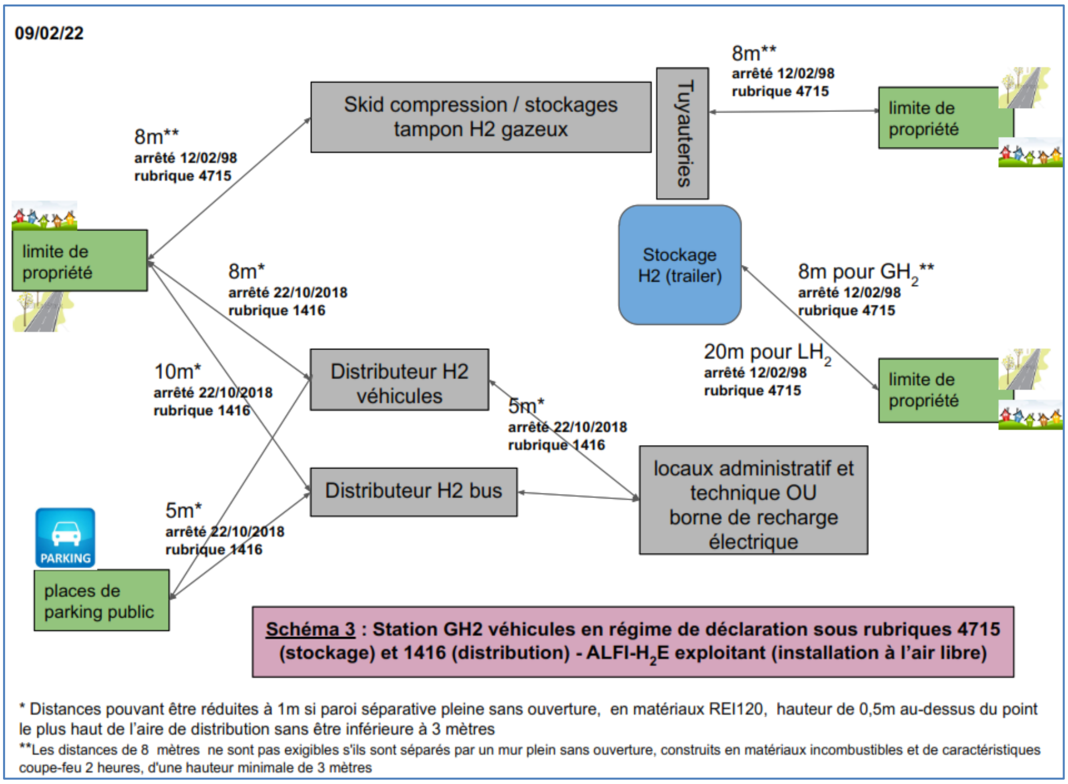


Figure 9 illustrative station design for a GH2 HRS in France (source: Air Liquide)

The Pont de l'Alma HRS

- The Mayor of Paris is a strong supporter of the Alma HRS as a showcase hydrogen refuelling location in central Paris. The permissions given for the installation for the December 2015 station carried over and no additional work was required.
- For the Pont de l'Alma HRS, the amount of on-site storage is less than 100 kg, that's mean not classified as ICPE 4715. But the station is classified under the ICPE 1416 and thus a tele-declaration has been done to the authorities. The Île-de-France DREAL (Direction régionale de l'environnement, de l'aménagement et du logement) ensured the station complied with ICPE 22 October 2018 regulation and approved the station design.
- Once the HRS is approved, there are no further steps mandated other than an inspection six months after HRS start up.
- A CEP test was also conducted.
- On-site legal metrology tests are already planned to pass the final step of global certification of the metrological chain according to MID directive, French regulation of 18 Decembre 2020 and OIML R139. CET certificates have already been obtained. This will make the first H2 vehicle refuelling equipment compliant with MID directive in operation in France.

6.2.5 The evolution of HRS and RCS in France

Gaseous hydrogen fuelling

- As discussed above, the initial focus of hydrogen refuelling in France was on stations for passenger vehicles with relatively small amounts of onsite storage (typically under 1 tonne stored at 200 bar) at vehicle flow rates up to 60 gH_2/second.
- As the focus for hydrogen mobility shifts to the wider rollout of passenger vehicles and HDVs, more capable HRS with higher flow rates (up to 300 gH_2/s for HDVs), dispensing capacities of up to 2 tonnes per day and more onsite storage are needed.
- Air Liquide is part of a working group led by Franch H2 organisations with the third-party expertise of Ineris (*L'Institut national de l'environnement industriel et des risques*, the National Institute for Industrial Environment and Risks established under the aegis of the Ministry of the Environment) which will provide a new regulation to cover these larger HDV stations.
- This new regulation is targeted to come into force in June 2024, around the time of the Paris Olympics.
- Importantly, this new regulation will not apply retrospectively to existing HRS such as Pont de l'Alma.

Liquid hydrogen storage and fuelling

- Air Liquide foresees that liquid hydrogen (LH2) fuelling stations could begin to be deployed in France from 2026 onwards.
- This means that there are under two years to prepare and agree RCS, but the experience gained with GH2 stations means that this is a feasible timescale.
- Air Liquide is part of a working group led by Ineris to agree a common approach to LH2 rollout. The target date for the first draft regulations is 2025.

Electrolysis

- Onsite electrolysis is not a part of Air Liquide's HRS strategy. However, for hydrogen produced on-site via electrolysis, the ICPE nomenclature has so far only provided for a classification called 'IED' activities (Industrial Emissions Directive) under item 3420-a), which would automatically classify the site under authorisation for the electrolyser part.
- The key issue concerns the definition of 'industrial quantity' (quantité industrielle) (Ineris, 2018). Discussions with the French authorities have made it possible, in application of the Interpretative Note *IR_180116 fab industrial quantity under IED_v1.1*, to decide that an electrolyser used to produce on-site hydrogen for the operation of the station does not fall under this heading, with no limit of power fixed to date.
- Consequently, the thresholds of ICPE section 4715 apply.
- Discussions with the authorities are continuing on hydrogen produced by electrolysis.

6.3 France – Hype

Launched in 2015, Hype (https://hype.taxi/) operates the world's largest hydrogen taxi fleet. The organisation currently operates over 400 FCEV taxis in Paris.

Hype has recently announced plans to open a total of eight HRS in the Île-de-France region before mid-2024,[23] growing to 26 at the end of 2025. The stations, including 20 of at least one tonne/day dispensing capacity, will be supplied by locally-produced green hydrogen.

Opened in April 2023, the standalone dual 350/700 bar Issy-Les-Moulineaux HRS can dispense up to 200 kg of hydrogen per day.[24] The station equipment was provided by HRS (Hydrogen Refueling Solutions).

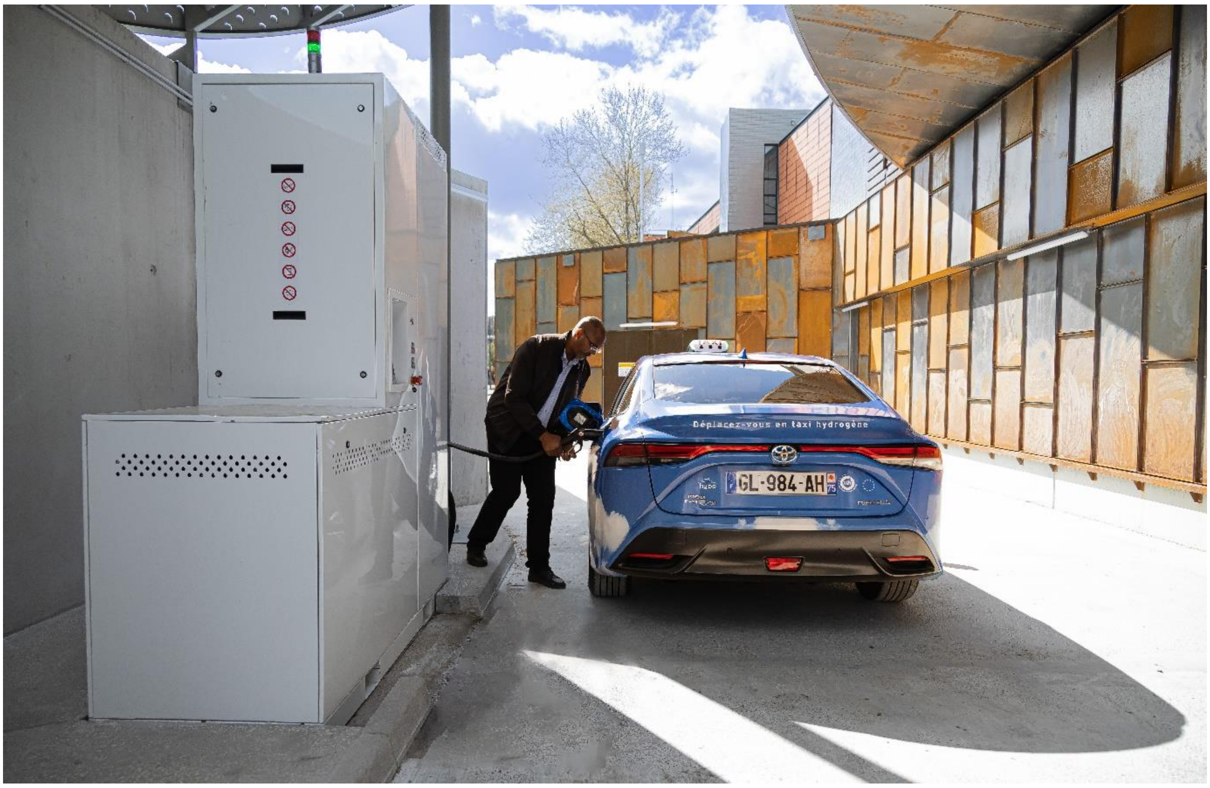


Figure 10 Issy-Les-Moulineaux HRS (source: Hype)

The author would like to thank Alice Jacquet and Baptiste Perlin of Hype for providing much of the content in this section. It should be read in conjunction with the information provided by Air Liquide on French RCS, particularly ICPE, in Section 6.2. To avoid repetition, the focus here will be on the process and timelines for the HRS development and construction.

[23] *Hype révèle la carte des 8 prochaines stations*. Available from https://hype.taxi/hype-revele-la-carte-des-8-prochaines-stations-de-son-reseau-francilien-dhydrogene-vert-qui-seront-deployees-avant-mi-2024-et-les-partenaires-associes/ (accessed 11th January 2024)

[24] *Une première station de distribution d'hydrogène développée par Hype et IntHy ouvre ses portes à Issy-les-Moulineaux*. Available from https://hype.taxi/une-premiere-station-de-distribution-dhydrogene-developpee-par-hype-et-inthy-ouvre-ses-portes-a-issyles-moulineaux/ (accessed 15th January 2024)

6.3.1 Getting approval for a French HRS: administrative and regulatory authorisation[25]

- There are two main steps in obtaining permission to build a HRS in France:

Administrative authorisation under the *code de l'urbanisme* (town planning code)

- Essentially there are two possible levels of authorisation:
  - Permis de construire (PC, building permit) is generally required for new constructions of over 20m^2. In the case of works concerning the transport or distribution of energy it is issued by the local *préfet*.
  - Déclaration préalable de travaux (DP, prior declaration of work) is an authorisation that is required for new construction not subject to a building permit, effectively acting as a lighter touch building permit. The DP allows the local town hall to check that the application complies with town planning rules.
- The *plan local d'urbanisme* (PLU, development plan) determines the appropriate planning rules that apply to the locality. When a PLU is in place, the local *mairie* can grant a DP or PC. If one is not in place, decisions are taken by the regional DREAL (DRIAT for the Île-de-France region).

Regulatory authorisation under the *code de l'environnement*

- As discussed in detail in Section 6.2.1, the two key regulations are ICPE rubrics 1416 and 4715.

6.3.2 The process of planning and implementing the Issy-Les-Moulineaux HRS

- The overall process of location, planning and implementing the HRS took around 18 months. Steps involved include:
- **Finding a suitable location** the Issy HRS is in an urbanised location surrounded by existing buildings.
- **Deciding the HRS configuration** a 200 kg/day HRS keeps the HRS on site storage below 1 tonne which makes the ICPE declaration relatively straightforward.
- **Perform hazard analysis** knowledge of the location and configuration means that Hype and HRS were able to carry out appropriate hazard and safety case analysis which facilitated building permitting application and future stakeholder discussions
- **Liaise with key stakeholders** ongoing discussions with all stakeholders were important in ensuring the successful project completion. Particularly important were:
  - **Mayor** the mayor was a strong supporter of the HRS which was important in the building permit application.
  - **DREAL** (DRIAT for the Île-de-France region) the ultimate arbiters of the ICPE declaration.

6.3.3 Milestones and timeline for installation of the Issy-Les-Moulineaux HRS

- Total building and permitting time for the station was around ten months:

[25] For more detail see *Fiche pratique sur la règlementation applicable à la filière hydrogène. Code l'environnement et code de l'urbanisme*. France Hydrogène. Available from https://s3.production.france-hydrogene.org/uploads/sites/5/2023/02/Fiche-Code-de-lEnvironnement-et-de-lUrbanisme.pdf (accessed 15th January 2024)

Milestone	Date
Application for Permis de construire (PC)	June 2022
ICPE declaration. Consultation period begins	
Building permit issued and construction begins	August 2022
FAT carried out by EPI (an engineering consultancy)	October 2022 – December 2022
SAT	December 2022
HRS commissioning, testing and inauguration	January-March 2022
Public opening	April 2023

6.3.4 Comparing the permitting and building of the Issy-Les-Moulineaux HRS with the Le Mans HRS

- Hype opened a second H2ME-2 HRS in Le Mans in June 2023. Like the Issy-Les-Moulineaux HRS, the station is a dual 350/700 bar HRS capable of dispensing up to 200 kg/day.
- In contrast to Issy-Les-Moulineaux, the Le Mans HRS is in a relatively uncluttered location with lots of space available for parking. This has two consequences:
    - A DP building authorisation was deemed sufficient by the mairie, a simpler administrative process than applying for a PC.
    - No firewall at the edge of the site was necessary since the 8m distance from the equipment to the site limit was respected.
- The figures below illustrate the differences between the two HRS locations.

Figure 11. Le Mans HRS

Figure 12. Hype's vehicles in front of the Issy-les-Moulineaux HRS

6.4 Germany – H2 MOBILITY Deutschland

Founded in 2015, H2 MOBILITY Deutschland (H2M) – a partnership of Air Liquide, Daimler, Linde, OMV, Shell and TOTAL – has installed over 90 HRS in Germany. The organisation's initial aim was to install 100 700 bar HRS in seven German metropolitan areas (Hamburg, Berlin, Rhine-Ruhr, Frankfurt, Nuremberg, Stuttgart, and Munich), and along the connecting arterial roads and motorways, to create a true national network. Opened in September 2018, the station in Potsdam was the first of 20 H2M-built stations in Germany supported by H2ME.

Since 2021, H2M's strategy has evolved towards building larger HRS located based on anchor demand from commercial vehicles and where a public filling station makes sense for a growing network of filling stations for cars. It is targeting having 120 350 bar-capable HRS to serve commercial vehicles by 2026.

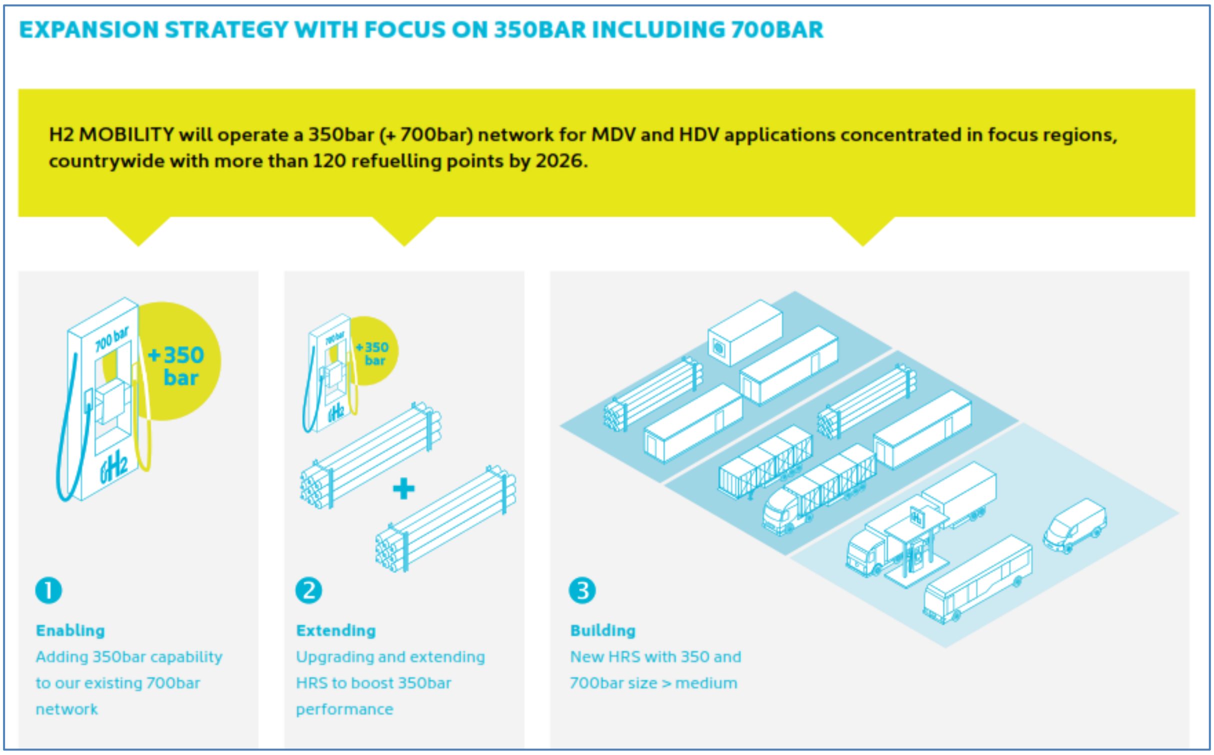


Figure 13. H2Mobility 350/700 bar strategy[26]

Upgrading existing locations to handle larger vehicles, and installing new, bigger HRS, raises challenges for HRS installers. These are discussed in Sections 6.4.7 and 6.4.8 below.

The author would like to thank Ben Becker, Mario Ludwig, and Volker Schlabach of H2M for providing much of the content in this section.

[26] *Annual Report 2022*. H2Mobility. Available from https://h2-mobility.de/wp-content/uploads/2023/02/H2M_IAC-AnnualReport2022_2023-02-01.pdf (accessed 2nd January 2024)

6.4.1 Key RCS for station installation in Germany

- In Germany it is necessary to apply for an operation permit and for a building permit.
- Operational permitting is governed by clear centralised RCS:
  - The most important are the BetrSichV, the German Operation Safety Directive, with its corresponding TRBS 3151 (Technical Rule for Operation Safety) regarding the building and operation of refuelling stations.
  - The ATEX zones classifications set in the TRBS and oriented on other gases used at refuelling stations allows a safe integration of HRS into existing refuelling infrastructure while keeping the footprint of the HRS to a minimum.
  - However, HRS with more than 3t of on-site storage fall under the BlmSchV; see further discussion below.
- Each federal state has its own building directive, which defines the application for the building permit.
- Compliance with Alternative Fuels Infrastructure Directive (AFID) 2014/94/EU is checked and proven by the Clean Energy Partnership (CEP) by the CEP-test (DIN EN 17127). The successful completion of the CEP Site Acceptance Test (SAT) is a precondition for the public release of a HRS in Germany; see Section 7 for a detailed discussion.

6.4.2 The effect of incorporating on-site electrolysis into an HRS in Germany

- H2M does not build stations with on-site electrolysis. However, it is working on several projects that use electrolysis as hydrogen source.
- The main difference is that the basis for the operation permit is no longer the BetrSichV, but the BImSchV, the Immission Protection Directive. The BImSchV has much stricter and more extensive regulations and this results in longer application duration.
- The BImSchV is also more demanding, e.g. operation of a hydrogen refuelling station with on-site electrolysis would necessitate the constant attendance of operators.
- The BImschV is intended to regulate large industrial plants. However, the rules currently include even the smallest electrolysers. It would make sense to discuss a power limit for electrolysis that can be operated without considering full BImSchV requirements. At the time of writing (January 2024) discussions to simplify permitting for smaller electrolysers (e.g., those under 5 MW) are under discussion.

6.4.3 How the process for installing HRS in Germany is evolving

- Together with its HRS suppliers, architects, safety assessors and the notified body H2M has improved its processes to generate the documents needed for the building and operation permits. The established standards and learnings by suppliers and authorities mean that H2M has reduced average project duration significantly from 18-24 months down to 12-16 months.
- However, evidence suggests that permitting and construction times will not decrease significantly in the near future, particularly for HRS co-located with conventional fuelling stations which is H2M's preferred option. The main reason for this is that the initial sites chosen in Germany for HRS installation were generally the most favourable, in terms of the key issues such amount of space available for integration of the HRS to avoid permitting problems. Future stations will inevitably involve building HRS in less favourable locations, which will mean that the permitting and building process will still require much stakeholder liaison and planning.
- The Erfurt HRS discussed below provides an example of why HRS permitting and construction times may not necessary fall in all locations in the future.

Erfurt HRS

- The station in Erfurt, capital of Thuringa, is a strategically important HRS location for H2MDE as it is close to the A4, a main east-west connection.
- This was H2MDE's first HRS in Thuringa. Permitting and construction of the Erfurt HRS has been relatively complex and involved considerable liaison with the local authorities, leading to delays from the initial proposed timetable. Reasons include:

- **Permitting:**
  - The site comprised seven parcels of land with different owners, of which four were relevant for building the HRS. Obtaining consents and their registration in the real estate registry led to a delay of eight months during the permitting process.
  - The site involves cryogenic liquid hydrogen storage (LH2) to support anticipated future high demand, a different design to that employed on previous H2M HRS (discussed further below).
  - Pressure vessels were moved to the roof of the HRS container following safety workshops after the Kjørbo incident.[27] This required a new housing design, which in turn increased planning and construction time.

- **Construction:**
  - A vacuum pipeline is required to move LH2 from container to the dispenser. Limited production capacities for pre-constructing the pipeline delayed the project several months.
  - HRS construction was postponed due to the limited availability of highly trained manpower for welding the pre-constructed pipeline onsite.
  - A vacuum leakage was found in the underground piping between container and dispenser, which involved much remedial work.
  - Lessons learned involve further inspection of the piping and its vacuum insulation before closing pipe trenches, as well as additional tests at factory level.
- Construction of Erfurt was initially scheduled to take about three months, but in fact including all additional work/constraints it took 14 months. The Erfurt HRS opened in September 2020.

[27] *Q2 2019 quarterly presentation*. Nel. Available from https://nelhydrogen.com/wp-content/uploads/2019/10/Nel-Q2-2019-presentation.pdf (accessed 2nd January 2024)

A project co-funded by from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 671438 and No 700350.

Figure 14. Erfurt HRS enclosure (including LH2 storage) and dispenser pictured during commissioning (source: H2M)

6.4.4 How HRS RCS and planning processes differ between Germany and other countries

- H2M's projects are exclusively carried out in Germany.
- The decentralised permitting process in Germany requires a repeated know-how build-up by the different authorities. This increases the permitting time and hinders standardised applications.
- However, from its experience the way the station itself is planned (e.g. whether standalone or on existing infrastructure) and how much experience the authorities, HRS manufacturer, contractors, notified body and HRS builder have, are far more important for the project duration than the country location of the HRS. As stated above, not every location is suitable for every HRS, and any legal requirement can lead to delays if options in design and technology are not known.

6.4.5 Practical measures adopted with contractors to speed HRS installation

- The awarding strategy includes the build-up of know-how by several suppliers to reduce future resource bottlenecks. H2M has established framework contracts with architects, electricians, civil constructers, HRS suppliers and notified bodies.
- H2M and its suppliers spend a lot of effort into creating a standardised set of documentation. These include documents for the application for permits, technical specifications, requirements for the layouts and civil work, plans of electrical cabinets and wiring and functional testing of its stations.

6.4.6 Measures taken to work with operators of conventional fuelling stations to ensure that forecourt-integrated HRS are safe and customer-friendly

- The safety and satisfaction of customers is H2M's top priority. Therefore, it is constantly striving to improve the hydrogen mobility experience, as evidenced by its growing network of HRS, and the ever-increasing availability and improved performance of its stations.
- H2M's H2.live app and 24-hour hotline enable close communication with its customers. All feedback is recorded and evaluated by its customer relation manager to identify customer needs or recurring problems.
- H2M HRS are mainly integrated into existing conventional refuelling stations of its shareholders. Selection of locations, layout, suppliers, and contractors are chosen in close communication and cooperation with its shareholders and H2M has adopted the tested and proven safety standards established by its shareholders who have many years of experience of operating refuelling stations, specifically Shell, TOTAL and OMV.
- Systematic recording of potential hazards and near misses and their discussion with the station operators to implement sufficient countermeasures.
- H2M performs joint safety training with the station operators to test and improve emergency response procedures.

Figure 15. Potsdam HRS. The left image shows the fire protection wall with the HRS. The right image shows the integration of the H_2 dispenser with the conventional refuelling points (source: H2M)

6.4.7 Upgrading existing HRS to provide HDV fuelling

- H2M plans to upgrade 30 of its existing 700 bar HRS to accomodate HDVs.[28]
- As well as the presence of hydrogn HDVs in a given location, addtional factors that must be considered in the upgrade include:
  - Space for vehicles, in terms of turning radii, access, and canopy height
  - Space for additional dispensers, H_2 storage and balance of plant.
- At present, there are two type of HDVs using H2M's network:
  - FAUN/ZÖLLER refuse collection vehicles with a tank capacity of 8.4 kg @ 700 bar per tank system. Some vehicles have two tank systems.
  - Trucks and buses with a tank capacity of up to 40 kg @ 350 bar.

[28] *Annual Report 2022*. H2Mobility. Available from https://h2-mobility.de/wp-content/uploads/2023/02/H2M_IAC-AnnualReport2022_2023-02-01.pdf (accessed 2nd January 2024)

- The differing refuelling requirements of these vehicles put different upgrade requirements on each HRS:

700 bar HDV refuelling

- One existing HRS is already capable of refuelling the FAUN/ZÖLLER vehicle.
- Others require retrofit to meet the needs to dispense the required volumes @ 700 bar.
- H2M is adopting two approaches to satisfy these vehicles
- **FAUN-compatible** (HRS software modification required only):
  - Capable of refuelling up to three vehicles per day.
  - Deliver 80%+ state of charge (SOC) with an extended refuelling time (> five minutes)
  - Upgrade targeted at up to 30 HRS.
- **FAUN-ready** (HRS software and hardware modification required)
  - Capable of refuelling more than three vehicles per day with a similar experience to LDV fuelling.
  - Deliver 95%+ state of charge (SOC) with a refuelling time of four-five minutes.
  - Upgrade targeted at up to ten HRS.

Figure 16: 700 bar refuelling test at Potsdam HRS (source: H2M)

350 bar HDV refuelling

- The upgrade will add a 350 bar or dual 350/700 bar dispenser for buses and trucks and provide onsite storage of at least 400 kg of hydrogen.
- The HRS will dispense hydrogen using SAE J2701 T10 fuelling.
- Nine HRS have been upgraded to this capability, including the H2ME HRS at Aachen and Herten.

A project co-funded by from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 671438 and No 700350.

Figure 17. Upgraded HRS with additional dispenser at Köln-Bonn Airport (source: H2M)

6.4.8 Future HDV HRS fuelling

Plans are still being developed, and locations sought, for additional HRS to support the wider rollout of hydrogen HDVs. The following factors are being considered in this rollout:

- Space requirements (for vehicle access and expanded storage and equipment).
- Securing sufficient anchor demand to support these larger stations.

350 bar HDV refuelling

- H2M has developed its own 350 bar dispenser with integrated control and cooling. The dispenser can be combined with any H_2 supply and is therefore independent of the HRS manufacturer. It is especially designed for high availability and ease of maintenance.
- The new dispenser will employ the Minimum Ambient Precooling (MAP) [29] refuelling protocol that allows refueling with and without precooling.
  - A-MAP: Refuelling in an average of 10 minutes with precooling between -10°C and 0°C, with and without communication
  - B-MAP: Refuelling in an average of 20 minutes with precooling between -5°C and +10°C, with and without communication
  - C-MAP: Refuelling without precooling (15-50 min depending on outside temperature), with and without communication.
- A first prototype was put into operation at Magdeburg in mid-2023 (Figure 18).
- All H2M's new HRS will all be equipped with this dispenser.

[29] *Minimum Ambient Precooling (MAP) Hydrogen Refueling Protocol for 35MPa Heavy Duty Vehicles (20-42.5 kg).* Wenger Engineering. Available from https://cleanenergypartnership.de/wp-content/uploads/2022/11/2022-11-09_MGR_MAP-Fueling-Protocol-for-35-MPa-Heavy-Duty-Vehicles-20-42.5kg_Wenger-Engineering_Rev1.41-min.pdf (accessed 5th January 2024)

Figure 18. 350 bar HDV refueller at Magdeburg (source: H2M)

700 bar HDV refuelling

- H2M is initially planning to offer 500 bar refuelling (which will give up to 80% SOC to a 700 bar tank) which can be achieved with the powerful and reliable compressors used in 350 bar HRS. From H2M's point of view, compressors for 700 bar refuelling with 100% SoC are not yet available on the market with sufficient performance and reliability for tank systems up to 40/80 kg H_2.

6.5 Netherlands – Resato & Kerkhof

B. Kerkhof & Zn (http://www.kerkhof.com) operates a refuelling station which, since 1966, has been at Binckhorstlaan in The Hague. The site offers:

- Hydrogen 350 & 700 bar (opened in March 2020)
- Petrol and diesel for passenger cars (10 pumps, four hoses each)
- Four high-speed diesel HDV pumps
- Two AdBlue and two GTL hoses
- Two BioCNG pumps
- Four LPG pumps
- Electric charging plus a 350 panel solar array capable of generating 100kW
    - 2x22kW AC
    - 4x150kW and 10x300 kW DC

Figure 19. The Hague HRS (source: J P Kerkhof)

Resato (https://resato-hydrogen.com/) is a Dutch company with more than 25 years' experience in high pressure systems and testing equipment. The Hague station was its first public fast-fill HRS installation providing considerable learning and experience as a first step to become one of the market leaders in HRS development and manufacture Successive series are now deployed in eight countries show belong to Europe's highest usage intensity stations. The company now has installed over 40 HRS in Europe.

The author would like to thank Jan Paul Kerkhof (Kerkhof), Nico van den Berg (Rijkswaterstaat, Dutch Ministry of Infrastructure and Water Management), Stefan Neis (WaterstofNet) & Gerard Schuiringa (Resato) for providing much of the content in this section.

6.5.1 Key RCS for HRS installation in the Netherlands

Given the ongoing rapid development of hydrogen mobility and anticipated increase in HRS numbers, Netherlands agencies such as the Ministrie van Infrastructuur en Waterstaat (Ministry of Infrastructure and Water Management) and the Dutch H2 Platform (https://opwegmetwaterstof.nl/) have been proactive in documenting information on HRS permitting and installation. The content of this and the following sections is primarily taken from the 2020 document *Permitting process on Hydrogen Refuelling Stations*,[30] which should be consulted for further detail and links. Key points include:

- **Environmental permitting** HRS are classified as Type C establishments under the Activities Decree (https://rwsenvironment.eu/subjects/environmental-0/activities-decree/) which means they require an environmental permit from the relevant municipality, which is the competent authority. In most cases the municipality delegates the permitting to the regional environmental agency (Omgevingsdienst or Regionale UitvoeringsDienst (RUD)); the appropriate safety region (veiligheidsregio) is also consulted on safety-relevant aspects. On average, the environmental permitting process could take up to 18 months, when starting from scratch. The regular process duration is legally set at 26 weeks.
- **Storage** HRS with onsite storage below 5 tonnes are under the SEVESO III threshold[31] and so are not covered by the Major Accident Risks Decree (https://brzoplus.nl/aanpak/brzo-2015/inleiding-brzo-2015/).
- **Primary road network permit** HRS on the primary road network require a permit under the Management of Rijkswaterstaat Structures Act (WBR, https://www.rijkswaterstaat.nl/wegen/wetten-regels-en-vergunningen/wetten-aanleg-en-beheer/wet-beheer-rijkswaterstaatswerken).
- HRS (whether new, or as part of an existing fuelling station) generally require a building permit.

6.5.2 The process for installing a HRS in the Netherlands[32]

- Figure 20 below summarises the HRS installation and licensing process in the Netherlands.

[30] *Permitting process on Hydrogen Refuelling Stations Summary of the practical guide for operators and local residents*. Hydrogen Safety Innovation Programme (Waterstof Veiligheid Innovatie Programma, WVIP) under the Dutch H2 Platform. Available from https://nlhydrogen.nl/wp-content/uploads/2020/06/Summary_Guide-permitting_process_hydrogen_refuelling_stations.pdf (accessed 5th January 2024)

[31] *HyTrEc2: Hydrogen Transport Legislation and Standards in the NSR*. Cenex. Available from https://northsearegion.eu/media/19500/hydrogen-transport-legislation-and-standards-in-the-nsr-final.pdf (accessed 5th January 2024)

[32] *Vergunningproces waterstoftankstations*. Ekinetix under the Dutch H2 Platform. Available from https://opwegmetwaterstof.nl/wp-content/uploads/2020/03/WVIP_uniforme_vergunnningverlening_rapport_23_03_2020_F-1.pdf (accessed 5th January 2024)

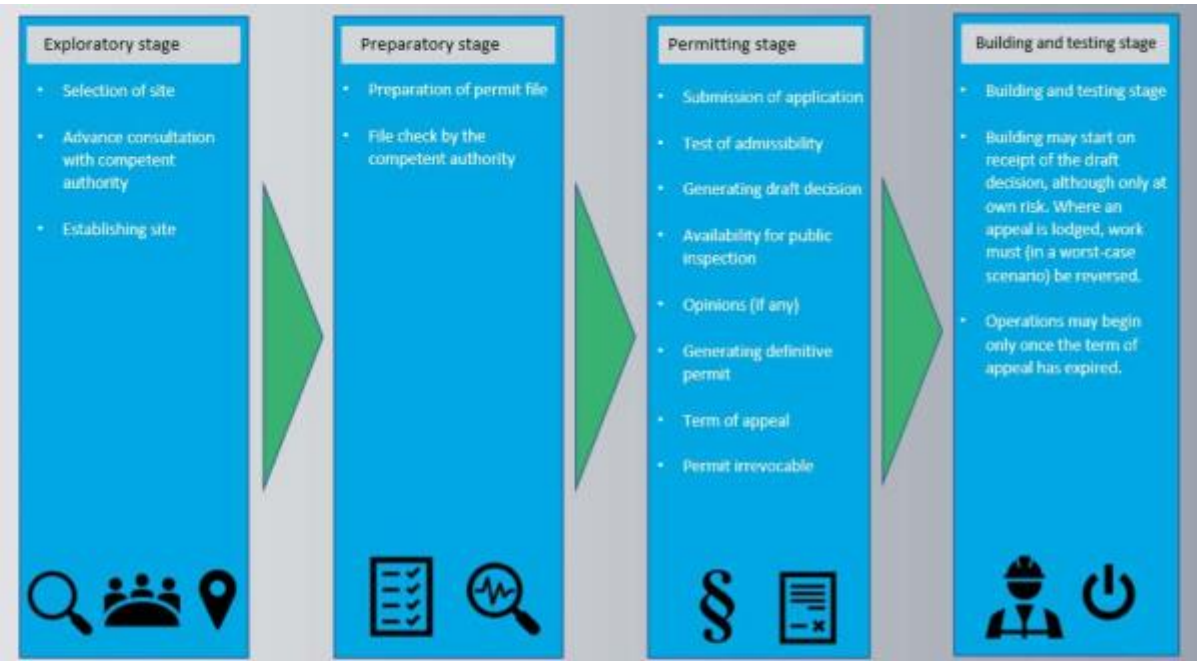


Figure 20. HRS planning, installation, and licensing process in the Netherlands

- Exploration and preparation
    - Spatial planning does not currently account for the use of hydrogen as a fuel. Therefore, it is important to allow as much time as possible for consultation with all stakeholders – including the municipality, environmental agency, safety region and local residents – in the Exploratory and Preparatory stage and to allow for amendment where needed of the appropriate development plan.
    - **PGS 35** *Hydrogen: Installations for Delivery of Hydrogen to Road Vehicles* (PGS Publicatiereeks Gevaarlijke Stoffen, Publication Series Dangerous Substances)[33] is considered the best available reference on hydrogen refuelling station design, construction, operation, testing and safety. It therefore forms the basis for the Environmental Permit.
    - Risk as assessed in line with the Decree on External Safety of Establishments[34] which means a Quantitative Risk Assessment (QRA) will be needed, even though HRS are not currently covered by the decree.
- Permitting

[33] *Hydrogen: Installations for Delivery of Hydrogen to Road Vehicles*. PGS. Available from https://publicatiereeksgevaarlijkestoffen.nl/documents/81474/1664358051-pgs-2035-20voor-20website-20ondertekend.pdf (2015 English version, accessed 5th January 2024); August 2021 version which is substantially unchanged from the 2015 version available from https://publicatiereeksgevaarlijkestoffen.nl/publicaties/online/pgs-35/2021/1-0-augustus-2021/ (accessed 5th January 2024)

[34] *Besluit externe veiligheid inrichtingen*. Overheaid.nl. Available from https://wetten.overheid.nl/BWBR0016767/2016-01-01 (accessed 5th January 2024, although it was noted that the version on line expired on 31st December 2023 and was in the process of being updated)

A project co-funded by from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 671438 and No 700350.

- The permitting procedure for HRS is the same as for other establishments (as described in the *Administrative Guide to Licensing Hydrogen Filling Stations*[35]), encompassing:
  1. Preliminary phase and 'quick scan' outlining the possibilities and potential sticking points
  2. Determining whether the application is admissible and licensable
  3. Justification of the group risk
  4. Formulation of rules
  5. Data input in the risk register/risk map
  6. Risk communication
  7. Enforcement
  8. Preparation of incident control.
- Information required is decided by the AHJ, but includes:
  - Environment and ecological surveys
  - Justification of land use change in development plan
  - Traffic study
  - QRA
  - Waste and energy management plans.
- It is also likely that the following information will be required once operation has begun:
  - Explosion protection document and emergency plan
  - HAZOP study
  - Hydrogen transport routes
- Interested parties have three options for issuing a formal response during the permitting process:
  - An opinion on the draft decision during an official six-week window.
  - An objection to the definitive decision during a further six-week window.
  - An appeal to the courts is also possible.

- Building and testing
  - As Figure 20 shows, station construction can begin if a positive draft decision is received. However, this is at the developer's risk pending the outcome of a review of potential objections.

6.5.3 Timeline for installation of The Hague HRS

- Initial discussion and planning for the HRS began in March 2017 between Kerkhof and Resato to be the launch customer for this new product line.
- The draft decision on the HRS was received in July 2019
- HRS construction began on October 2019
- CEP acceptance tests were carried out in June 2021

[35] *Bestuurlijke Handreiking Vergunningverlening Waterstoftankstations*. IFV. Available from https://nipv.nl/wp-content/uploads/2022/02/20190619-IFV-Bestuurlijke-handreiking-vergunningverlening-waterstoftankstations.pdf (accessed 5th January 2024)

- The HRS was opened in December 2019.
- The Den Haag HRS was the first HRS built by Resato and operated by Kerkhof. As such, many lesson were learned in the process such as:
    - *A new market approach: moving from business to business to a more complex situation involving multiple stakeholders*
    - *Customer experience is important to maintain success of HRS. H2ME-2 has been invaluable for obtaining feedback on fuelling experience and system availability, and to allow Resato to make design and performance improvements*
    - *Using the lessons learned from The Hague, Resato is productising HRS to ensure long term performance and reliability*
    - *The product line is being built and developed in a modular fashion to allow rapid response to the continually-changing market and to allow for individual module improvements.*
- With this knowledge, it is possible that building and permitting a new HRS will take 9-12 months. In practice we see a period of ~12-14 months due to the stakeholder complexity.

6.5.4 How the process for installing a HRS in the Netherlands is evolving[36]

- Coming into force on 1st January 2024, The Environment and Planning Act (Omgevingswet) combines 26 existing acts around built environment, housing, infrastructure, environment, nature and water and is designed to make it easier and faster to apply for permits.
- All municipalities are now connected to single online service point (Digitaal Stelsel Omgevingswet, DSO). DSO is a one-stop shop to apply environmental and planning permits. The competent authority that has to decide on the application will do so via this counter.
- In many cases it should be possible to issue a permit within 8 weeks of application. More complex cases, which are likely to include HRS, may take up to six months.
- For activities involving risk however, such as HRS installation and operation, the need to ensure that regulations are observed will remain paramount. For example, for the first time fixed safety distances of 35 metres will be mandated from the refueller where hydrogen is delivered by tube trailer, and 55 metres from the buffer tank.

[36] *Introduction of the Environment and Planning Act (Omgevingswet)*. RVO. Available from https://business.gov.nl/amendment/introduction-environmental-and-planning-act-omgevingswet/ (accessed 5th January 2024)

7 Vehicle manufacturers' perspective on hydrogen refuelling

Honda R&D Europe (H2ME-2) and Toyota Motor Europe (directly in H2ME-1, and through National Marketing and Sales Organisations in Denmark and Norway in H2ME-2) have deployed vehicles across Europe as part of H2ME. Both manufacturers have been active in work coordinated by the CEP aimed at establishing processes and documentation to ensure the safe and reproducible refuelling of hydrogen vehicles to accepted performance expectations.

The author would like to thank Thomas Brachmann of Honda R&D Europe and Vincent Mattelaer of Toyota Motor Europe for providing much of the content in this section, including presentation material for the graphics.

7.1 Vehicle refuelling protocols: SAE J2601

A refuelling protocol is a set of procedures that dictate the process that a HRS follows to safely fuel a vehicle's compressed hydrogen storage system (CHSS).[37] Refuelling protocols ensure:

- The CHSS stays within its operating temperature and pressure limits
- An acceptable refuelling speed and final SOC.

As introduced in Section 3, for H2ME, the relevant refuelling protocol is SAE J2601, which is the worldwide protocol standard for light duty fuelling. The objectives and implementation of J2601 are summarised below.

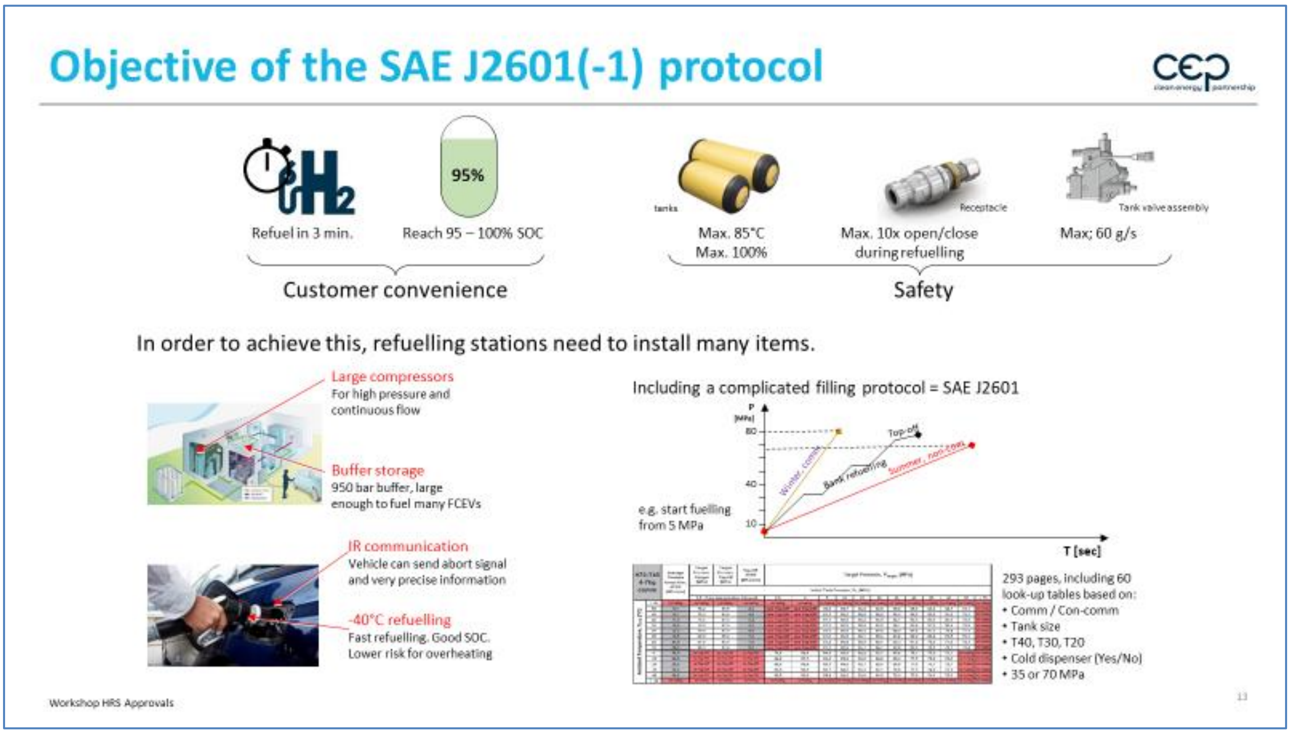
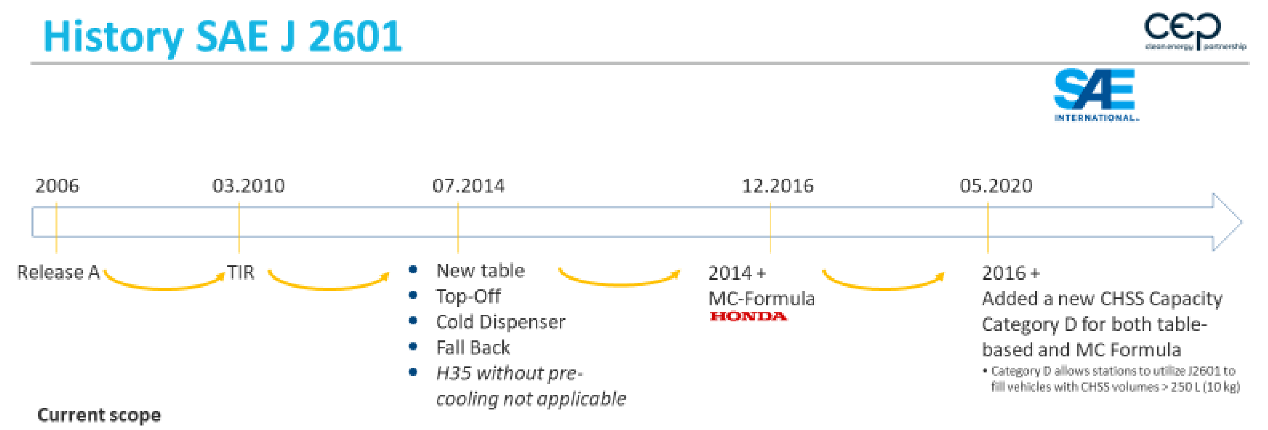


Figure 21. SAE J2601

[37] *How Advanced Hydrogen Fueling Protocols Can Improve Fueling Performance & H_2 Station Design*. NREL. Available from https://www.nrel.gov/docs/fy20osti/77368.pdf (accessed 11th January 2024)

J2601 has evolved since its first introduction, and during H2ME, as shown below.



Current scope

Pressure Class Designation		H35			H70		
CHSS Capacity Range (Liters)		< 49.7	49.7 to 248.6	> 248.6	< 49.7	49.7 to 248.6	> 248.6
CHSS Capacity Range (kg)		< 1.19	1.19 to 5.97	> 5.97	< 2.0	2.0 to 10.0	> 10.0
CHSS Capacity Categories (nomenclature)		TBD	A, B, C	D	TBD	A, B, C	D
Maximum Flow Rate (g/s)		≤ 60	≤ 60	≤ 60	≤ 60	≤ 60	≤ 60
Fuel Delivery Temperature Category	T40	Not Included	Included	Not Included	Not Included	Included	Included
	T30						
	T20						
	T10						
	Ambient						

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Figure 22. Evolution of SAE J2601 (TIR = Technical Information Release)

7.2 Implementation of hydrogen refuelling station RCS in Europe

The 2014 Alternative Fuels Infrastructure Directive (AFID) required EU countries to develop national policy frameworks (NPFs) for developing publicly available refuelling and recharging points for alternative fuel vehicles and vessels.[38] The requirements of the AFID were integrated into the Alternative Fuel Infrastructure Regulation (AFIR 2023/1804) in September 2023 as summarised in Figure 23.[39] The figure shows the necessity of compliance with EN 17124, EN 17127 (and therefore J2601), and EN ISO 17268 in ensuring safe and reproducible refuelling.

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[38] *Revision of the Directive on Deployment of Alternative Fuels Infrastructure*. Available from https://www.europarl.europa.eu/legislative-train/package-fit-for-55/file-revision-of-the-directive-on-deployment-of-alternative-fuels-infrastructure (accessed 22nd December 2023)

[39] *REGULATION (EU) 2023/1804 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU*. Available from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1804 (accessed 21st December 2023)

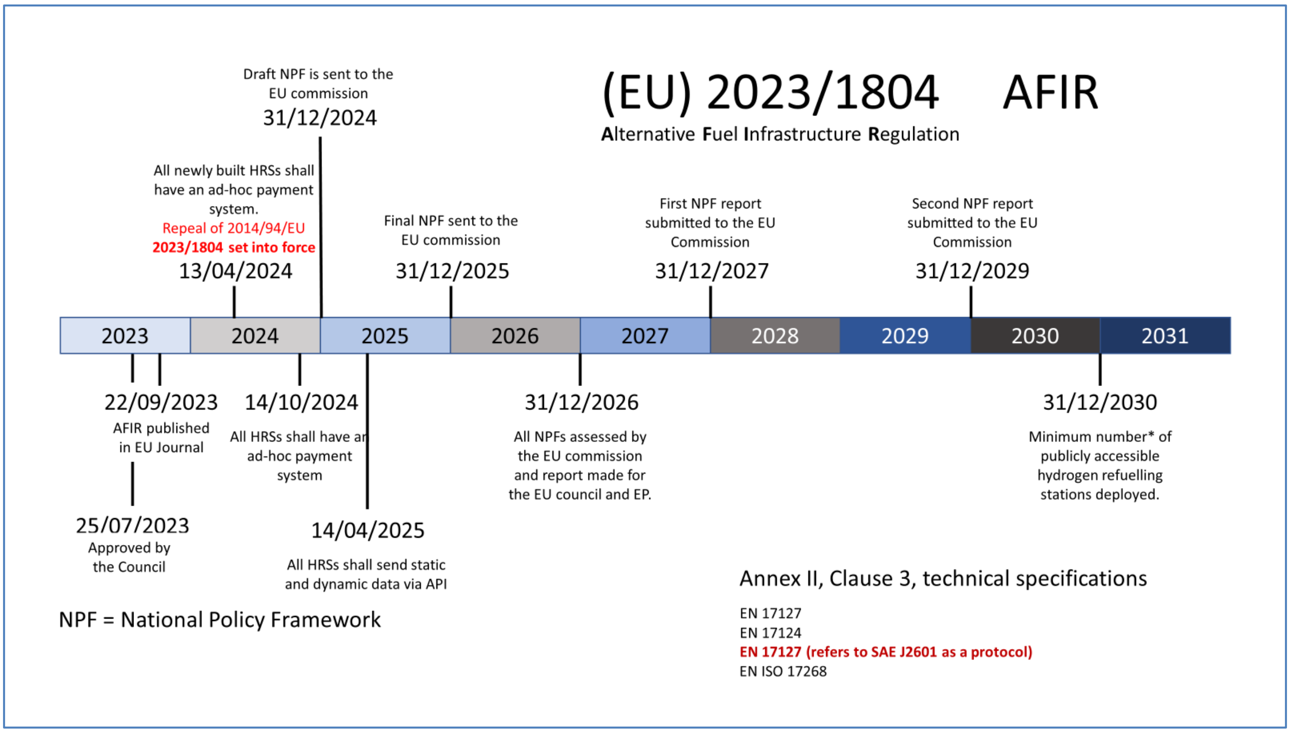

Figure 23. AFIR EU 2023/1804

7.3 HRS approvals process and the Site Acceptance Test (SAT)

Given the issues observed with low vehicle SOC (discussed in Section 3.3), and the potential issues of maintaining tank integrity in non-compliant refuelling, vehicle OEMs have worked with HRS suppliers in the CEP OEM Group to devise a process to approve HRS for refuelling of their vehicles based on EN 17127.[40] The HRS operator must also supply for OEM inspection: [41]

- *Factory Acceptance Test* (FAT) report (in general provided by the HRS supplier to the HRS operator)
- Hydrogen quality sampling and analysis report
- *Site Acceptance Test* (SAT) report

The SAT is summarised in Table 2.

[40] *CEP Guideline for ISO 19880-1 FAT/SAT Tests*. CEP. Available from https://cleanenergypartnership.de/wp-content/uploads/2022/03/CEP-Guideline-for-ISO-19880-1-FAT-SAT-tests-v7-04112020-min.pdf (accessed 5th January 2024)

[41] *Approved Acceptance Procedure for Fuelling Stations*. CEP. Available from https://cleanenergypartnership.de/en/approved-acceptance-procedure-for-fuelling-stations (accessed 5th January 2024)

Table 2. HRS SAT (NWP = Nominal Working Pressure)[42]

Test Name	Prep to be performed	Test info	Acceptable Test	CEP/ISO test #
Ambient, fuelling pressure and temperature sensor accuracy table	-	Verification of ambient and fuelling temperature sensor and fuelling readings, review of calibration	Sensors show value reasonable to state of the refuelling point; calibration certificates OK	3 (ISO 19880-1)
Fault: CHSS starting pressure	CHSS with starting pressure greater than the appropriate vehicle NWP to be refuelled (attempted)	Connect the CHSS to the HRS and initiate the refuelling. HRS shall recognize full CHSS and not start main part of refuelling	Main refuelling is not allowed to start.	8 (ISO 19880-1)
Communication break	Simulated communications and then a break in communication signal	Confirm that the refuelling switches to non-communication fuelling	Dispensing system switches to non-com refuelling or stops refuelling.	16 (ISO 19880-1)
Fault: Communication Abort Signal	Simulated communications Abort Signal, e.g. by manipulation of the signal loop	To be monitored even with non-communications refuelling (if applicable)	Refuelling Stop within 5 seconds of Abort Signal being sent	18 (ISO 19880-1)
Non-comm refuelling validation for each pressure level (H70 and H35)	2 different starting conditions	Two tests per hydrogen service level where applicable	P_{target} ±2 MPa without exceeding the fuelling protocol process limits	36 (ISO 19880-1)
Communication refuelling validation	2 different starting conditions, one of which is below 2 MPa starting pressure	Two tests per hydrogen service level where applicable	SOC or P_{target} without exceeding the fuelling protocol process limits and with no abort signal received.	37 (ISO 19880-1)

7.4 Implementation of the CEP HRS approvals process and the SAT

When HRS station testing began in Germany in 2011, each new HRS was tested separately by each vehicle OEM, which was an inefficient and lengthy process. In moving to a more efficient, repeatable process for new HRS, questions to be addressed included:

- How tests are to be performed and evaluated?
- How should the tests be documented?
- Who should do the testing and evaluation?
- How frequently (if at all) do tests need to be repeated?

[42] Table derived from EN 17127

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The status of the CEP process and SAT in Germany and other countries in the EU such as Denmark is summarised in Table 3. A key aspect of the implementation of the SAT is the use of a mobile testing rig capable of carrying out and recording tests that are representative of the range of OEM vehicles using the station (as discussed in Section 3 this covers vehicles with tank capacities ranging from 4.6 kg to 6.3 kg H_2 at 700 bar), such as the mobile *Fuelling Station Test Module (FSTM)*[43] developed by ZSW. FSTM testing is also carried out by ZSW, and the results documented in an acceptance report.

However, as shown in Table 3, the evaluation of the results of the SAT is still carried out individually by each vehicle OEM in a long, manual process before the station can be approved. If any issues are found in the evaluation, the testing and evaluation process must generally be repeated, further delaying the HRS approval.

Table 3. Current CEP HRS approval process

	Procedure	**Description**	Responsibility
1	declaration	The HRS supplier declares the SAE conformity of the system.	HRS Supplier
2	testing	The HRS supplier tests the HRS, or a qualified independent 3rd party test the HRS on behalf of the operator/supplier in accordance with the CEP acceptance programme. The results are documented in detail in an acceptance report.	HRS Supplier / 3rd Party
3	evaluation	The acceptance report and declaration of conformity are submitted to the OEMs, who check the conformity of the test results. Deviations from standards are discussed with the HRS supplier bilaterally.	OEMs
4	approval	Explicit approval of the acceptance reports by OEMs.	OEMs

7.5 Future streamlining of the SAT

Discussions during the compilations of this report have indicated that, at times, the limited number of, and availability of, FSTMs that are certified for CEP usage have delayed the SAT. This should be addressed by the provision of additional FSTMs as currently there are two in use in CEP approvals.

Table 4 shows however that work is underway to transfer responsibility for HRS testing, evaluation, and approval on behalf of the CEP vehicle OEMs to an independent third party. At the time of writing (December 2023) this has been accomplished for the German region where TÜV-SÜD, TÜV-Rheinland and DEKRA are allowed to approve the stations on behalf of the CEP. Seven other international independent 3rd parties have already been trained and are likely to get their CEP approval by the end of 2024. By bringing an external body to carry out this work, it is expected that a smoother process for HRS testing and approval will result, and that typical station testing, evaluation and acceptance times will reduce to around one month.

[43] *Acceptance tests of hydrogen refueling stations*. ZSW. Available from https://www.zsw-bw.de/en/leistung/translate-to-englisch-wasserstoff-efuels/acceptance-tests-of-hydrogen-refueling-stations.html (accessed 5th January 2024)

Table 4. Future HRS approval process (key changes from current marked in red)

	Procedure	**Description**	Responsibility
1	declaration	The HRS supplier declares the SAE conformity of the system.	HRS-Supplier
2	testing	The HRS is tested by a qualified independent 3rd party on behalf of the HRS operator/supplier in accordance with the CEP acceptance programme/EN 17127. The results are documented in detail in an acceptance report.	3rd Party
3	evaluation	The acceptance report and declaration of conformity are checked and confirmed by a qualified independent 3rd party on behalf of the HRS operator/supplier. Deviations to the standard will be discussed between the independent 3rd party and the HRS acceptance report creator.	3rd Party
4	approval	Explicit approval of the acceptance reports by the independent 3rd party.	3rd Party

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