



State of the Art Hydrogen Liquefaction

DOE Workshop

Engineering & Construction

Houston, TX, Feb. 22nd 2022

Agenda

1. Safety Moment
2. Air Liquide & Hydrogen
3. Hydrogen Liquefaction Technology



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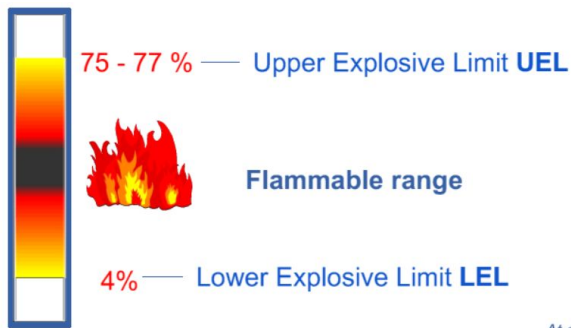
Safety Moment

Safety Moment: Hydrogen Flames



H220 - Category 1A
Extremely flammable gas

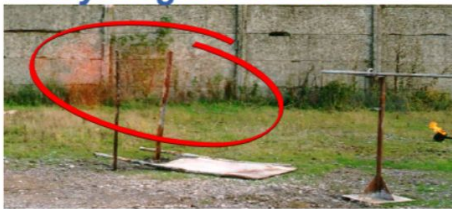
Large flammable range:



At atmospheric conditions

As comparison methane flammable range is much smaller 5-15%

Hydrogen Flame



CnHm flame



Nearly **invisible**
Wavelength 925 nm
(slightly red/orange)



Lightly radiant and
high temperature
(2 000 DegC or 3 630 °F)



Impossible to extinguish,
unless stopping the flow

Reminder: Systemic protection safeguards

Personal Protection Equipment (PPE)



H₂ portable detector :

- CE certified (89/336/CEE & ATEX II 1G EEX ia IIC T4; NFPA ASTM F2413-05)
- Alarms : 20% & 40% LEL
- Turn on and check before entering the site



Clothing and shoes :

- Anti electrostatic & Flame retardant (GT-PR-HSE-009)
- High visibility either the jacket or the yellow vest



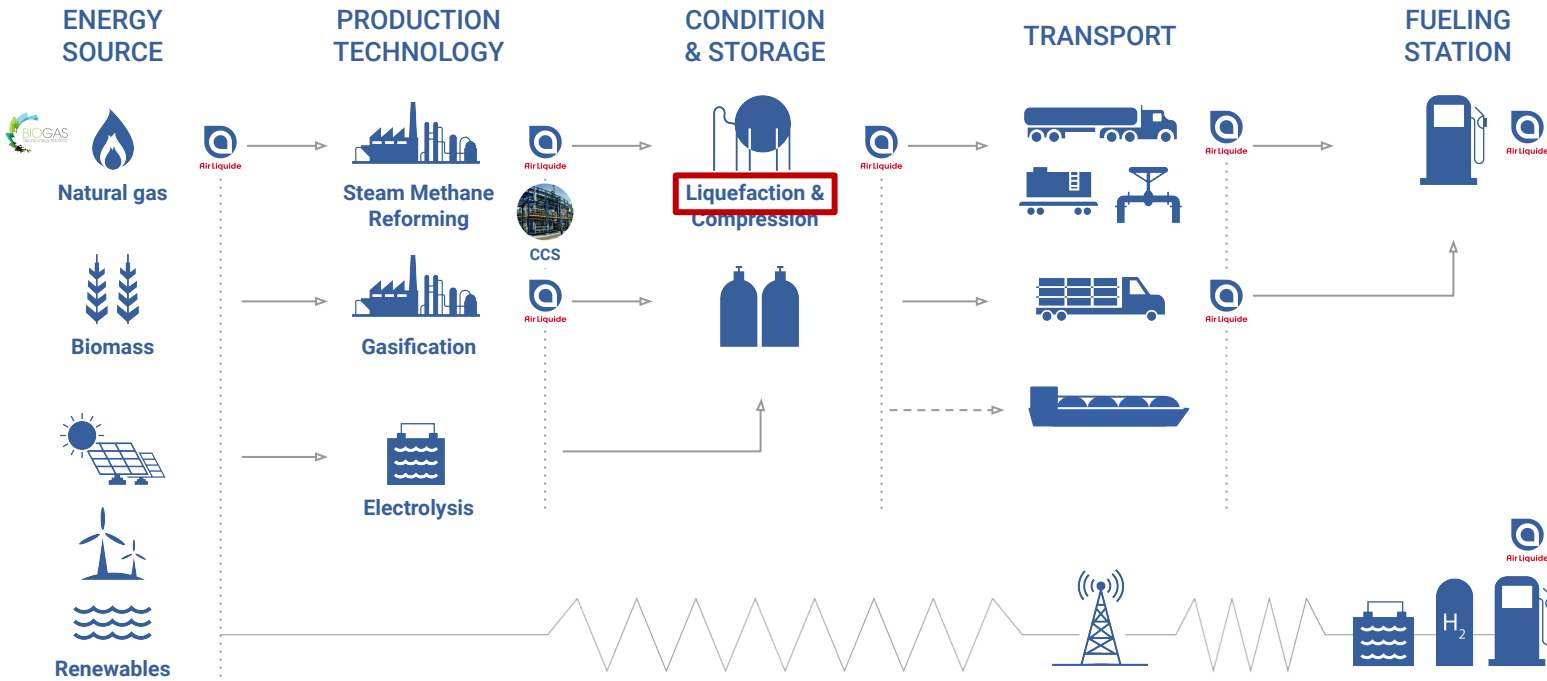
Gloves, ear protection and glasses for equipment manipulation

Add Helmet for interventions inside the skid.

2

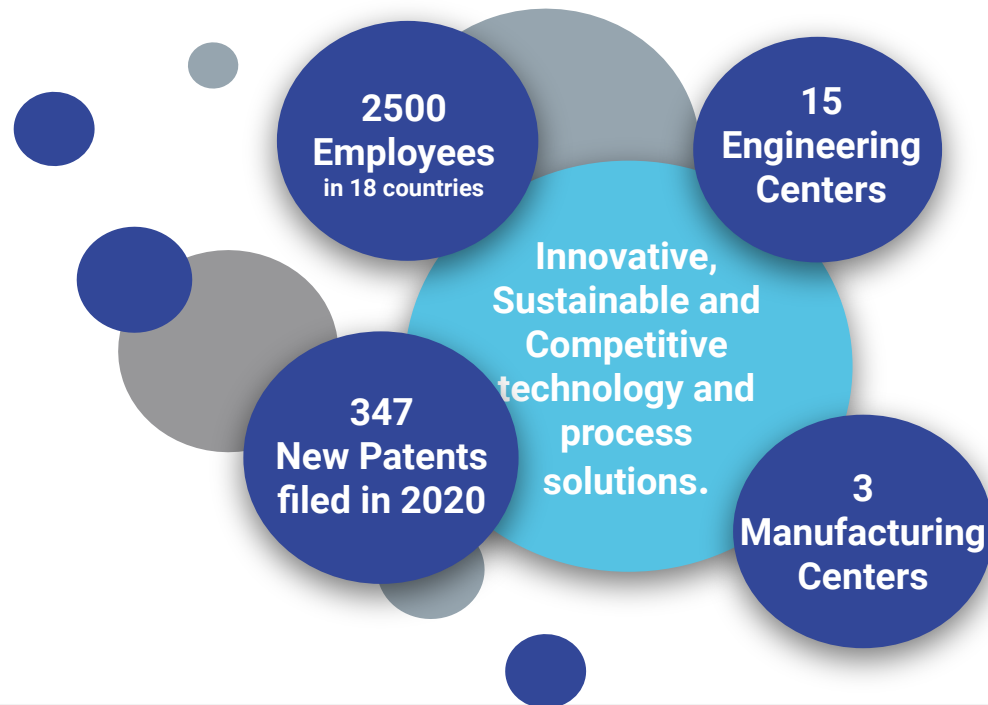
Air Liquide & Hydrogen Liquefaction

Technology leveraged at every step in the chain

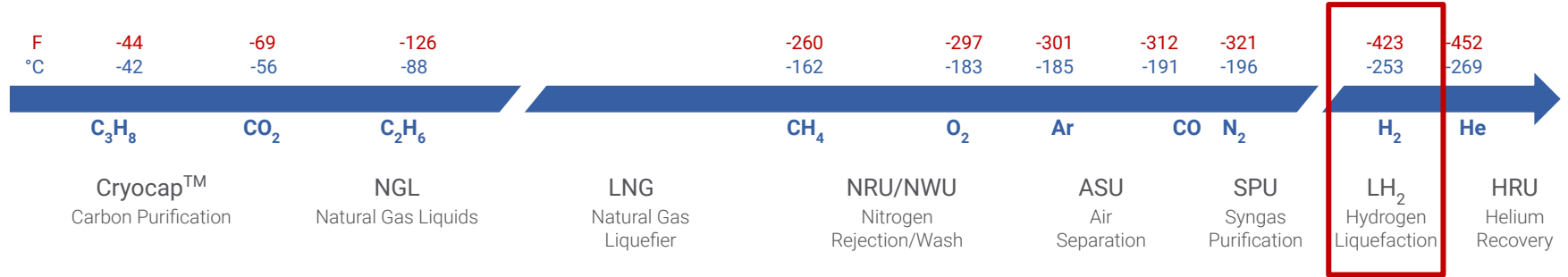


AL Engineering & Construction at a glance

- Within Air Liquide:
design and build industrial gas
production units.
(Build Own Operate / Over The Fence MODEL)
- For external customers: technology,
engineering and equipment packages.
(Sale Of Equipment MODEL)



Air Liquide worldwide technology leader in Cryogenics



Air Liquide is a technology leader for all cryogenic products

Unique technologies for deep Cryo applications (LH2, LHe)

- **Unique Deep Cryo references:**
 - LH2: **10+ units** in operation by AL or third party
 - LHe: **10+ units** in operations, 4 in construction
 - Largest He plant in operation in the world (Scale up x 2)
- **Proprietary purification and liquefaction process**
 - H2 and He cycle liquefaction processes
 - Solutions for efficient LH2 Boil-Off management
- **Proprietary equipment in house manufacturing:**
 - Gas bearing cryogenic turbines
 - 4K and 20K high performance vacuum cold box
- **Strong Technical Expertise on cryogenic bricks**
 - Backed-up by Operation Experience
 - Dedicated Support throughout the project & plant life cycle



Recent AL Large Cold Box (CB) Projects; « Science » & Helium



Equivalent to a 50 tpd H2 Cold Box !



AL Proprietary gas bearing turbine



[Air Liquide acquires cryogenic turboexpander](#)

Decades of LH2 Operation



- Operation of LH2 plants **since 1964**
- **AL pioneer in LH2** driven originally by space industry
- Multiple LH2 plants today in operation worldwide by AL - accumulating more than **800kh of operation.**
- **Largest Operating PEM Electrolyser WW**, in Becancour (Canada) s/up in 2020
- **30 tpd LH2 Plant in Nevada** to supply LH2 mobility market in 2022

**Proven design incorporating lessons learnt
from more than 50 years in LH2 plant operations**



3

Hydrogen Liquefaction Technology

Basis for designing a Hydrogen Liquefaction Plant

Purity

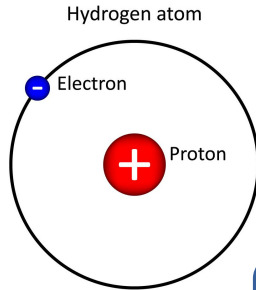
Material Efficiency

Heat Leaks / BOG

-253C / -423F

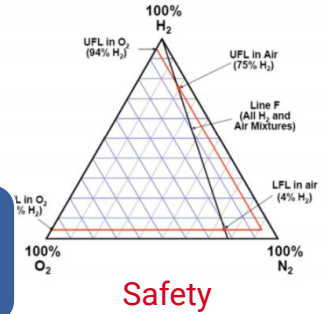


Deep Cryogenics



Quantum mechanics!

Safety



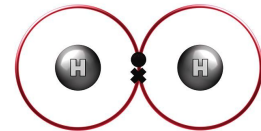
Scale-up

Innovation

Major lever for decarbonization of the industry

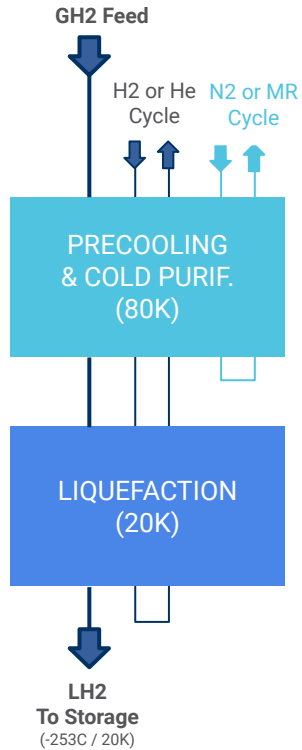
Fast growing market

Extremely Light



One proton, one electron
14 times lighter than air

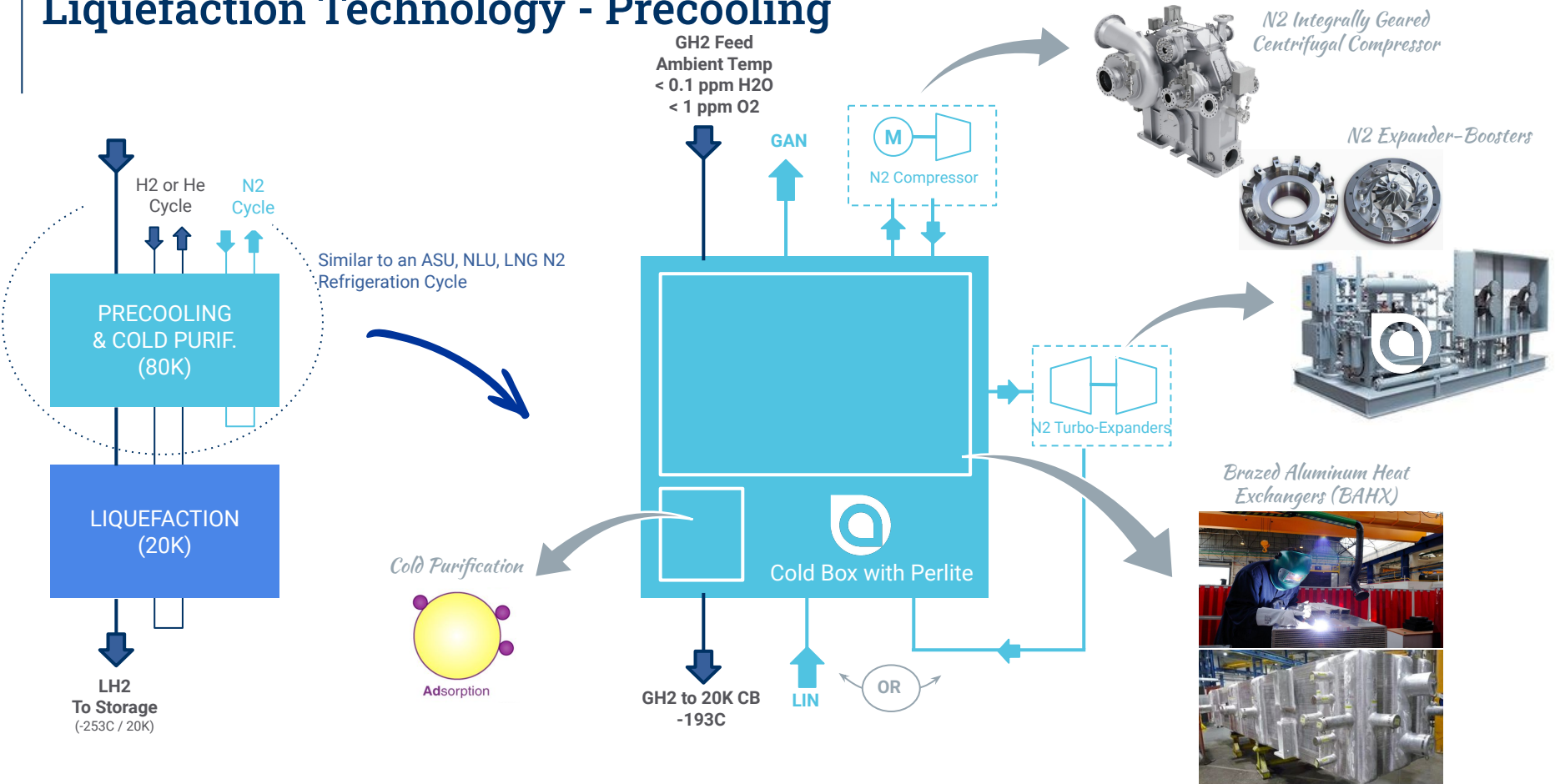
Liquefaction Technology vs Capacity



State of the Art

		Small Size	Medium size	Large size	Future XL	
Capacity	tpd	1 - 10	10 - 50	50 - 100	> 100	
Precooling Technology		LIN or N2 Cycle	N2 Cycle	N2 Cycle	MR cycle	MR cycle
Liquefaction Technology		He Cycle or H2 Cycle	He Cycle or H2 Cycle	H2 Cycle	H2 Cycle	H2 Cycle
Maturity		References under operation	References under operation	Design validated Ready for industrialisation	Under study	Under study
Optimization		CAPEX oriented	CAPEX oriented	CAPEX oriented	OPEX oriented	OPEX oriented
Efficiency	kWh/kg LH ₂	> 12 kWh/kg				< 7 kWh/kg

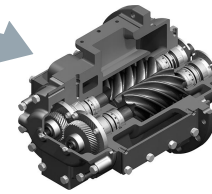
Liquefaction Technology - Precooling



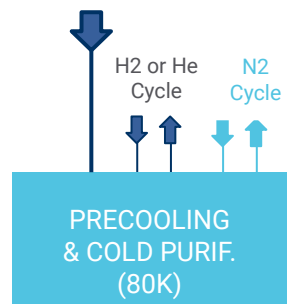
Liquefaction Technology - Liquefaction

Deep Cryogenics

From small Screw Compressors...

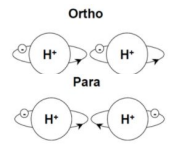


...to Large Reciprocating Compressor



LH2
To Storage
(-253C / 20K)

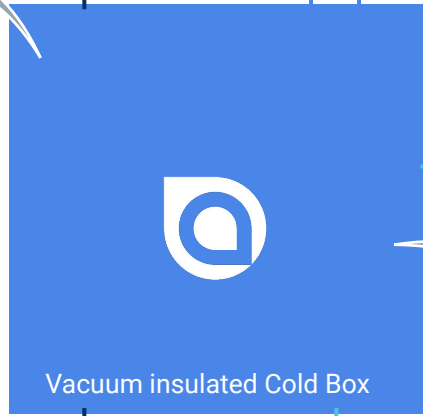
ortho/para conversion



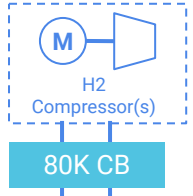
Air Liquide world-leading experience down to 4K
Leverage large H2 liquefaction with He experience



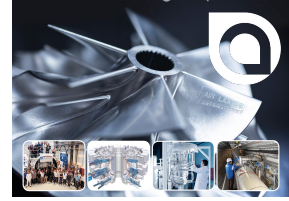
GH2 from 80K CB
-193C



LH2 to Storage
-253C



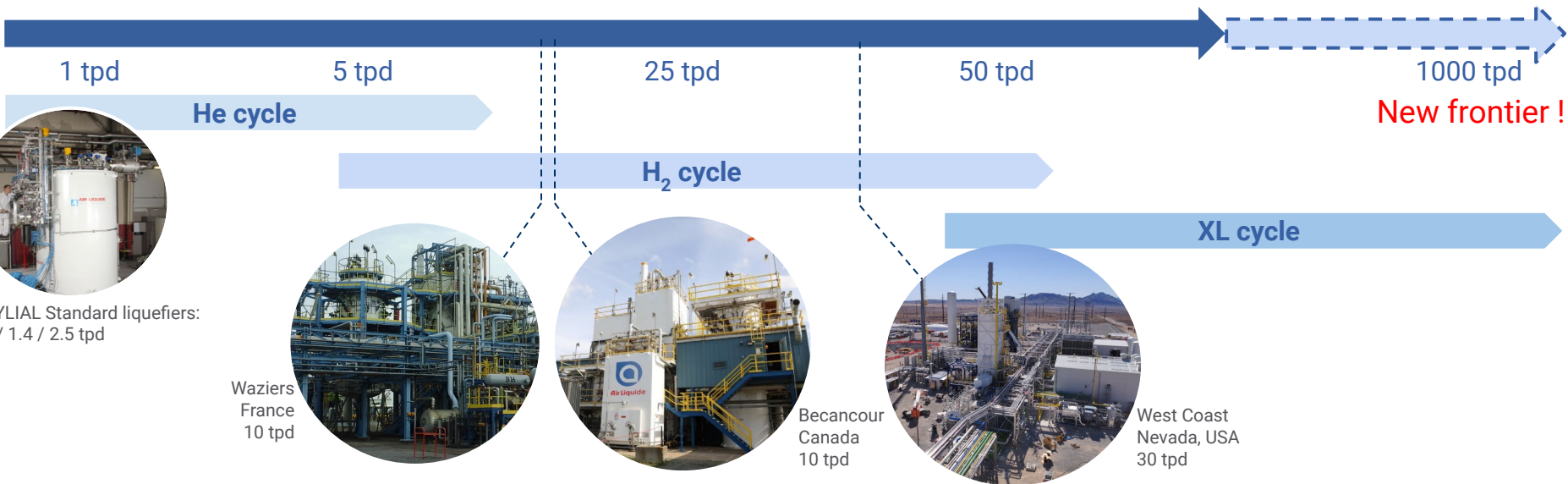
H2 Gas Bearing Expanders



Vacuum CB with Multi Layer Insulation



H₂ Liquefiers - Scaling up for mobility



Main Air Liquide References	China 2012	China 2011	France 1988	Canada 1990	USA 2022	South Korea 2023	South Korea 2023
LH ₂ production (TPD)	1	2.5	10	10	30	5	3x30



Q&A



Thank you

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