

EasiSchool2 H₂ production & liquefaction overview

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**GLOBAL MARKET
& TECHNOLOGIES**

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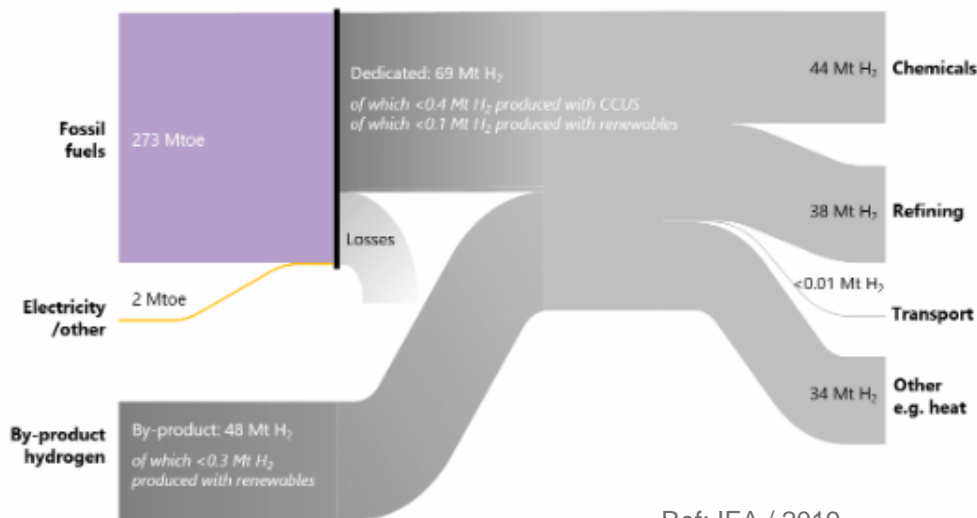
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Chapter 1

Hydrogen singularities

Orders of magnitude

Hydrogen supply and demand



Ref: IEA / 2019

Syngas Production
WW~160 kTPD

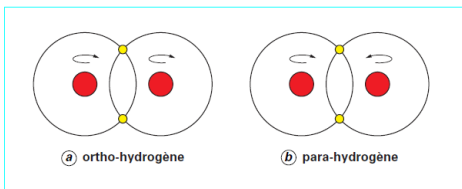
Pure GH₂ production
AL~6 kTPD

LH₂ Production
WW~330 TPD (~85% in the USA)

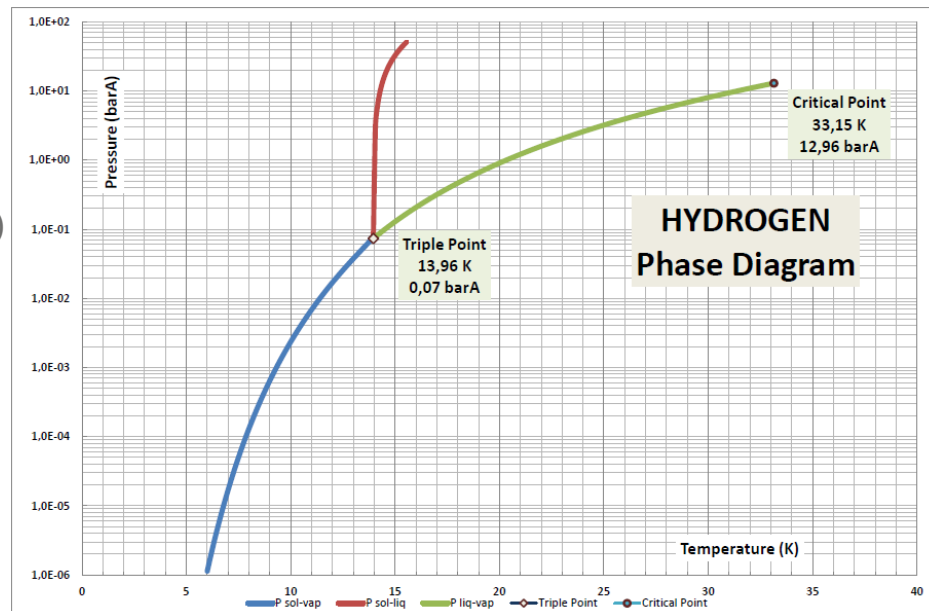
Notes: Mtoe = million tonnes of oil equivalent. MtH₂ = million tonnes of hydrogen.

Hydrogen singularities

- **Hydrogen = somewhat imprecise**
 - Dihydrogen (2 protons)
 - linked thanks to covalent bond (1 shared e-)
 - Ortho-H₂ and para-H₂ coexist



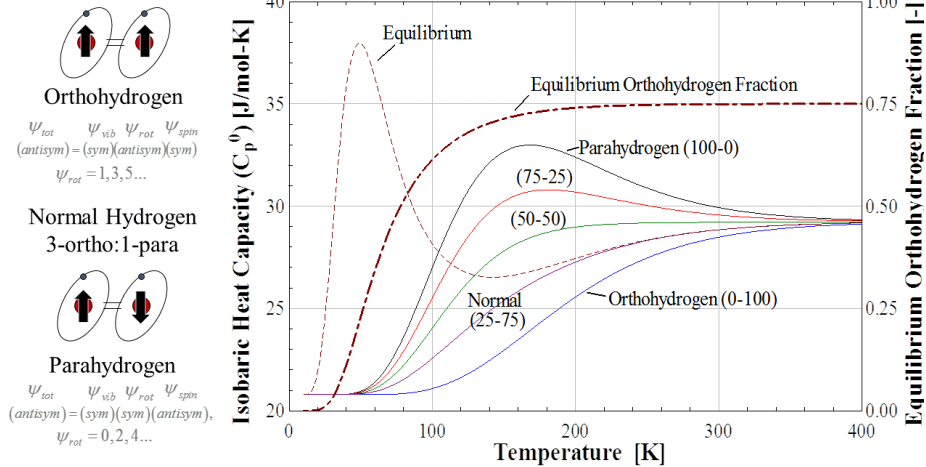
Ref: TI J3-603



Hydrogen singularities

H2 nuclear spins isomerics

- Normal H2 (n-H2) = 75% o-H2 / 25% p-H2
- Ortho-H2 (asymptotic state @ warm temp.
- Para-H2 (equilibrium @ 20K)
- Ortho-H2 to para-H2 conversion is an **exothermic** reaction
- Whole Exothermia (n-H2 → 100% p-H2) ~520 J/g **> Latent Heat (450 J/g @ 1 bara) !!!!**
- Catalyst is used in order to speed up natural conversion
(1 month in natural conversion to go from normal H2 to 50 % p-H2 state)



Ref: Leachman (2015)

Chapter 2

Main ways for H2 production

Steam Methane Reformer (SMR)

1. Pre-reforming reaction



- endothermic reaction

2. Reforming reaction



- endothermic reaction
(226 kJ/mole à 760 °C)

3. CO conversion reaction



+ Exothermic reaction
(34 kJ/mole à 760 °C)

Steam Methane Reformer (SMR)

Howe Baker Reformer, Bayport, USA (110'000 Nm³/h)

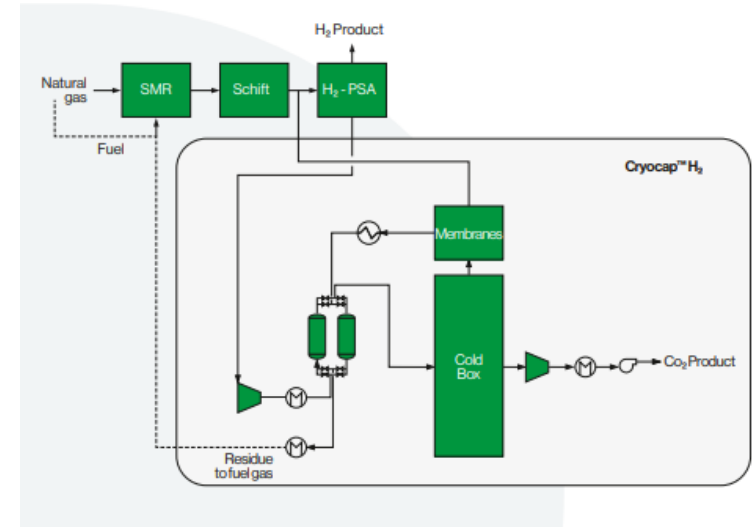


Steam Methane Reformer (SMR)

Close to 9 kg CO₂ / kg H₂ produced...

2 main ways are studied in order to reduce carbon footprint:

- CO₂ purification & liquefaction (CRYOCAP)
- 1 ref @ 100'000 TPY
- Carbon Capture & Storage (CCS)
- No industrial solutions in operation up to now



Water Electrolysis (ELY)

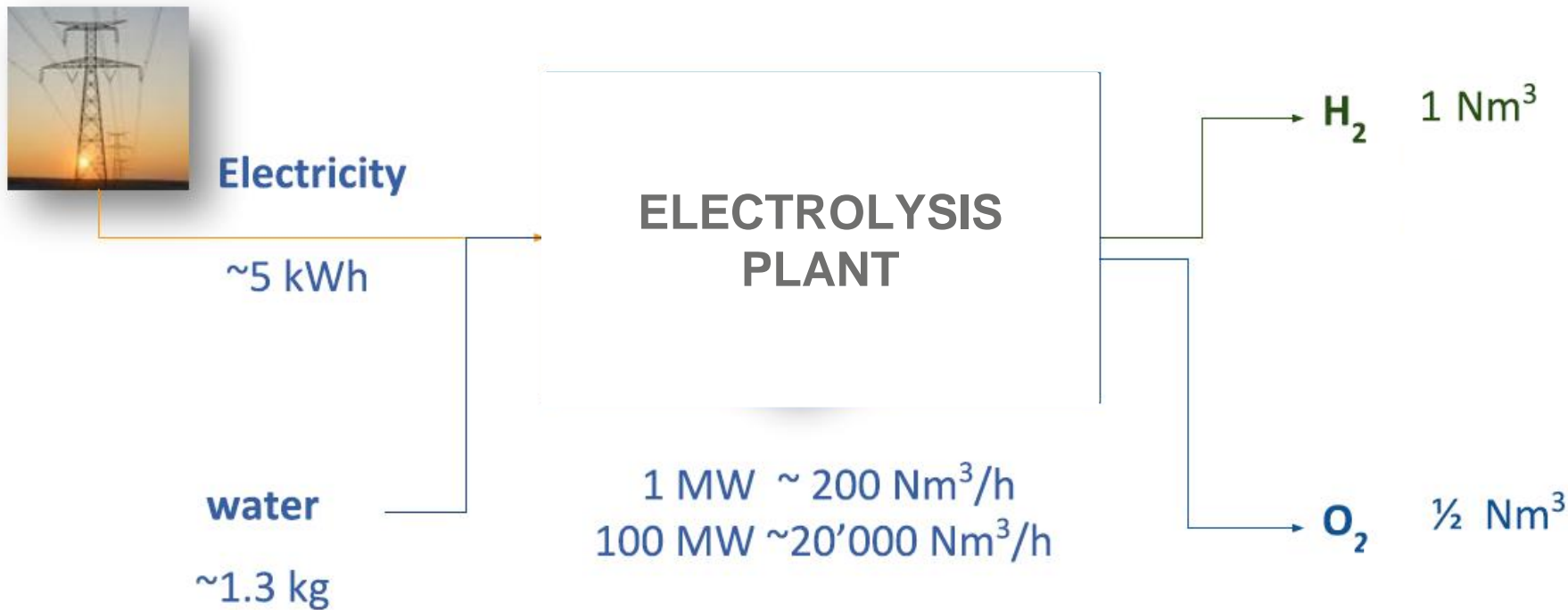


If electrical supply is carbon-free, it is fully decarbonated H₂ production

Decentralized production is more classical (local & low quantities)

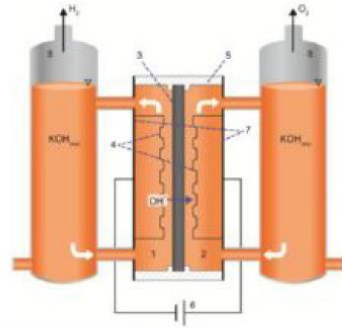
Specific Energy ~60 kWh/kg ($\eta \sim 60\%$ regarding H₂ HHV = 33 kWh/kg)

Water Electrolysis (ELY)

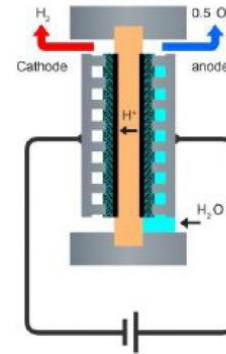


Water Electrolysis (ELY)

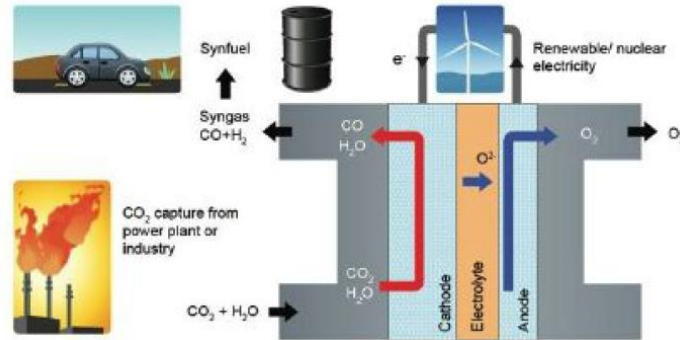
Alkaline
Electrolyte must
be circulated
and regenerated



PEM



Solid Oxide
Can be reversible



Chapter 3

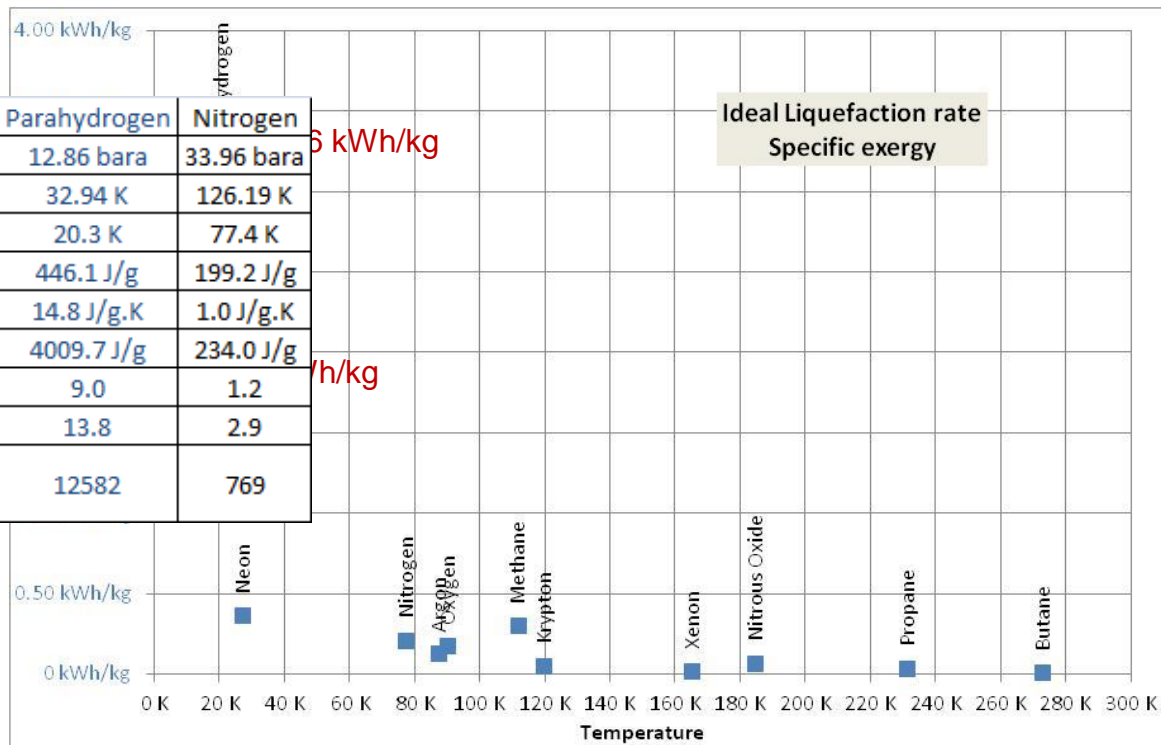
Air Liquide (AL)

H2 liquefaction plants

Hydrogen singularities

Critical state	Helium	Hydrogen	Parahydrogen	Nitrogen
P	2.28 bara	12.96 bara	12.86 bara	33.96 bara
T	5.20 K	33.15 K	32.94 K	126.19 K
Normal boiling point (K)	4.2 K	20.4 K	20.3 K	77.4 K
Latent heat @ 1 bar	20.6 J/g	448.7 J/g	446.1 J/g	199.2 J/g
Cp @ 300K (J/g.K)	5.2 J/g.K	14.3 J/g.K	14.8 J/g.K	1.0 J/g.K
Sensible heat Tvp --> 300K	1542.8 J/g	3509.6 J/g	4009.7 J/g	234.0 J/g
Dhsens / L'	74.7	7.8	9.0	1.2
Carnot eff. (W@Tch / W@Tfr)	70.0	13.7	13.8	2.9
Min. Energy to spend to liquefy 1 g/s	6840	12081	12582	769

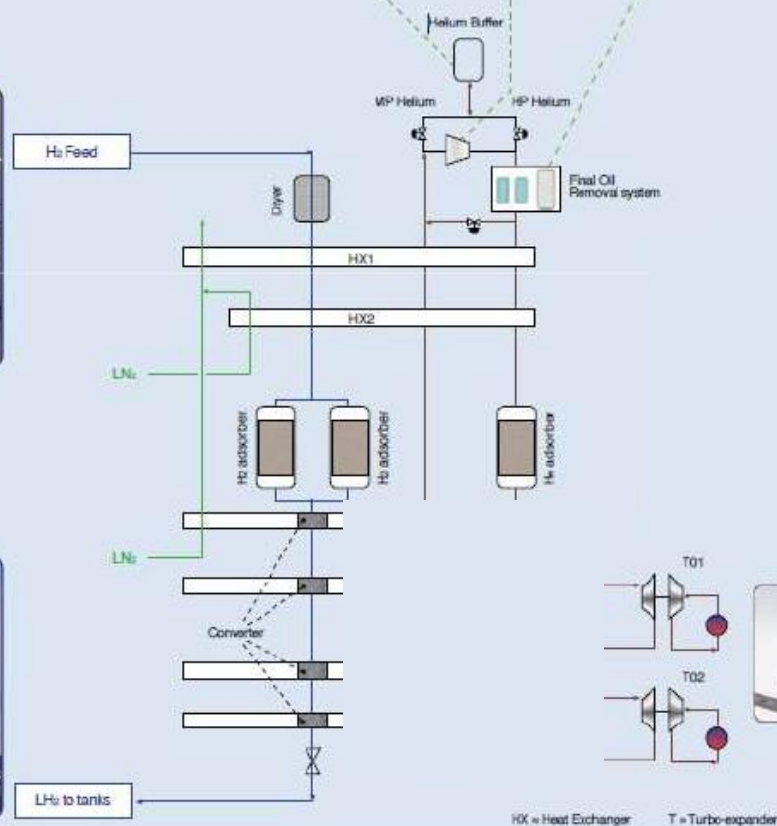
Conversion: 1 tpd = 600 L/h
= 12 g/s = 460 Nm3/h



HYLIAL – PFD

Reverse Brayton cycle

- Pure Helium closed loop
- LIN precooling
- Vacuum CB (MLI usage)



Subcooled LH2
BOG reduction on whole supply chain

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P. BARJHOUX – Cryogenic dev.

AL Large liquefiers

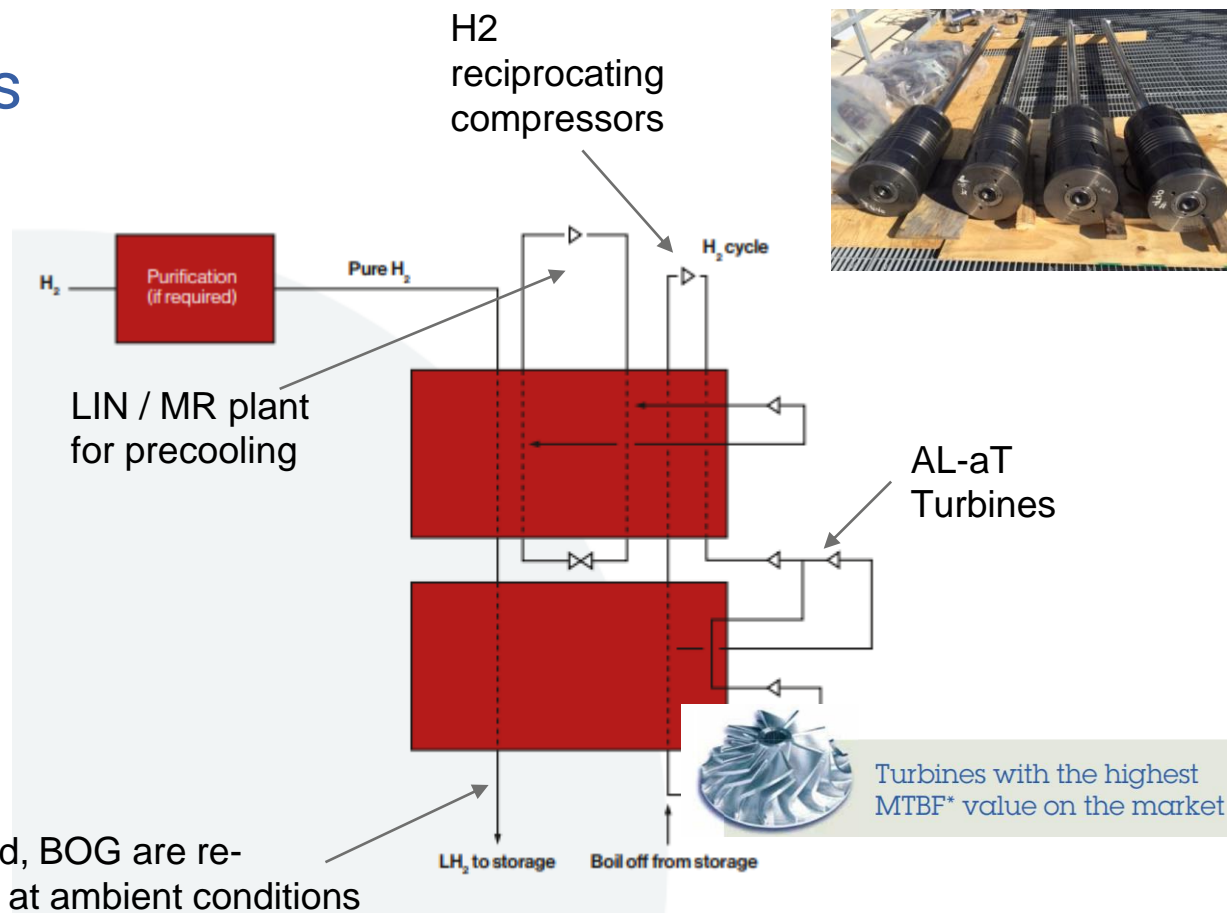
Pure H₂ closed loop

References:

WAZIERS – France (10 tpd)

BECANCOUR – Canada (10 tpd)

LH₂ is saturated, BOG are re-compressed at ambient conditions



AL H2 liquefiers

HYLIAL

2012	BLC, China	600 L/h
2011	Xichang, China	600 L/h
2011	Hainan, China	1,500 L/h
2007	BLC, China	600 L/h

Previous H₂ liquefiers

1990	Ariane Space, Guyana	1,375 L/h
1988	Pacific H ₂ , Japan	850 L/h
1987	Hydrogenal, Canada	6,000 L/h
1987	Wazier, France	6,000 L/h
1977	Iwatani, Japan	760 L/h
1966	Frais Marais, France	600 L/h
1964	Predictown, USA	3,600 L/h

...and over 30 H₂ liquefiers in several labs (14-40 L/h)

Chapter 4

Loading Bays & Trailers

H2 Logistics



KOUROU
semi-mobile tanks (360 m3)



Becancour LH2 storage (1'000 m3)



AL Canada – LH2 trailer (>3 tons LH2)

Chapter 5

H2 stations

H2 stations

120 H2 stations
installed all over
the world



Chapter 6

AL investments

AL investments

H2 council : AL among the active founders

13, then 18 and now
53 members
at council level by Q3
2018, in just one year



H₂ COUNCIL
covers Europe, Japan,
Korea, US, Middle
East & China

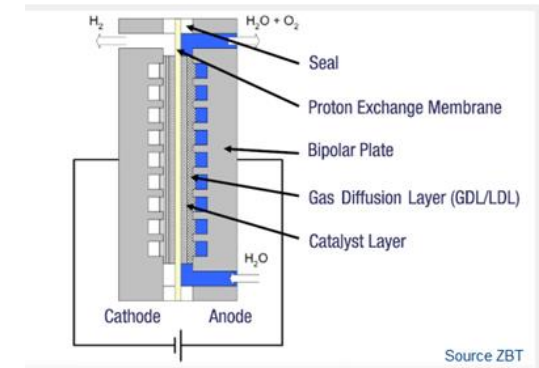


The largest scale Electrolyser is under manufacturing (supplier & partner = Hydrogenics Corp.) in order to feed existing liquefier in Canada

20 Mwe / Majorly renewable energy supply / 3000 TPY

Large scale H₂ liquefaction plant in California (30 TPD)

It will be able to feed up to 35'000 Fuel Cell Electrical Vehicles



Source ZBT

QUESTIONS ?

