Liquid Hydrogen Distribution Technology

HYPER Closing Seminar

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Brussels, December 11, 2019

Making our world more productive

Agenda

1. Linde's Product & Service Portfolio for Liquid Hydrogen Distribution
2. LH_2 / GH_2 Distribution and Storage
3. Linde manufacturing - LH_2 Products
4. HRS - LH_2 Fueling Station
5. Conclusion & Outlook

Linde's Hydrogen Value Chain for H_2 Mobility

Linde Covers the Full Value Chain!

Production

Conventional (e.g. SMR)

Renewable (e.g. electrolysis)

Onsite electrolysis

Distribution & Storage

LH_2 liquid hydrogen

LH_2 route

CGH_2 Compressed gaseous hydrogen

Liquefaction

H_2 Fueling Stations

Cryopump

Ionic compressor

Boil-off mgmt. system

Dispenser

Infrastructure & Vehicles

Out of one hand Reliable operations of H_2 supply and fuelling equipment to a range of mobility applications

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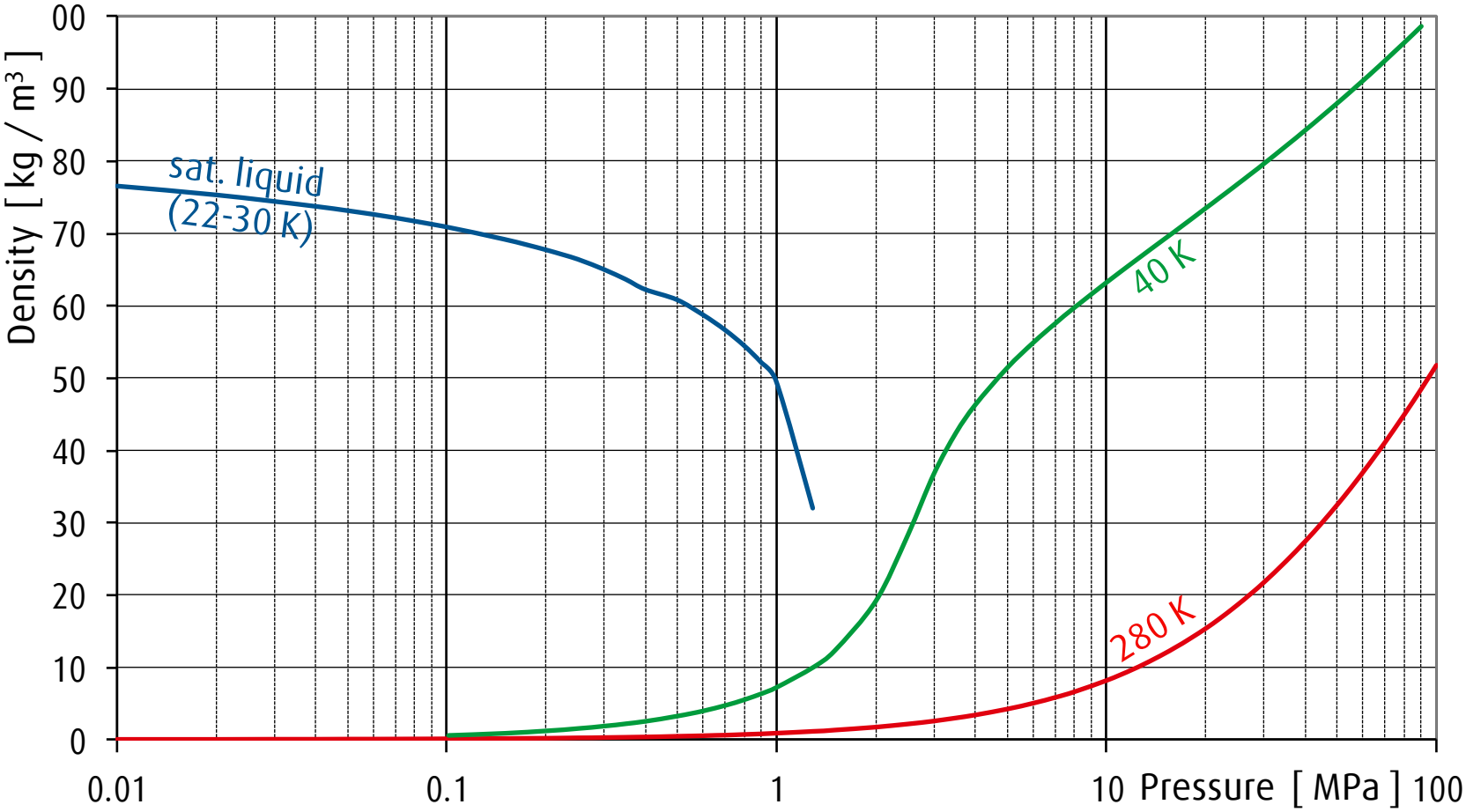
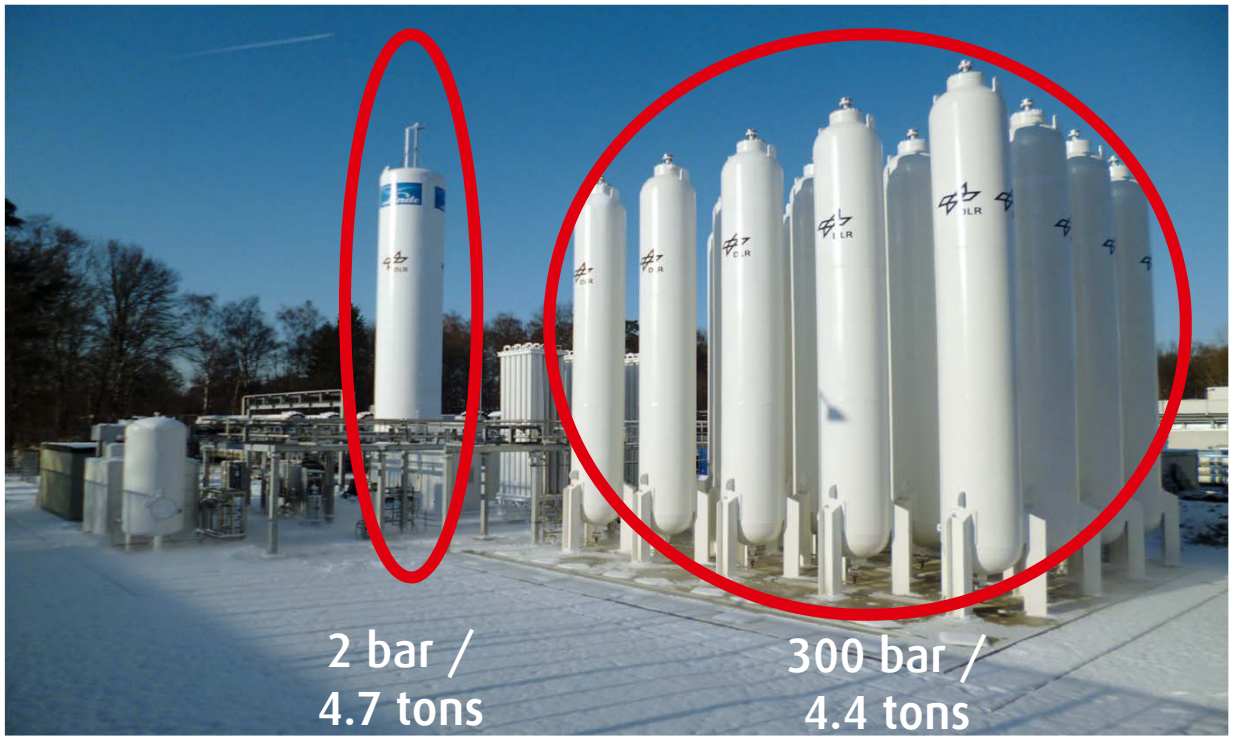
Physical properties of hydrogen

Transport & storage – density differences



Liquid and gaseous hydrogen
Comparison of energy density

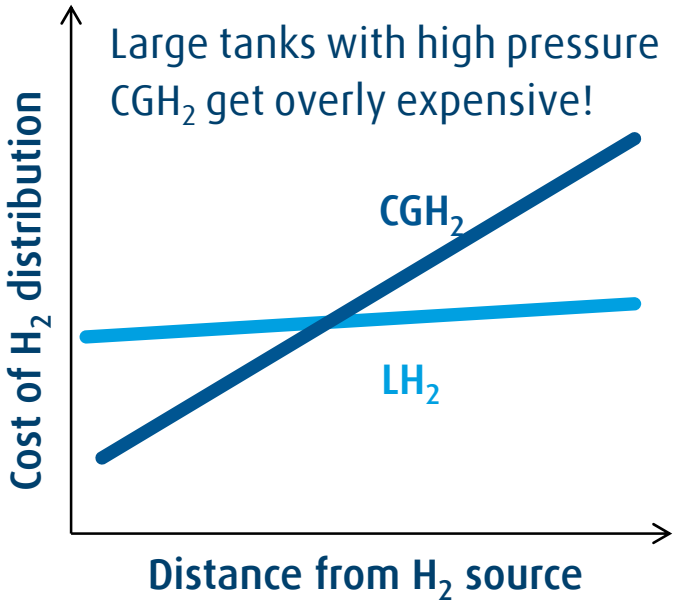


Installation at DLR, Cologne, Germany

- Hydrogen in its liquid form allows a significant reduction of the storage footprint!
- Total weight of the equipment and supporting structures are equally reduced.
- Rule of thumb: gaseous hydrogen requires 4 time more footprint than liquid

➔ Where size & weight matter, liquid Hydrogen offers benefits.

How to supply Hydrogen?
LH_2 versus CGH_2



consumer	close <250 km	far >250 km
small	CGH_2	CGH_2 / LH_2
large	CGH_2 / LH_2	LH_2

"Small consumer" means:
~100-200 kg/day

© Norled, ferry boat

Liquid and gaseous Hydrogen
Comparison of logistical aspects

Method	Facts	+ Pros	- Cons
CGH_2 Trailer	- Transport at 20MPa & above - Capacity: ~900kg - Time to fill: 4 hours - Time to off-load: 45 minutes (tube trailer swap!)	- Economical transport for short to medium distances	- Comparatively low capacity (high delivery frequency) - Comparatively large on-site footprint - Residual gas in trailer (=waste) the higher the pressure in the supply chain, the higher the amount/tonnage of CGH_2 in circulation!
LH_2 Trailer	- Transport at -253°C - Capacity: ~4,000kg - Time to fill: 4 hours - Time to off-load: ~1.0 hour	- Economical transport for medium to long distances - Comparatively small footprint	- Comparatively high energy demand (~10kWh/kg for liquefaction) - Some liquid needs to remain in the distribution equipment to keep it cryogenic cold during return to the LH_2 source! ➔ usable volume: ≤ 90%
LH_2 Container	- Transport at -253°C - Capacity: ~3,000kg - Time to fill: 3 hours - Time to off-load: ~0.5 hours (container swap!)	- Economical transport for medium to long distances - Comparatively small footprint, - By remaining at customer site, 1x LH_2 transfer can be avoided ➔ less boil-off! - Overseas transport possible - Longer holding times possible (LIN shield)	

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Linde Engineering, Schalchen Plant in Germany

The Manufacturing Facility for Cryogenic Equipment!

- Location: about 100 km east of Munich
- 25 workshops, large indoor manufacturing area (~65,000m^2)
- All necessary disciplines available: engineering, sales & production, etc.
- High-quality materials only: Aluminum & Stainless Steel

Linde Manufacturing – Product Portfolio

Vast experience in the field of cryogenic plant equipment!

Custom engineered Products

Brazed Aluminum HX & Cold boxes

Coil-wound HX

Standardized Products

Spirally-welded Aluminum Pipes

HELICS™ & HYLICS™

Vaporizers

Cryogenic Storage Tanks

Liquid Hydrogen Tanks – Examples
Design for Industrial Applications

Key Data

- Inner volume: **71 m³ (references up to 270m³)**
- Design pressure: **12 bar(g)**
- Storage capacity: **4,600 kg LH_2** (1bar, 5% ullage)
- Vacuum-perlite insulation
- Integrated cryogenic valves
- Designed for industrial applications with high demand (electronics, chemical, etc.)
- Horizontal & vertical design

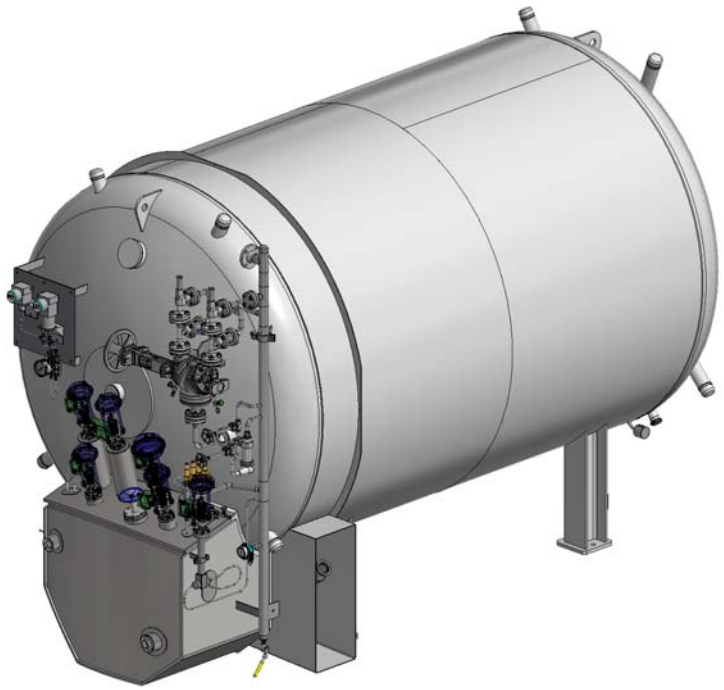
Performance

- Boil-off ratio: **<44 kg/day** (<0.95%/d)

Applications

- Typical industrial applications with high Hydrogen demand

Liquid Hydrogen Tanks – Examples
Optimized Design for Fueling Stations



Key Data

— Inner volume: **11.5 m^3**

— Design pressure: **6 bar(g)**

— Storage capacity: **900 kg LH_2** (1bar, 5% ullage)

— Special integrated cryogenic valves

— Multi-layer insulation inside vacuum space

— Especially designed to fit into a 40ft container, and for fueling stations

Performance

— Boil-off ratio: **<5.5 kg/day** (<0.6%/d)

Applications

— Fueling stations, with low to medium Hydrogen demand

Liquid Hydrogen Tanks – Examples

Special Design for extremely low Boil-off!

Key Data

- Inner volume: **6,000 liters**
- Design pressure: **12 barg**
- Storage capacity: **400 kg LH_2** (1bar, 5% ullage)
- Special integrated cryogenic valves
- Special insulation material inside vacuum space
- All necessary connections for LH_2 pump

Performance

- Boil-off ratio: **<2 kg/day** (<0.5%/d)

Applications

- Fueling stations, with low Hydrogen demand (tank for the early market phase)

Liquid Hydrogen Tanks – Examples
Larger Capacities for Bulk Storage

Key Data

— Inner volume: **300 m³**

— Design pressure: **3.5 barg**

— Storage capacity: **19.3 t LH_2** (1bar, 10% ullage)

Performance

— Boil-off ratio: **<58 kg/day** (<0.3%/d)

Spherical Tanks:

Key Data

— Inner volume: **1100 - 2300 m³**

— Design pressure: **2.6 barg**

— Storage capacity: **70.2 – 145 t LH_2** (1bar, 10% ullage)

Performance

— Boil-off ratio: **<70 - 145 kg/day** (<0.1%/d)

Linde Liquid Hydrogen Container

HYLICS™

Key Technical Data	
Frame Size	40ft Container
Design	UN Portable Tank
Design Pressure	12 bar(g)
LH2 capacity	3,000 kg (5% ullage)
Option	LIN-Shield

Linde Liquid Hydrogen Trailer

More Tons of LH_2 on the Road!

Key Technical Data	
Vessel length	13.7 m
Approvals	TPED / ADR 6.8
Design Pressure	12 bar(g)
LH2 capacity	~4,000 kg (5% ullage)
	No LIN-Shield

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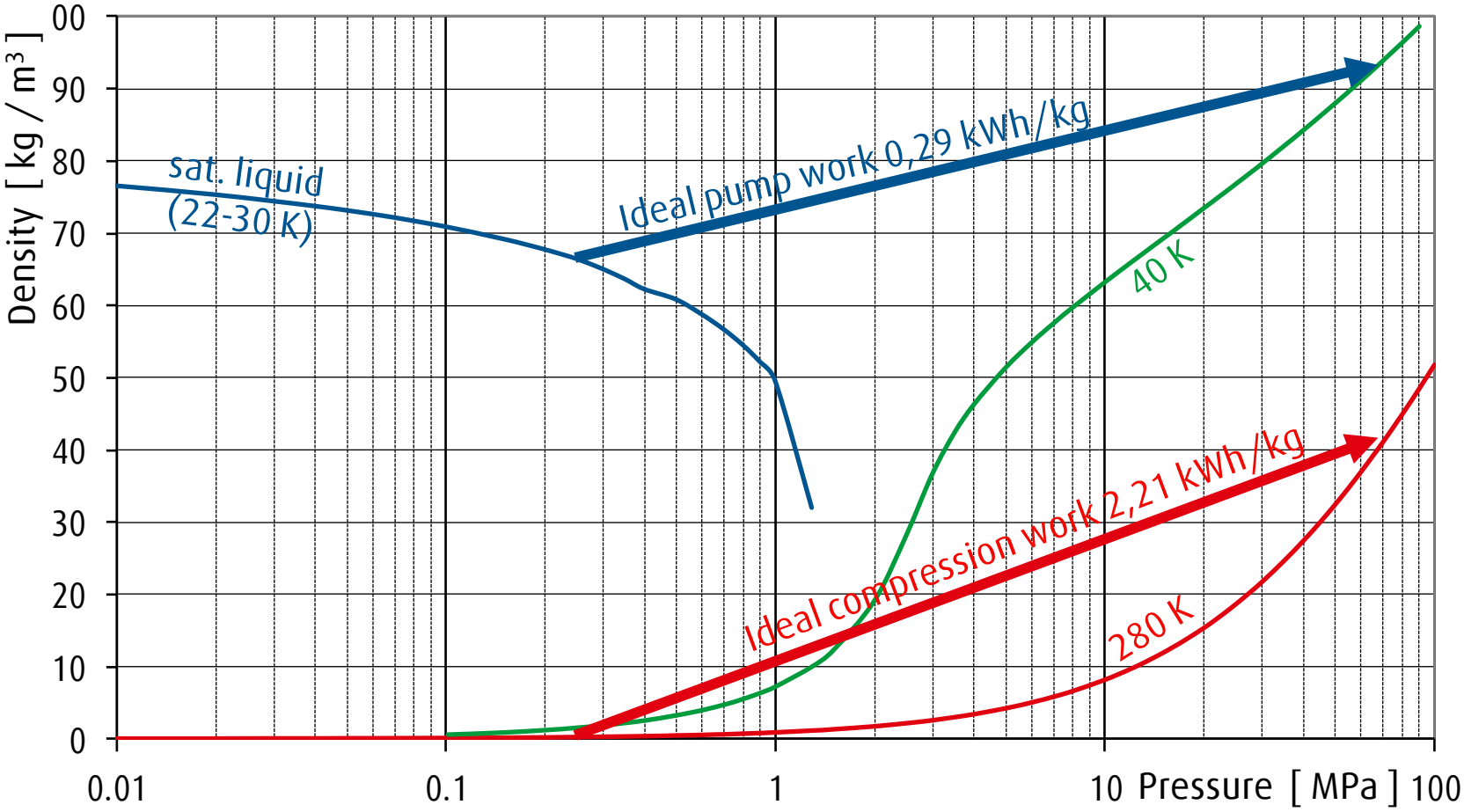
Physical properties of hydrogen

Ideal compression work – pump – vs - compressor



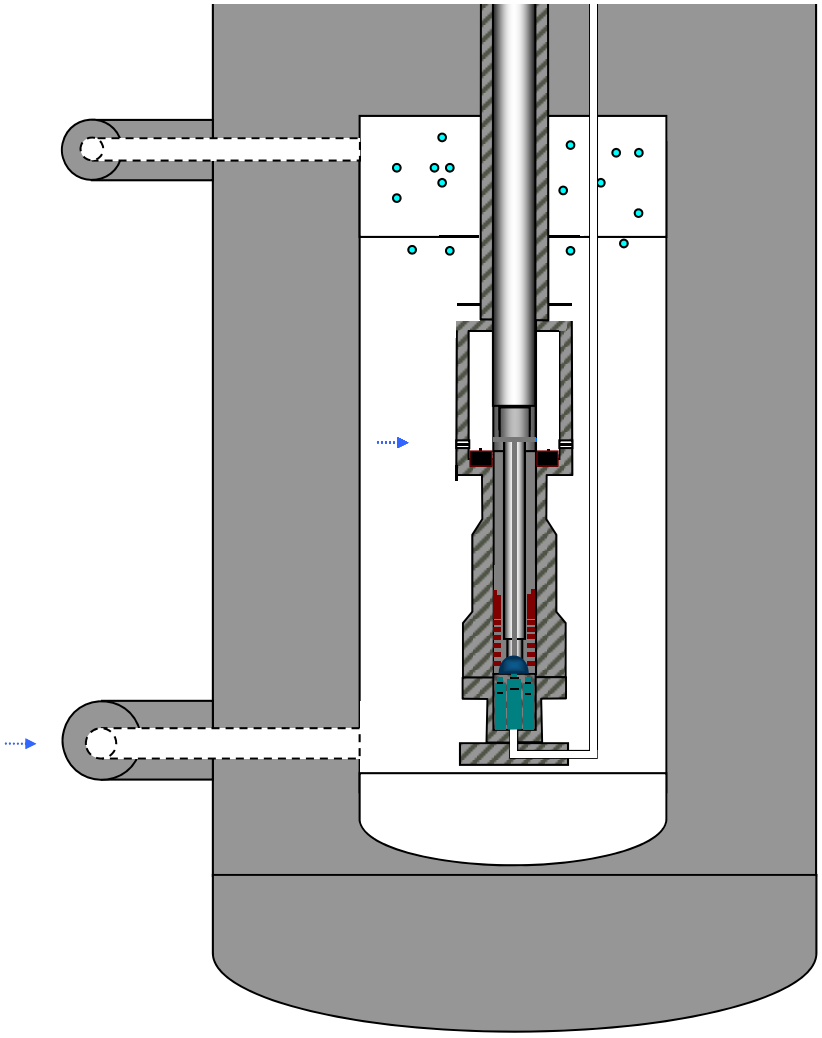
Liquid hydrogen fueling station
Type CP90

Performance

- Footprint: **6.10 x 3.40m**
- Capacity: **Up to 50kg/hr.**
- Bulk storage capacity: **400kg LH_2**
- MAWP: **100 MPa**
- Energy consumption (total): **45kW**
- Specific energy consumption:
  1.2 kWh/kg H_2 → Energy saving of ~ 70% [1]
- Boil-off: **4 kg/day, utilized for stand-by cooling**
- Refueling protocol: **SAE J2601-A70 and CEP**
- Refueling performance: **6 FCEV cars/hr.**
- Consequent development for installations at existing gasoline/ diesel retail stations, based on joint workshops with oil companies Shell, Total, OMV

[1] Compared to a conventional piston compressor

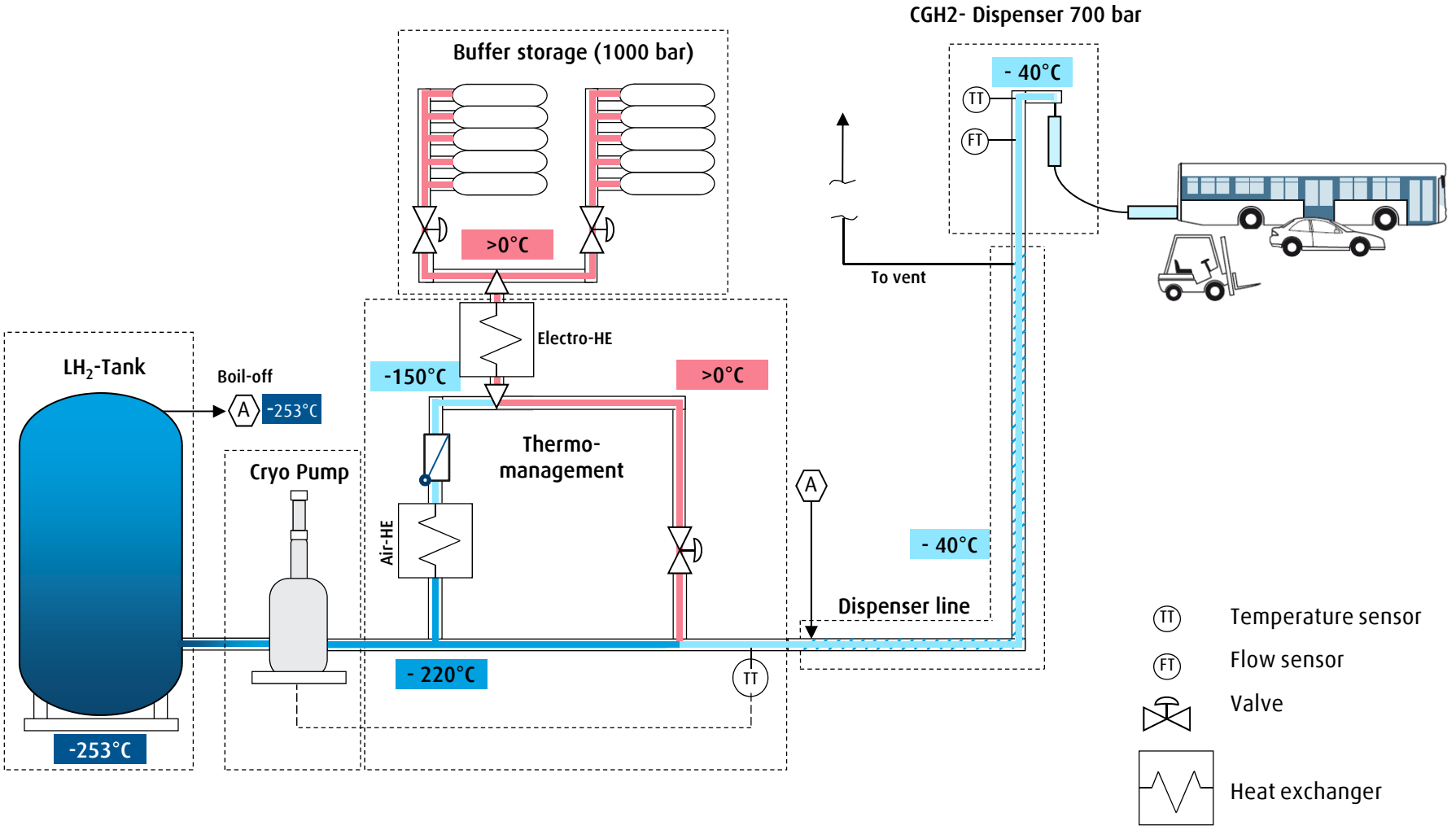
Cryogenic piston pump
How it works



Special design provisions :

- Super insulated Design
- Frequency drive (up to 4 Hz)
- Pump immersed in liquid hydrogen
- Double stage compression with LH_2 feeding piston

System function
Type CP 3.0



Liquid hydrogen fueling station
Installation of type CP90 in Munich, Germany

Key Features

- Start of operation: Q2/2017 and Q3/2017
- Dispensing lines: 1x 70 MPa PV
- Technology: Cryo pump CP90
- Main user: CEP fleet, FCEV passenger cars
- Small footprint than CNG station
- 400kg LH_2 storage; equivalent to 40,000km of driving

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Conclusion & Outlook

Drivers

— Regulations and policies will continue to change the energy mix and will require a reduction of emissions in the various modes of transportation.

— Hydrogen & Fuel cell technology has a set of advantages over other zero emission technologies.

Liquid Hydrogen

— LH_2 is not a "one-size-fits-all" solution, but is most efficient especially for larger FC power units, typically required for ships, energy storage systems, trains, etc.

— Supply chains for LH_2 have to be well thought-through, in order to reach an optimum between CAPEX and OPEX.

Next steps and key success factors

— Our innovations will focus on:

  — High-performing mobile & stationary LH_2 distribution equipment to make transportation and loading/unloading as simple as possible

  — Minimization of boil-off losses over the complete supply chain, incl. CAPEX/OPEX considerations

Thank you for your attention.

Making our world more productive

Linde's Hydrogen Value Chain for H_2 Mobility

Liquid Hydrogen Fueling Station Type "CP90"