LH_2 transfer ecosystem, infrastructure and loading procedures



Dissemination Conference
Deborah HOUSSIN (AL)
16.09.2026

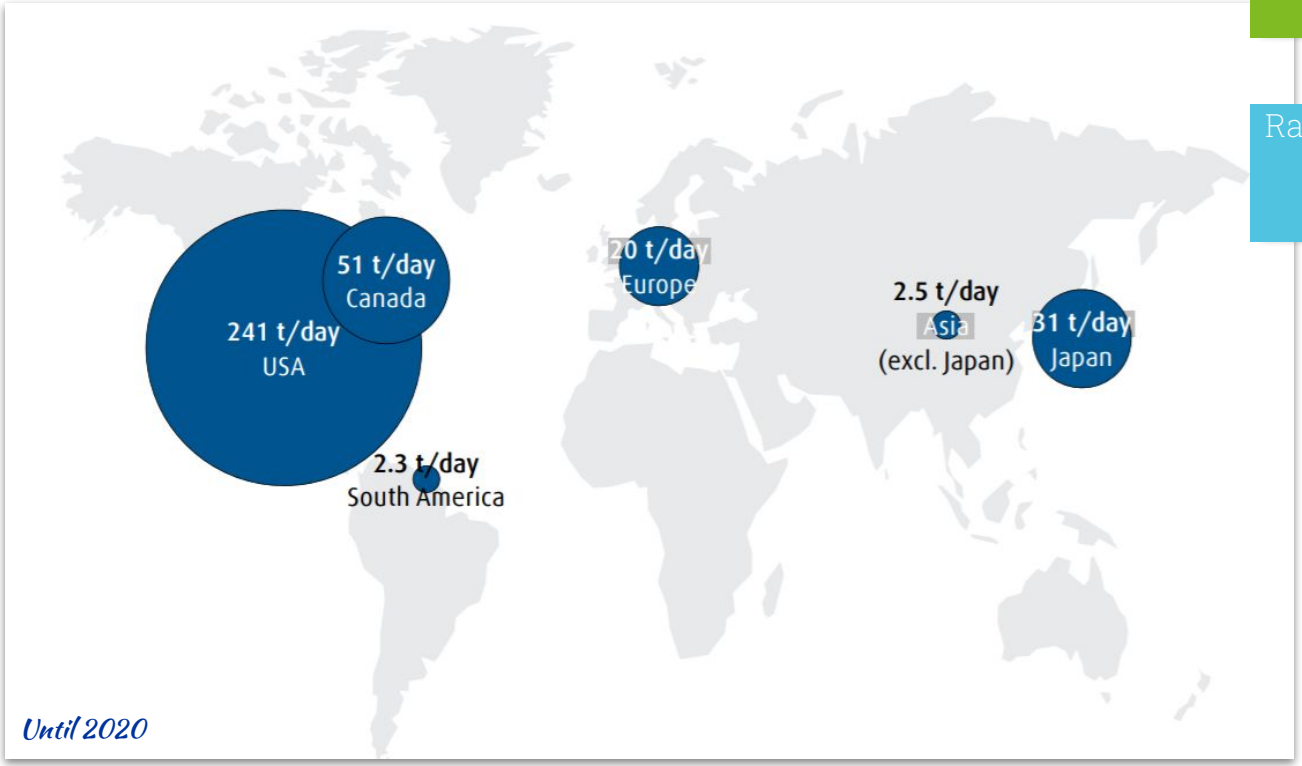
ELVHYS project No. 101101381 is supported by the Clean Hydrogen Partnership and its members. UK participants in Horizon Europe Project ELVHYS are supported by UKRI grant numbers 10063519 (University of Ulster) and 10070592 (Health and Safety Executive)

General information

on LH_2 value chain and motivations

Liquid Hydrogen

Worldwide production capacities



2020

~430 tpd

Ratio LH_2 vs GH_2 prod

0.3%

2026 update

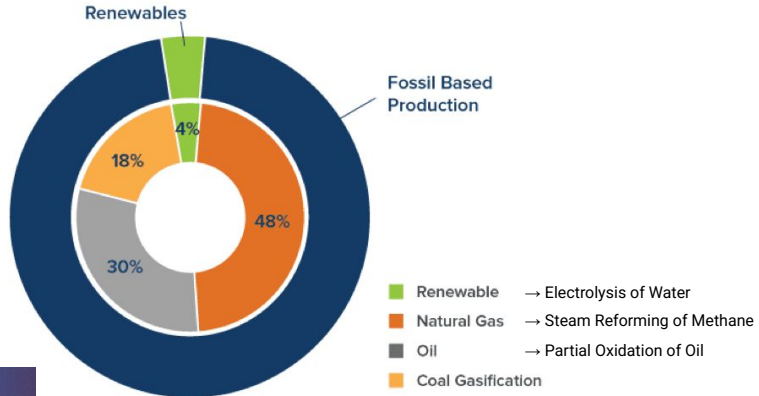
500 to 600 tpd LH_2

- 40-45% USA
- 35-40% Asia
- 10-15% Europe

Worldwide hydrogen production

Quick reminder

- **Hydrogen is mainly produced from fossil fuels**









Clean and renewable production processes now used for low-C hydrogen needs

Low-Carbon H_2 pathways

*tpd = ton per day

$BioCH_4$ Reforming



Electrolysis

Low carbon electricity
DK PEM 1.5 MW 0.6 tpd
Canada PEM 20 MW 8 tpd
Taiwan AEM 25 MW 10 tpd
NormandHy PEM 200 MW 80 tpd



Natural Gas Reforming + Carbon Capture & Sequestration (CCS)

Projects in AL bassins
(Kairos, Antwerp@Sea, Portos,...)
CO_2 shipping OCEOS JV AL-SOGESTRAN

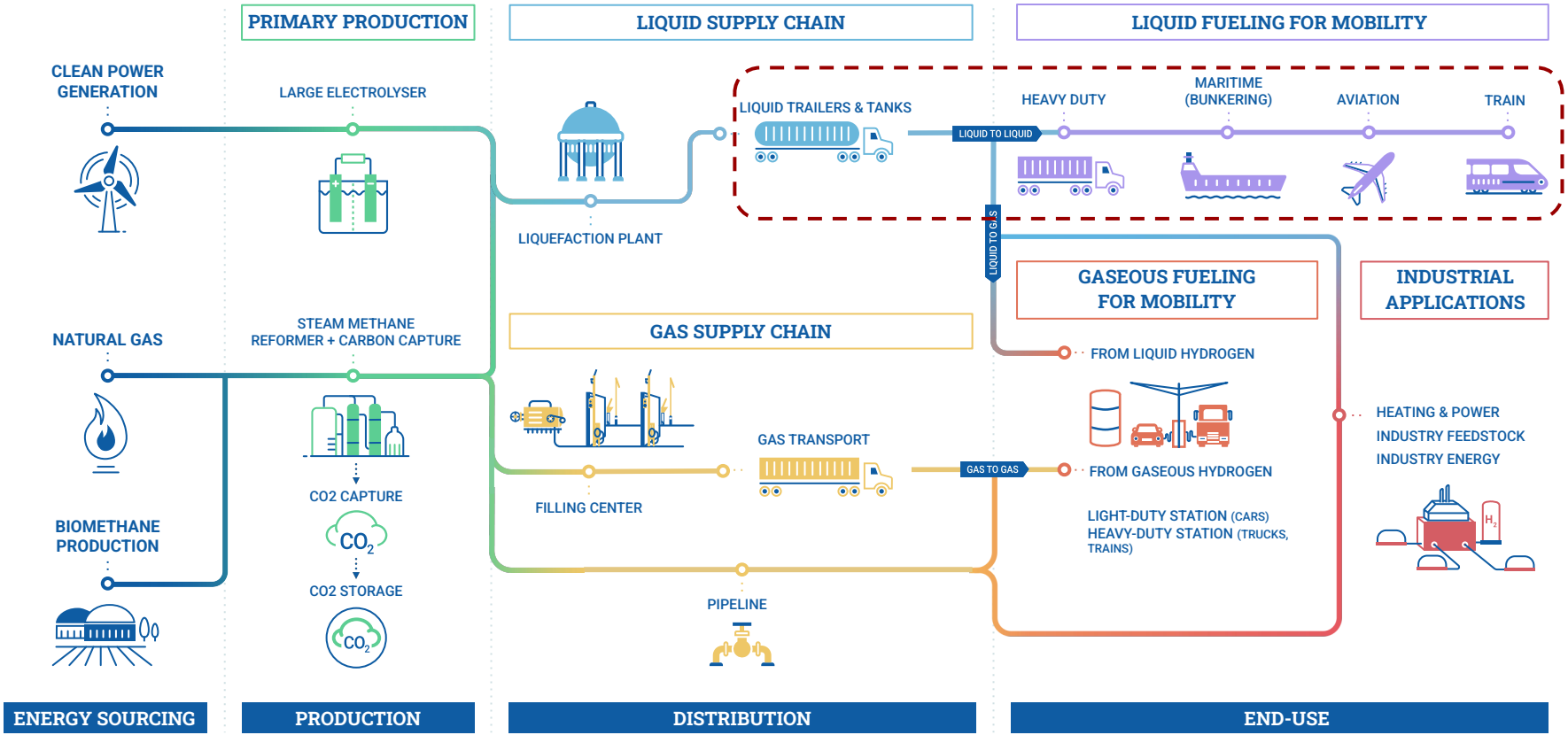


Low Carbon Hydrogen



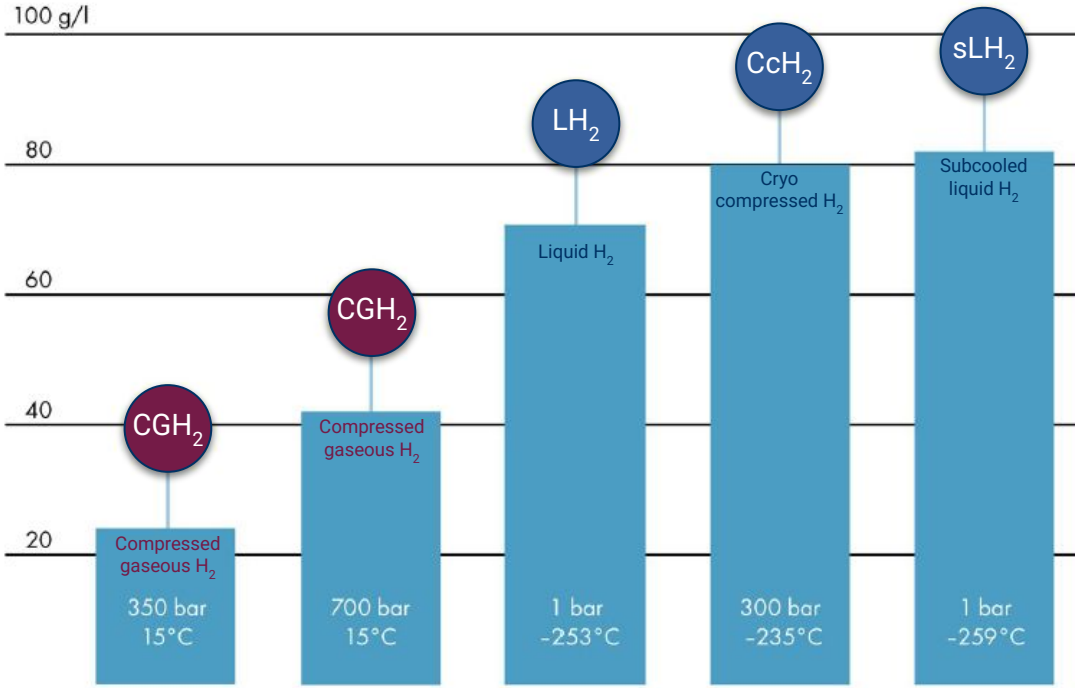
Hydrogen supply chain

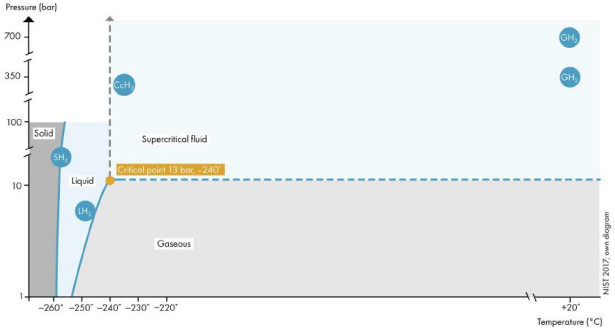
Infrastructure - From Production to End-Users

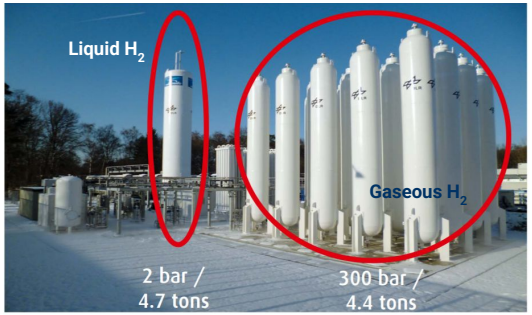


Hydrogen densities

A few numbers







Installation at DLR, Cologne, Germany

Why liquid hydrogen?

Concretely, the benefits

LOGISTIC: MORE VIABLE AT SCALE

LH_2: large amount of H_2 with minimum volume & mass **= minimum storage & transport costs**

Equivalence in usable payload

	#1 LH_2	3.6 t	
=	#3 635 bar	1.1 t	
=	#5 300 bar	0.7 t	
=	#16 200 bar	0.2 t	

Usable payload (swap @ 50 bar for GH_2 trailers) based on 2022 prices for GH_2 in Europe and LH_2 in US

ONBOARD: HIGH POWER DENSITY

LH_2 has a role to play for energy intensive mobility applications **with large quantities of energy onboard**

- **Allowing short refueling time:**
  - Example: **Truck fueling** - 60 kg in 10 min = **360 $kg.h^{-1}$** = 6 times higher flowrate than for H_2 cars

- And **maximum of hydrogen stored in a minimal volume**
  - Example: **Plane Liquid to liquid** - 15 min to refill a turbofan (3.5 tons) = **15 $t.h^{-1}$**

LAYOUT: REDUCED FOOTPRINT

LH_2 for stationary applications

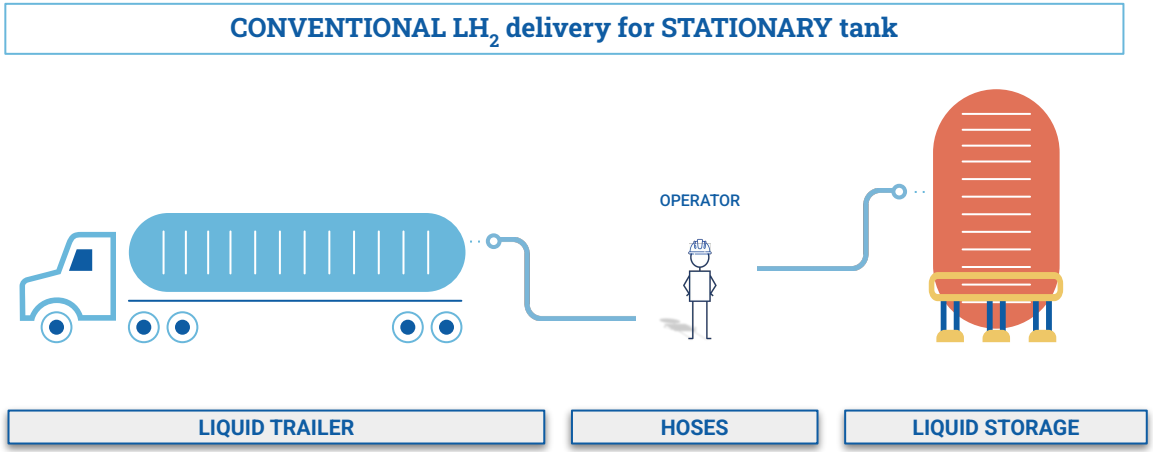
- **Allowing increasing stored amount of H_2 in urban areas where space is limited**
  - Example: Lower footprint (factor 2) for Light Duty FCV refueling stations

LH_2 loading procedures & Ecosystem

Introductive words

Introduction

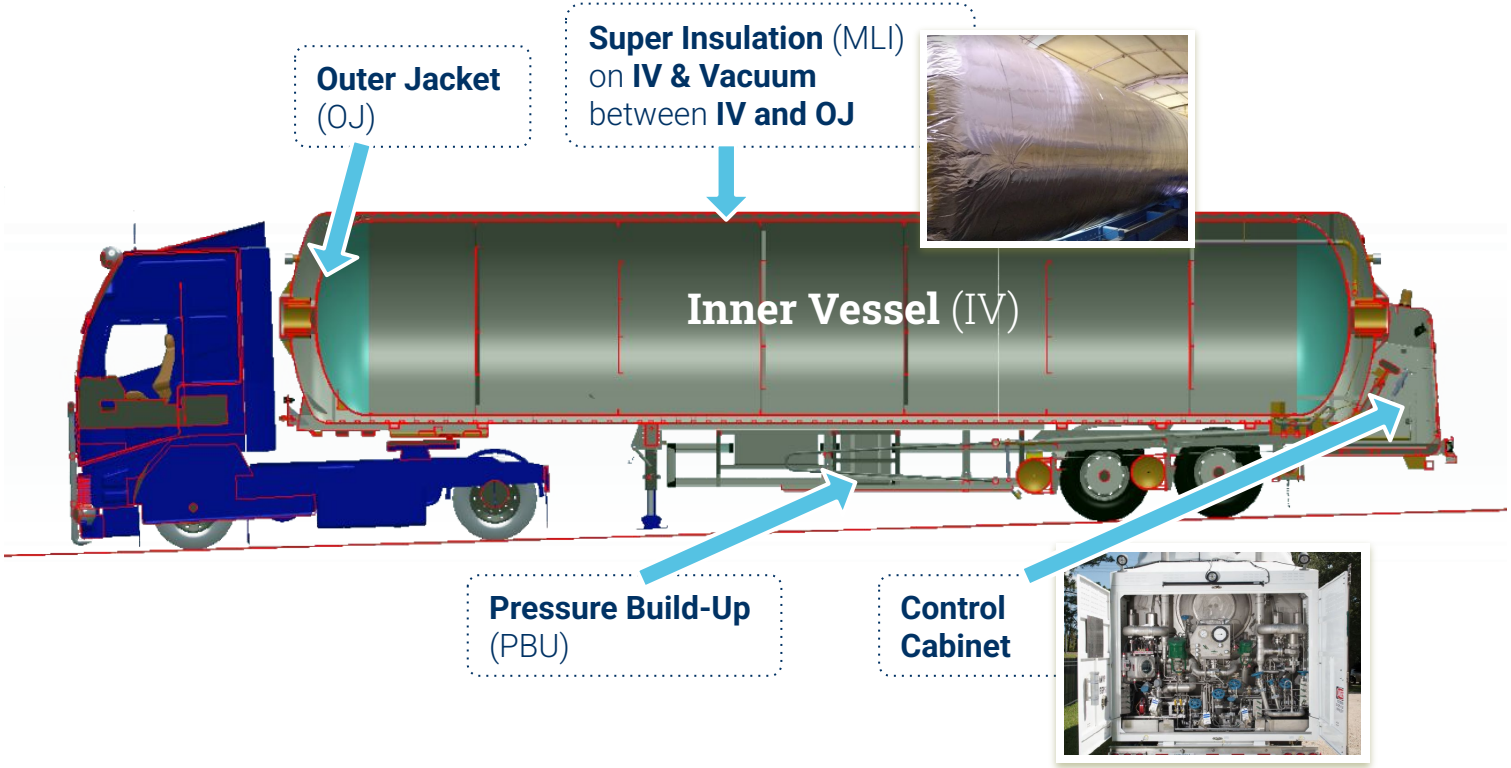
- **Topic**
  - Procedures for LH_2 transfer from trailer to a stationary tank
- **Described procedures**
  - Based on Air Liquide practices
  - Potentially some deviations regarding to the company



About LH_2 trailer and stationary tank

LH_2 trailer - the “mother storage”

Main parts and functions



LH_2 stationary tank - the “daughter storage”

AL technical specifications



Horizontal liquid hydrogen tanks

- 20 to 75 m^3
- 9.9 to 12 barg
- LH_2 capacity up to 4 tons

Technical specifications

	Horizontal storage* RH20 - 143 PSIG / 9.9 BARG (up to 12 barg with PED)	Vertical storage* C56 - 143 PSIG / 9.9 BARG (up to 12 barg with PED)
Range of products	From 20 up to 75 KL (gross tank capacity) for vertical storage and equivalent for horizontal storage	
Total gross tank capacity @ ambient temperature (US Gal / liters)	5,051 / 19,121	14,754 / 55,850
Total net tank capacity @ cold temperature (US Gal / liters)	5,005 / 18,948	13,160 / 49,816
Ullage volume (%)	10	10
LH_2 payload (lbs/ kg) (LH_2 density @ 101 325 Pa)	2,734 / 1,240	7,776 / 3,527
Maximum Allowable Working Pressure (MAWP) (psig / barg)	143 / 9.9 (up to 12 barg with PED)	143 / 9.9 (up to 12 barg with PED)
Normal Evaporation Rate (NER)	< 1% per day	< 0.9% per day
Length (inches / m)	220 / 5.59	147 / 3.73
Width (inches / m)	132 / 3.35	154 / 3.91
Height (inches / m)	119 / 3.02	579 / 14.70
Estimated tare weight (lbs / kg)	22,267 / 10,100	47,180 / 21,400
Design temperature (°F / °C)	-423 °F to +212 °F / -253 °C to +100 °C	
Design code	ASME Section VIII Division 1 / PED Europe Pressure Equipment Directive / Korea Gas Safety certification	

** Datas given for indicative purpose only.*



Vertical liquid hydrogen tanks

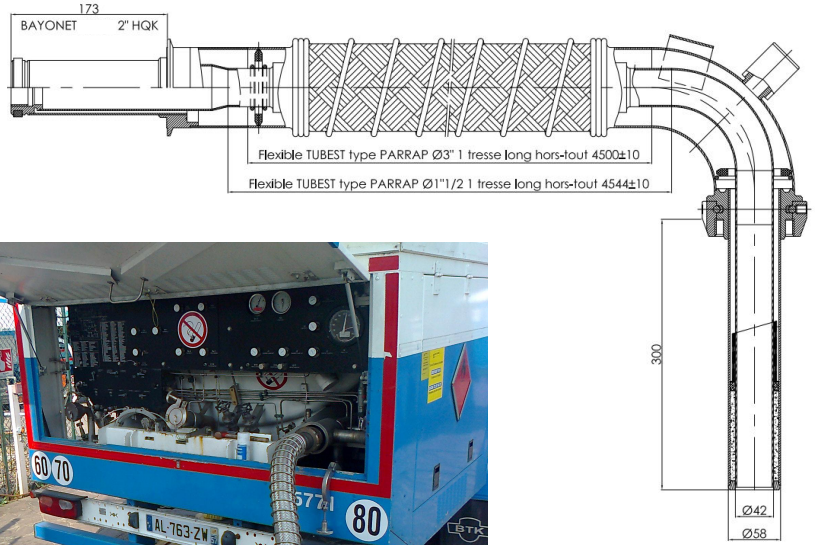
- 44 to 75 m^3
- 9.9 to 12 barg
- LH_2 capacity up to 4 tons

Perlite



LH_2 trailer to stationary tank connection

Insulated flexible hose







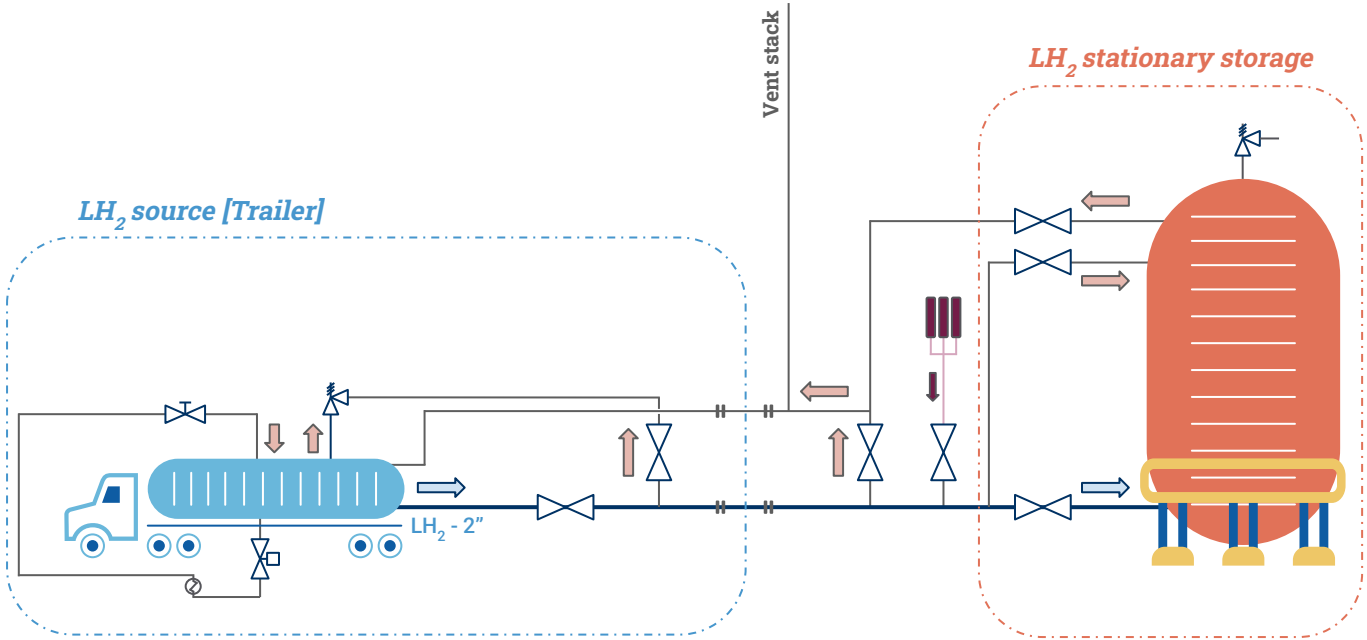
Connection between LH_2 trailer and stationary tank

Simplified P&ID

Principle of LH_2 transfer

LH_2 stationary storage tank filling

Simplified P&ID



SET
1 - Grounding
2 - Connect Lines
3 - Inert Lines - GN_2
4 - Condition Lines - GH_2

FUEL
5 - Pressurize Source
6 - Transfer LH_2
7 - Receiver EOF* Detect

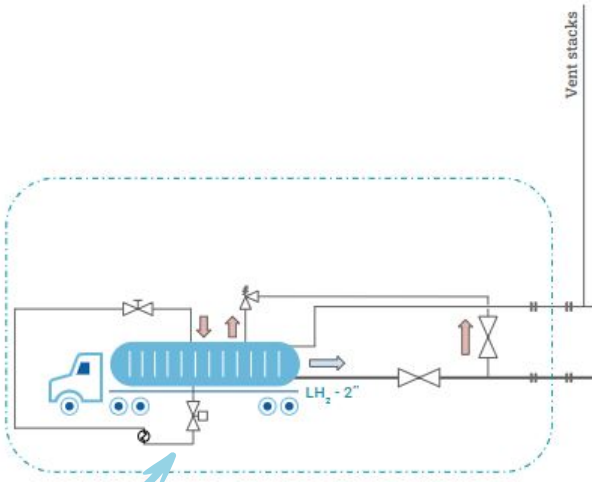
CLOSE
8 - Depressurize Source
9 - Warm-up Lines
10 - Inert Lines
11 - Disconnect

* EOF = End Of Filling

LH_2 stationary storage tank filling

Principle

- **For transferring LH_2 from the LH_2 trailer to a LH_2 stationary storage tank the main method is the pressure build-up**
  - This method is widely used in the gas industry
- **Pressure build-up is "natural" or a voluntary vaporization of LH_2 via a small external heat exchanger (PBU)**
- **Hence, for LH_2 transferring from the LH_2 trailer**
  - The pressure in the "**mother storage**" - i.e. the LH_2 trailer - is higher than the pressure in the "**daughter storage**" - i.e. the LH_2 stationary storage tank
  - LH_2 transfer - driven by the pressure difference - is easy
- **The main drawbacks of this method are**
  - A long operating time
  - And an increase of the pressure in the LH_2 trailer leading sometime to the need of a voluntary and controlled pressure venting
- *Pumping in the "mother storage" using an appropriate transfer centrifugal cryogenic pump is possible, but rarely used for LH_2*



Pressure Build-up Unit (PBU) to pressurize LH_2 in the trailer

LH_2 transfer procedures

In detail, Step-by-Step

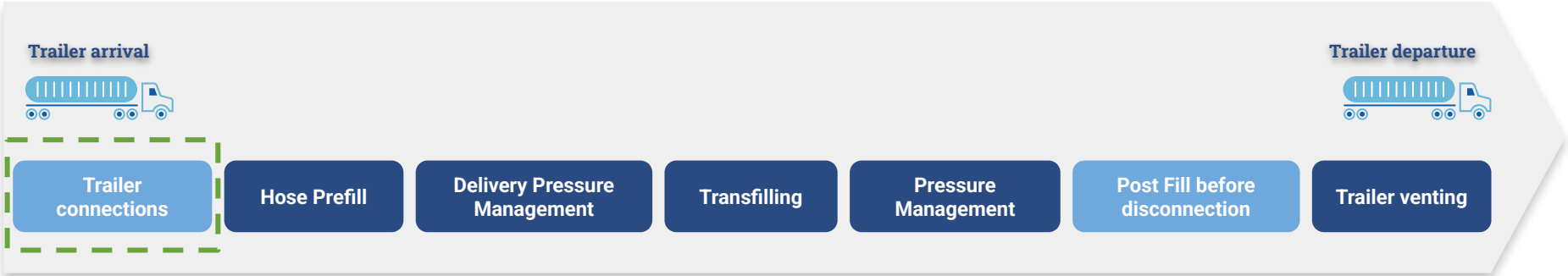
Conventional LH_2 unloading/transfer

Main steps



Conventional LH_2 unloading/transfer

Procedure in detail

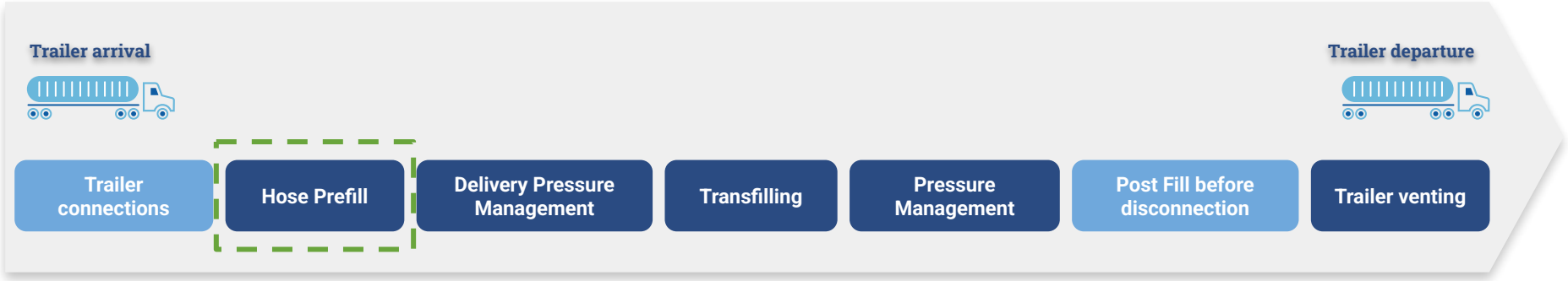


- ***Installation and connection***
  - Block the truck with wheel chocks
  - Switch off the truck battery
  - **Ground** the truck-trailer system
  - **Connect the degassing hose** to the trailer tank and to the degassing **venting chimney**
  - Close road pressure safety valve…



Conventional LH_2 unloading/transfer

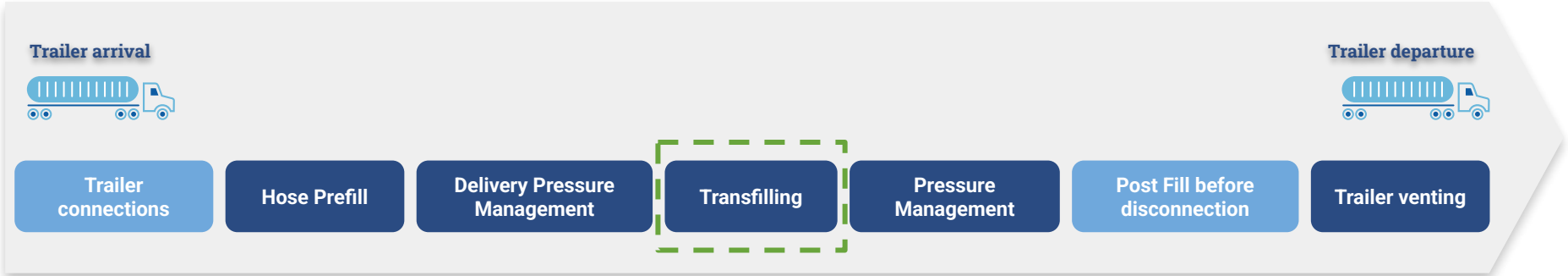
Procedure in detail



- ***Sweeping of hoses before transfer***
  - Close the nitrogen inlet valve after 10 minutes
  - **Open the hydrogen flushing** valve for 2 minutes
  - At the end of the hydrogen sweep, check the tightness, with the explosimeter, of the connections of the liquid hose and local liquid storage
  - Close source of hydrogen sweep

Conventional LH_2 unloading/transfer

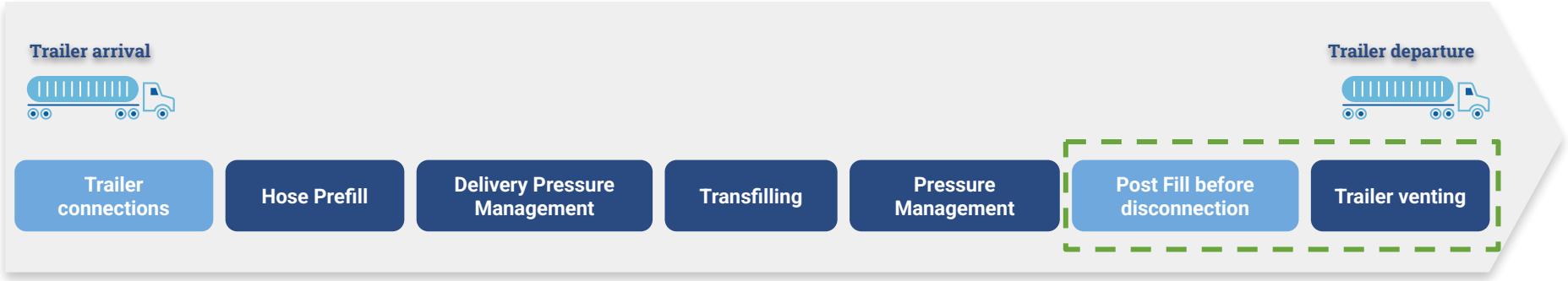
Procedure in detail



- ***Liquid hydrogen transfer***
  - Record and note levels and pressures of the trailer tank and the local liquid storage
  - **Raise the trailer tank pressure by 1 bar above** that of the **local liquid storage** by adjusting the dedicated valves
  - **Open the filling valve of the local liquid storage**
  - **Open the filling valve of the trailer tank**
  - **Maintain the trailer tank by 1 bar above that of the local liquid storage**
  - **Monitor levels**
  - When the local liquid storage level indicator reaches **80%**, put the maximum level bulb into service

Conventional LH_2 unloading/transfer

Procedure in detail



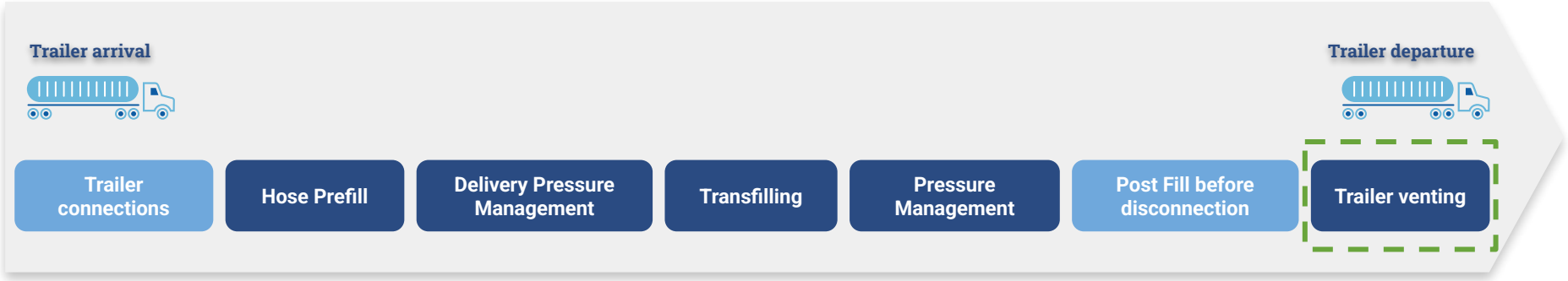
- ***Stopping the transfer***

  When the level marked is reached:

  - **Close** the pneumatic valve on **the trailer tank**
  - **Close the heater supply** valve on the trailer tank
  - **Close** valves on the **local liquid storage**
  - Open the **purge** valve on the trailer tank or the flexible discharge valve on the local liquid storage
  - Record and note pressures and levels of the trailer tank and the local liquid storage

Conventional LH_2 unloading/transfer

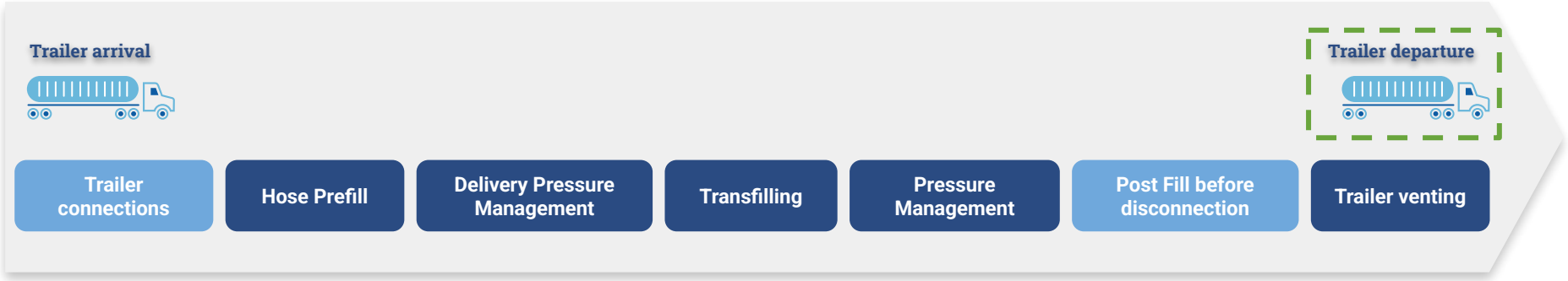
Procedure in detail



- ***Sweeping of hoses after transfer***
  - **Degas the trailer tank up to 2 bar** by opening dedicated valves, then close the valves
  - **Sweep the hydrogen gas transfer hose** from the local liquid storage,
  - Wait 20 minutes, then close valves and the gaseous hydrogen flushing source
  - **Flush the transfer hose with nitrogen**, taking care never to exceed a pressure of 1 bar,
  - When the valve outlet is defrosted, close the sweep nitrogen source

Conventional LH_2 unloading/transfer

Procedure in detail



- ***Preparation for departure***
  - **Disconnect** the nitrogen supply
  - **Disconnect** the liquid hose, cap it and store it in the sheath,
  - Close relevant valves
  - Disconnect the gas hose and store it in the sheath,
  - **Cap** the terminals on the trailer tank and on the local liquid storage
  - **Unplug the earth plug**,
  - **Check** that all **valves are closed**
  - Close the valve boxes on the trailer tank vehicle
  - Resealing of the cryogenic box
  - Check all the points on the specific checklist
  - Remove the wheel chocks

And departure

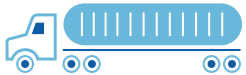
LH_2 transfer

A few additional data

LH_2 transfer

Generic characteristics

Trailer filling



- **Loading of a trailer**
  - Filling center: 8 000 to 10 000 $L.h^{-1}$
    depends on the initial conditions:
    - trailer temperature, level of residual H_2
  - Gravity-based filling
    e.g. 37 m^3 filling in 2h (1 $t.h^{-1}$)
- **Unloading at the customer**
  - 50 $kg.min^{-1}$
    ΔP-based filling

Stationary tank



- **Process**
  - Temperature = 20 to 24 K
  - Pressure = 1 to 10 bara
- **Characteristics**
  - Time: ~ 2 ½ hrs (½ + 1 + ¾)
  - Mass flow: Up to 2 $t.h^{-1}$
  - Losses: 5% (up to 10%)

About safety

Examples of safety features for LH_2 trailers & stationary storage tanks

LH_2 trailers

What	Where	For what
Two safety valves with at least one pneumatics	Tank	According to ADR, during transportation all storage are isolated by a valve
Road safety valve	Tank	Evacuate overpressure
Rupture disc	Tank	Avoid burst of the storage in case of pressure increase
PRD	Tank	Limit the risk of boil-off



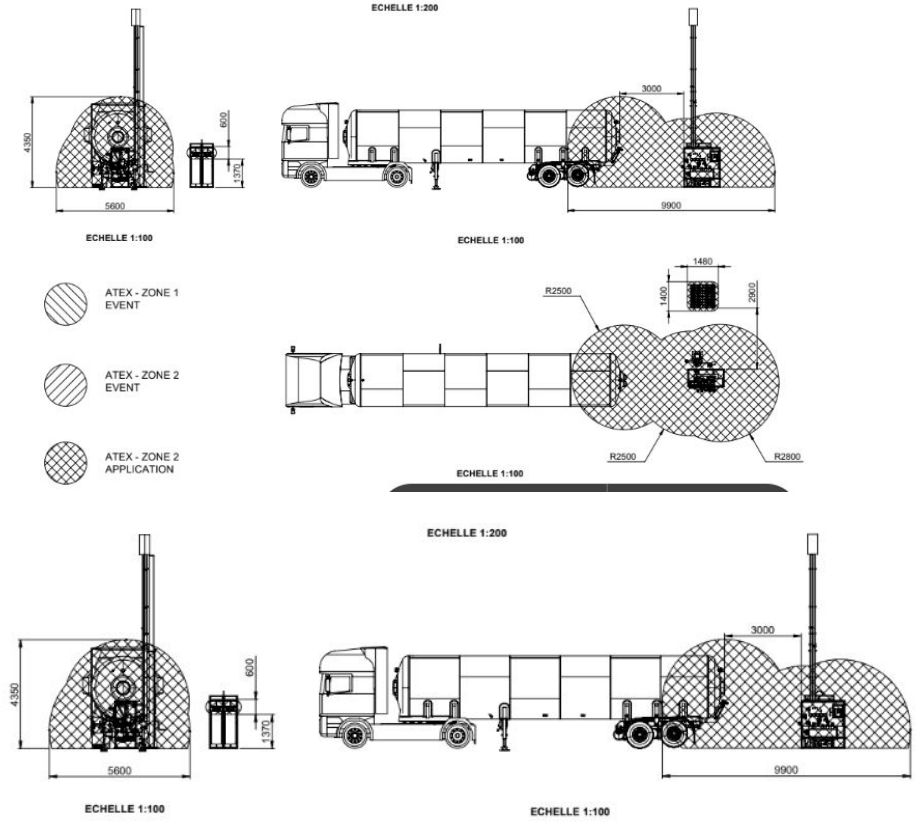
LH_2 stationary tanks

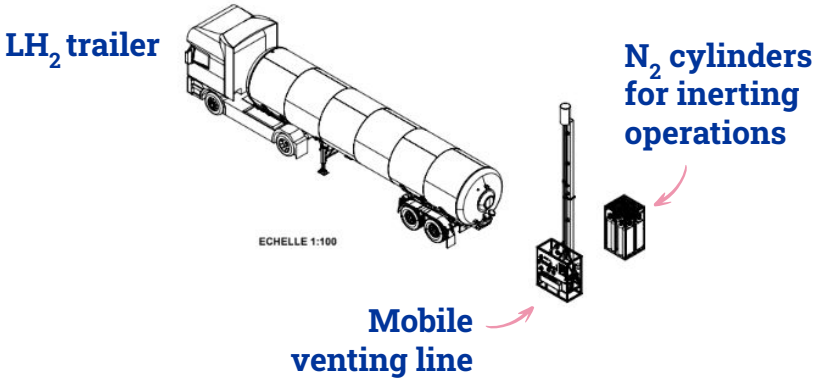
What	Where	For what
Pressure and temperature monitoring	Tank	Detect insulation default
Level monitoring	Tank	Avoid overfilling
Rupture disc	Tank	Avoid burst of the storage in case of pressure increase
PRD	Tank	Limit the risk of boil-off

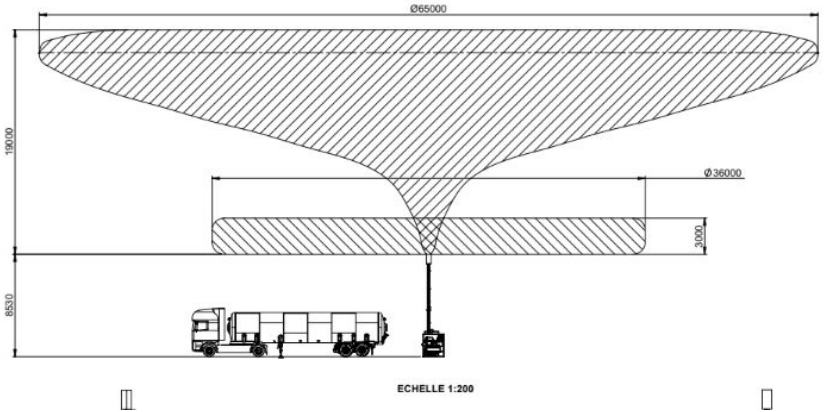


LH_2 trailer

About ATEX zoning for safe transfer operations







LH_2 for heavy duty vehicles

Examples

LH_2 applications

LH_2 system for mobility - Trucks





Musashi-9 LH_2 truck Musashi Institute of Technology (Japan)

H_2-powered engine with a 150 L LH_2 tank
A high pressure LH_2 pump delivers fuel to ICE



Mercedes FC truck GenH2 concept with LH_2 storage

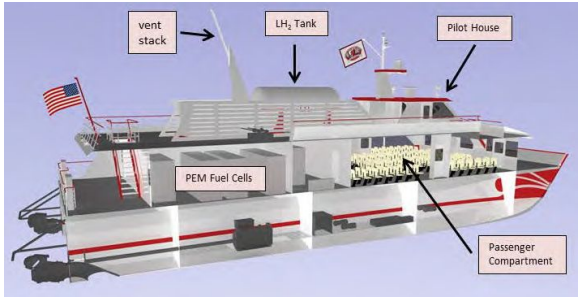
Total output of 300 kW with 2 FC stacks
1000 km on a single tank filling recently demonstrated

Q4 2026 →

Daimler Truck AG
sLH_2-FCEV "NextGenH_2-Truck"
50-vehicle testing fleet

LH_2 applications

LH_2 system for mobility - Ships



- **SF-BREEZE**
  - A zero-emission, H_2 fuel cell, high-speed passenger ferry (California)
  - Designed for 150 passengers - 100 km / day at a top speed of 35 knots (~65 km/h)
  - 1,2 t of LH_2 are stored in a single tank installed on the roof
  - 41 PEMFC racks (4 x 30 kW FC stacks) ⇒ 4.92 MW



- **NORLED HYDRA ferry**
  - Power is provided by two 200-kW fuel cell modules
  - The LH_2 tank (3.8 t) will be installed on the roof

- **TOPEKA prototype FC ship**
  - Starting in 2021 the EU project HySHIP with 14 partners and led by the Norwegian shipping operator Wilhelmsen
  - Equipped with a 3 MW PEM fuel cell stack and supported by a 1 MWh battery pack
  - On-board single LH_2 tank (6 t installed on the roof)



- **And on-going projects…**

LH_2 ship

Information from NORLED

A few data

- The energy stored in batteries onboard, without charging them at every port stay, will last for **4 hrs** before (practically) empty.
- The route can be operated by fuel cells, with batteries only used for peak-shaving (acceleration loads).
- The energy stored in the LH2 storage system onboard can operate the ferry for **13 days** when running on fuel cells alone.
- M/F Hydra sailing at route speed (in a straight line without stopping), a distance of > **1000 nm** can be covered on one full LH2 tank.

On-board LH_2 storage tank: 80 m^3
1000 nm ⇋ **1800 km**
nm = nautical miles

LH_2 bunkering

- DSB approved Norled bunkering operations
- Full system approach for LH_2 transfer by Linde
- All transfer pipes double-wall, vacuum insulated
- 3 tons per hour transfer rate
- Pre-cooling prior to bunkering for fast and efficient bunkering operations
- Quick-connect coupling with break-away function, allowing connection at cryogenic conditions
- No H_2 release during bunkering
- Keeps warm-low-pressure hydrogen in pipes between two bunkering operations, to avoid purging and releases.
- Moveable tower, moves from quayside to storage area
- Loading arm used to connect the onshore bunkering system to the ship's LH_2 fueling system



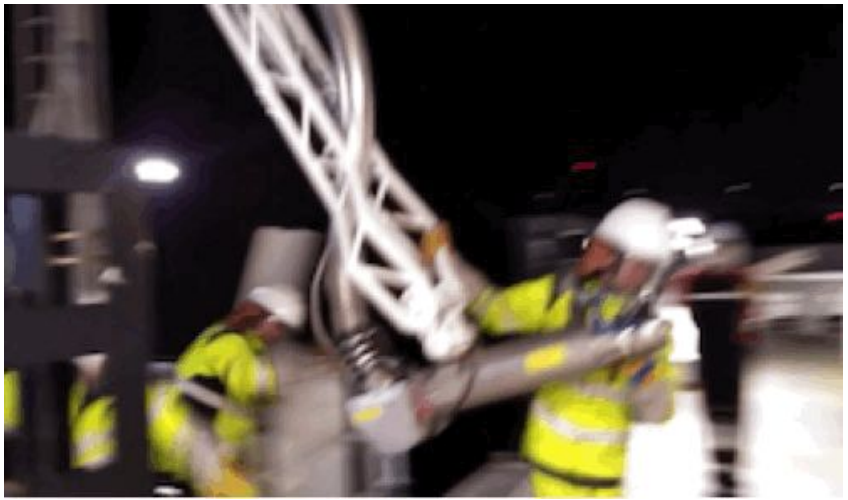




LH_2 ship

Connection operation for fueling





Loading arms with Quick-Coupling
for fueling the Hydra ferry (Norled bunkering operation)

LH_2 transfer

Additional safety considerations & Potential improvements

Conventional LH_2 unloading/transfer

Remarks

- **Slight changes can appear depending on the type of the liquid hydrogen trailer and on the local liquid hydrogen stationary storage**

- **Nevertheless, as shown through the main steps of the unloading of liquid hydrogen from the liquid trailer to a local liquid hydrogen storage, the transfilling requires lots of manual actions and checking operated by the driver alone**

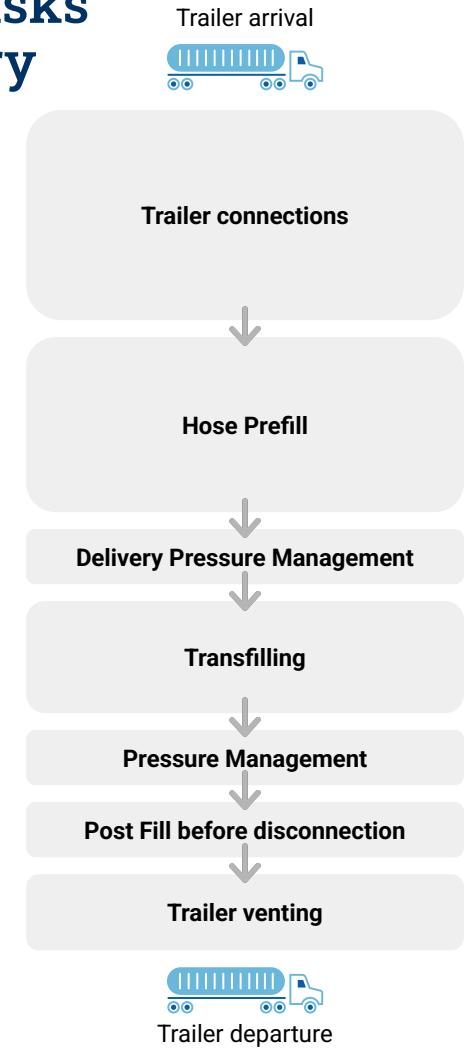


Main safety risks during delivery

Root causes Focus on 2 areas:

INTERFACES
Site configuration, safety rules

PROCEDURE
Human factor



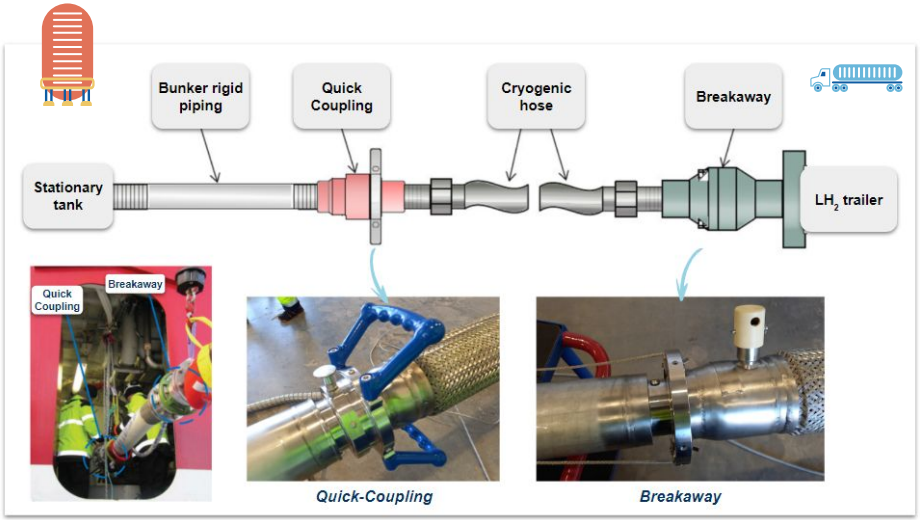
POTENTIAL RISK	EXAMPLE OF SCENARIO
External fire	Trailer Emergency Shut Off (ESO) not connected to site, fire & detection system
Loss of utility	Instrument air supplied from brake circuit instead of point of delivery
Ignition source	Grounding failure
Small leakage	Hose coupling failure
H_2/O_2 mixture	Wrong purge of the hose
Large release	Automatic valve opening when hose disconnected
High pressure	Trailer delivery pressure above receiver tank pressure
High level receiver tank	Overfilling
Large release	Hose rupture
High pressure trailer	Forget closing Pressure Builder Unit before departure
Large release	Residual LH_2 in hose when disconnecting
Unsafe venting	Trailer vent stack used instead of customer vent stack

Ref: AL - 2023 CHS Conference, Rotterdam

Safety of LH_2 unloading and transfer

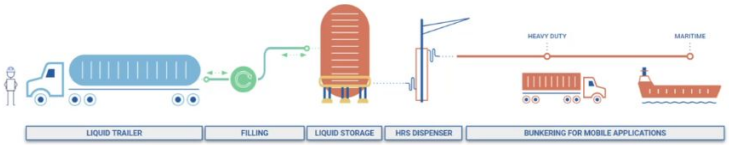
Example of feature for safer transfer operations

- **Some improvements are under development in order to deploy safer filling aiming - for instance - to decrease the likelihood of non respect of the procedure**
  - **Advanced monitoring** and more **automated procedures**
  - **Equipment** is a part of the solution as well



- In fine, **experimental** and **modelling investigations** can bring valuable information for **procedures improvement/optimization** for **safety**, **efficiency** and **limit losses**

Conclusions



- **Good practices, protocols and associated safety feature developed through the years for conventional usages industry-oriented**
- **But now, Diversified usages, New tanks (volume, shape, conditions) in New environments requiring adaptations**
  - **Associated needs are:**

Development of semi-automatic delivery in public area with LH_2 trailers	Loading/unloading guidelines and advanced procedures	Safety rules minimum requirements and guidelines for interface panels *(e.g. interoperability of delivery)*	Standardization workgroups intensification

In this way, ELVHYS project outcomes will contribute to meet these challenges and help provide solutions for Safer and Smarter LH_2 transfer

Thank you for your attention

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Clean Hydrogen Partnership

UK Research and Innovation

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