White Paper Requirements Specification

Subcooled Liquid Hydrogen Fuelling Interface for Ground Vehicles

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List of involved parties

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1. Content

2. List of Abbreviations

CEP	Clean Energy Partnership Germany
CNG	Compressed Natural Gas
ECU	Electronic Control Unit
FS	Fuelling Station (as Prefix/Suffix: Component belongs to fuelling station)
H2	Hydrogen gas
MAWP	Maximum Allowable Working Pressure
NIST	National Institute of Standards and Technology
NWP	Nominal Working Pressure
OEM	Original Equipment Manufacturers of vehicles
PRV	Pressure Relief Valve (Mechanical valve in fuelling station overpressure protection)
SAE	Society of Automotive Engineers
sLH2	Subcooled Liquid Hydrogen
SoC	State of Charge (in %). Ratio of actual to target hydrogen density
Tbc	To be confirmed
Tbd	To be determined
TCU	Tank Control Unit (of vehicle)

3. Referenced Documents

3.1 CEP Documents

* WP sLH2 “Process” - White Paper Subcooled Liquid Hydrogen Fuelling Process (July 21, Release 1.5)

3.2 ISO Documents

* ISO 19880-1: 2020 – Gaseous hydrogen – Fuelling Stations – Part 1: General requirements

* ISO 19880-8: 2019 – Gaseous hydrogen – Fuelling Stations – Part 8: Fuel Quality Control

* ISO 14687: 2019 – Hydrogen Fuel Quality: Product Specification

* ISO 17268: 2020 – Gaseous hydrogen land vehicle Fuelling Connection Devices

* ISO 13732-3:2005 – Ergonomics of the thermal environment – Methods for the assessment of human responses to contact with surfaces — Part 3: Cold surfaces

3.3 CEN Documents

* EN 17124: 2018 – Hydrogen fuel – Product specification and quality assurance – PEM fuel cell applications for vehicles

* EN 17127: 2018 – Outdoor hydrogen fuelling points dispensing gaseous hydrogen and incorporating filling protocols

3.4 UNECE Documents

* GTR 13: Global technical regulation on hydrogen and fuel cell vehicles

* R 134: Uniform provision concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV)

3.5 SAE Documents

* SAE J2579 Standard for Fuel Systems in Fuel Cell and Other Hydrogen Fueled Vehicles

* SAE J2578 Recommended Practice for General Fuel Cell Vehicle Safety

* SAE J2574 Fuel Cell Vehicle Terminology

* SAE J2600 Compressed Hydrogen Surface Vehicle Fuelling Connection Devices

* SAE J2601 Fuelling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles

* SAE J2719 Hydrogen Quality Standard for Fuel Cell Vehicles

* SAE J2799 Hydrogen Surface Vehicle to Station Communications Hardware and Software

* SAE J2760, “Technical Information Report For Pressure Terminology Used In Fuel Cells and Other Hydrogen Vehicle Applications”

3.6 IEC Documents

* IEC 61508 Application of Safety Instrumented Systems for the Process Industries

* IEC 61511 Functional safety – Safety instrumented systems for the process industry sector

* IEC 62061 Safety of machinery - Functional safety of safety related electrical, electronic and programmable electronic control systems.

3.7 EU Documents

* (EC) 79/2009 - type-approval of hydrogen-powered motor vehicles

* (EC) 406/2010 - implementing Regulation (EC) No 79/2009 of the European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles

* (EU) 2021/535 – Commission implementing regulation - uniform procedures and technical specifications for the type-approval of vehicles, and of systems, components and separate technical units intended for such vehicles, as regards their general construction characteristics and safety

* 2014/68/EU – Directive on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment

* 2014/34/EU – Directive on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres

3.8 Other Documents

* TRBS 3151 - Technische Regeln für Betriebssicherheit/ Gefahrstoffe – Vermeidung von Brand-, Explosions- und Druckgefährdungen an Tankstellen und Gasfüllanlagen zur Befüllung von Landfahrzeugen

4. Terminology

* Break-away coupling: Device which divides the hose from the fuelling station and stops the flow in case of high forces occurring at the hose and nozzle.

* Coupling: The combination of nozzle and receptacle

* Fuel level sensor: Device that measures the level of the liquid hydrogen in the vehicle storage tank.

* Fuelling interface: The combination of break-away coupling, hose, nozzle and receptacle

* H2: Hydrogen

* Hose: Vacuum insulated metallic hose.

* LH2: Liquefied hydrogen

* Ncm3: Amount of gas at a pressure of 101 325 Pa and temperature to 0 °C.

* Nozzle: Coupling part on the fuelling station side.

* Pressure: Gauge pressure against atmospheric pressure, unless otherwise stated.

* Pressure relief device: A device, which prevents a pre-determined pressure from being exceeded by releasing the pressure.

* Receptacle: Coupling part on the vehicle side.

* sLH2: Subcooled liquefied hydrogen

* sLH2 Fuel System: Complete sLH2 tank system in the vehicle consisting of one or more sLH2 tank(s), receptacle, inlet and outlet valves, interconnecting lines, control system, boil-off gas management and safety devices. Designed according to implementing act 2021/535. (Note: implementing act 2021/535 may be superseded in the future by UN ECE regulation.)

5. Introduction

Increasing environmental pollution, the limited amount of fossil fuels and the reduction in the emission of climate affecting gases lead to a great effort in finding an alternative to traditional combustion engines in trucks fueled with diesel. Therefore, manufacturers all over the world develop alternative engine concepts, which do not use fossil fuels.

One of the most promising concepts based on hydrogen is fuel cells combined with an electric engine. Fuel cells are miniature electrochemical power plants that release energy from the chemical reaction between hydrogen and oxygen. Offering a high efficiency factor and producing mainly pure water vapor.

There are various technical options for storing hydrogen on board of a vehicle and feeding it into the propulsion system. This project is based on the option of liquid hydrogen storage at temperatures as low as minus 253°C, calling for technical challenges.

Having the vehicle storage system, connected to the propulsion unit, on one hand and the fuelling unit on the other, a component joining both units for hydrogen transfer is required. Therefore, the goal of this project is the development of a liquid hydrogen fuelling interface applied in trucks. This coupling component shall be easily reproducible in a series production process.

The initiators of this project are truck manufacturers, which carry out research and development (R&D) around liquid hydrogen applications as energy source for automotive propulsion units. Fuelling possibilities of trucks with liquid hydrogen are analyzed within this focus as well. The partners aim to develop a standardized fuel system with regard of an essentially uniform infrastructure for liquid hydrogen fuelling. The components of this fuel system shall be easily reproducible in a series production process.

Furthermore, the system shall be suitable for international standardization since it is intended to propose a successful result of standardization for recommended industrial practice.

LH2 fuelling from station into the truck is well known from former projects, but has some disadvantages as e.g., gas return from tank to the fuelling station and fuelling stops only based on the signal from the truck. Therefore, in this project, sLH2 (subcooled liquified hydrogen) fuelling is proposed to avoid gas return from vehicle tank and definite fuelling stop without data communication by stopping the fuelling process when a certain fuelling pressure is reached. sLH2 fuelling is a process in which the liquefied hydrogen is subcooled and can be filled in this state to a pressure exceeding the critical pressure of hydrogen at approx. 1.3 MPa. Once this threshold is exceeded the hydrogen is in a single-phase state with no liquid-to-gas interface.

6. Project Scope and Organization

6.1 Scope

This document will serve as interim guidance. It applies to the design, safety, operation, and verification of subcooled liquefied hydrogen fuelling stations (sLH2 FS) that fuel vehicles with sLH2 storage systems with a set pressure of PRV1 (PPRV1) of 2.2 MPa (see WP sLH2 “Process”). Target Pressure (PTARGET) of the fuelling is 1.6 MPa.

This document focuses on FS for heavy duty ground vehicles with nominal capacities of the fuel storage system 40 kg to 120 kg sLH2. However, these requirements might also be applied to fuelling of other vehicles – such as buses or distribution trucks – with lower fuel capacities. The fuel storage system may consist of several sLH2 tanks.

This document is intended to be submitted to the Clean Energy Partnership (CEP) Working Group. It assumes the fuelling process is specified in White Paper “Subcooled Liquid Hydrogen Fuelling Process for Ground Vehicles” and that the fuel quality is being addressed through ISO 14687:2019.

The document is intended to provide minimal elements of expected commonality, not to restrict implementation of additional features in individual fuelling stations.

An experimental program is under way to evaluate the response (internal temperature & pressure) of currently representative sLH2 tanks and sLH2 storage systems to variations in initial conditions, nozzle fuel temperature and fuelling rate. It is expected that this information will be used to define an sLH2 fuelling protocol that will specify common industry-wide characteristics and limits that all fuelling processes implemented at sLH2 fuelling stations (all variations of hardware, controls, and control algorithms) shall satisfy.

It would then be the responsibility of the station operators to periodically verify that fuelling processes performed at the fuelling stations provide fuelling within the boundaries of the fuelling protocol and according to applicable standards. It would be the responsibility of the vehicle manufacturers to ensure that vehicle storage systems are designed and verified to be capable of being fueled at fuelling stations that provide fuelling in accordance with the sLH2 fuelling protocol. Verification means a documentation proving the compliance of the fuelling of the sLH2 tank systems with multiple storage sLH2 tanks that may differ in size and construction, and that may not fuel simultaneously, and that may not have the same initial temperature or pressure. Therefore, both vehicle manufacturers and fuelling station providers have an interest in developing a clear, well-validated sLH2 fuelling protocol specification and ensure its robustness.

6.2 Project implementation and participating parties

The participating parties aim to establish sLH2 fuelling according to this specification. In addition, the participating parties expect, that the described sLH2 fuelling will be a future main path in the fuelling technology of LH2 for heavy duty trucks. Therefore, this working group has been established, coordinated by CEP Germany with the goal to develop an international standard for sLH2 fuelling. The standardization process for the fuelling process has been started by CEP on 12th of May 2021.

6.3 Time Schedule

The White Paper process will be started on 12th of May 2021 and should be finished by the End of 2021 (refer to Figure 2-1).

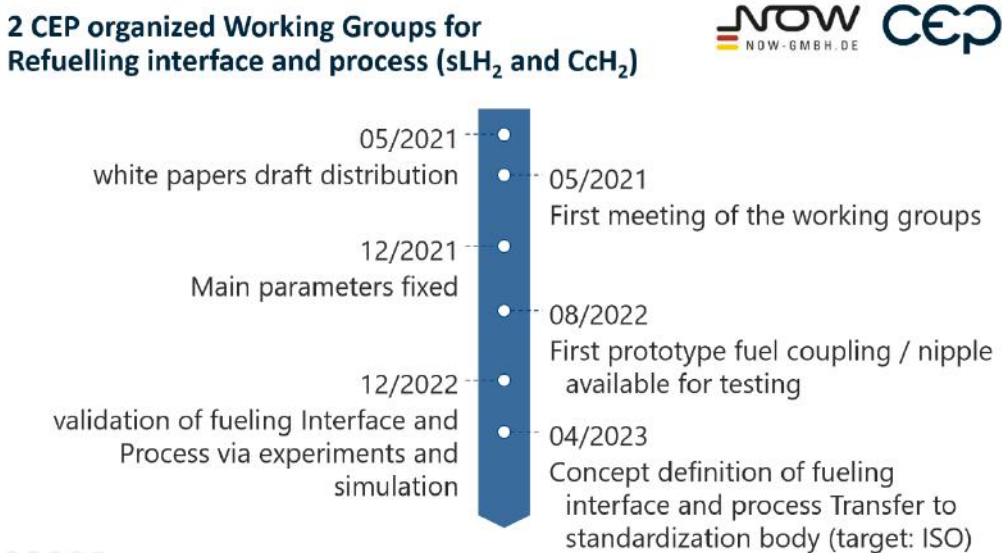


Figure 2-1: Time Schedule for the White Paper process and further Standardization

7. General information and definitions

7.1 Hardware Components

This Whitepaper specifies requirements on the fuelling interface for usage of fuelling trucks with hydrogen according to the process as specified in WP sLH2 “Process”.

The fuelling interface comprises the components

- Receptacle
- Nozzle
- Hose
- Break-away coupling

The connection between hose and dispenser is not part of this specification. Its design shall be agreed between FS and coupling manufacturer.

As shown in Figure 3-1, the break-away coupling, hose, and nozzle are part of the fuelling station. The receptacle is part of the truck.

The receptacle is integrated into the vehicle tank system, see Figure 3-2.

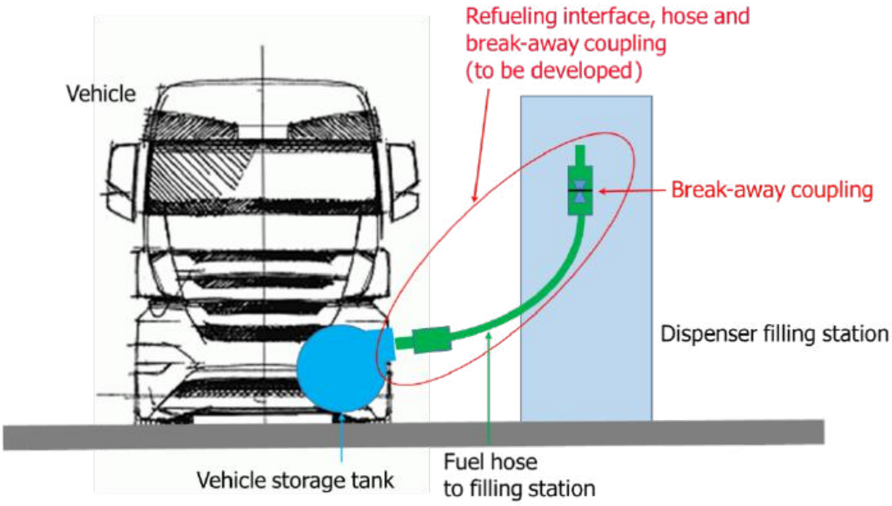


Figure 3-1: Overview of Fuelling Interface components

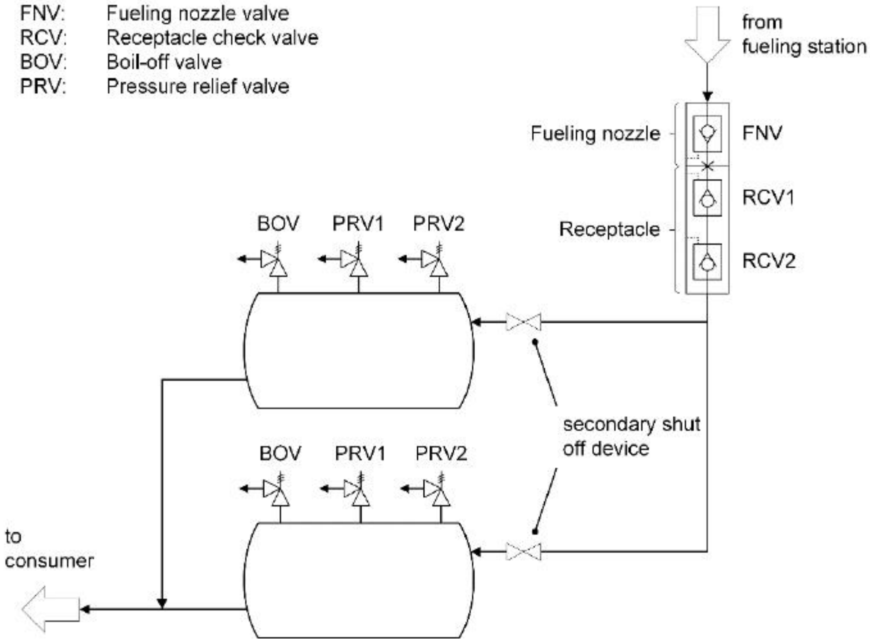


Figure 3-2: Schematic drawing of sLH2 tank system

7.2 Fuelling Process

Figure 3-3 shows an exemplary diagram of an sLH2 fuelling process. The operating target range (pressure, temperature) of the sLH2 fuelling interface can be seen. Details on the fuelling process are given in WP sLH2 “Process”.

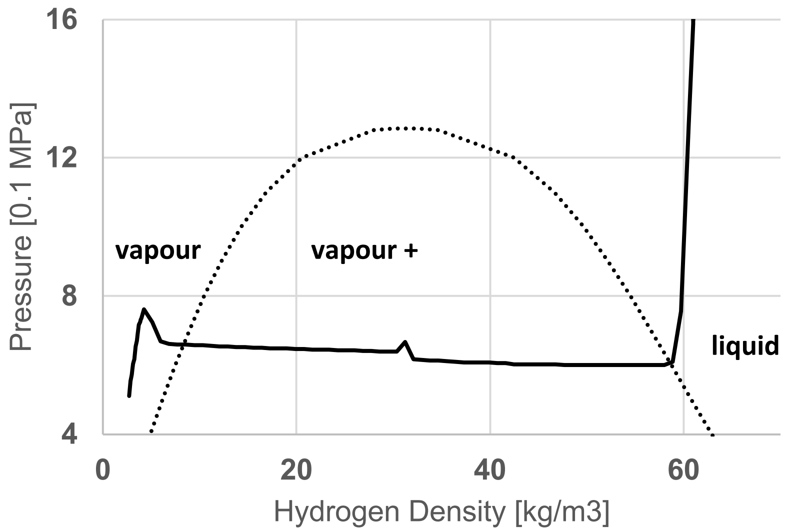


Figure 3-3: sLH2 Fuelling process (solid: sLH2 fuelling characteristics, dotted: H2 vapor pressure curve)

The process of fuelling can be divided into the following steps:

- Pre fuelling (driving into station, connecting the interface etc.)
- Fuelling (filling process etc.)
- Post fuelling (disconnecting interface, leaving station)

On details concerning the fuelling process, see WP sLH2 “Process”, section 4.4.

Two different configurations of fuelling interfaces shall be supported by the interface hardware (see Figures 3-4 and 3-5).

7.2.1 One-Hose Operation (Standard sLH2 fuelling mode):

- The vehicle is connected to the fuelling station by one line only (LH2).
- Fuelling LH2 and potential GH2 vent-back to the station (to decrease vehicle tank pressure prior to fuelling in special cases) is done via the same line.
- The line must be capable of supporting the flow in both directions.

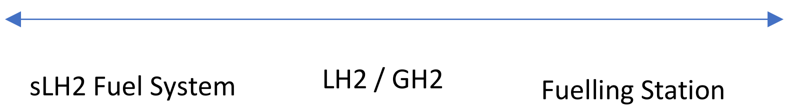


Figure 3-4: Schematic of One-Hose Operation

7.2.2 Two-Hose Operation (LH2 fuelling – Compatibility mode)

Fuelling stations for trucks are intended to work on one-hose operation only.

Two-hose operation is comparable to the LH2 fuelling, that has been developed for passenger cars some time back. It may be used in the future for not yet specified non-automotive applications.

- The vehicle is connected to the fuelling station by two lines (LH2 and GH2).
- Fuelling LH2 is done via the LH2 line.
- Potential GH2 vent-back to the station is done via the GH2 line.

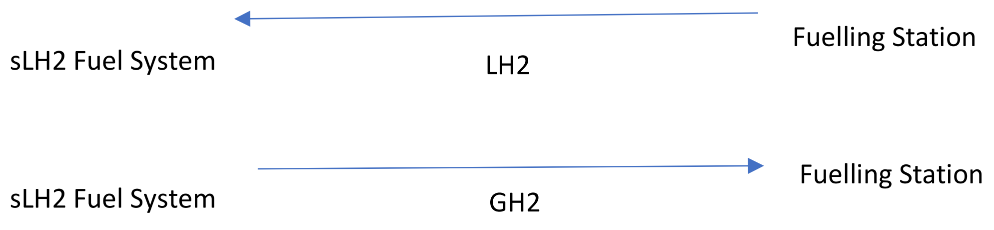
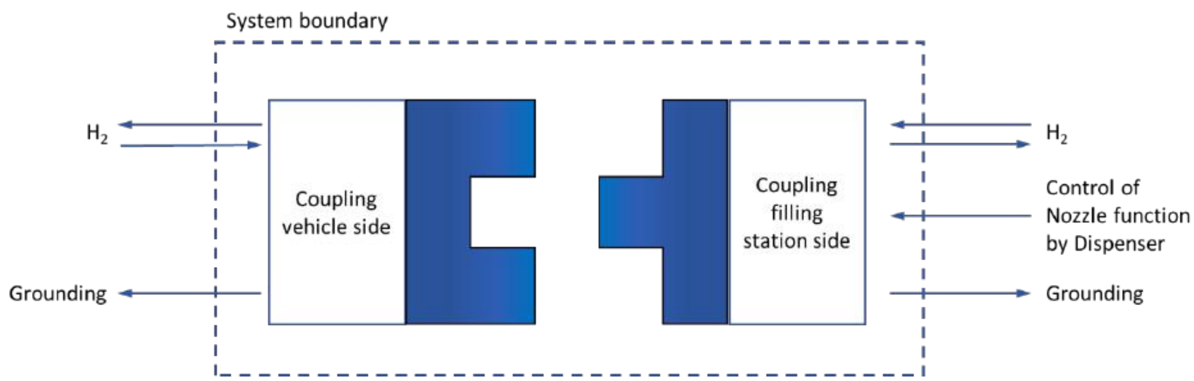


Figure 3-5: Schematic of Two-Hose Operation

7.3 System boundaries and Interfaces

Figure 3-6 shows the system boundaries of the sLH2 fuelling interface and the interfaces to the surrounding systems.



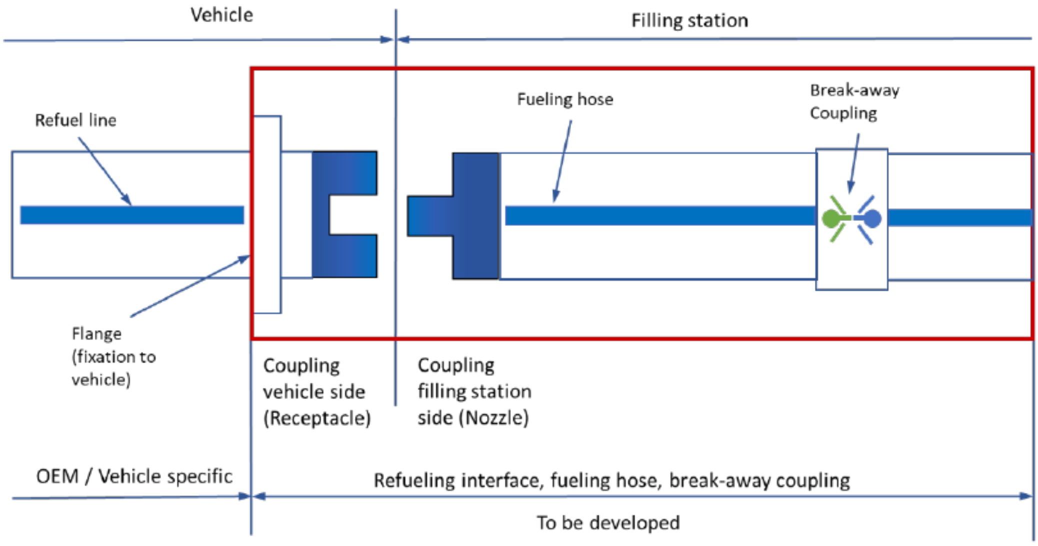


Figure 3-6: System boundaries, input, and output

8. Fuelling Interface Requirements

8.1 Functional Requirements

8.1.1 General

No	Requirement	Remark
1	The components of the fuelling interface, receptacle, nozzle, hose, and break-away coupling shall be designed for the fuelling of vehicles with sLH2 according to the fuelling process specified in WP sLH2 "Process".	
2	The fuelling interface shall be compatible with the requirements, functions and fuelling process in WP sLH2 "Process".	
3	The main function of the fuelling interface is to enable flow of LH2 from the fuelling station to the sLH2 fuel system and, in special cases, allow flow of cryogenic GH2 from the sLH2 fuel system back to the fuelling station.	
4	The fuelling interface shall allow flow of hydrogen in both directions.	Main mode of operation is "one-hose operation" per section 3.2.
5	The break-away coupling shall disconnect the hose from the fuelling station if a force of > 1000-1200 N is applied.	Note: The specified force equals the applied force under straight pull along the

		axis of the break-away coupling.
6	In case of activation of the break-away coupling during fuelling the remaining hydrogen in the hose shall be safely released. The amount of hydrogen shall be limited to a minimum.	
7	The fuelling interface components as well as the corresponding mountings shall not be damaged or deformed if the break-away-coupling triggering force is applied. The leak rates shall stay below the normal operation limit.	
8	The nozzle shall include one automatic valve (FNV) controlled by the fuelling station	Note: valve control can be done e.g. electric or pneumatic
9	The receptacle shall include two redundant valves (RCV1 and RCV2) that can be opened mechanically by the valve plate of the nozzle automatic valve. If the valves are not opened mechanically, they shall act as check valves.	See Figure 3-2

8.1.2 Control

No	Requirement	Remark
1	The nozzle to receptacle interface shall allow the following conditions: Position 0: Nozzle mechanically fixed to the receptacle, intermediate space sealed, FNV, RCV1, RCV2 closed Position 1: Nozzle secured against disconnection by the user, FNV, RCV1, RCV2 closed Position 2: FNV, RCV1 open; RCV2 closed Position 3: FNV, RCV1, RCV2 open	
2	The nozzle shall include a means to purge the intermediate space between nozzle and receptacle with hydrogen when in Position 1	

3	The nozzle shall allow an automatic check to verify the locking mechanism (Position 1) has been applied correctly. If the check fails, no fluid flow through the nozzle shall be possible.	
4	The nozzle shall allow automatic leak tests during coupling, fuelling and decoupling.	
5	The nozzle shall allow an automatic test to verify the status of FNV, RCV1, RCV2 in Position 1.	Note: verification of external and internal tightness via pressure measurement and pressure supply through purge line (e.g. during decoupling)
6	Actuating elements of the nozzle shall react to fuelling station commands in all steps of the fuelling process.	

8.1.3 Dimensioning

	Requirement	Remark
1	Operating pressure range: 0.1 MPa – 1.6 MPa	
2	Nozzle, hose, and break-away-coupling: Maximum allowable pressure (PS): 2.5 MPa according to 2014/68/EU	
3	Receptacle: Maximum allowable working pressure (MAWP): 2.2 MPa according to (EU) 2021/535	Note: The receptacle is tested as part of the sLH2 fuel system and must carry over its requirements.
4	Internal operating temperature: -253 °C to +50 °C Coupling system must withstand at least 120 min at fuel temperature of -253 °C.	Note: It is assumed that 120 min are sufficient to confirm stationary temperature robustness.

5	The volume of the intermediate space between nozzle and receptacle shall have a maximum volume of 3 cm^3.	Note: See TRBS 3151, section 4.1.7 (4); point 6 must be considered
6	During decoupling, no safety relevant amount of hydrogen shall leave the coupling.	Note: Inside an imagined sphere with a diameter of 100 mm, the H2 concentration shall be < 4 %
7	Average mass flow during Fuelling Stage 2: 400 kg/h	For definition of Fuelling Stages see WP sLH2 "Process", section 4.4
8	Maximum transient mass flow: 500 kg/h	
9	Maximum leak rate of receptacle and nozzle when not connected: 20 Ncm^3/h at all operating temperatures.	Reference: ISO17268 (20 Ncm^3/h)
10	Maximum leak rate of the nozzle to receptacle interface during fuelling process: 10 Ncm3/h at all operating temperatures.	
11	Maximum pressure drop of fuelling interface (between break-away coupling and receptacle): 0.03 MPa at mass flow of 400 kg/h	
12	Maximum heat input of the fuelling interface (from break-away coupling to receptacle) during fuelling condition: 15W	
13	Maximum mass of the fuelling interface sub-components in contact with cryogenic fluid: 5 kg	Note: This is to specify max. heat input during cool-down of the interface, assumed is stainless steel
14	All parts in contact with the environment shall be designed in such a way that condensation and icing of humidity and atmospheric gases is avoided in coupled and decoupled state.	Note: In decoupled state a holder shall be available for the nozzle that heats up cold surfaces to ambient by using electrical heaters or/and warm inert gas (e. g. Nitrogen) – refer also to chapter 8.3 – requirement 9.

15	All parts in contact with the environment that can be touched by the user shall be design in such a way that cold burning is avoided under any circumstances. According to ISO 13732-3:2005 a minimum temperature of -12.5 °C shall be maintained. If the environment temperature is below -12.5 °C the surface temperatures shall not fall below ambient temperature.	Reference: ISO 13732-3:2005 Note: temperature derived based on a contact duration of 10 seconds.

8.2 Environmental Requirements

	Requirement	Remark
1	Ambient temperature range receptacle: -40 °C to +85 °C	(see (EC)406/2010, Annex III, Part 1, Section 1.3) (Rationale: GTR13, Section I. E. 1.(b) 61. (h) (ii), page 21)
2	Ambient temperature range nozzle: -40 °C to +50 °C	(Rationale: See GTR13, Section I. E. 1.(c)(b)(i), page 22)
3	Fuelling shall be possible under all weather conditions.	e.g. rain, snow, direct sunlight, etc. humidity 1% - 100%.
4	Materials shall be resistant to intercrystalline hydrogen corrosion and free of micro cracks.	
5	Materials shall be compatible to all relevant media and temperatures in normal operation mode.	This includes components in contact with the environment
6	Nozzle and receptacle shall be designed to avoid accumulation of water and dirt. To avoid damages to the sealings, ingress of pollution into the tank system shall be avoided.	

8.2.1 Geometry and Design

	Requirement	Remark
1	The receptacle shall be standardized according to the following geometry and design requirements. There shall be no variants of the geometry for different applications.	
2	The nozzle geometry shall fit to the standardized receptacle.	
3	The receptacle shall comply to the geometry shown in Figure 4-1.	
4	The receptacle shall be installed in a space not extending the dimensions given as in Figure 4-2.	
5	The fuelling and gas return (if applicable) connection shall not be installed in the engine compartment, passenger compartment or in any other unventilated compartment.	GTR 13 to be implemented
6	Torsion of the fuelling hose shall be avoided.	
7	The receptacle shall be designed for mounting in an angle in the range of -30° to +30° from the horizontal plane.	

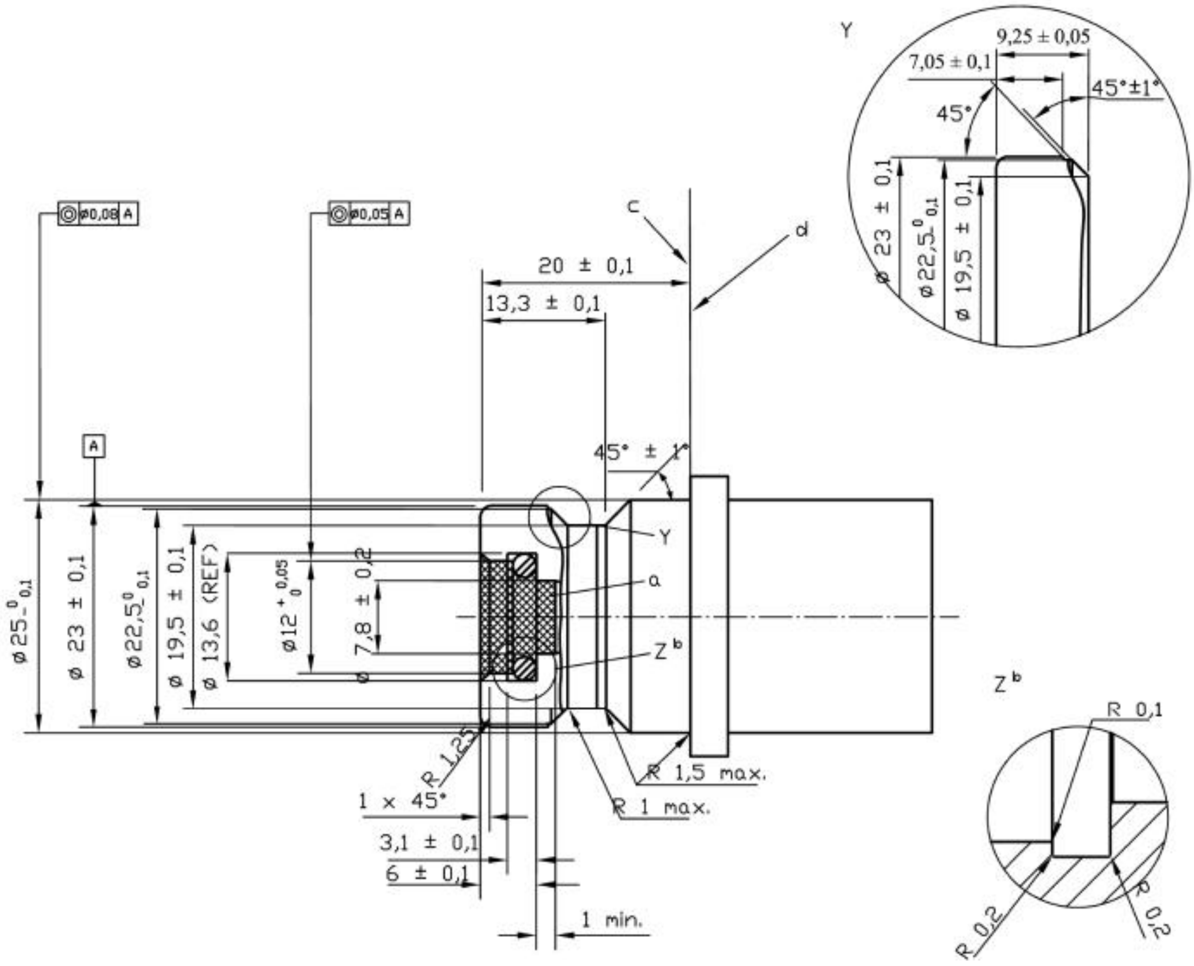
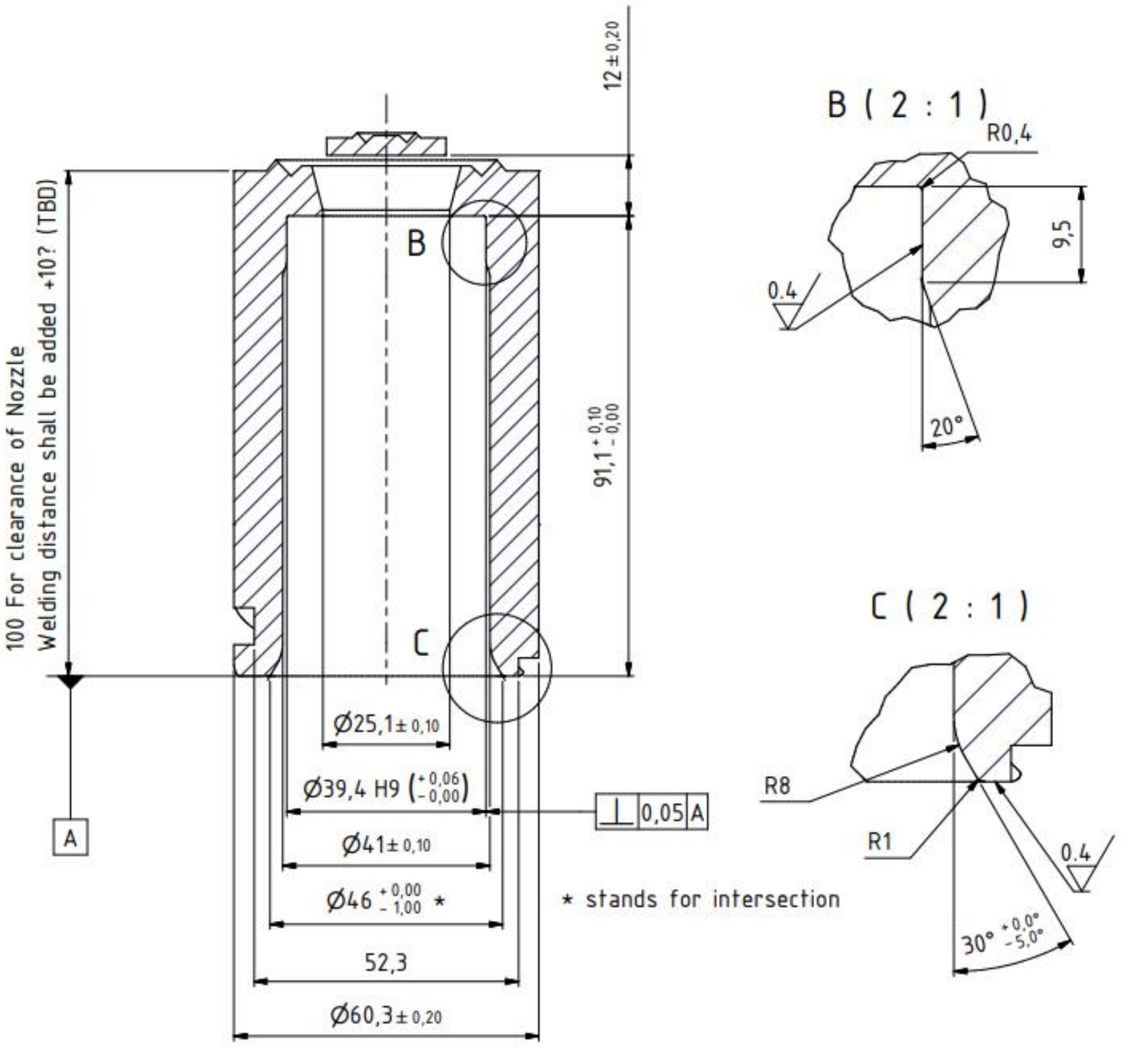
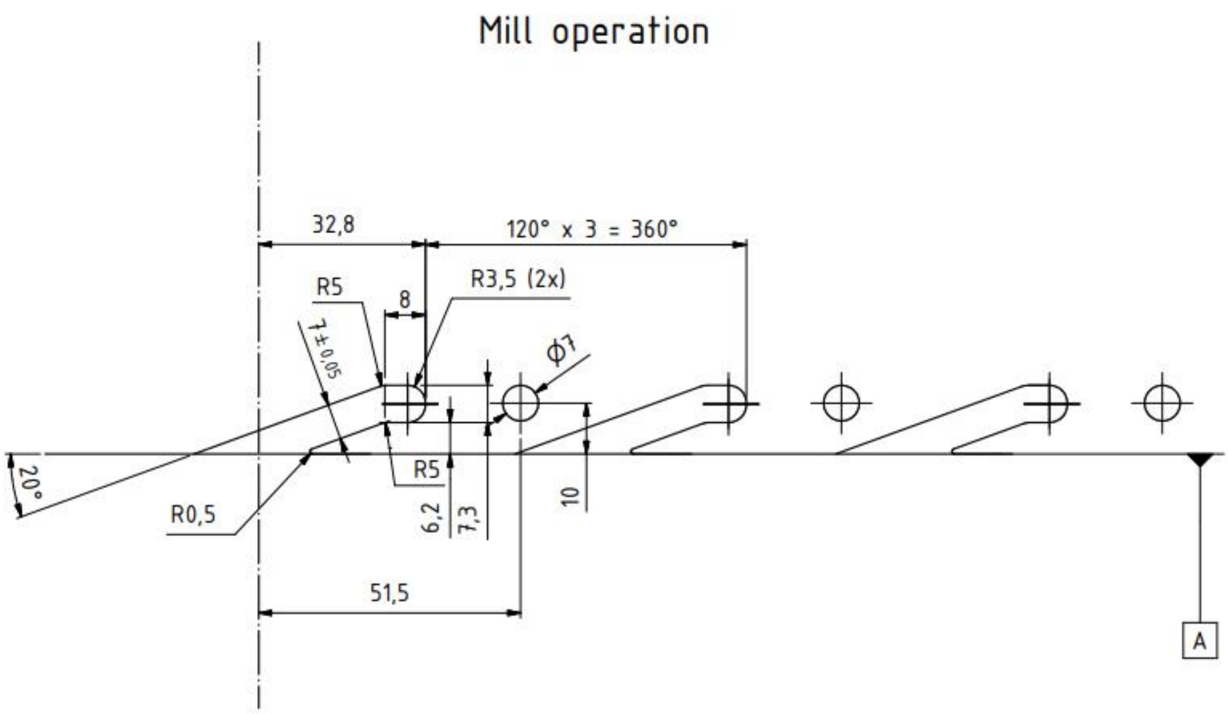


Figure 41: Fuelling Receptacle Interface Geometry


12±0,20
B (2 : 1)
R0,4
9,5
0.4
20°
100 For clearance of Nozzle
Welding distance shall be added +10? (TBD)
B
91,1 +0,10 -0,00
C
C (2 : 1)
Ø25,1±0,10
Ø39,4 H9 (+0,06 -0,00)
0,05 A
Ø41±0,10
Ø46 +0,00 -1,00 *
* stands for intersection
52,3
Ø60,3±0,20
A
R8
R1
0.4
30° +0,0° -5,0°


Mill operation
32,8
120° x 3 = 360°
R5
8
R3,5 (2x)
7±0,05
Ø7
20°
R0,5
R5
6,2
7,3
10
51,5
A

Installation space for the receptacle at the vehicle:

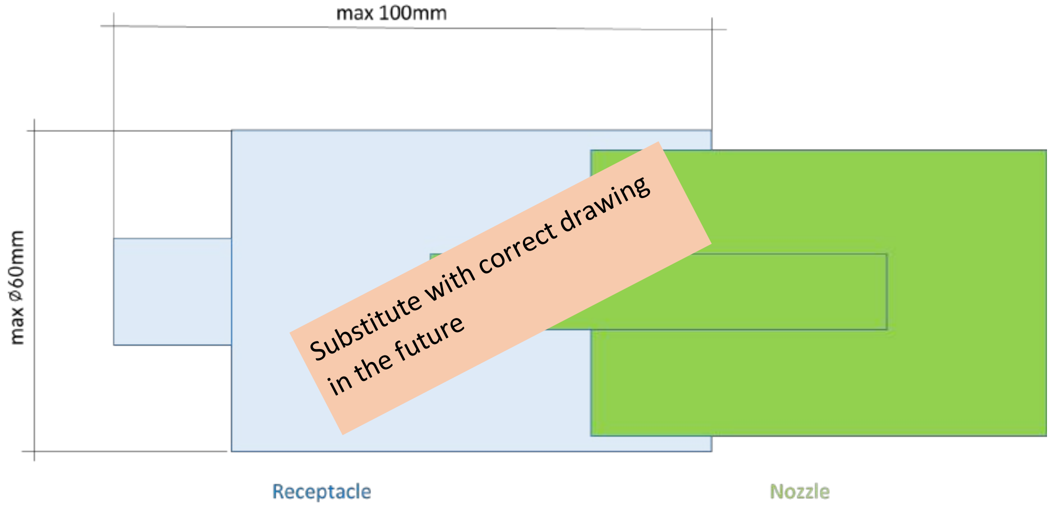


Figure 42: Maximum installation space

8.2.2 Electrical Requirements

	Requirement	Remark
1	Grounding of the vehicle prior to fuelling shall be done via the tires / fuelling station ground surface (fuelling pad). (see Figure 43)	Note: See Figure 4-3
2	Maximum resistance of the fuelling station ground surface (fuelling pad) and the grounding point of the fuelling station: 100 MΩ	Note: Requirement carried over from ISO 19880
3	The fueling interface shall be grounded to the fuelling station. Maximum resistance between fueling interface and grounding point of fuelling station: 1 MΩ	Note: Requirement carried over from ISO 19880

4	Maximum resistance of fuelling interface (from break-away coupling to receptacle) when connected: 100 kΩ	<u>Note:</u> Requirement carried over from ISO 19880
5	The receptacle shall be grounded to the truck grounding point. Maximum resistance between receptacle and grounding point of truck: 1000 Ω	
6	Maximum resistance of the truck grounding point to the fuelling station ground surface (fuelling pad): 1 MΩ	

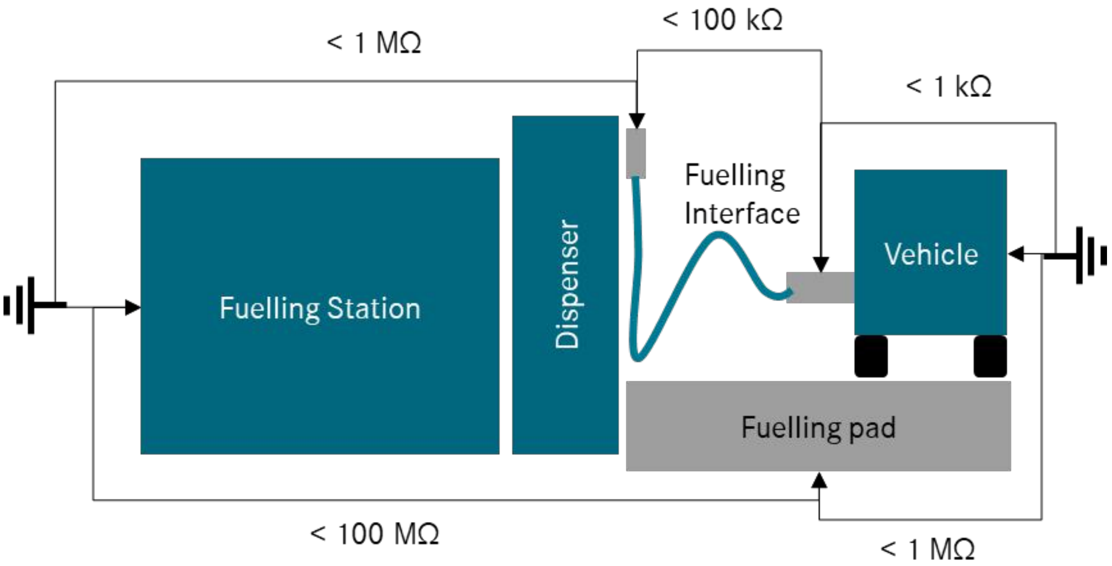


Figure 4-3: Electrical grounding resistances

8.3 Operational Requirements

	Requirement	Remark

1	The fuelling interface shall be designed for public individual use	
2	The fuelling interface shall be designed for manual operation	
3	The fuelling interface shall have an ergonomic and user-friendly design.	
4	For fuelling, connecting only one component shall be required.	
5	No special training shall be required to use the fuelling interface.	
6	The nozzle shall be disconnectable immediately after fuelling at operating conditions.	
7	Re-evacuation of the vacuum insulation of the fuelling interface should be possible.	
8	The length of the hose should be between 4 and 5 meters.	
9	A mounting shall be available that allows storage of the nozzle at the fuelling station. In the mounting, the nozzle shall be kept dry, free of ice, grease and clean when not in use. The mounting may include means to heat and dry cold surfaces of the nozzle.	
10	The nozzle shall allow continuous back-to-back fuelling.	
11	Disassembly of the receptacle shall only be possible with special tools.	
12	The receptacle shall withstand 30.000 fuelling cycles.	Note: SAE J2600 and ISO 17268 specify 15.000 cycles for passenger cars. Due to expected higher number of fuelling cycles for commercial vehicles the requirement has been increased by a factor of 2.

13	The nozzle shall withstand 100.000 fuelling cycles.	Note: Requirement carried over from ISO 17268.
14	If parts, e. g., sealings, are required to be exchanged during the lifetime, they shall be easily exchangeable.	

9. Tests to Verify Compliance of Hardware

9.1 Verification of main functions:

- To be done using hydrogen
- Tightness of the connection: before coupling and after decoupling
- Coupling/decoupling: functionality
- Moisture: no moisture and ice at surfaces of nozzle and receptacle
- Thermal insulation: measurement of heat input to sLH2 process lines.
- Pressure drop: under sLH2 conditions (e.g. measurement with water and extrapolation to sLH2)
- Grounding: measurement of resistance <1000 Ohm

9.2 Environmental conditions test

- Test shall include verification of
- temperature
- humidity
- precipitation

9.2 Durability test

- verify lifetime requirements
- include back-to-back fueling

9.3 Mishandling test

- rough or improper handling by the customer
- drop