CRYOMOTIVE

CcH2 - CRYO-COMPRESSED HYDROGEN GAS

GASEOUS HYDROGEN LAND VEHICLE REFUELLING PROCESS

WHITE PAPER PROCESS

Status: December 1, 2021

Release: 1.2

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White Paper Process - List of involved parties

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CONTENT

Definition of the pressure level

The cryo-compressed system pressure according to IS0 Standard is 40 MPa as follows:

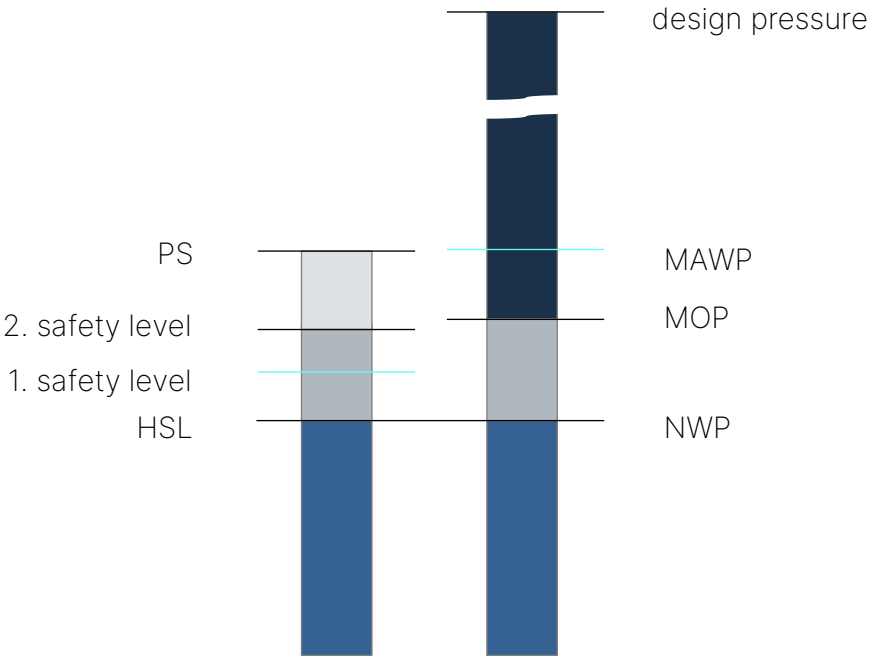


Figure 1: Definition of pressure level (40 MPa)

refuelling station

nomenclature	description	HSL x	p [MPa]
PS	Minimum dispenser component pressure rating	1.24	49.5
2. safety level	PRD: fully open PRD: start (min. activate pressure)	1.21 1.10	48.4 44.0
1. safety level	refuelling control system: stop refuelling	1.05	42
HSL	hydrogen service level	1.00	40

vehicle

nomenclature	description	NWP x	p [MPa]
design pressure	vessel - burst pressure	2.25	90
MAWP	PRD	1.24	49.5
MOP	blow off pressure	1.125	45
NWP	nominal working pressure	1.00	40

Table 1: Definition of pressure level (40 MPa)

Glossary

CcH_2	Cryo-compressed Hydrogen Gas
Receptacle	Part of refueling interface on the vehicle side
Nozzle	Part of the refueling interface on the station side
Dispenser / dispensing unit	Station-side dispenser unit, the interface to the customer. One station can be equipped with a certain number of dispensing units.
Nozzle parking station	Rain-proof holder for the nozzle mounted onto the dispenser unit for storing the nozzle in between refueling processes
Truck parking position	Parking range of the truck next to the dispenser unit
CcH_2 storage system	Cryo-compressed Hydrogen Gas tank system in the truck
ERS	Emergency release system
ESD	Emergency shut down system
tbd	To be defined

Language Definitions

The use of “shall”, “should”, “must”, “will” and “may” within this document has the following meaning:

- “shall” denotes a mandatory requirement
- “should” denotes a recommendation
- “must” denotes a legislative or regulatory requirement
- “will” denotes a provision or service or an intention
- “may” denotes a permissible practice or action

1 Introduction

1.1 Scope

This document defines the process of public and non public refuelling stations for heavy duty vehicle.

International industry is increasing its research and development activities on using clean energies in order to mitigate climate change effects arising from the use of fossil fuels. The automotive industry has identified its environmental impact and therefore successively introduces emission-free electric drive technologies into the market.

While pure battery-electric drive systems are applicable for passenger cars, they face challenges for the use in heavy duty long haul trucks because of special boundary conditions regarding weight, range and the refueling process.

This Whitepaper is focusing on the refuelling process and the interface needed for heavy duty trucks, which are driven by hydrogen fuel cells or hydrogen combustion engines. Interested parties, industrial partners and stakeholders are invited to contribute to the further development of this Whitepaper finally used as a basis for the standardization process of CcH2 in ISO, SAE and CSA.

This document defines the generic requirements of the fuelling process of a public and non public refuelling stations. The minimum system performance, for refuelling of heavy duty road vehicle, are defined to following:

- refuelling station for heavy duty application
- mobile fuelling station
- trailer fuelling station.

The Figure 2 shows the deviation to ISO 19880. The main deviations from the state of the art of gaseous refuelling (CGH_2) relate to the precooling devices of the gas temperature and the buffer storage technology. The cryogenic approach enables to use existing H35 refuellingstations/infrastructures with small modification.

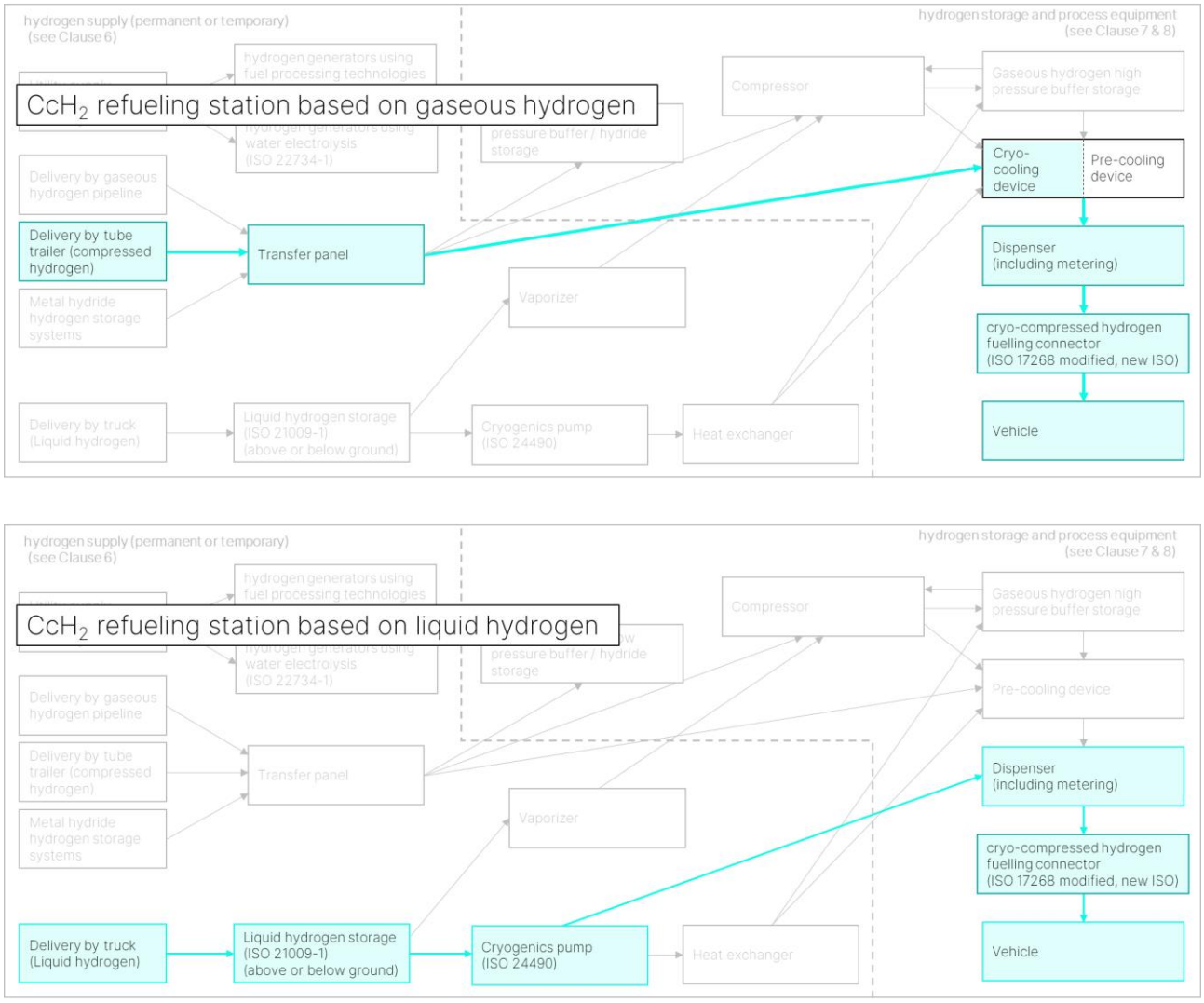


Figure 2: schematic overview of typical elements that a fuelling station consists of, including hydrogen supply. (based on ISO 19880-1 (Fig. 1) source: ISO 19880-1)

1.2 Cryo-compressed hydrogen refueling station

The CcH2 refueling station provides cryo-compressed hydrogen gas either by the compression of liquid hydrogen up to 40 MPa (see Figure 3 and Figure 4) or by cooling of gaseous hydrogen from ambient to cryogenic temperatures (see Figure 5).

Liquid hydrogen delivery On-site liquid hydrogen storage High pressure cryogenic hydrogen pump CcH2 dispenser

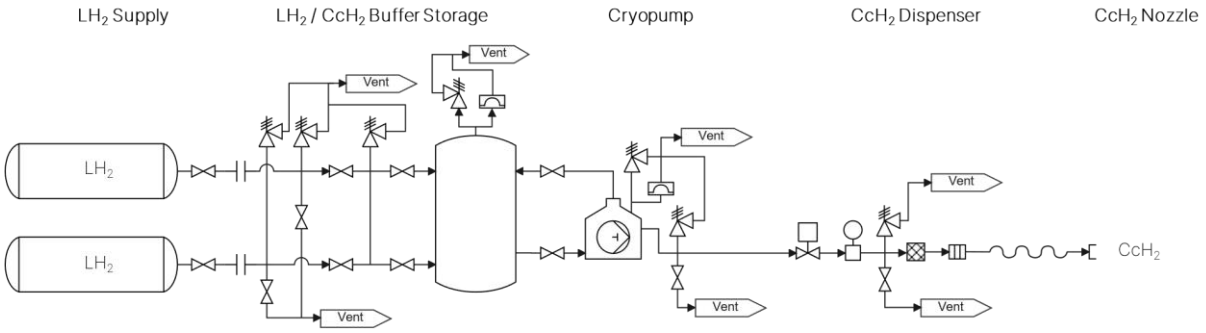


Figure 3: CcH_2 refueling station based on liquid hydrogen.

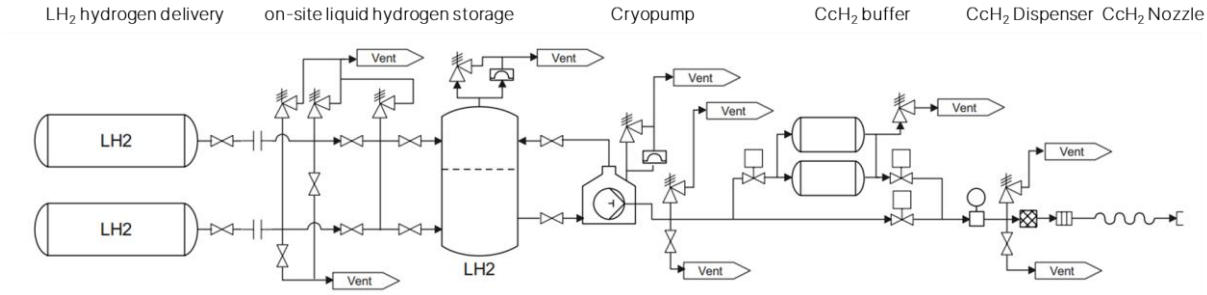


Figure 4: CcH_2 refueling station based on liquid hydrogen and CcH_2 buffer system.

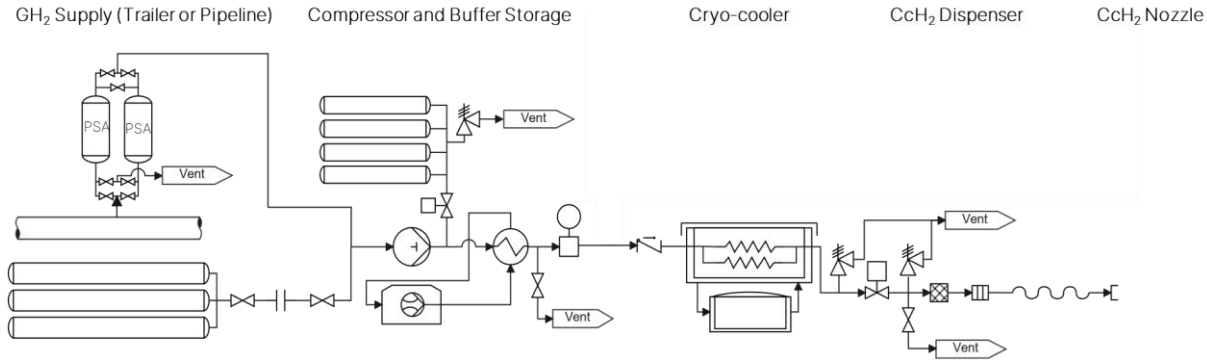


Figure 5: CcH_2 refueling station based on gaseous hydrogen.

1.3 Organization of this Whitepaper process

This Whitepaper process is coordinated by the Clean Energy Partnership (CEP). Partners contribute their input either verbally during the official meetings or in written form by Email to the CEP coordinators.

Meeting invitations and the distribution of new versions lie in the responsibility of CEP coordinators.

1.4 Timeline

A finalized Whitepaper version will be distributed in December 2021. The subsequent standardization process targets to start in 2022, see Figure 6.

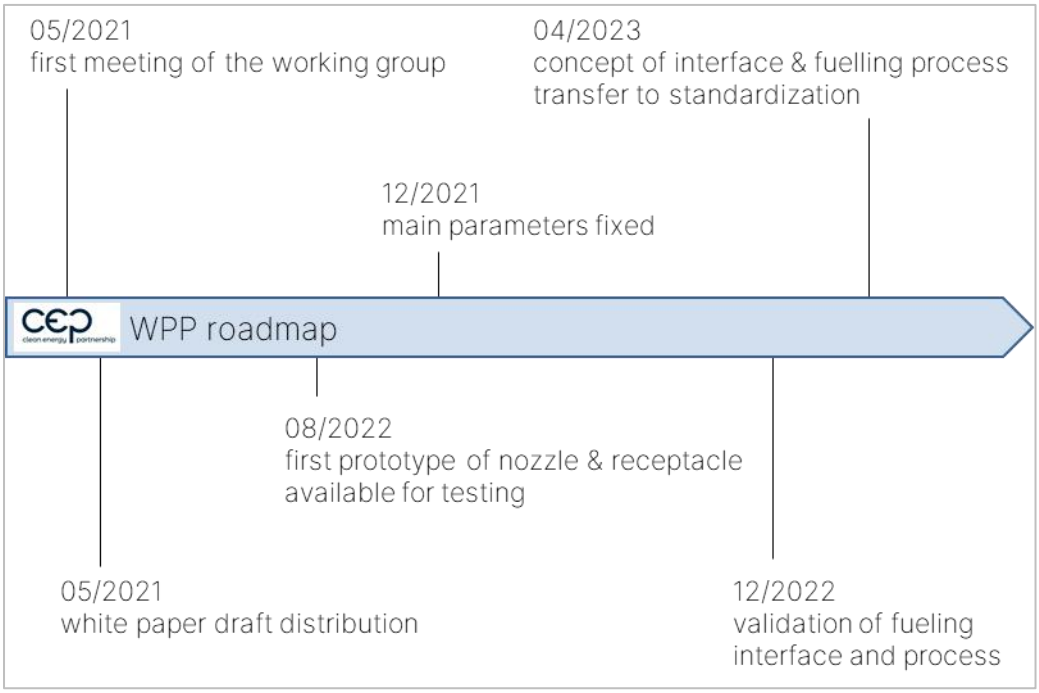


Figure 6: Illustration of the CEP-WPP roadmap.

2 Code & Standard references

Standard	Title
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
SAE J2578	Recommended Practice for General Fuel Cell Vehicle Safety
SAE J2574	Fuel Cell Vehicle Terminology
SAE J2579	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Fuelled Vehicles
SAE J2600	Compressed Hydrogen Surface Vehicle Refueling Procedure
SAE J2601	Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles
SAE J2719	Hydrogen Fuel Quality for Fuel Cell Vehicles
SAE J2760	Pressure Terminology Used in Fuel Cells and Other Hydrogen Vehicle Applications
SAE J2799	Hydrogen Surface Vehicle to Station Communications Hardware and Software
ISO 13850	Safety of machinery — Emergency stop function — Principles for design
ISO 13984	Liquid Hydrogen - Land Vehicle Fueling System Interface
ISO 14687	Hydrogen fuel — Product specification
ISO 17268	Gaseous Hydrogen Land Vehicle Refueling Connection Devices
ISO 19880 (all parts)	Gaseous hydrogen — Fuelling stations
ISO 21013-1	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 1: Reclosable pressure-relief valves
ISO 21013-2	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 2: Non-reclosable pressure-relief devices
ISO 21013-3	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 3: Sizing and capacity determination
ISO 22734	Hydrogen generators using water electrolysis
ISO/IEC 80079 (all parts)	Explosive atmospheres

Standard	Title
IEC 60079 (all parts)	Explosive atmospheres
IEC 60204-1:2005	Safety of machinery — Electrical equipment of machines — Part 1: General requirements
IEC 60529	Degrees of protection provided by enclosures (IP Code)
IEC 62282-3-100	Fuel cell technologies. Stationary fuel cell power systems. Safety
EN 13445-5	Unfired pressure vessels. Inspection and testing
ECE R134	Regulation No 134 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fueled vehicles (HFCV) [2019/795]
EC 79 / 2009 Annex II	Type-approval of hydrogen-powered motor vehicles: Applicable test procedures for hydrogen components, other than containers, designed to use liquid hydrogen
Commission regulation (EU) No 406/2010	Imple79menting Regulation (EC) No 79/2009 of the European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles
Commission Implementing Regulation (EU) 2021/535 of 31 March 2021	EU regulation on homologation of vehicle storage systems.
ECE/TRANS/180 Global technical regulation No. 13	Global technical regulation on hydrogen and fuel cell vehicles
Pressure equipment directive (2014/68/EU)	The PED applies to the design, manufacture and conformity assessment of stationary pressure equipment with a maximum allowable pressure greater than 0,5 MPa
ATEX DIRECTIVE 2014/34/EU	Equipment and protective systems intended for use in potentially explosive atmospheres

Table 2: summary of normative references

3 Terms & definition

The following terms and definitions apply to this document.

breakaway device:
breakaway coupling is a device on the hose with the functionality to disconnect the fuelling hose from the dispenserm if a critical force is reached.

buffer storage vessel:
local pressure vessels (CGH_2/CcH_2) for addition of pressurized gas supply for vehicle fuelling.

compressed hydrogen storage systems (CHSS)
defined in GTR13: hydrogen storage on-board vehicle.

component pressure rating (PS)
maximum pressure at which it is permissible to operate a component. The pressure rating and specified temperature are defined by the manufacturer.

control system:
system that responds to input signals from the process and/or from an operator and generates output signals.

connector:
matching parts, that can be put together for a "connection" to enable the transfer of fluids, electric power, or control signals.

- nozzle “connector” (fuelling station) and receptacle “connector” (vehicle) permits the transfer of cryo-compressed hydrogen as specified in ISO 17268 (modificated/new CcH2-ISO)
- the hose have a connector on each end for the following asslemblies:
  - “connector” of hose to breakaway coupling
  - “connector” of hose to nozzle

dispenser:
the dispenser is a local system in the fueling station area.

dispenser fuel pressure:
cryo-compressed hydrogen pressure of the fueling station to supply the vehicle.

dispenser fuel temperature:
cryo-compressed hydrogen tempreature of the fueling station to supply the vehicle.

dispenser system:
system downstream of the hydrogen supply system.

fuelling assembly:
the parts of the fuelling assembly (interface fuelling station and vehicle) are:

- hose breakaway device / breakaway coupling
- hose
- nozzle
- connection between the components

fuelling hose
used for dispensing cryo-compressed hydrogen to the vehicle, connected to fuelling nozzle

hydrogen fuelling station / fuelling station
facility unit for fuelling of cryo-compressed hydrogen to vehicle
Note:
according to nomenclature: hydrogen refueling station (HRS) or hydrogen filling station.

fuelling station operator
person or company, which are response for the fuelling station (operating, maintenance,...).

hydrogen service level (HSL)
cryo-compressed pressure level in MPa used to describe the hydrogen service of the dispensing system. The HSL based on the nominal working pressure of the vehicle.

nominal working pressure (NWP)
cryo-compressed pressure of a CHSS vehicle.

maximum operating pressure (MOP)
highest cryo-compressed operating pressure that is expected for a component or system.

maximum allowable working pressure (MAWP)
maximum cryo-compressed pressure permissible in a system

target pressure
maximum dispenser fuel pressure at the refuelling process, the target pressure is defined in the hydrogen refuelling protocol.

maximum developed pressure
maximum accumulated pressure

nozzle
device connected to a fuel dispensing system

receptacle
connecting device of the vehicle

pre-cooling
process of cooling hydrogen to specified fueling temperature

cryo-cooling device
device for cooling hydrogen to sepcified fueling temperature prior to dispensing.

pressure class
non-dimensional rating of components to characterise the fuelling pressure level on the refuelling station.

Pressure relief device (PRD)
safety device that releases gas or liquid hydrogen over a critical defined set point (operating / emergency conditions)

state of charge (SOC)
density (or mass) ratio of hydrogen in the cryo-compressed hydrogen storage system

Note:
Further components are described under the following link: ISO 19880-1:2020(en) (public)

4 Refuelling system parameter

Regarding to ISO 19880 & GTR 13, the main deviations of the cryo-compressed system parameters are as follows, see Table 3:

	CcH_2 cryo-compressed hydrogen	CGH_2 (H35) compressed gaseous hydrogen
H_2-storage typ	type III vessel	type III/IV vessel
NWP	p ≤ 40 MPa	p ≤ 35 MPa
MOP	45 MPa	43.75 MPa
T_{H2min} (hydrogen gas temperatures)	-251°C (22K)	-40°C (233 K)
Nozzle - Receptacle	may have any mechanical means of opening the receptacle check valve	shall not have any mechanical means of opening the receptacle check valve
Communication	design criterion, communication devices in the nozzle is not required	vehicle <-> refuelling station

Table 3: deviation of system parameters (CcH_2, CGH_2).

The following Table 4 lists the CcH_2 refueling parameters. The CcH_2 refueling station provides cryo-compressed hydrogen gas either by the compression of liquid hydrogen (liquid hydrogen based) up to 40 MPa or by cooling of gaseous hydrogen to cryogenic temperatures (gaseous hydrogen based).

pos.	refuelling process parameters/characteristics	liquid H_2 based CcH_2-refuelling	gaseous H_2 based CcH_2-refuelling
i.	Expected working temperature during the refueling process in steady state phase (after initial cool-down) Note: given at interface point to refueling hose	-223°C (50 K)	-193°C (80 K)
ii.	Minimum working temperature Given at interface to refueling hose	-251°C (22 K)	
iii.	Target pressure	40 MPa	
iv.	[vehicle] Minimum fuelling pressure at start up	0.5 MPa	
v.	[vehicle] Maximum fuelling pressure at start up	under investigation	under investigation
vi.	Target fuelling rate (80 kg CcH_2 storage capacity)	500 kg/h	
vii.	Maximum fuelling rate	900 kg/h	
viii.	[HRS] Refuelling control system: stop refuelling	42 MPa	
ix.	[HRS] PRD: start (min. activate pressure)	44 MPa	
x.	[HRS] PRD: fully open	48.4 MPa	
xi.	[HRS] Component pressure rating	49. 5 MPa	
xii.	[vehicle] Blow off pressure	45 MPa	
xiii.	[vehicle] PRD set point	49.5 MPa	
xiv.	[vehicle] Minimum design pressure of vessel	90 MPa	
xv.	decoupling pressure receptacle – nozzle	< 1.0 MPa	
xvi.	[HRS] ambient temperature acc. to ISO 19880-1	$-40°C \leq T_{HRS} \leq 50°C$	
xvii.	[HRS] nozzle temperature acc. to ISO 17268 (mod.)	$-251°C \leq T_{HRS} \leq 85°C$	
xviii.	[vehicle] receptacle temperature acc. to ISO 17268 (mod.)	$-251°C \leq T_{vehicle} \leq 85°C$	
xix.	Usable* storage density (fill from cryo-compressed LH_2)	72 g/L	
xx.	Usable* storage density (fill from cryo-compressed CGH_2)	61 g/L	
xxi.	Minimum medium purity response: fuelling station operator	acc. to ISO 14687-2, ISO 19880-8	
xxii.	leak rate	20 cm^3/h	
xxiii.	connected nozzle & receptacle withstand abnormal loads (acc. ISO 17268)	≥ 2.000 N	
xxiv.	electrical resistance of interface	> 1.000 Ω	
xxv.	fuelling pad (earth connection HRS) vehicle – dispenser ground	100 MΩ	
xxvi.	fuelling pad	non-flammable material	

xxvii.	total electrical resistance for bonding and grounding	100 MΩ
xxviii.	Maximum length fuelling hose	< 5 m
xxix.	fuelling hose assembly	cold surfaces should be avoided
xxx.	[HRS] Operational safety	acc. to ISO 19880 (all parts), TRBS 3151

Table 4: Output parameters of CcH_2 fuelling station given at interface point to refueling hose.

Note:

- to avoid a damage and protect the CcH_2 storage system: the target fuelling rate should define the vent-gas capaticity of the PRD components (vehicle side).
- Pressure and temperature shall be continuously measured and recorded during refueling to verify compliance to the requirements listed above.
- *) Usable density with 1.5 MPa minimum storage pressure
- fuelling assembly and interface, see Figure 7

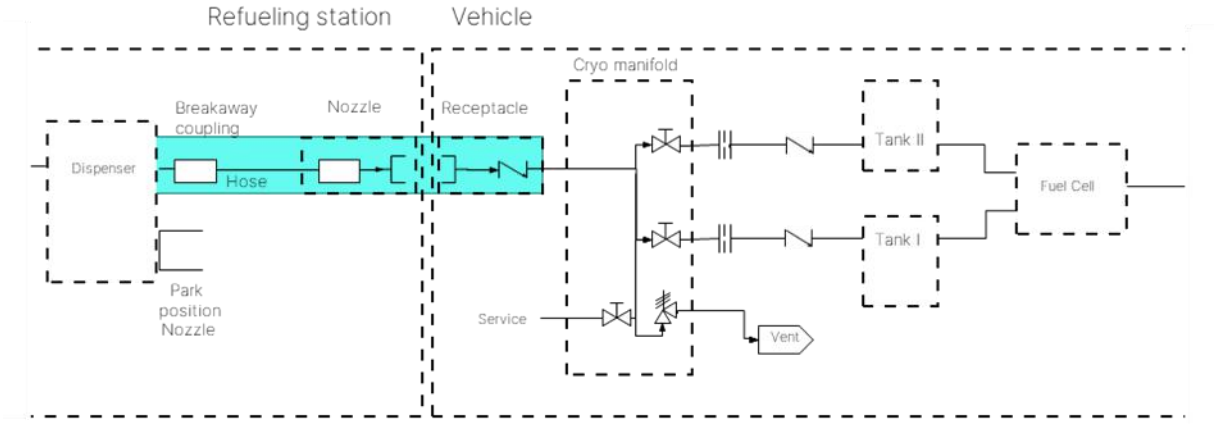
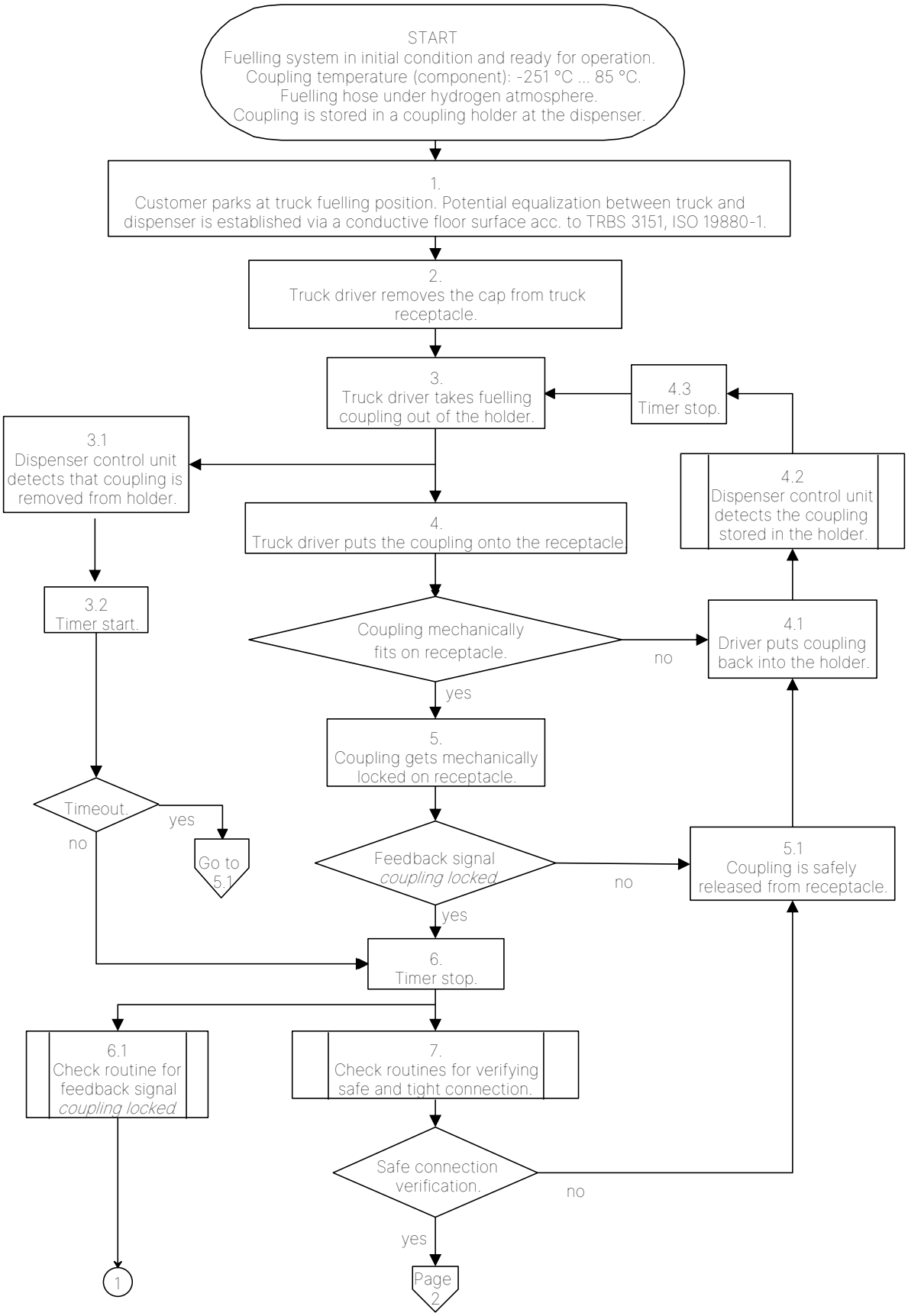


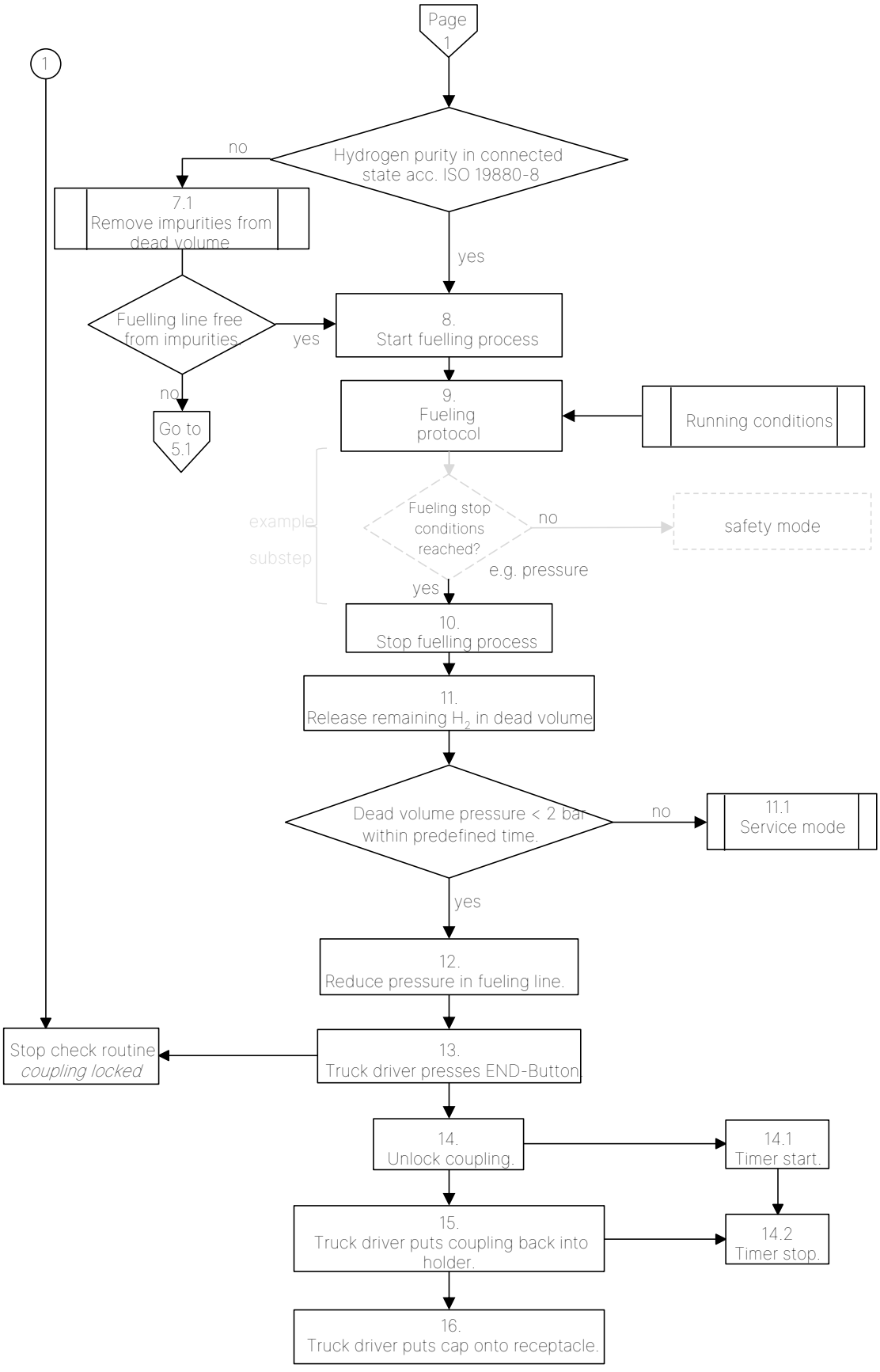
Figure 7: schematic overview of the fuelling assembly and interface

5 Refuelling process

The refuelling process is subdivided in three subprocesses as follows:

- pre - fuelling (1. - 6.)
- main – fuelling (7. – 10.)
- post – fuelling (11. – 16.)


START
Fuelling system in initial condition and ready for operation.
Coupling temperature (component): -251 °C ... 85 °C.
Fuelling hose under hydrogen atmosphere.
Coupling is stored in a coupling holder at the dispenser.
1.
Customer parks at truck fuelling position. Potential equalization between truck and dispenser is established via a conductive floor surface acc. to TRBS 3151, ISO 19880-1.
2.
Truck driver removes the cap from truck receptacle.
3.
Truck driver takes fuelling coupling out of the holder.
4.3
Timer stop.
3.1
Dispenser control unit detects that coupling is removed from holder.
4.2
Dispenser control unit detects the coupling stored in the holder.
4.
Truck driver puts the coupling onto the receptacle
3.2
Timer start.
Coupling mechanically fits on receptacle.
no
4.1
Driver puts coupling back into the holder.
yes
5.
Coupling gets mechanically locked on receptacle.
Timeout.
yes
no
Go to 5.1
Feedback signal coupling locked
no
5.1
Coupling is safely released from receptacle.
yes
6.
Timer stop.
6.1
Check routine for feedback signal coupling locked
7.
Check routines for verifying safe and tight connection.
Safe connection verification.
no
yes
1
Page 2


Page 1
1
Hydrogen purity in connected state acc. ISO 19880-8
no
7.1 Remove impurities from dead volume
yes
Fuelling line free from impurities
yes
8. Start fuelling process
no
Go to 5.1
9. Fueling protocol
Running conditions
example
substep
Fueling stop conditions reached?
no
safety mode
e.g. pressure
yes
10. Stop fuelling process
11. Release remaining H_2 in dead volume
Dead volume pressure < 2 bar within predefined time.
no
11.1 Service mode
yes
12. Reduce pressure in fueling line.
13. Truck driver presses END-Button
Stop check routine coupling locked
14. Unlock coupling.
14.1 Timer start.
15. Truck driver puts coupling back into holder.
14.2 Timer stop.
16. Truck driver puts cap onto receptacle.
End of process

The process step sequence of CcH_2 refueling is based on pressure equalization between station supply system and vehicle tank.

Normal refueling operation		
Step	Description	Station / Dispenser
0	Initial condition	Nozzle in holder (parking station) at dispenser
1	Customer parks at truck parking position	Electrical potential equalization between parking position floor and dispenser (*
2	Customer connects the nozzle to the truck receptacle	Mechanical lock
3	Customer pushes start button	-
4	Enabling system for refueling	Check sequence • locked • pressure test - tightness • air removal from dead volume between nozzle and receptacle
5	Refueling starts	CcH_2 delivery starts, opening of valves in fueling path, mass flow / pressure, temperature measuring activated
6	Refueling	Mass flow / pressure and temperature measuring, leakage monitoring / hydrogen sensors active
7	Refueling stops at 40 MPa or manual stop button activated	Valves close, CcH_2 delivery stops
8	Enabling for release (decoupling)	Control sequence for • depressurizing to < 1 MPa • hydrogen removal from dead volume between nozzle and receptacle
9	Customer decouples the nozzle and puts it back into the holder	Nozzle in holder (parking station) at dispenser

(* Electrical resistance between station floor (parking position of truck) and dispenser pipe equipment has to comply with the API Recommended Practice 2003, Sect. 4.6.9.2.

Table 5: Refueling parameters of CcH_2 station.

6 Safety requirements

6.1 Pressure measurement, limitation and relief

Pressure measurement devices shall be calibrated on a regular basis.

System pressure and overpressure control shall follow a staged principle:

- HSL - normal control process: 40 MPa
- Refuelling control system - stop refuelling : 42 MPa
  (1st safety level redundant electronic protection level)
- Mechanical protection (2nd safety level protection), pressure relief valves 44 MPa

6.2 Leakage monitoring

Leakage monitoring shall be carried out continuously during operating time of the dispenser/station.

6.3 Emergency release system ERS

When the nozzle is connected to the vehicle, movements of the vehicle shall not lead to a hazardous incident. The hose–nozzle–receptacle connection and the piping on vehicle side shall be protected from tensile forces exceeding a value, which will be defined within this Whitepaper process.

Protection levels

A) Vehicle software lock (brakes engaged, vehicle start disabled)
B) Break away coupling in dispenser

7 Dispenser control

The control unit of the dispenser shall be able to control all functions of the nozzle listed in Table 5.

Following time-stamped process parameters shall be stored:

- Tightness test result after connecting nozzle to receptacle
- Leakage occurrence
- Duration of refueling process (step 5 to 7, Table 2)
- Duration for connecting (step 2 to 4, Table 2)
- Duration for release (step 8 to 9, Table 2)
- Handle temperature during refueling

Dispenser control unit shall visualize its operating status and the refueling process status via a display.