Current Status of ISO AWI 19888-1

Liquid Hydrogen Fuel Storage System for Aerial Vehicles

ISO TC 197/SC1/WG2

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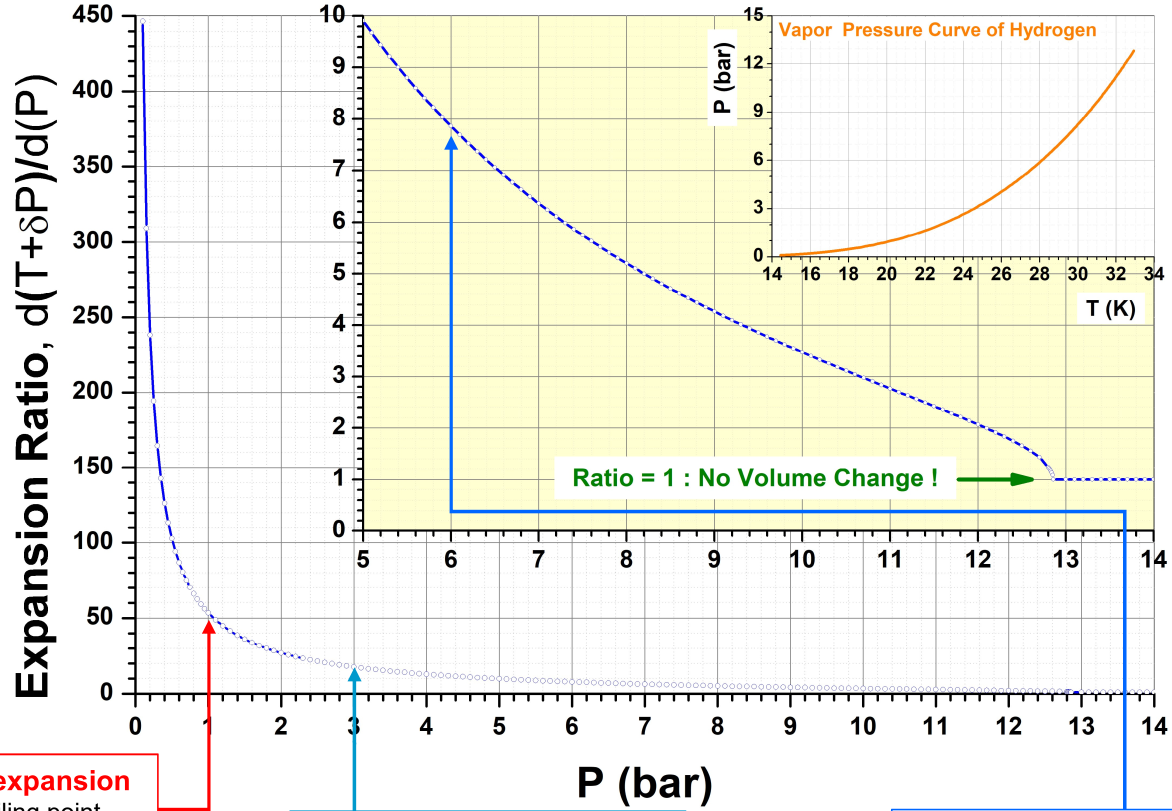
The 5th ELVHYS Workshop

June 5, 2025 [Hybrid Meeting]

CONTENTS

1. Introduction – Pressure Increase by LH_2 boiling

Expansion Ratio after the phase transition ($LH_2 \rightarrow GH_2$)



~60 times expansion
@ normal boiling point
(1 bara, 20 K)

※ LN_2 case @ 1 bara, 77K
~ 177 times expansion

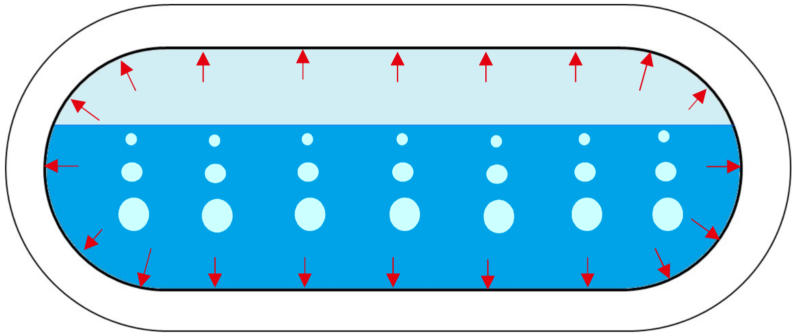
~20 times expansion
@ normal operating pressure
of LH_2 fuel tank (3 bara, 24 K)

nLH_2 fueling protocol

~7.8 times expansion
@ normal operating pressure
of sLH_2 fuel tank (6 bara, 29K)

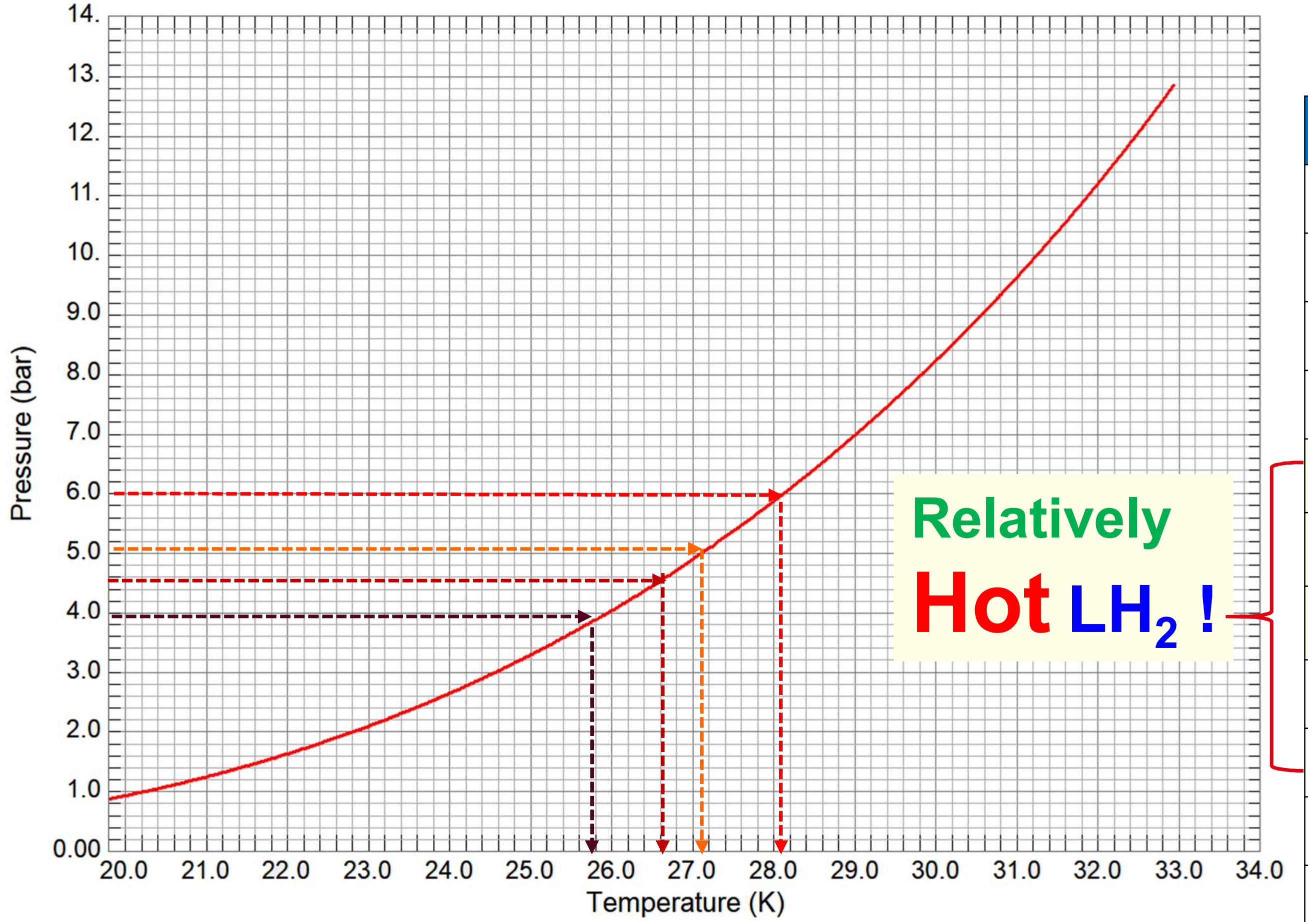
sLH_2 fueling protocol

Pressure Increase
caused by Boil-off ($LH_2 \rightarrow GH_2$)



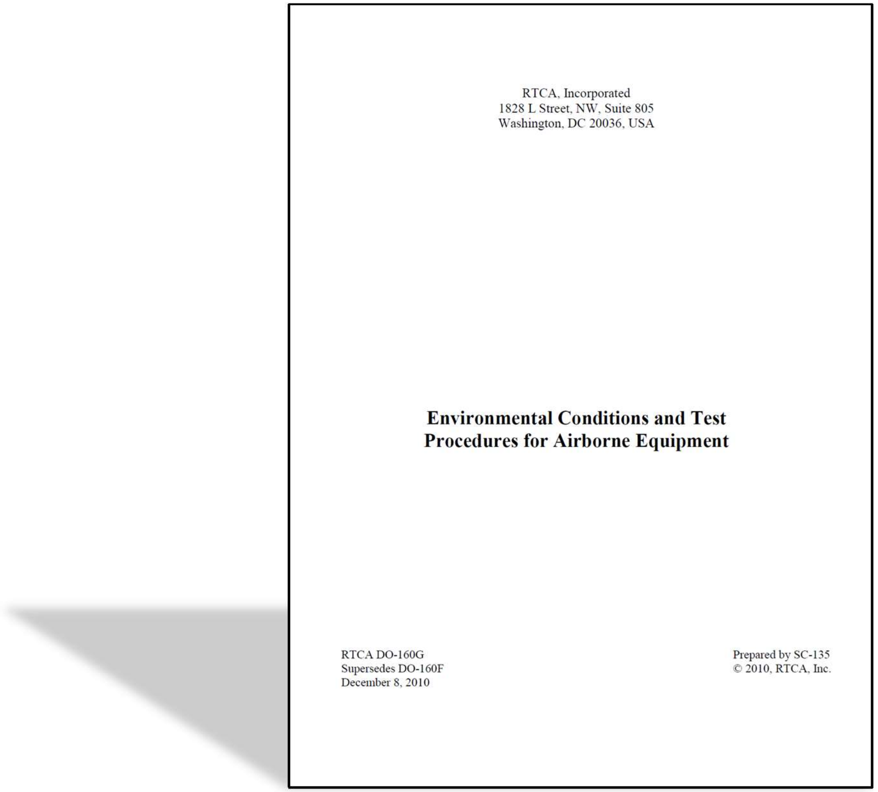
1. Introduction – T & P of LH_2 within a Storage Tank in a LHRS

Typical operating pressure of LHRS ranges 3.0 ~5.0 barg (4.0 ~ 6.0 bara)!



T (K)	P (bara)	d(g/L)
22.80	2.0	67.69
23.75	2.5	66.38
24.57	3.0	65.16
25.29	3.5	64.01
25.95	4.0	62.91
26.55	4.5	61.84
27.11	5.0	60.79
27.63	5.5	59.75
28.12	6.0	58.72
28.58	6.5	57.69
29.01	7.0	56.64

1. Introduction – Overview of RTCA/DO-160G



RTCA, Incorporated
1828 L Street, NW, Suite 805
Washington, DC 20036, USA

Environmental Conditions and Test Procedures for Airborne Equipment

RTCA DO-160G
Supersedes DO-160F
December 8, 2010

Prepared by SC-135
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RTCA is a private, **not-for-profit association** founded in **1935** as the **R**adio **T**echnical **C**ommission for **A**eronautics, now referred to simply as "RTCA".

A Standards Development Organization (SDO), RTCA works with the Federal Aviation Administration (FAA) to develop comprehensive, industry-vetted and endorsed standards that can be used as means of compliance with FAA regulations.

Table of Contents

1. Introduction – Overview of RTCA/DO-160G

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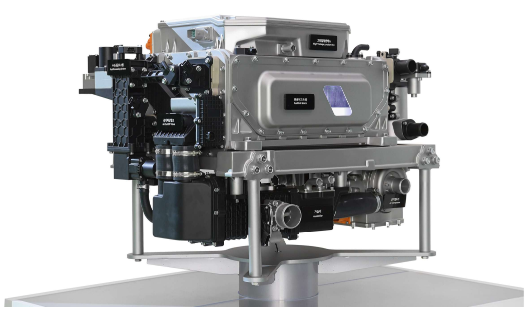
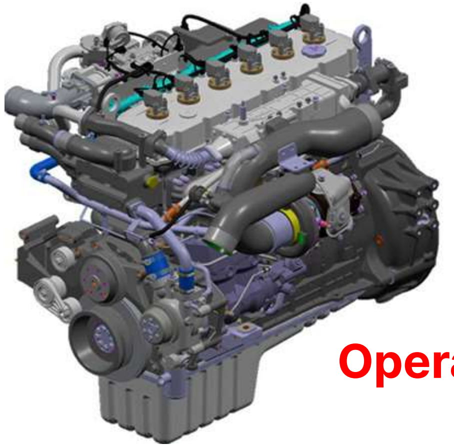
1. Introduction – Hydrogen Consumers for Aircrafts



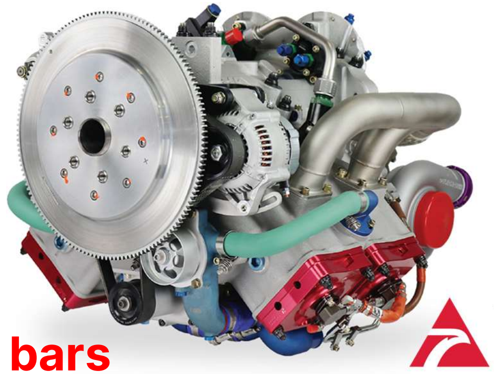
PEMFC, HMC (Hyundai Motor Company)

Operating P: a few bars



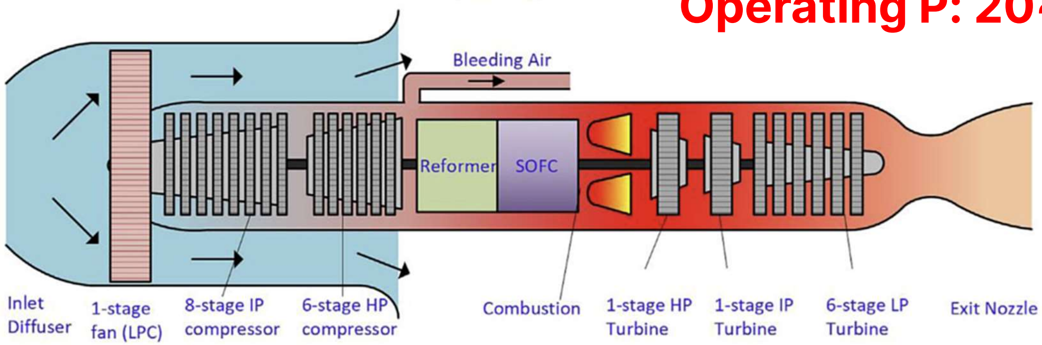
Combustion Engine (HD Hyundai Infracore)

Operating P: 10~20 bars



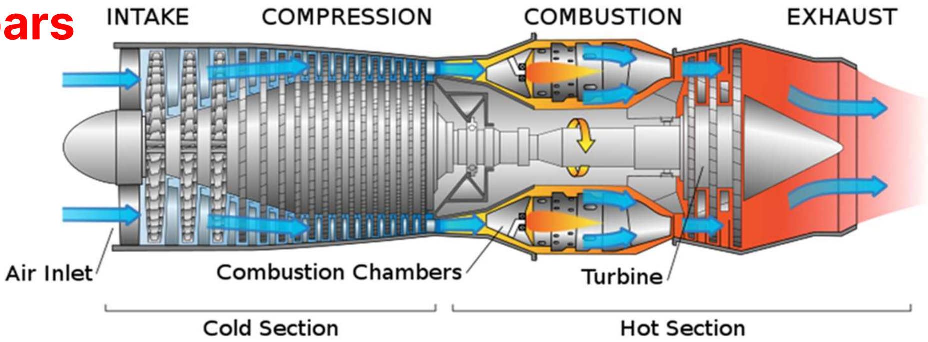
Combustion Engine (Delta Hawk)

Operating P: 20~40 bars



Hybrid SOFC-turbofan engine

M. Soleymani et. Al., International Journal of Hydrogen Energy 91 (2024) 137–171



Jeff Dahl, ***Jet Engine (Gas Turbine Engine)***, 2007, Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Jet_engine.svg.

1. Introduction – Hydrogen Consumers for Aircrafts

	Design Point (cruise)	Off-Design Point (Take-off)
Height (km)	**10.668**	**0.00**
Mach No.	0.85	0.00
RAMPR, Ram Pressure Ratio	1.59	1.00
FRR, Fan Pressure Ratio	1.65	1.58
LPCPR, Low Pressure Compressor Pressure ratio	1.14	1.10
HPCPR, Low Pressure Compressor Pressure ratio	21.50	23.00
ORR, Overall Pressure Ratio	**40.44**	**39.97**
P_a (bara)	**0.239**	**1.014**
T_a (K)	218.82	288.16
C_a (km/h)	907.20	0.00
BPR	8.10	8.40
TIT (K)	1380.00	1592.00
m_a (kg/s)	576.00	1350.00
TRUST (kN)	69.20	375.30
m_f (kg/s)	1.079	2.968
SFC (mg/N-s), special fuel consumption	15.60	7.91
Sp. Thrust (N-s/kg)	120.10	278.10

GE 90 Turbine Engine

Cruise (@ 10.7 km)
P_{in} = 40.44 x 0.239 = **9.67 bara**

Take-off (@ 0.0 km)
P_{in} = 39.97 x 1.014 = **40.53 bara**

P_{in}: 10~40 bara

ISO/TC 197/SC1

Hydrogen at scale and horizontal energy systems

ISO 19888-1

Hydrogen Technologies - Aerial Vehicles:

Part 1. Liquid Hydrogen Fuel Storage System

2. Progress of ISO AWI 19888-1

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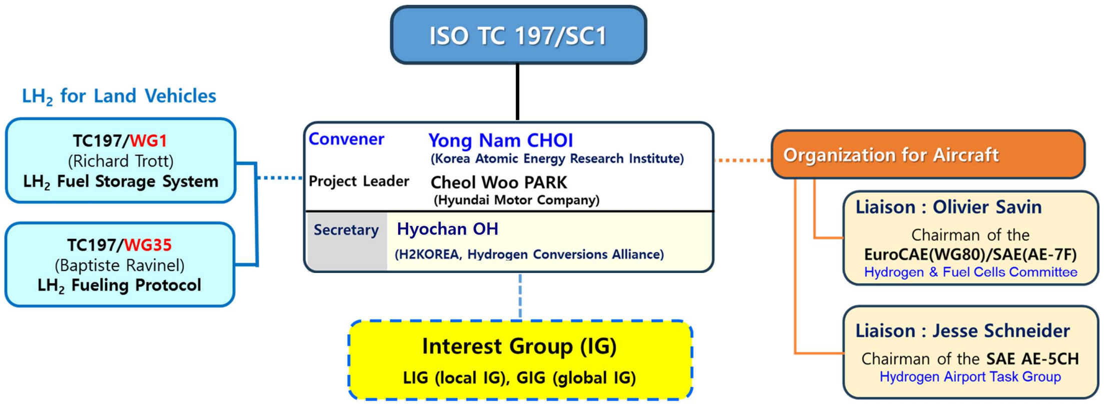
Presentation

at the **ELVHYS Project 5th Workshop**

June 5th, 2025

Online



2. ISO 19888-1: Outline of WD

1. Scope

2. Normative references

3. Terms and definitions

4. Requirements

- 4.1 General requirements
- 4.2 Design Requirements
- 4.3 Mechanical loads
- 4.4 Thermal stresses
- 4.5 Materials
- 4.6 Vacuum
- 4.7 Thermal Insulation
- 4.8 Sensors
- 4.9 Leak rate
- 4.10 Accessories

5. Manufacturing and assembly

- 5.1 General
- 5.2 Metallic and composite vessels
- 5.3 Brazing
- 5.4 Welding
- 5.5 Thermal insulation materials and supports
- 5.6 Safety valves
- 5.7 Withdrawal system
- 5.8 Fuel gauge sensing unit

6. Conformity assessment

- 6.1 General
- 6.2 Inner tank burst pressure test
- 6.3 Thermal autonomy test
- 6.4 Insulation performance test
- 6.5 Withdrawal test
- 6.6 Temperature cycling test
- 6.7 Maximum filling level test
- 6.8 Vibration test
- 6.9 Drop/impact test
- 6.10 Fire test
- 6.11 Leakage test
- 6.12 Accessory type test

7. Routine tests and inspection

- 7.1 General
- 7.2 Pressure test
- 7.3 Visual inspection
- 7.4 Verification of the dimensions
- 7.5 Welding inspection
- 7.6 Fuel gauge sensing inspection

8. Marking and labelling

- 8.1 Marking method
- 8.2 Inner tank markings
- 8.3 Outer jacket markings
- 8.4 Temporary markings for first filling

9. References

Annex A, B, C, D, ...

2. ISO 19888-1: 2. Scope of WD

This document specifies the requirements for the design, materials, construction, manufacture, testing, and inspection of a refillable liquid hydrogen fuel storage system for aerial vehicles subject to current or near-future aircraft certification systems. These include:

- **AAM (advanced air mobility) including UAM (urban air mobility including cargo drone) and RAM (regional air mobility)**
- **Small Aircraft with a maximum take-off weight of 8,600 kg or less**

This document considers the universal fueling protocols for liquid hydrogen such as the subcooled liquid hydrogen protocol as well as the normal (conventional) liquid hydrogen fueling protocol.

It applies to all parts of permanently attached fuel storage system for aerial vehicles as installed, from the liquid hydrogen storage container to the balance of tanks (BOTs). In case of UAV, a detachable fuel storage system can be adopted. The liquid hydrogen storage system (LHSS) is composed of the following elements :

- **Liquid Hydrogen Storage Container (LHSC)**
- **Sensor Units: pressure, temperature, fuel gauge, …**
- **Balance of Tanks: pressure relief systems, valves, tubes/pipes, vaporization device and auxiliary parts**

Note 1. Small UAVs (unmanned aerial vehicles) with a maximum take-off weight of 25 kg or less and the airplane class are not considered in this standard. However, those aerial vehicles could be included at the later revision of this standard if the technologies and market readiness is matured enough.

Note 2. For LHSS having appropriate size of the inner vessel (*ca.* 600 L ~ 4,000 L), sLH_2 fueling protocol addressed by ISO 13984 (to be published in 2025) can be applied and the physical parameters such MAWP and MOP and its structure should be designed and fabricated according to the guideline of ISO 13985 (to be published in 2026). All LHSS can consider a *so called* 'conventional LH2 fueling protocol' of which fueling pressure is low enough (typically less than ca. 6 bara).

Note 3. Components of FGSS (fuel gas supply system) are not included unless it is closely located or attached to the LHSC.

2. ISO 19888-1: 4.1 General requirements

Design philosophy for Aviation LHSS

- ✓ It should be as light as possible.
- ✓ Heat intrusion paths must be minimized.
- ✓ It must comply with airworthiness certification rules.

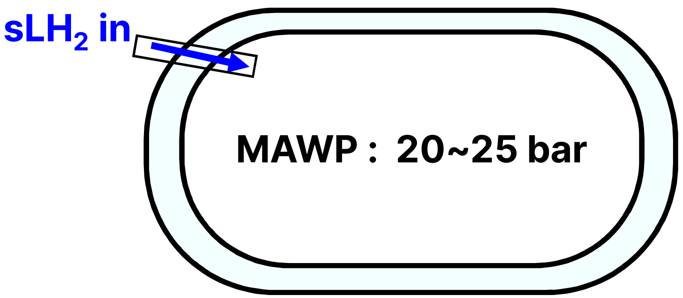
2. ISO 19888-1: Fueling Protocols

Subcooled LH_2 Fueling (sLH_2)

- **Fueling Pressure : 14~16 bara**
- **Fueling Speed: 8 ~ 16 kg/min (0.5~1.0 t/h)**
- **MAWP of Fuel Tank : 20 ~ 25 bars**
- **Fueling line : SINGLE (No back-gas line)**

  TWO, optional (LH_2 in + GH_2 out)
- **Applicable to : Small Aircraft**

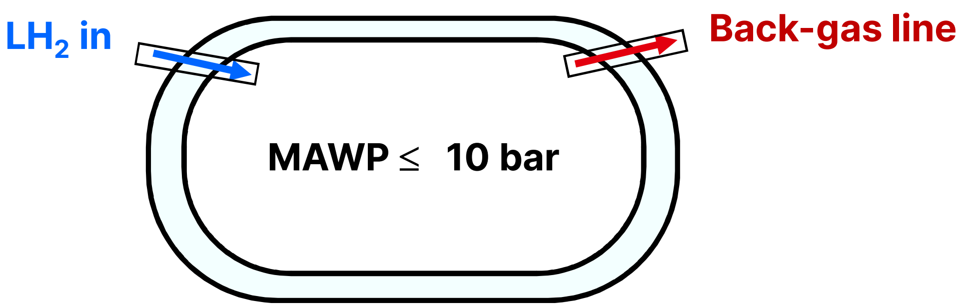
  [fuel tank: 600 ~ 4,000 L (35 ~ 250 kg)]



Normal (conventional) LH_2 Fueling (nLH_2)

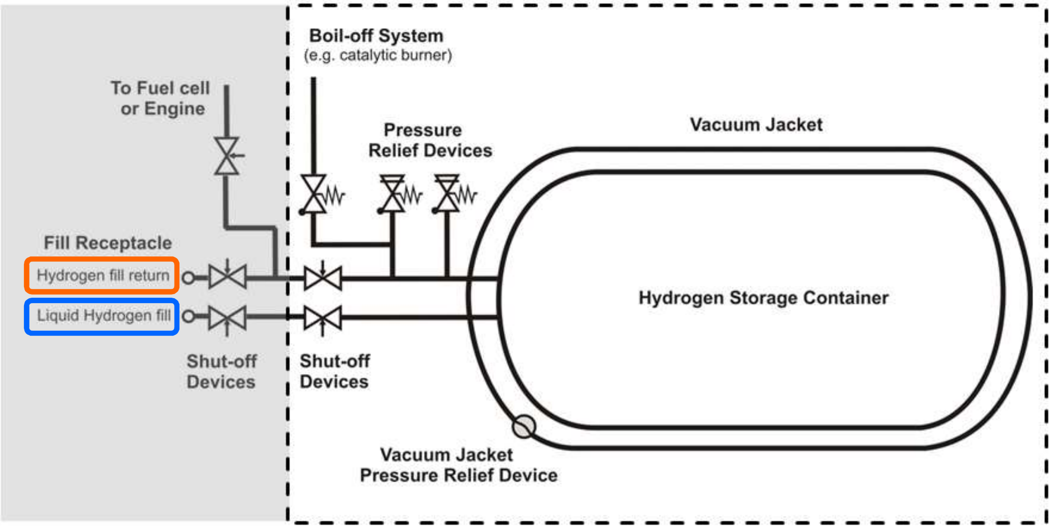
- **Fueling Pressure : ≤ typically a few bars**
- **Fueling Speed: 0.1 ~ 400 kg/min**
- **MAWP of Fuel Tank : ≤ 10 bars**
- **Fueling line : TWO (LH_2 in + GH_2 out)**
- **Applicable to : Small UAV ~ Large Airplane**

  [fuel tank: a few L ~ 3,000 m^3 (0.4~ 20,000kg)]



2. ISO 19888-1: LH_2 fuel tanks of GTR-13 vs ISO 13985

Typical Liquid Hydrogen Fuel Storage System in (GTR 13 Ph2, published in 2023)



Typical Liquid Hydrogen Fuel Storage System in (ISO TC197/WG1/CD, colored to clarify the components)

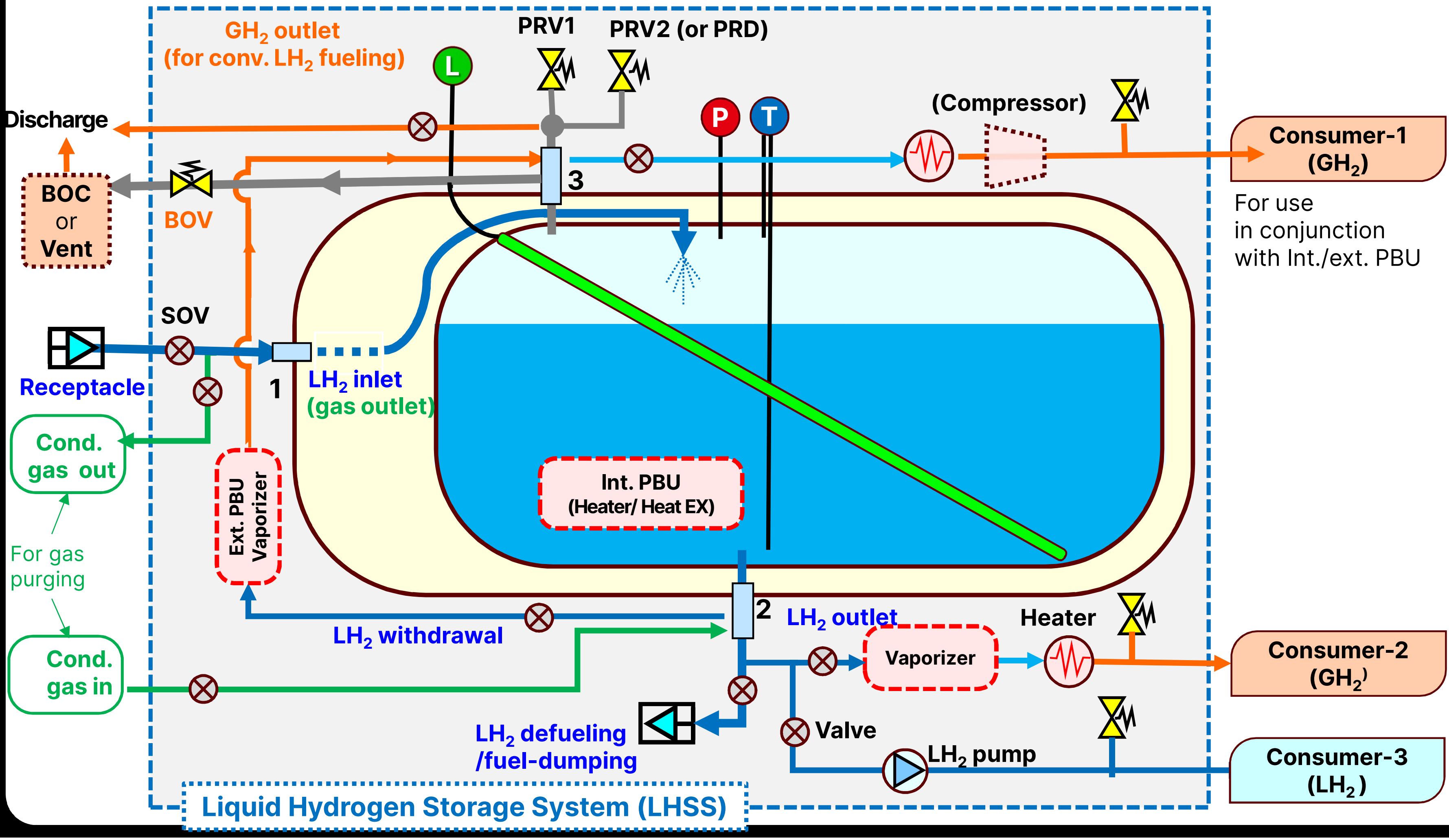
Sorry !

The content of ISO CD 13985 can not be shared until it is published !

Volume of LH_2 fuel tank for sLH_2 fueling : 600 L ≲ V ≲ 4,000 L

2. ISO 19888-1: 4.1 General requirements

Schematic Diagram of LHSS for Aerial Vehicles (Just for consultation or Comment !!!)



< Gas/Liquid Ports >

1: LH_2 inlet

2. LH_2 outlet / Cond.-gas inlet

3. GH_2 inlet/outlet

< H_2 Consumers>

1. GH_2 for FC

2. GH_2 for FC or ICE

3. LH_2 for H_2 Turbine

< Pressure Building Unit>

1. int. PBU
2. ext. PBU

< Sensors>

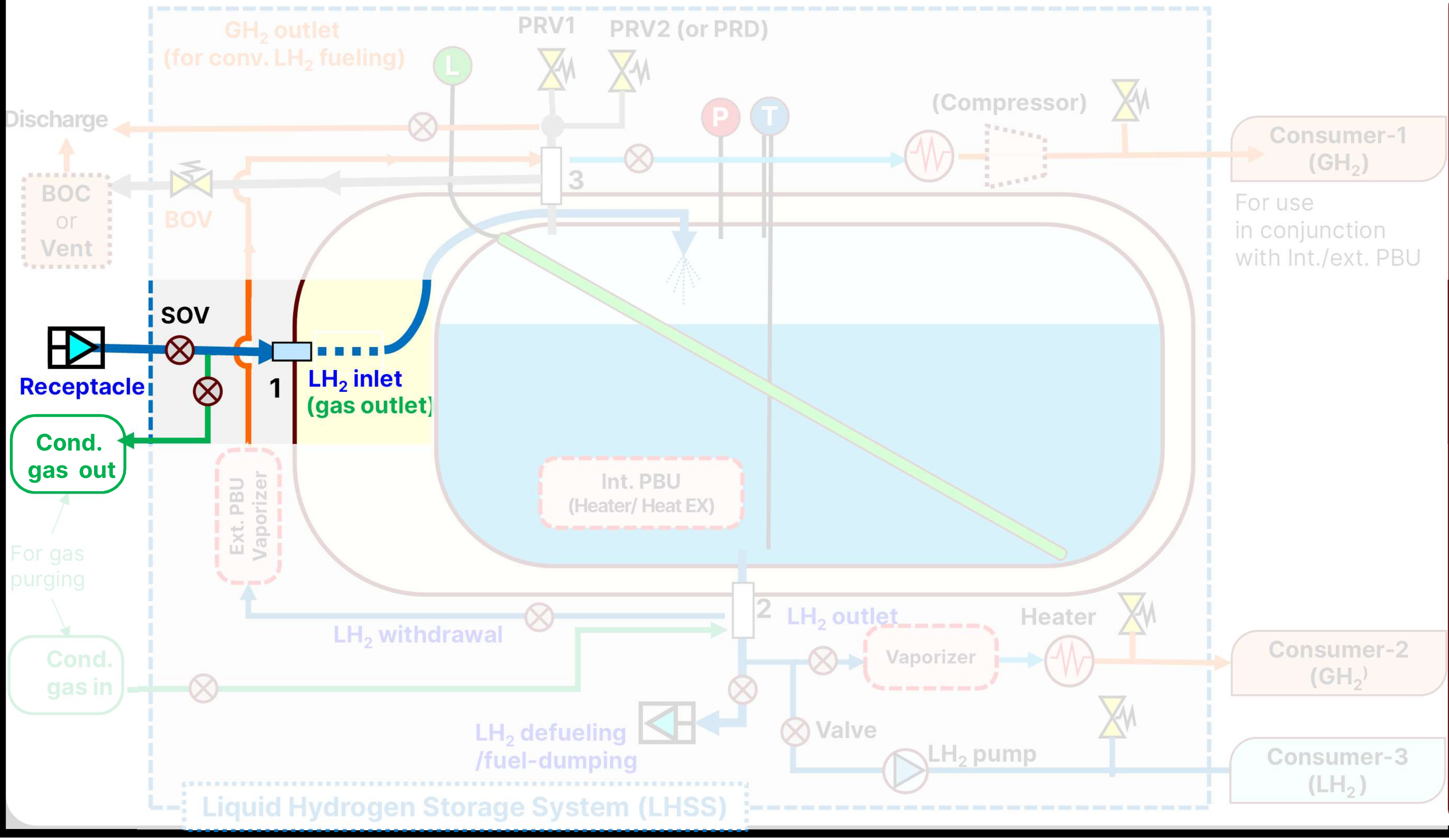
T Temperature

P Pressure

L Level

2. ISO 19888-1: 4.1 General requirements

Schematic Diagram of LHSS for Aerial Vehicles (Just for consultation or Comment !!!)



< Gas/Liquid Ports >

1: LH$_2$ inlet

2. LH$_2$ outlet / Cond.-gas inlet

3. GH$_2$ inlet/outlet

< H$_2$ Consumers>

1. GH$_2$ for FC
2. GH$_2$ for FC or ICE
3. LH$_2$ for H$_2$ Turbine

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- L Level

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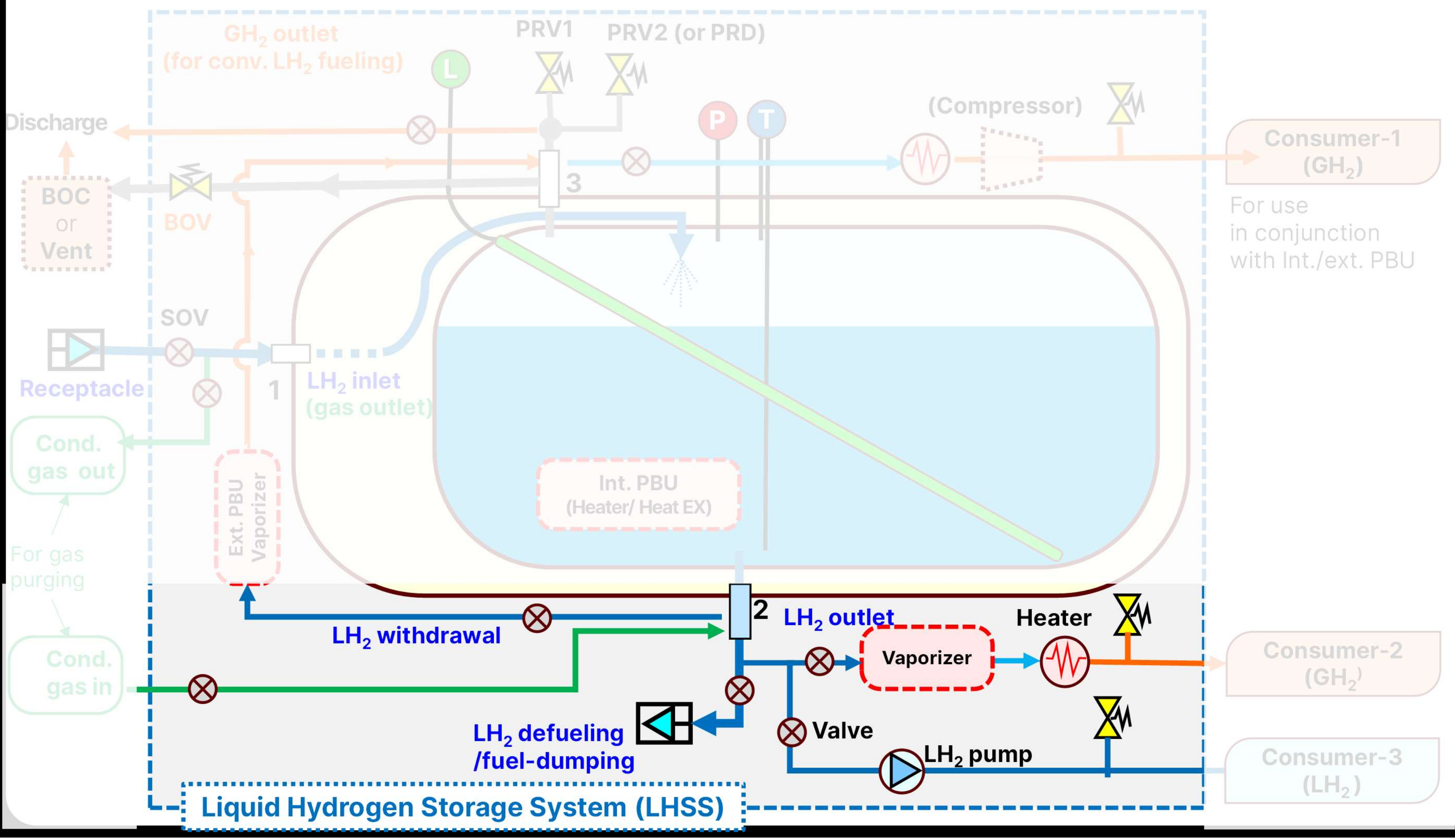


< Gas/Liquid Ports >

1: LH$_2$ inlet

2. LH$_2$ outlet / Cond.-gas inlet

3. GH$_2$ inlet/outlet

< H$_2$ Consumers>

1. GH$_2$ for FC
2. GH$_2$ for FC or ICE
3. LH$_2$ for H$_2$ Turbine

< Pressure Building Unit>

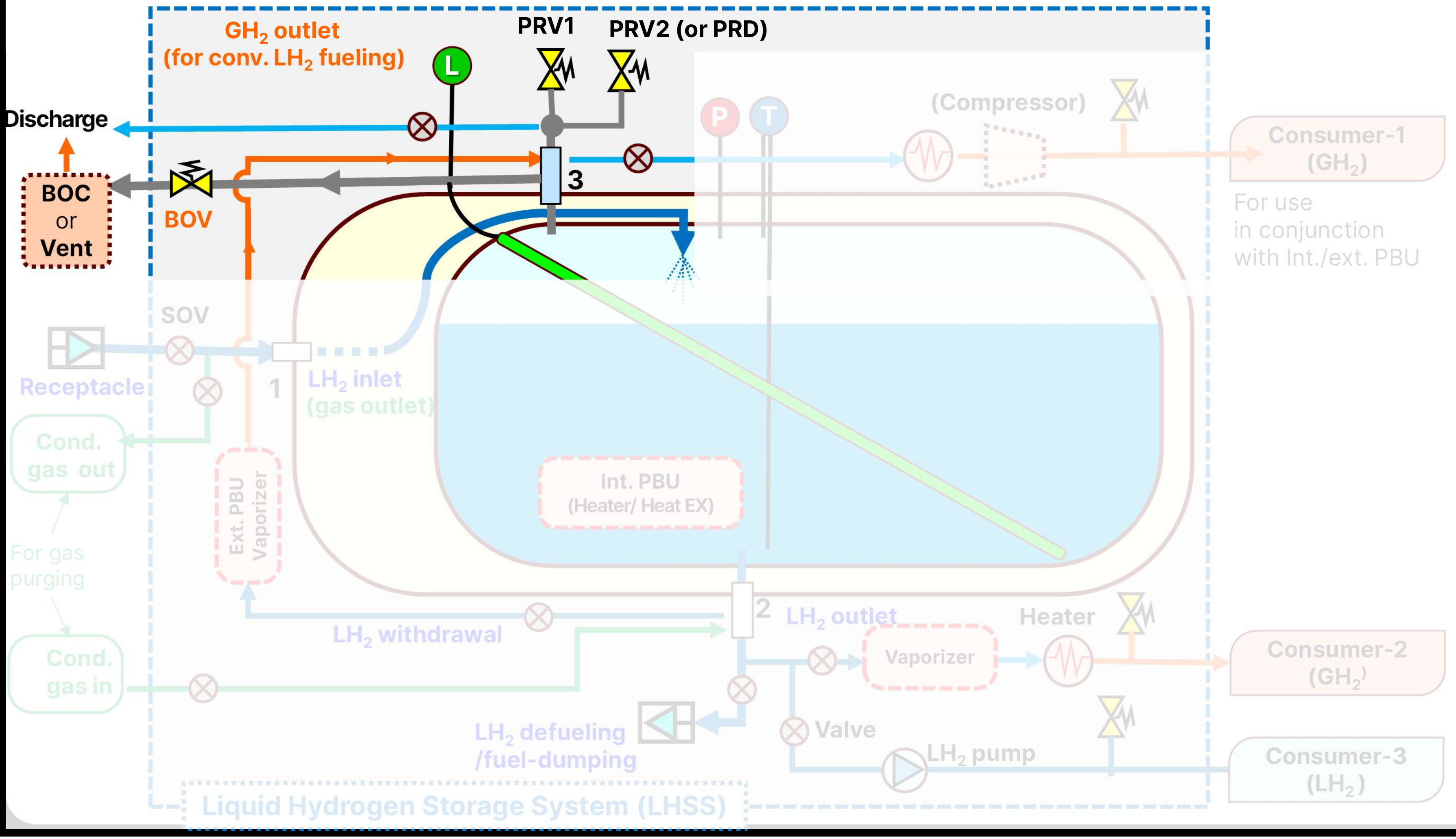
1. int. PBU
2. ext. PBU

< Sensors>

- T Temperature
- P Pressure
- L Level

2. ISO 19888-1: 4.1 General requirements

Schematic Diagram of LHSS for Aerial Vehicles (Just for consultation or Comment !!!)



< Gas/Liquid Ports >

1: LH$_2$ inlet

2. LH$_2$ outlet / Cond.-gas inlet

3. GH$_2$ inlet/outlet

< H$_2$ Consumers>

1. GH$_2$ for FC
2. GH$_2$ for FC or Comb. Engine
3. LH$_2$ for H$_2$ Turbine

< Pressure Building Unit>

1. int. PBU
2. ext. PBU

< Sensors>

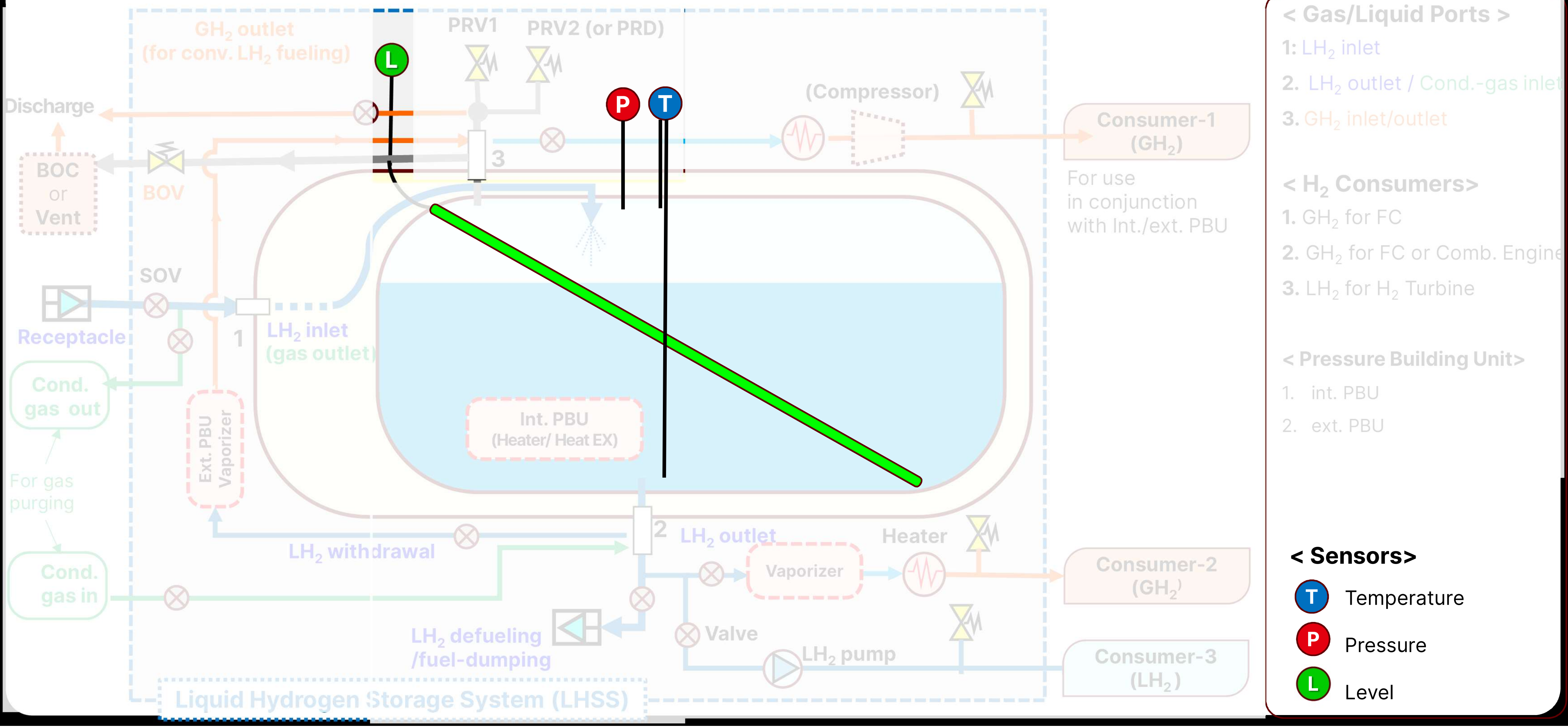
T Temperature

P Pressure

L Level

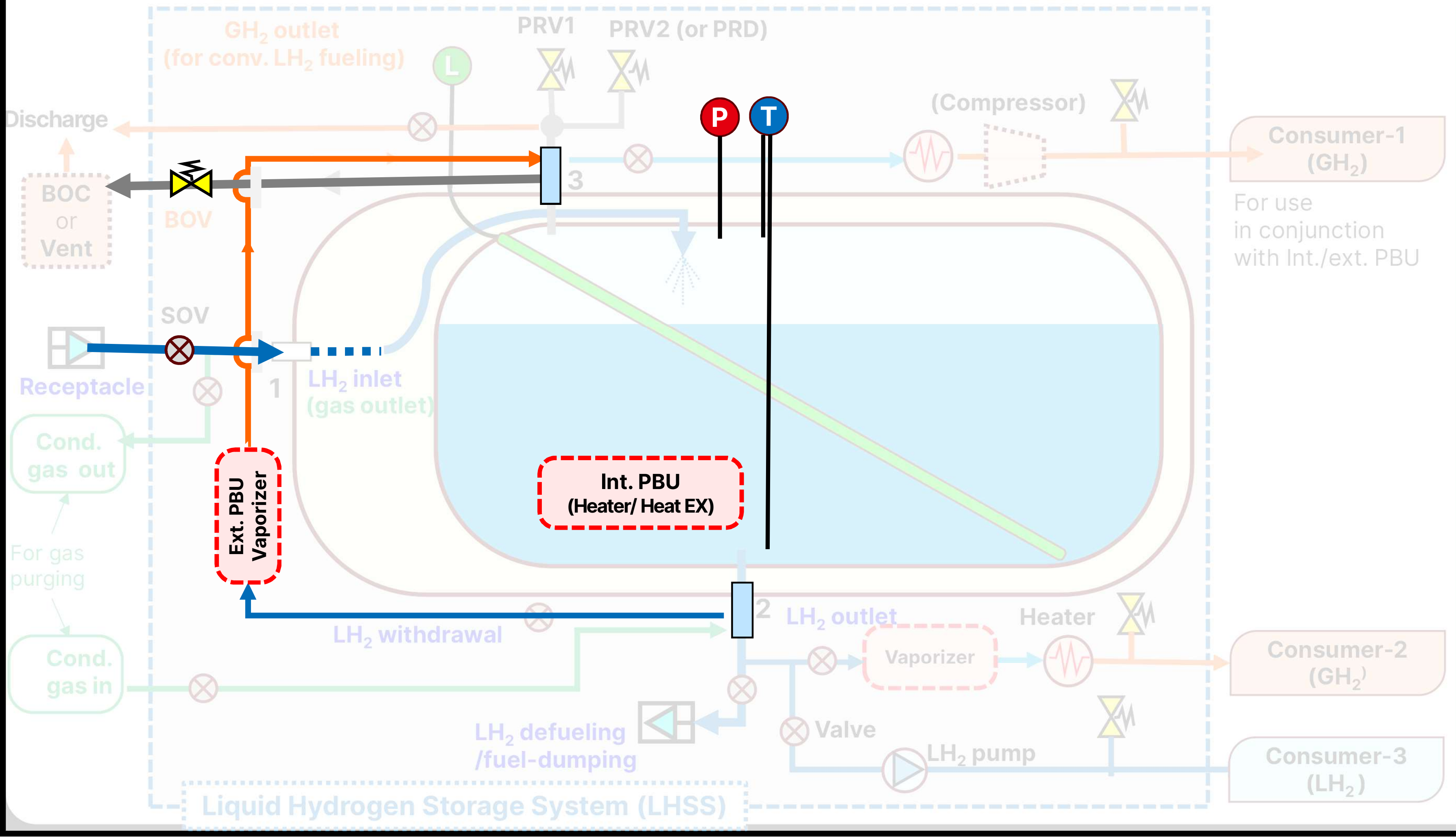
2. ISO 19888-1: 4.1 General requirements

Schematic Diagram of LHSS for Aerial Vehicles (Just for consultation or Comment !!!)



2. ISO 19888-1: 4.1 General requirements

Schematic Diagram of LHSS for Aerial Vehicles (Just for consultation or Comment !!!)



< Gas/Liquid Ports >

1: LH$_2$ inlet

2. LH$_2$ outlet / Cond.-gas inlet

3. GH$_2$ inlet/outlet

< H$_2$ Consumers>

1. GH$_2$ for FC
2. GH$_2$ for FC or Comb. Engine
3. LH$_2$ for H$_2$ Turbine

< Pressure Building Unit>

1. **int. PBU**
2. **ext. PBU**

< Sensors>

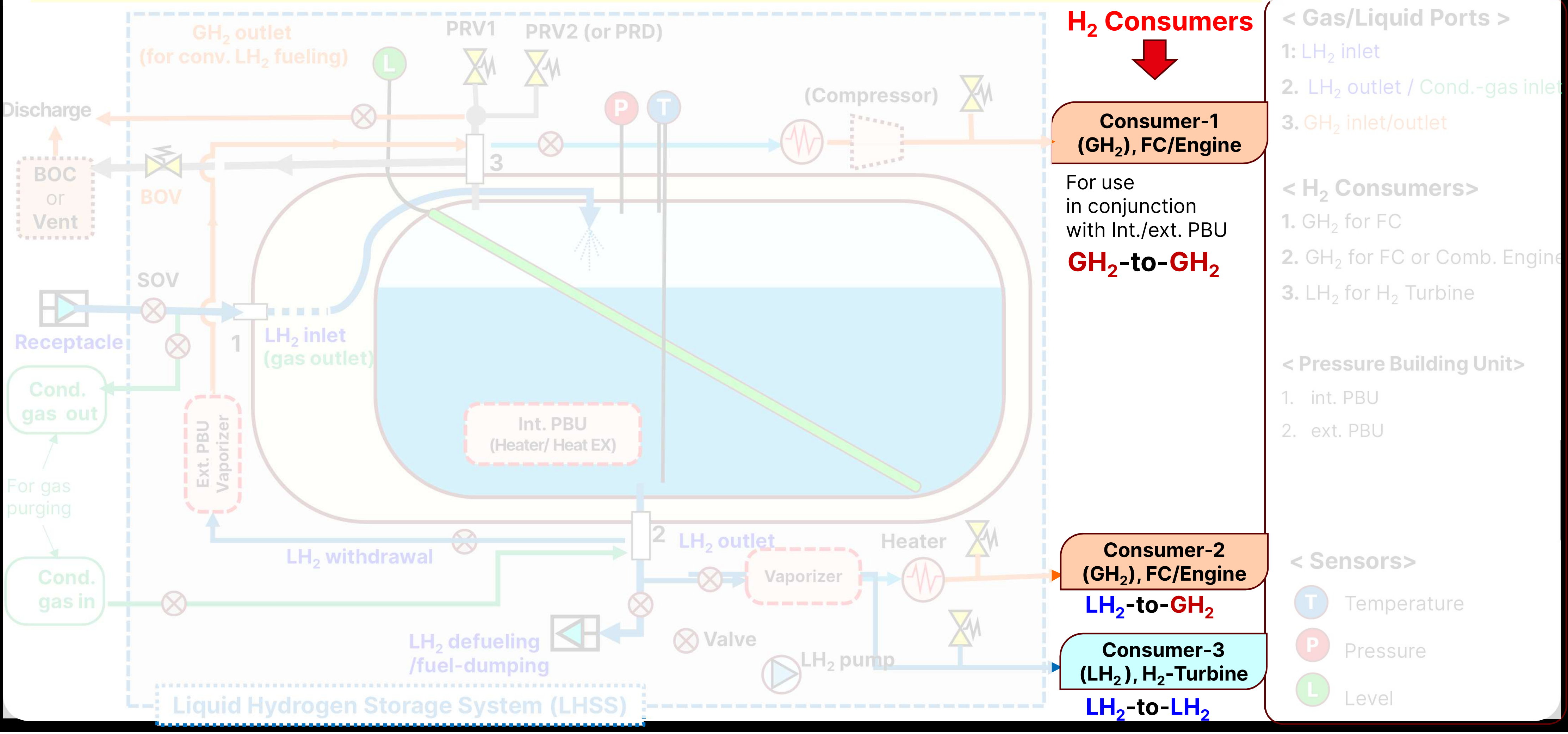
Temperature

Pressure

Level

2. ISO 19888-1: 4.1 General requirements

Schematic Diagram of LHSS for Aerial Vehicles (Just for consultation or Comment !!!)



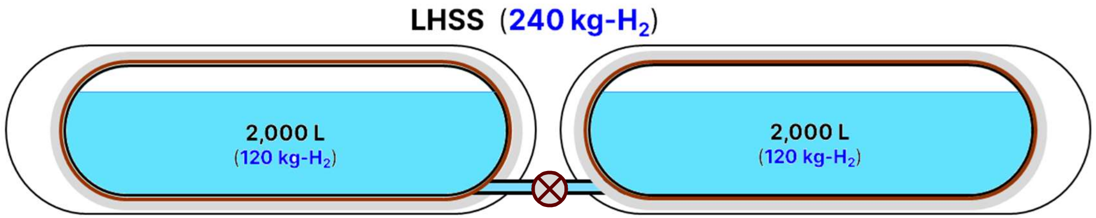
2. ISO 19888-1: 4.1 General requirements

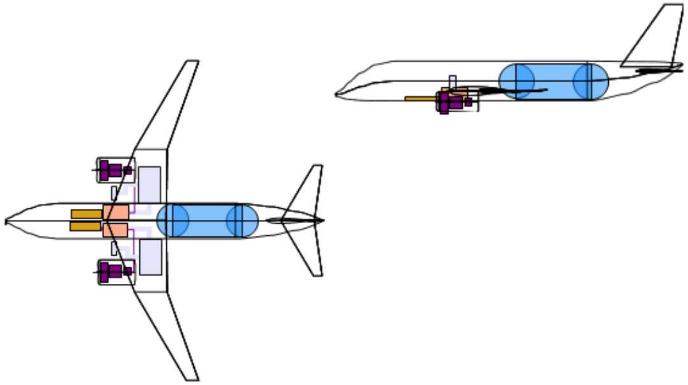
Connection of multiple LHSC's

For
land vehicles
(Daimler Truck)

Fueling is possible through either inlet.

For
aerial vehicles





Fueling through one tank vs individual fueling.

2. ISO 19888-1: 4.1 General requirements

Minimum Holding Time ➔ Short HT(≤ 1 day) is acceptable, if the a/c has the function of defueling

C.1.2 Initial insulation performance test

ISO CD 13985

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The measured holding time shall be ≥ 64 hours.

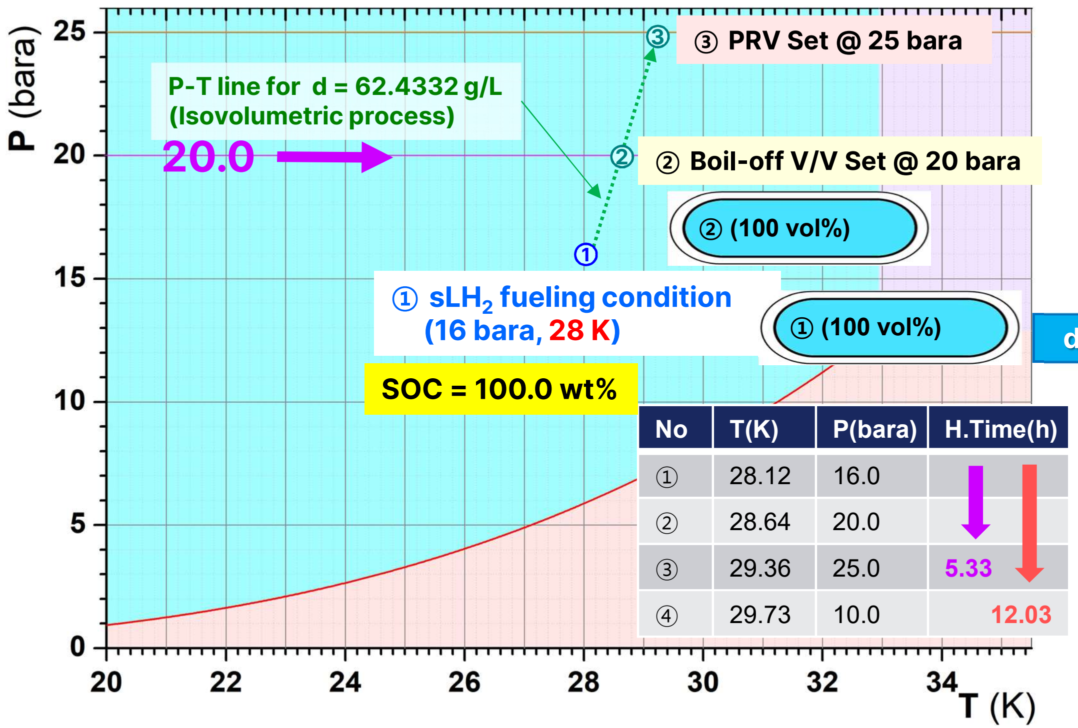
NOTE: This is a minimum requirement as a prerequisite for the number of cycles according to 5.1.1. For a LHSS having this minimum insulation performance the pressure rise during parking can be neglected for

➔ For very small aircraft which has no defueling function ➔ longer HT(≥2 d) is recommended !

2. ISO 19888-1: Hydrogen states and Holding Time (sLH_2 fueling)

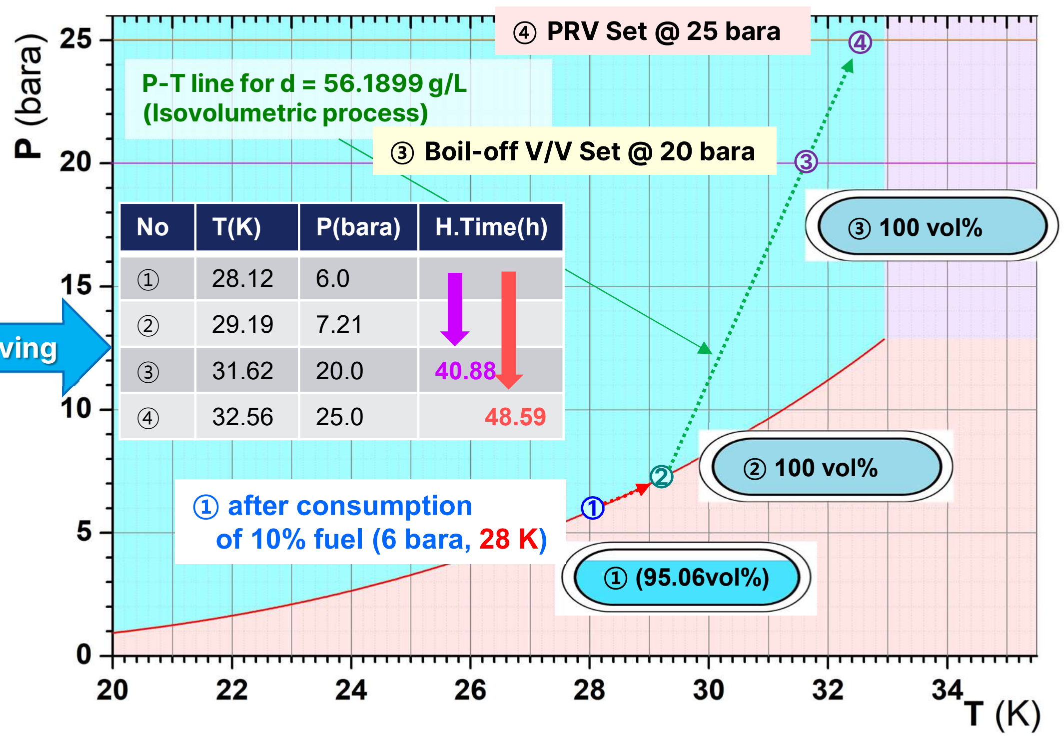
Discussion

sLH_2 fueling : SOC 100% → (driving) → SOC 90%



No	T(K)	P(bara)	H.Time(h)
①	28.12	16.0	
②	28.64	20.0	
③	29.36	25.0	5.33
④	29.73	10.0	12.03

driving



No	T(K)	P(bara)	H.Time(h)
①	28.12	6.0	
②	29.19	7.21	
③	31.62	20.0	40.88
④	32.56	25.0	48.59

ΔU_{12} = U(②) - U(①) = 81.62007 kJ/kg x 47.4492 kg – 77.8596 kJ/kg x 47.4492 kg = **178.43 kJ**

→ HT (20 bara) = 178.43 x 10^3 J / (9.3 J/s) = 19,186 s = **5.33 h**

ΔU_{14} = U(④) - U(①) = 86.34582 kJ/kg x 47.4492 kg – 77.8596 kJ/kg x 47.4492 kg = **402.66 kJ**

→ HT (25 bara) = 402.66 x 10^3 J / (9.3 J/s) = 43,297 s = **12.03 h**

ΔU_{13} = U(③) - U(①) = (129.05 kJ/kg x 42.7043 kg) – (95.1761 kJ/kg x 42.4238 kg + 372.38 kJ/kg x 0.2805 kg = **1,368.81 kJ**

→ HT (20 bara) = 1,368.81 x 10^3 J / (9.3 J/s) = 147,184 s = **40.88 h**

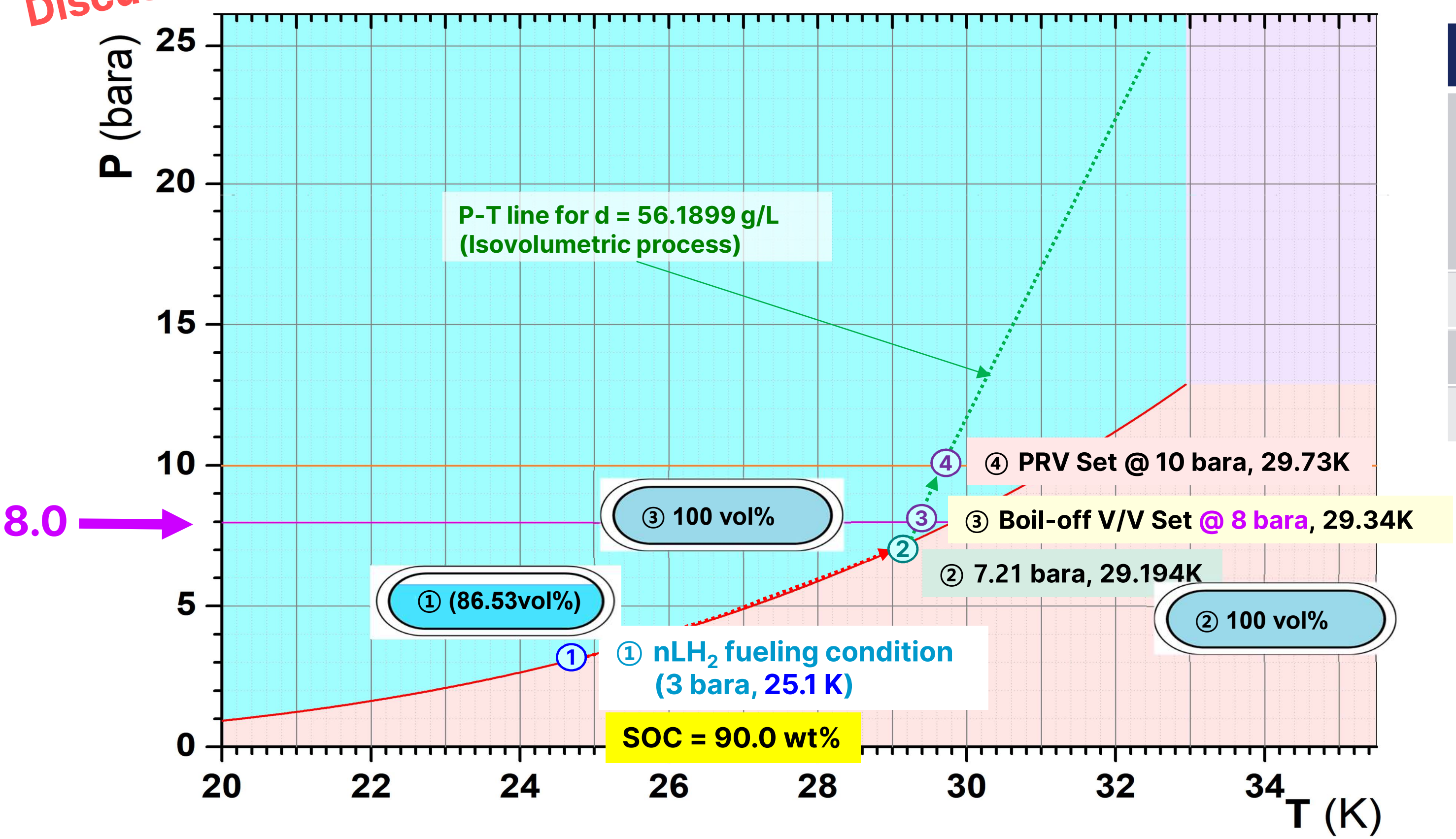
ΔU_{14} = U(④) - U(①) = (135.09 kJ/kg x 42.7043 kg) – (95.1761 kJ/kg x 42.4238 kg + 372.38 kJ/kg x 0.2805 kg)= **1,626.74 kJ**

→ HT (25 bara) = 1,626.74 x 10^3 J / (9.3 J/s) = 174,920 s = **48.59 h**

2. ISO 19888-1: Hydrogen states and Holding Time (nLH_2 fueling)

Discussion

nLH_2 fueling : fueling up to SOC 90%



No	T(K)	P(bara)	H.Time (h)
①	25.12	3.0	
②	29.34	7.21	
③	29.19	8.0	75.42
④	29.73	10.0	78.52

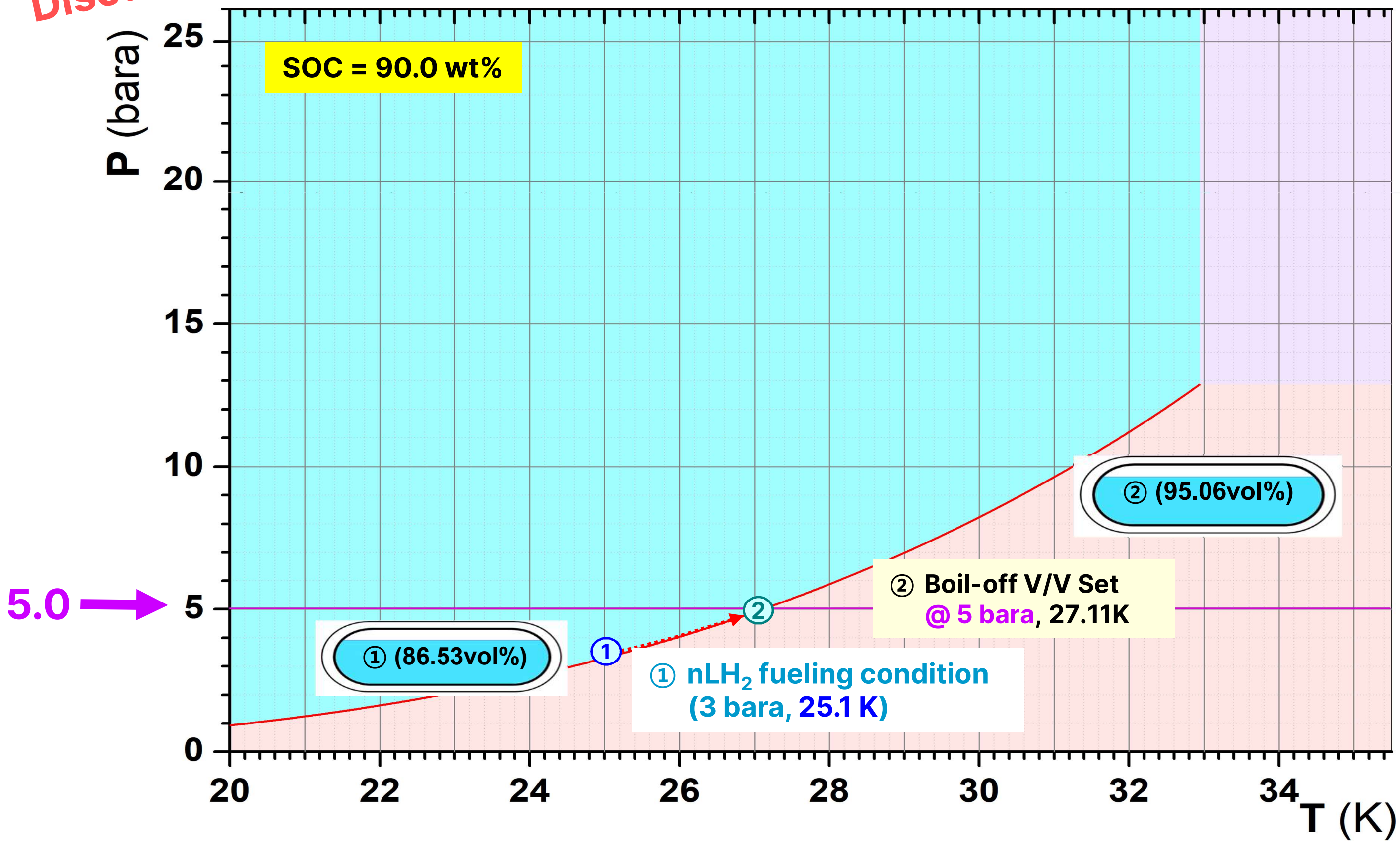
ΔU_{13} = U(③) - U(①) = (114.5254 kJ/kg x 42.7043 kg) – (52.1754 kJ/kg x 42.2828 kg + 378.656 kJ/kg x 0.42148 kg) = 2,525.00 kJ ➔ HT (8 bara) = 2,525.00 x 10^3 J / (9.3 J/s) = 271,506s = 75.42 h

ΔU_{14} = U(④) - U(①) = (116.9547 kJ/kg x 42.7043 kg) – (52.1754 kJ/kg x 42.2828 kg + 378.656 kJ/kg x 0.42148 kg) = 2,626.75 kJ ➔ HT (10 bara) = 3,403.20 x 10^3 J / (9.3 J/s) = 282,661 s = 78.52 h

2. ISO 19888-1: Hydrogen states and Holding Time (nLH_2 fueling)

Discussion

nLH_2 fueling : fueling up to SOC 90%



No	T(K)	P(bara)	H.Time (h)
①	25.12	3.0	
②	27.11	7.21	34.33

ΔU_{13} = U(③) - U(①) = (79.588 kJ/kg x 42.312 kg + 375.873 x 0.3926) – (52.1754 kJ/kg x 42.283 kg + 378.66 kJ/kg x 0.4215 kg) = **3,515.06 – 2,365.72 = 1,149.34 kJ**

➔ **HT (5 bara) = 1,149.34 x 10^3 J / (9.3 J/s) = 123,585s = 34.33h**

2. ISO 19888-1: 4.5 Materials for the inner vessel

Land vehicles (ISO 13985, CD)

6 Material requirements

Sorry !

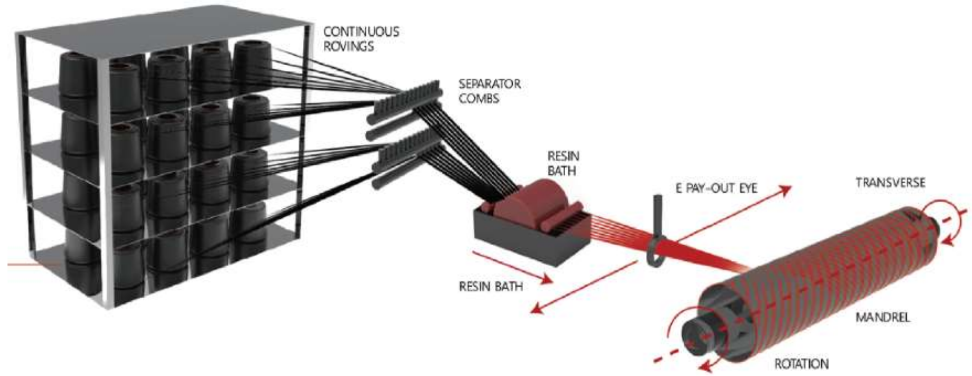
The content of ISO CD 13985 can not be shared until it is published !

Aerial vehicles (ISO 19888-1, WD)

Choice 1. Austenitic stainless steels

Choice 2. Aluminum alloys having enough mechanical strength

Choice 3. Thin metals composited with a structure reinforcing materials (e.g., carbon fibers or glass fibers)

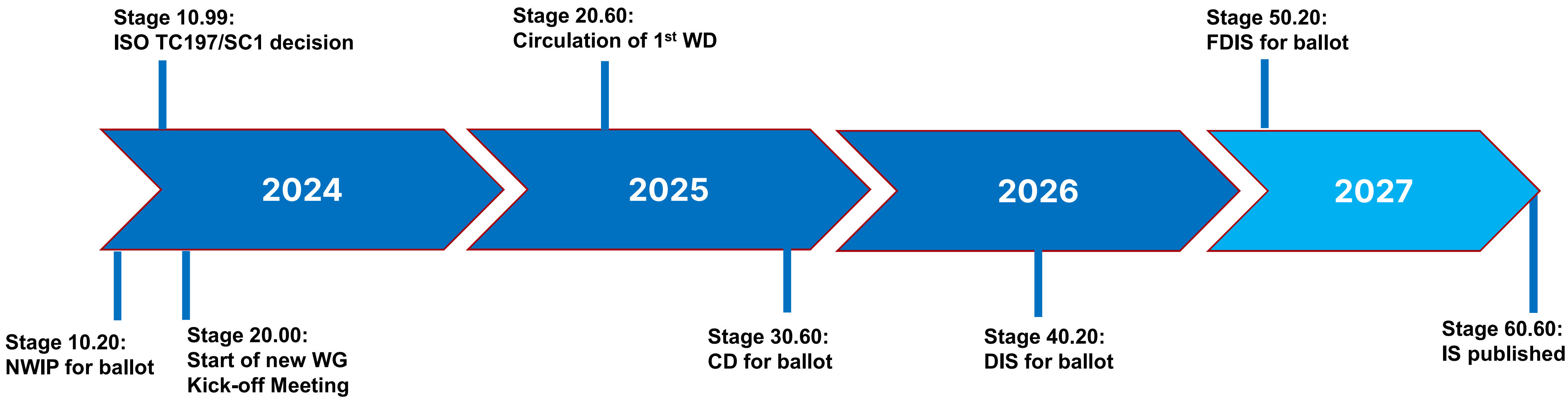


Aircraft LHSS may be in a warm state much more frequently than land vehicles.

➔ Should have enough resistance against stress caused by frequent thermal cycling.

2. ISO 19888-1: Time Plan of ISO AWI 19888-1 (To be changed)

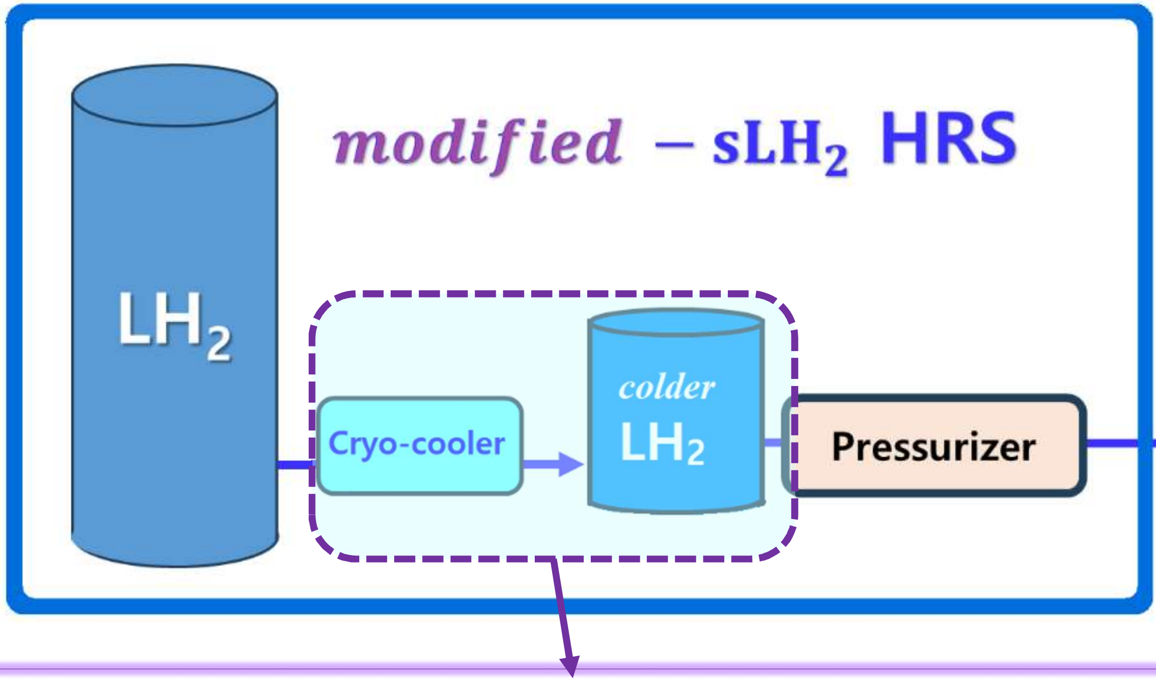
- Total Time for Proposed Standard Development ➔ 36 + 10 months (should receive a CIB approval)
- Project plan (Timeline)



- Reasons for the extension :
  1) To reflect / reference common technical items within the ISO 13985 (will be published in 2026)
  2) To harmonize with the DP003 (of EuroCAE WG80/SAE AE-7F) (will be published in 2026)

"Pre-cooled" sLH_2 fueling is very useful for aerial vehicles

modified - sLH_2 Fueling Protocol (with precooling)



Pre-cooling (2-3K) process prior to Daimler-Linde's sLH_2 fueling process to increase H.Time

※ ***Especially useful for the small aerial vehicles !***

➔ Due to weather conditions, there may often be very long waiting times !

Newly published document, SAE AIR 8466

SAE INTERNATIONAL

AEROSPACE INFORMATION REPORT	AIR8466™
	Issued 2024-11

Hydrogen Fueling Stations for Airports, in Both Gaseous and Liquid Form

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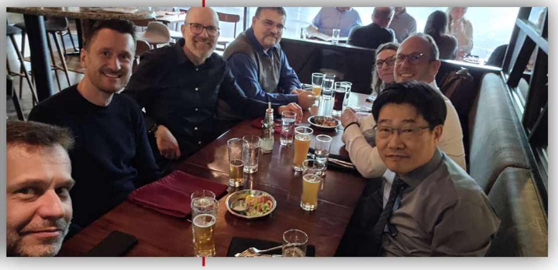
ISO

The 1st TC 197 Joint WG Meeting on LH_2 Technology for Mobility
(9/12-15, 2023 Daimler Truck)

The 2nd TC 197 Joint WG Meeting on LH_2 Technology for Mobility
(4/15-19, 2024 Seoul Global Center).

The 3rd TC 197 Joint WG Meeting on LH_2 Technology for Mobility
(4/7-11, 2025 DVGW, Berlin).



2025-1 Plenary Meeting of EuroCAE WG80/SAE AE-7F (5/6-8, 2025 Vancouver Convention Center).

Thank you.

Making lives ***easier***, ***safer*** and ***better***.

Yong Nam CHOI

Convener *of ISO TC197/SC1/WG2*

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