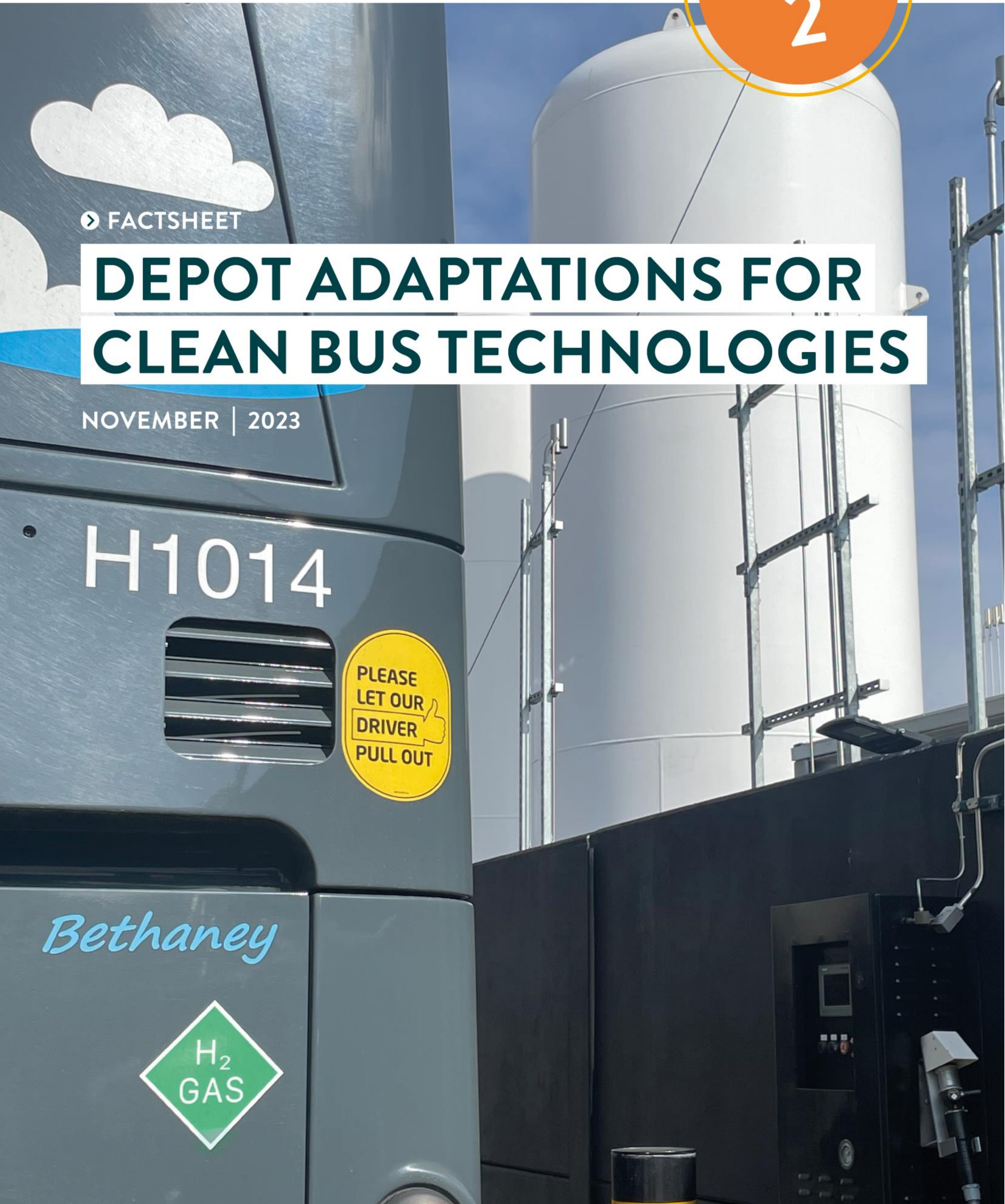
UITP ADVANCING PUBLIC TRANSPORT

CLEAN BUS SERIES 2

FACTSHEET

DEPOT ADAPTATIONS FOR CLEAN BUS TECHNOLOGIES

NOVEMBER | 2023



INTRODUCTION

Climate change and local air pollution are the main factors driving the transition towards clean- and zero-emission technologies in the transport sector. Around the world, national and local governments have issued transport decarbonisation visions and plans and set up targets and timelines supporting the transition from fossil-fuelled fleets towards clean and zero-emission technologies.

As a key stakeholder in this transition, the bus sector is demonstrating a strong commitment to the decarbonisation goals and is embracing clean technologies and innovation whilst investing in substantial fleet renewal in many of our cities. However, while transitioning towards low- and zero-emissions buses can significantly improve the quality of life and liveability in our cities, the introduction of new technology poses several challenges to operators' daily business.

When diversifying the technology portfolio, operators need to consider many aspects related to the specificities of each technology and its operational requirements, like the introduction of new equipment, functions and tasks, as well as local regulations and standards. Lack of space, finding a suitable location, and energy supply, design for high efficiency of operations, and ensuring compliance to regulations for a specific technology, are usual constraints to cope with when planning for a new depot.

This factsheet series is aimed at providing an overview of the main aspects to consider in the different phases of planning and deploying a new depot or upgrading an existing one. As public bus fleets are usually made of several technologies, it is not uncommon that depots are shared for different types of buses. These factsheets set the focus on three of the most popular technologies that can be found globally: battery electric, fuel cell hydrogen and natural gas technologies, and it is part of the UITP Fleet Renewal Checklist, released in June 2020 by the UITP Bus Committee.

ELEMENTS OF A BUS DEPOT

A bus depot can be defined as the premises where buses are serviced and parked after daily operation. It entails several facility areas designed to cover the managerial, maintenance and administrative tasks needed to operate a fleet of buses. The main elements of a bus depot can be listed as follows:

- **Entry and exit**
- **Parking bays for buses**
- **Washing and cleaning**
- **Charging and/or fuelling, incl. energy storage (2nd life of batteries)**
- **Maintenance workshops, incl. fire safety systems**
- **Warehouse & storage**
- **Administrative & operational facilities**
    - Operational control centre
    - Facilities for drivers (cloakrooms, personnel rooms, etc.)
- **Parking for staff and externals**

Based on the elements and tasks performed in a depot, this series highlights the main considerations and provide tips for the different elements and phases of depot planning, deployment and operation for battery electric, fuel cell hydrogen and natural gas buses.

RUN-IN	• Inspection • Fuelling (applying to hydrogen, CNG) • Washing and cleaning • Processing onboard system data • Parking or allocation to workshop
STORAGE	• Charging (applying to battery buses) • Maintenance (preventive, predictive, corrective)
RUN-OUT	• Driver check for readiness for run-out • Inspection and ok for run out

► *Source: UITP Field Study Bus Depot, 2013*

FACTSHEET 2. FUEL CELL HYDROGEN BUS DEPOTS

Figure 1. Fuel cell hydrogen bus. © UITP

A fuel cell electric bus combines a hydrogen fuel cell with batteries to power its operation. The fuel cell supplies the main energy for the vehicle, while the batteries support peak power demands such as rapid acceleration and steep uphill gradient driving. This hybrid setup allows for optimising the size of each component according to the specific route requirements.

The fuel cell power module generates electric energy through an electro-chemical reaction, producing only water and heat as by-products, resulting in zero emissions at the tailpipe. This electric energy is used for direct electric traction and to recharge the onboard battery pack.

Because of the considerations above, please note that a fuel cell bus is still a type of battery-electric bus. Hence, the maximum available power is limited by the lower of the two power outputs: the fuel cell and the battery. It is essential to conduct simulations and tests to equip the vehicle in the most efficient and effective way for a particular use case.

> Most considerations made for depot adaptations towards battery electric buses are valid for fuel cell hydrogen buses as they are also equipped with high-voltage equipment and electric powertrain. Please refer to *'Factsheet 1. Battery Electric Bus'*

The use of hydrogen as an energy source offers higher energy density compared to battery systems, enabling buses to achieve longer ranges than those relying solely on energy stored in batteries. Hence, the service planning is less dependent on the range capabilities of the vehicles, generally matching the requirements for typical day-round urban bus operations. Furthermore, no additional buses are required to keep the same service provision in the transition from traditional fossil-fuel to zero-emission vehicles, easing the surface exigencies for parking at the depot.

Hydrogen fuel cell buses are fuelled with hydrogen that can be delivered to the depot either in liquid or gaseous (high pressure 700 bar gaseous form is more common than liquid) form via tank trucks or pipelines, or produced onsite, for instance through water electrolysis with electricity. Depending on the source of the hydrogen, the requirements for the depot location and supply can differ.

Some of the main activities to prepare a depot for fuel cell hydrogen buses include the adaptation and upgrade of workshops, installation of hydrogen sensors and related safety equipment, installation of refuelling infrastructure (in case of onsite hydrogen generation), risk assessments, staff training and employee engagement, and developing emergency procedures, among others.

Finally, fuel cell hydrogen depots share operational and safety characteristics with natural gas depots. Operators experienced with Compressed Natural Gas (CNG) technology will find the main procedures and principles familiar when planning and operating FCHB depots. However, ensuring hydrogen safety requires operators to acquaint themselves with the properties of hydrogen as a fuel and the specific requirements involved.

Figure 2. Fuel cell hydrogen bus in Barcelona. © UITP

UITP

HYDROGEN PRODUCTION AND SUPPLY

Hydrogen is the most abundant chemical structure in the universe. It can be produced through multiple processes and energy sources. While the two most common production processes are Steam Methane Reforming (SMR) and Electrolysis, hydrogen can be produced or obtained through other methods such as biological hydrogen production, photoelectrochemical water splitting, thermochemical water splitting or biomass gasification. Nevertheless, around three-quarters of the total hydrogen produced today is through SMR.

The environmental impact and energy efficiency of hydrogen depend on the production method and mostly on the capability to produce green hydrogen using renewable energy. Although this is out of scope of this factsheet, detailed information is to be found in the UITP Report 'The road to sustainability. Transition to renewable energy in public transport'.

Proximity to production areas can positively impact the deployment of fuel cell hydrogen technology. For instance, the German region of North Rhine-Westphalia benefits from large amounts of hydrogen obtained as a by-product of industrial activities. Differently, the Noord-Nederland region in the Netherlands is one of the "hydrogen valley" regions in Europe[1], aiming at accelerating the deployment of fuel cells and hydrogen technologies for different applications through developing a favourable ecosystem for green hydrogen, thanks to offshore wind power and surface for electrolysers, and a dense gas network[2].

Two main strategies are followed to supply hydrogen in current FCHB operations: it can be produced elsewhere and transported to the depot or refuelling facilities through trucks or a pipeline; or it can be produced on-site. Both strategies have an impact on the equipment and requirements in depot design.

Hydrogen production on-site, whether at the depot or nearby, is feasible when favourable conditions are met in terms of space availability, renewable energy generation or access to a reliable electricity grid with sufficient power, and sufficient water supply.

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1 https://s3platform.jrc.ec.europa.eu/hydrogen-valleys

2 The project NortH2 aims to produce 4 GW of green hydrogen by 2030, and scaling up to 10 GW by 2040 (equivalent to the electricity consumption of approximately 12.5 million Dutch households). Find more here: https://www.groningen-seaports.com/en/hydrogen/.

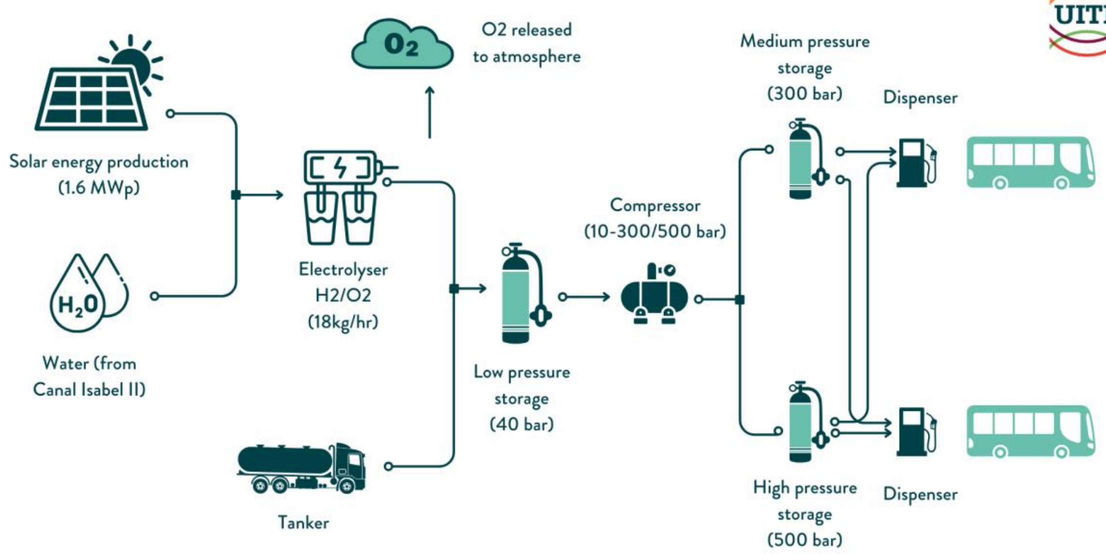

Figure 3. Hydrogen supply process with on-site hydrogen production. Source: EMT Madrid.

Provided that the renewable energy production rate is rather unpredictable, the on-site production of hydrogen is one of the alternatives to storing locally produced energy when the buses are not charging at the depot. Furthermore, through close cooperation with the electricity supplier and the grid operator, significant savings can in turn be achieved on electricity prices as another way of reducing the spikes in energy demand from the grid.

On the other hand, transported hydrogen requires investments in pipelines or considering logistics costs when delivered through trucks. But water supply and the connection to the grid should not pose major issues as the total amount of water and electricity required is less than for a battery electric bus depot and similar to a CNG bus depot.

LOCATION

The production of hydrogen and its supply is a central element of the planning phase, and analogously to battery electric bus technology, it is a key factor for the timely execution of the project.

As said above, selecting the optimal location for the construction of a bus depot to accommodate a FCEB fleet is heavily impacted by the local conditions favouring the access or production of hydrogen.

Should hydrogen be produced on-site, determining the location of a new depot or selecting a suitable depot to be transformed is driven by the following considerations regarding the inputs required for the production:

- Availability to connect to the high voltage (HV) electricity grid, which should be dimensioned not only to ensure availability of high power for the production of H_2 but also to take into account the long-term strategy for the depot: future extensions and depot upgrades, especially if the depot will allocate other technologies such as battery electric buses.
- If green-hydrogen is considered, favourable conditions for on-site renewable energy sources are needed along with physical space to accommodate the energy production infrastructure (photovoltaic cells, wind turbines…)
- Water supply for H_2 production.

CASE STUDY

EMT MADRID

In 2021, EMT Madrid awarded almost €11 million for the development of a refuelling plant, part of EMT Madrid Strategic Plan, which includes the creation of the first fuel cell hydrogen depot at Entrevías Operations Centre, that will be fully dedicated to hydrogen buses. The refuelling plant will rely on onsite generation via electrolysers, also powered by photovoltaic energy.

In addition, other factors to consider when locating a depot is the availability of enough space to accommodate the fuelling infrastructure (vessels, compressors,…), workshop, and parking bays, along with meeting operational (distance to service area) and safety requirements to mitigate risks (fire, flooding,…).

Indicative figures for hydrogen production. Source: AFHYPAC Fiche 3.2.1 - Production d'Hydrogène Par Electrolyse de l'Eau

→ 4 - 5kWh and 1 litre of water are needed per nm^3 (normal cubic meter) of hydrogen produced

→ 45 - 56kWh and 11 litres of water per kg of hydrogen produced

REFUELLING INFRASTRUCTURE AND STRATEGY

Two main refuelling strategies apply to FCHB, similarly to CNG buses. Vehicles are either refuelled at a refuelling station or while parked at the parking bay.

Refuelling with a pump at a refuelling station (analogous to traditional diesel pumps) is the most common strategy, where multiple buses use the same dispenser following a first-in first-out protocol. When waiting times to refuel buses get too long, buses can be redirected to the parking spots and refuelled the buses at different times during the night reducing the burden on the HRS system during peak times, of course not without adding complexity to the depot operations.

Alternatively, a dispenser can be installed at each parking spot to allow the vehicles to be refuelled typically during the night or no/reduced service hours with an automatic system opening and closing the flow of hydrogen to the different dispensers to ensure that the totality of vehicles is ready for the next day's operations by considerably simplified operations. The depot operations in this case are similar to the CNG bus refuelling at parking spots, but of course, this has a big impact on the design of the depot and HRS infrastructure and requires additional space at the parking bays. As a reference, this is the strategy deployed in Pau [3](France), for the 8 fuel cell hydrogen BRT bus operations.

Figure 4. Hydrogen refuelling at the parking bay. © Pau Béarn Pyrénées Mobilités

[3] ASSURED Clean Bus Report: https://cms.uitp.org/wp/wp-content/uploads/2022/05/ASSURED-Clean-Bus-report_final2.pdf

Furthermore, a combined strategy could be considered as the hydrogen bus fleet grows in a depot to benefit from the strengths of both strategies: fast instantaneous refuelling and reducing the waiting lines when a large number of buses return to the depot. Again as a reference, this is the strategy currently followed at the RATP CNG bus depot in Créteil (Paris, France).

Hydrogen fuel cell buses are fuelled via hydrogen dispensers, similar to natural gas dispensers. The number of refuelling points/dispensers needed will depend on the number of buses in the fleet and the duty cycles.

The design and installation of hydrogen dispensers must be done by certified infrastructure providers, working closely with the bus operator to understand constraints at the site and other operational priorities, and according to the overall depot design principles.

If the refuelling strategy involves using delivered hydrogen (rather than on-site production), the access and manoeuvrability of delivery trucks need to feed the design phase, along with accurate delivery timing to minimise interference with the ordinary processes of the depot while ensuring enough hydrogen supply at all times[4].

Refuelling time for big fleets can increase as the station compressor needs time to recover to the right pressure levels to be able to dispense the fuel.

CASE STUDY

ALSA/NATIONAL EXPRESS (MOBICO)

In Spain, Alsa worked together with Toyota/Caetano and Air Products to conduct various pilot tests in urban operations during 2021 and 2022. The initiative culminated with the first Hydrogen Bus (Toyota/Caetano) on a scheduled route in Madrid – Torrejón de Ardoz, starting in January 2022, and a second unit (CAF/Solaris) in March 2023.

These two buses refuel green H_2 produced on-site at the EXOLUM facilities next to the Alsa depot, through a pioneering solution from Fusion Fuel. This is a technology based on solar panels with integrated microelectrolyzers. In the UK, National Express in the West Midlands is already operating 20 hydrogen-fuelled double-decker buses.

[4] JIVE2 Project, Operator's Guide to Fuel cell bus deployment, 2019: https://www.fuelcellbuses.eu/sites/default/files/documents/JIVE_2_D2-1_Operators_Guide_to_FCB_Deployment_final.pdf

Hydrogen refuelling station components:

- Transfer station from hydrogen transport trailers to storage tanks (if applicable)
- Storing tanks usually at 200 bar: That could be the same trailers transporting the hydrogen to the depot or dedicated fixed tanks
- Compressors to increase H_2 pressure from 200 bar to 400 bar.
- Pre-cooling facilities for H_2 before refuelling. For safety reasons, the temperature of the tank on the vehicles must be kept below 80°C, which can be ensured either through slowing the refuelling process or by cooling down the H_2 after compressing.
- Pump to refuel the buses able to work at 350 bar. The vehicles must be equipped with a standardised communications and telemetry system that allows two-way communication between the refuelling station and the IT systems of the depot and operations.

Additionally, the facilities may need to include a cable connection for fuel cell freeze protection when parked and an on-site hydrogen production plant if applicable.

RUN-IN AND RUN-OUT PROCESSES

The depot's daily operations for fuel cell hydrogen buses following a fast refuelling strategy do not differ from the CNG buses in terms of run-in, refuelling, cleaning, parking, and run-out.

Nevertheless, it is worth summarising the main differences and similarities:

- ➔ Refuelling is done at 350 bar, 75% higher than CNG buses.
- ➔ The vehicle washing and cleaning regime is applied according to the operator's strategy. Due to the gaseous condition of the hydrogen supplied, there is no big impact on the tasks nor differences compared to CNG buses.
- ➔ When parked, some vehicles -especially the older generations- and depending on the climate conditions, a cable connection for protecting fuel cells from freezing might be needed. Current developments include self-protection freezing countermeasures to prevent the potential damage due to ice expansion.

Should the refuelling take place at the parking bay, the operations at the depot would be similar to the ones applying for CNG refuelling at the parking spot.

DESIGNING OPERATIONS

Designing operations in terms of hydrogen bus scheduling is homologous to diesel or natural gas ones, as hydrogen technology is not constraining range, speed, or vehicle capacity more than its traditional counterparts, and especially as opposed to battery electric buses if zero-emission technologies are to be compared.

When focusing on bus routing, there might be issues of permitting depending on the specific local regulations, which might, for example, discourage or prevent hydrogen vehicles from driving through tunnels.

Although numerous experiences[5] have been gathered for different types of operations and topography, it is recommended to thoroughly analyse and determine the most suitable zero-emission technology for your line or operations.

IT TOOLS AND MONITORING

The factsheet for battery electric buses of this series provides a wide overview of IT tools to consider when deploying battery electric buses which are applicable for fuel cell hydrogen buses too: UITP_template_Bus_Depot-Final.pdf.

CASE STUDY

TMB BARCELONA

Pioneering the deployment of fuel cell hydrogen technology in Spain, TMB put into service the first 8 hydrogen buses in Line X1 in April 2022, with an estimated consumption of 16kg H2/day per bus. It follows TMB's strategic plan to deploy 44 units until 2024.

The buses will be refuelled with green hydrogen, produced at hydrogen plant in the Zona Franca. The plant, the first of its kind in Spain, has been commissioned to the electricity provider Iberdrola. Green hydrogen will be produced via electrolysis powered by certified green electricity.

Additionally, during refuelling, the communication between the vehicle and the dispenser will optimise the process and ensure a safe refuelling process. Communication between a fuel cell hydrogen bus and a fuelling station is essential for efficient and safe refuelling. Infrared and wired communication are two methods used for real-time monitoring and control of hydrogen flow rate during refuelling. More specifically, using a fuelling nozzle allowing InfraRed communication ("TK17" type) between bus and

[5] Fuel cell hydrogen bus demo sites: https://www.fuelcellbuses.eu/demomap

station allows a higher flowrate, decreasing in turn the time to refill the bus, while ensuring a “one-step” operation for the operator (no additional cable needed).

Real-time data exchange of the bus's state-of-charge, hydrogen pressure and temperature allow the fuelling station to adjust the hydrogen flow rate. Particularly, this real time communication allows addressing the potential stress caused by the expansion of hydrogen as to temperature increase during refuelling to auto-control the hydrogen flow.

Furthermore, additional parameters are suggested to be monitored and recorded beyond the now typical parameters for electric buses. These include the fuel cell temperature, cooling system performance, hydrogen temperature and pressure, and instantaneous fuel cell power output.

Figure 5. RVK fuel cell hydrogen at parking bay. © UITP

HYDROGEN SAFETY HANDLING

Fuel cell hydrogen depots are similar to natural gas depots in terms of operation and safety requirements. Operators used to CNG (compressed natural gas) technology will feel familiar with the main procedures and principles to follow when operating hydrogen depots.

When designing facilities for hydrogen buses, it is essential to keep any source of ignition out of the workshops. The fire triangle summarises the safety principles when using flammable fuels and must be applied at any hydrogen depot.

►*Fire triangle. Source: Wikipedia*

Though being classified as a "highly flammable gas (H220 Classification)", when following the safety principles and guidelines, hydrogen use is safe and its differences with fossil fuels like natural gas or gasoline provide additional safety benefits.

Indeed, hydrogen is lighter than air and diffuses rapidly, rising at a speed of around 20 m/s, thus it entails a low risk of explosion in the open air. It has also a wide flammability range (4 to 74%, as opposed to 1.4 to 7.6% for gasoline and 5.3 to 15% for Natural Gas), although in low concentrations (less than 10%) the ignition energy for the combustion of energy is lower and there is less radiant heat near the flame, thus reducing the risk of second fires, but be aware that flames are invisible in the daylight, which needs specific detecting technologies such as thermal cameras and OGI cameras (Optical Gas Imaging) for indoor or ultrasound leak detection systems to ensure early detection on parking lots and workshops, and safety procedures. Ideally, this technological equipment should be linked through an AI layer to optimise detection.

We can consider three types of hydrogen leaks to be aware of in the workshop[6]:

a) Hydrogen cloud: when trapped and in a concentration of 4-75% in the air, hydrogen can be explosive. If ignited, it can cause a detonation or deflagration; either can cause serious injury and damages.
b) Hydrogen jet: as hydrogen is stored at high pressure (350 bar for heavy-duty vehicles), in case of damage to the hydrogen tank, a release of the hydrogen can cause a jet of gas that could seriously injure someone on its path.
c) Hydrogen jet flame: if a hydrogen flame is formed, and ignited, the flame could reach, even if extremely rare, 10 meters. Due to the low flame heat, it is rare that it can cause secondary fire, but not impossible.

[6] Fuel Cell Electric buses: Adapting Maintenance Facilities for Hydrogen, Ballard, 2020.

Main risks to be assessed

a) Hydrogen leaks: As hydrogen is not a toxic gas, the main risk in hydrogen leaks resides in meeting flammability conditions to cause an explosion. To prevent the risk of explosion, hydrogen accumulation should be avoided by accelerating the diffusion of hydrogen in the open air.
As a general consideration, pipeline systems are considered a potential source of hydrogen emission at points where the pipeline is interrupted by fittings such as flanges, valves, connection points, and others.
The safety distances to other constructions or activities will depend on the quantity stored. These safety distances can be waived with appropriate safety measures following an accurate safety risk assessment and mitigation plan, such as the one proposed for each of the scenarios hereafter:

1. Hydrogen leak from the tanker (when applicable)
    - ➔ Planning and constructing to ensure the minimum safety distances are respected between the hydrogen transfer facilities and other constructions, vehicles, etc.
    - ➔ Building fireproof walls or fire protection curtains.
    - ➔ Installing fire detectors
    - ➔ Equipping the facilities with hydrogen detectors able to discriminate two situations:
        - o low risk → Alarm
        - o high risk → Automatic shut-off

2. Hydrogen leak during compression
    - ➔ Planning and constructing to ensure the minimum safety distances are respected between the compressors and other constructions, vehicles, etc.
    - ➔ Fireproof walls
    - ➔ Fire detectors
    - ➔ Equipping the facilities with hydrogen detectors able to discriminate two situations:
        - o low risk → Alarm
        - o high risk → Automatic shut-off
    - ➔ Allow vertical ventilation to allow hydrogen to diffuse in open air

3. Hydrogen leak from the tank.
    - ➔ Fireproof walls
    - ➔ Fire detectors
    - ➔ Hydrogen detectors, with 2 limits:
        - o low → Alarm
        - o high → Automatic shut-off

4. Hydrogen leak during bus refuelling
    - ➔ Breakaway duct, to stop automatically the hydrogen dispenser in case a flexible hose would break

- ➔ Pressure and temperature monitoring
- ➔ Fire detectors
- ➔ Normally-closed valves on both sides of the flexible ducts

b) Refrigerant leaks (if applicable)

To decrease hydrogen density after compression, it might be necessary to refrigerate it prior to refuelling the buses. In this case, preventive measures valid for the handling of refrigerant gases (HFC) must be followed.

Risk preventing considerations

To prevent the hydrogen leak risk scenarios presented previously, proper vehicle maintenance is crucial. The causes of hydrogen leaks can be mitigated through the following measures:

- Regular maintenance is crucial in preventing wear and tear damage. Any parts that are at risk of failure must be replaced before the next scheduled check to avoid further complications.
- Optimal tools and specialised technicians must be utilised to ensure the highest maintenance standards.
- Robust processes, continuous training, and risk assessment procedures should be established to prevent maintenance mishaps. Secondary sign-off and inspections are also necessary to reduce such incidents.
- In case of an accident, accidental damage may occur, and a specialised technician must thoroughly inspect the hydrogen system before putting the vehicle back in service. Even a small leak can trigger an early warning, while collision sensors will activate a "safe shutdown" to lock the high-pressure hydrogen in the tank and isolate the high-voltage elements from the system.

Basic principles to work safely in a hydrogen depot

- Prevent the accumulation of ignitable concentrations of hydrogen.
- Remove all sources of ignition from the facilities.
- Set up a safety regime in the workshop.
- Respect the fire triangle, as a basic principle in the workshop.

Additional aspects to consider are the commissioning of the necessary facilities for the production, storage, and distribution of hydrogen, as well as the design and space needs of the different depot elements and areas (maintenance, refuelling and defuelling, parking) to ensure safe operation.

General considerations

- As for storage, safety regulation requirements depend on the total of hazardous materials stored in the depot. For bigger fleets, please be

aware of the "5-tonne-limit" of the "Seveso Regulation"[7] for low-tier establishments, including:
    - any hydrogen storage (including buses, tankers, tanks…)
    - any other explosive material: gasoline, natural gas…

  Hence, it might be easier to limit the amount of hydrogen stored on site. In the case of a depot managing several technologies, all types of fuels must be taken into account in the total risk assessment. As a clarification, batteries not counting as fuels.
- When possible, always try to avoid or limit the domino effect, by maximising the distance between the hydrogen transferring, compressing or storing facilities and any other infrastructure. Please note that this will also ease the permitting process, by limiting its scope.
- Before commissioning the hydrogen refuelling station, a visit shall be organised with the relevant fire prevention service. This visit shall be repeated regularly (every 5 years, for example).
- In general, the permit to commission the hydrogen facilities is awarded for a limited period of time, hence works must have started and advanced significantly within a limited period after the permit is granted.

To provide guidance, the competent public administration in Brussels region (Belgium) has established safety distances which are shared by the public transport operator STIB-MIVB for this publication.

[7] https://eur-lex.europa.eu/eli/dir/2012/18/oj

*Table 1. Safety distances based on the quantity of hydrogen gas stored applicable to the **specific STIB-MIVB project** in the Brussels region. Source: STIB-MIVB*

ACTIVITY/OBJECT	***SAFETY DISTANCE***		
	<99 m³	***99–425 m³***	***> 425 m³***
Building or structure, whose wall adjacent to the system being constructed is made of non-flammable or low-flammable materials, equipped with a sprinkler system, or having a fire resistance of more than 2 hours. (b).	0 m (a)	1,5 m (a)	1,5 m (a)
Building or structure whose wall adjacent to the system being constructed is made of non-flammable or low-flammable materials, not equipped with a sprinkler system, and has a fire resistance of less than 2 hours. (b).	0 m (c)	3 m	8 m
Building or structure whose wall adjacent to the system being constructed is made of materials other than non-flammable or low-flammable materials.	3 m	8 m	15 m
Openings in the walls, not located above an element of a given installation.	3 m	3 m	3 m
Openings in the walls located above an element of a given installation.	8 m	8 m	8 m
Above-ground storage of flammable liquids: 0 – 4000 litres Above-ground storage of flammable liquids: over 4000 litres	3 m 8 m	8 m 15 m	8 m 15 m
Underground storage of flammable liquids: 0 – 4000 litres Underground storage of flammable liquids: over 4000 litres Purge pipes or fill openings for underground tanks	3 m 6 m 8 m	3 m 6 m 8 m	3 m 6 m 8 m
Storage of flammable gases: 0 – 250 m³ Storage of flammable gases: over 250 m³	3 m 8 m	8 m 15 m	8 m 15 m
Storage of rapidly combustible solid products (construction wood, paper...) Storage of slowly combustible solid products (hardwood, coal...)	15 m 8 m	15 m 8 m	15 m 8 m
Sources of ignition (at ground level)	8 m	8 m	8 m
Distribution installation(s) for vehicles	5 m	5 m	5 m

Air compressor intake ports, ventilation system intakes...	15 m	15 m	15 m
Above-ground electrical cables (including those for trams or trolleybuses)	15 m	15 m	15 m
Places where many people gather	8 m	15 m	15 m
Public sidewalks and parking strips	5 m	5 m	5 m
Distance from neighbouring building plots	1,5 m	1,5 m	1,5 m

(a) The walls or parts thereof, over a horizontally measured distance of less than 3 meters from any element of the hydrogen system, must have a fire resistance of at least 30 minutes.
(b) The doors and windows of a building or structure are not subject to the provisions applicable to that building or structure, but have their own minimum safety distance.
(c) The walls or parts thereof, over a horizontally measured distance of less than 3 meters from any element of the hydrogen system, must have a fire resistance of at least 1 hour.
(d) The minimum safety distance is always greater than half the height of the adjacent wall.
(e) When possible, always try to avoid or limit the domino effect, by the sectorisation of the fleet to limit the loss of assets in case of fire. This sectorisation could be done maximising the distance between vehicles, fire protection curtains or fireproof walls.
(f) When possible, set up a quarantine area. Space dedicated to positioning vehicles at risk of fire. Intended for ZEV vehicles with breakdowns that lead to fire or damaged vehicles.
(g) When possible, all vehicle to be parked for forward departure.

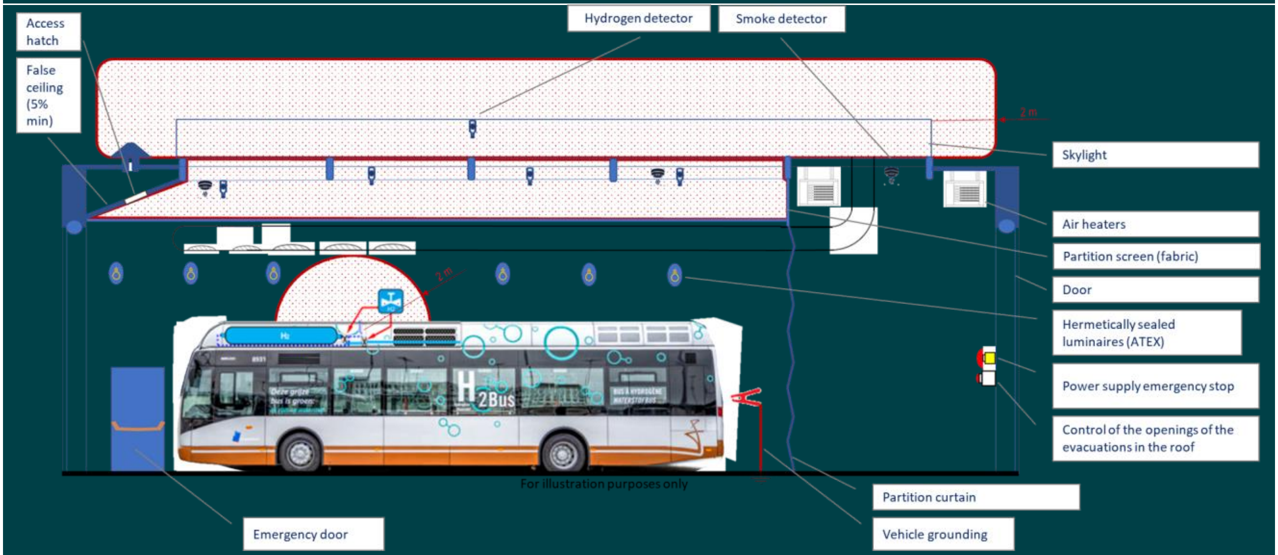

Figure 6. Workshop elements for hydrogen buses. Source: STIB.

ADAPTING THE WORKSHOP FOR HYDROGEN BUS MAINTENANCE

As for any other technology, fuel cell hydrogen bus workshops must be designed to comply with all the requirements of workshop facilities and equipment while ensuring safe working conditions.

With the same importance, robust procedures for maintenance tasks and protocols in case of emergency need to be developed and followed along with simulations regularly run.

Safety recommendations for fuel cell bus depots

- Ensure compliance with local regulations and health and safety laws
- Make sure you understand the properties of hydrogen and its behaviour inside and outside a building
- Ensure the appropriate level of training for your technicians and other staff operating this technology
- Create robust and clear work procedures to facilitate maintenance and operation
- Develop robust risk assessment and identify any potential situation that might lead to either an escape, a leak or maintenance mishap
- Create a management and supervision scheme that allows you to proof that correct and safe procedures are followed and carried out
- Adapt the workshop area as necessary to ensure a safe working area, applying the fire triangle principles.

(Source: Fuel Cell Electric buses. Adapting Maintenance Facilities for Hydrogen, Ballard, 2020)

A hydrogen workshop requires the design and consideration of the following elements:

- Indoor facilities roofline: if any leak, hydrogen rises quickly and cumulates in the ceiling. Having a sloped roof facilitates the cumulation in specific spots, making the ventilation and elimination of cumulations much easier.
- Air renovation to ensure proper ventilation and avoid cumulation of hydrogen in case of a leak. Automatic active ventilation can be also implemented.
- Equipment for emptying the hydrogen tanks on buses:
  a. buses are not allowed to enter a workshop with more than 80% of hydrogen content, to allow gas expansion due to potential temperature increase.
  b. certain maintenance tasks might require complete defuelling of the buses to safely work on the bus.

  In both cases, the hydrogen can be extracted with a defuelling system and transferred to a tank for storage and posterior utilisation. Alternatively, the hydrogen can be released into the atmosphere, although this option requires additional safety measures, and it is recommended to do so in the open air.
- Gas detection systems: hydrogen sensors programmed at two detection levels, usually at 20% and 40% of the lower explosive limit (LEL). In the case of a leak, the

first level will activate a warning flash-beacons; the second level will activate the sound alarm prompting the evacuation of the installations. In both cases, the protocol to follow must be clearly defined and staff should train regularly in simulation exercises.

In addition to the specific elements of a hydrogen workshop, common requirements need to be put in place, as in the case of battery buses:

- Electrical equipment tools and safety procedures to operate them
- Grounding devices, ATEX-compliant specific tools and Individual Protection Equipment
- Hot work operations like welding, brazing, or any activity that produces sparks, flames, or heat must be performed outside the hydrogen workshop.
- Automatic detection and extinction system: smoke detectors and sprinklers, fire alarm, and as indicated earlier, hydrogen and heat detection systems.
- Access equipment (facility to access the top of the vehicles, safety harness) and working at height training may be required in scenarios where repair and maintenance on a vehicle roof need to take place (hydrogen tanks, HVAC…).

Any task related to the electrical maintenance and fuel cells related must be performed by specialised, trained, certified staff. Likewise, workshops and in particular control areas must be duly defined and identified to perform the corresponding function. This might be not necessary in the case of depots operating only one technology, but certainly, in the case of multi technologies depot, the different workshop areas should be accordingly designated and recognisable. Finally, the refuelling infrastructure requires trained and certified-for-dealing with hydrogen specialists for maintenance and reparations.

STAFF TRAINING

To ensure the safe and efficient operation of hydrogen fuel cell buses, it is essential to provide specialised training for drivers and maintenance staff. This training should include both theoretical and practical components, and all depot employees should be familiarised with the properties and safe handling of hydrogen fuel and vehicles.

To achieve this, it is recommended to establish clear working procedures and promote a safety culture that empowers all employees to take responsibility for safety.

Figure 7. Refuelling H_2 bus. © UITP

Similarly to battery electric buses, maintenance staff should be trained and certified in fuel cell technology, systems, engine design, safety, and maintenance, among others. Likewise, drivers will require driving training, an overview on the technical characteristics of the vehicle, etc; (see table below). Usually, these trainings are provided by bus manufacturers.

Training programmes should be tailored to the local context, considering the regional safety regulations and requirements, as well as variations in design and functionality of vehicles and refuelling infrastructure between sites. Training manuals and written instructions should be always provided accompanying the trainings, including safety data sheets and information on emergency procedures.

Refreshing trainings should be held regularly every year. Part of the regular trainings should be the continuous engagement of the staff (not only specialised technicians and drivers) with the new technology, creating a positive environment and reassuring employees on the safety and correct handling of the technology. In this regard, addressing safety concerns (working with high voltage components and pressurised hydrogen) and provide factual, clear information is key to reassure staff in their daily work with the new technology.

	Type of training and main contents
Bus drivers	• Vehicle characteristics and differences with conventional buses, incl. reference to potential hazards related to the operation of high voltage and pressurised hydrogen • Procedure to follow in case of emergency
Technicians	• Potential hazards and handling of high voltage elements, fuel cell technology and systems, pressurised hydrogen • Procedure to follow in case of emergency
First responders (fire services, others)	• Information on the deployment plans, design and layout of the depot installations (number of hydrogen tanks, buses, fuel dispensers, etc.), design of the refuelling systems, workshops, safety equipment, fire protection systems and fire extinguishing systems on site, etc.

► *Source: Adaptation from JIVE2 Project, Operators' Guide for FCHB deployment, 2019*

FOCUS ON PERMITTING

Figure 8. H_2 BRT bus in Pau, France. © UITP

It is worth stating that these guidelines are general considerations, unable to gather all context-specific rules that might exist in every location. Please refer to your local relevant authorities in the very first stage of your project.

1. Issues to be addressed are numerous, so are the involved administrations. Typically:

- Environment
- Climate change
- Air quality
- Waste management
- Land use
- Agriculture
- Energy
- Noise
- Wildlife protection
- Soil, air, and water protection
- Risk management
- Local fire brigades
- …

Thus, the first priority is to identify the Single Point Of Contact ("SPOC") for the permitting undertaking.

2. Evaluate the (longest) response time from all relevant administrations, including complementary requests, rights of appeal…

3. Typical topics to be evaluated when permitting procedures are undertaken:

- Hydrogen distribution stations
- High-pressure gas storage
- Cold production using fluorinated refrigerant gases, if hydrogen has to be refrigerated between compression and bus feed
- Fix or mobile tanks for flammable gases
- Other gas treatments (depending on installed power)

PROCEDURES AND DOCUMENTATION

The documentation required for adapting a bus depot for fuel cell hydrogen buses will vary based on project requirements, relevant regulations and standards, and factors like budget and timeline. As an example and guidance, below some of the most common ones are mentioned:

a) Risk assessment: A risk assessment should be conducted to identify and evaluate any potential hazards associated with the operations, maintenance and parking of fuel cell hydrogen buses and to develop appropriate risk management strategies.

b) Emergency response procedure: An emergency response procedure should be established that outlines the actions to be taken in the event of an emergency, such as a hydrogen leak or fire. This document needs to count with the participation of the local emergency services.

c) Safety equipment testing procedures: Procedures for testing and maintaining safety equipment, such as hydrogen sensors and fire suppression systems, should be established to ensure they are functioning properly.

d) Maintenance procedures: Procedures for the maintenance and repair of fuel cell buses and hydrogen storage and refuelling systems along with other equipment should be established to ensure safe and reliable operation.

e) Incident procedure: Procedures for reporting and investigating incidents should be established to identify the root cause and prevent similar incidents from occurring in the future.

g) Design and construction documentation: This may include the architectural and engineering project, and specifications for the construction of any new infrastructure or modifications to existing infrastructure at the bus depot.

i) Quality control and assurance documentation: Documentation related to quality control and assurance may be needed to ensure that fuel cell hydrogen infrastructure is installed and maintained to the highest standards.

f) Permitting and regulatory documentation: Depending on the location of the bus depot, various permits and approvals may be required for the installation of fuel cell hydrogen infrastructure as mentioned earlier in this document. In addition to these specific documentation requirements and recommendations, there may be other regulations and standards that must be followed depending on the specific location.

Here below relevant and transversal standards and regulations are proposed:

For hydrogen:

- ISO 19880
- ISO 17268
- PGS 35:2018 Design, construction, operation and maintenance of hydrogen refuelling stations[8]
- ISO-17840: Emergency Response Guide, Rescue Sheets…
- SAE J2719 (identical to ISO 14687): hydrogen quality
- SAE J2600: refuelling nozzle
- SAE J2601-2: refuelling protocol

8 https://publicatiereeksgevaarlijkestoffen.nl/documents/81474/1664358051-pgs-2035-20voor-20website-20ondertekend.pdf

For refuelling station:

- ISO19880-1: Hydrogen stations
- 2006/42/CE Machinery Directive
- 2014/68/UE: pressure equipment
- 1999/92/CE, 2014/34/UE: ATEX Directive
- 89/336/CE, 93/31/CE: Electromagnetic Compatibility

For CFC (chlorofluorocarbon) gases:

- Regulation (EC) No 1516/2007 of the European Parliament and of the Council of 19 December 2007 on Air Transport of Dangerous Goods and Amending the Regulation on the Common Rules for the Operation of Air Services in the Community[9]
- Regulation (EC) No 1005/2009 of the European Parliament and of the Council of 16 September 2009 on Substances that Deplete the Ozone Layer (recast)[10]

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[9] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007R1516&from=EN

[10] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R1005&from=EN

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