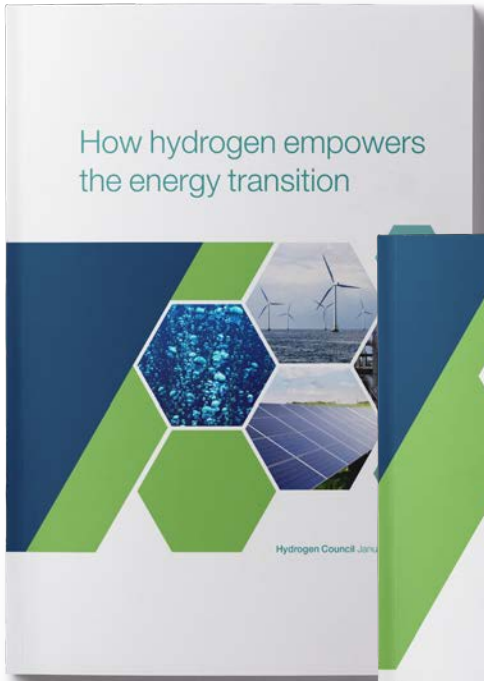
Air Liquide

H_2 Energy TECHNOLOGY Challenges

Laurent ALLIDIERES - H2 technologies director
Hydrogen Energy World Business Line

Hydrogen
Vision, Volumes, Costs

Jan. 2017



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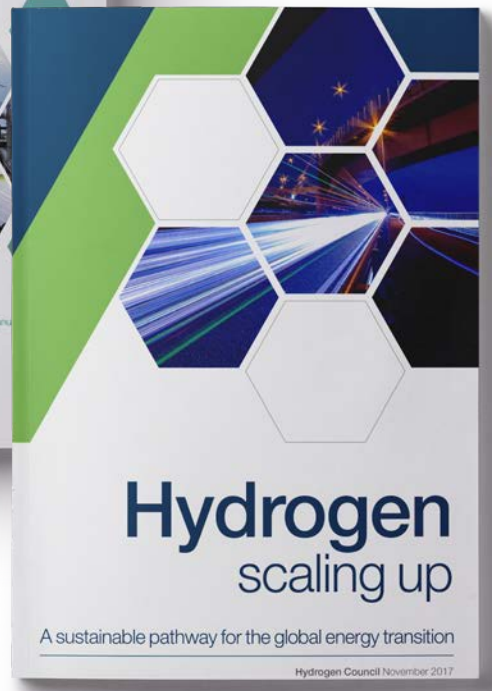
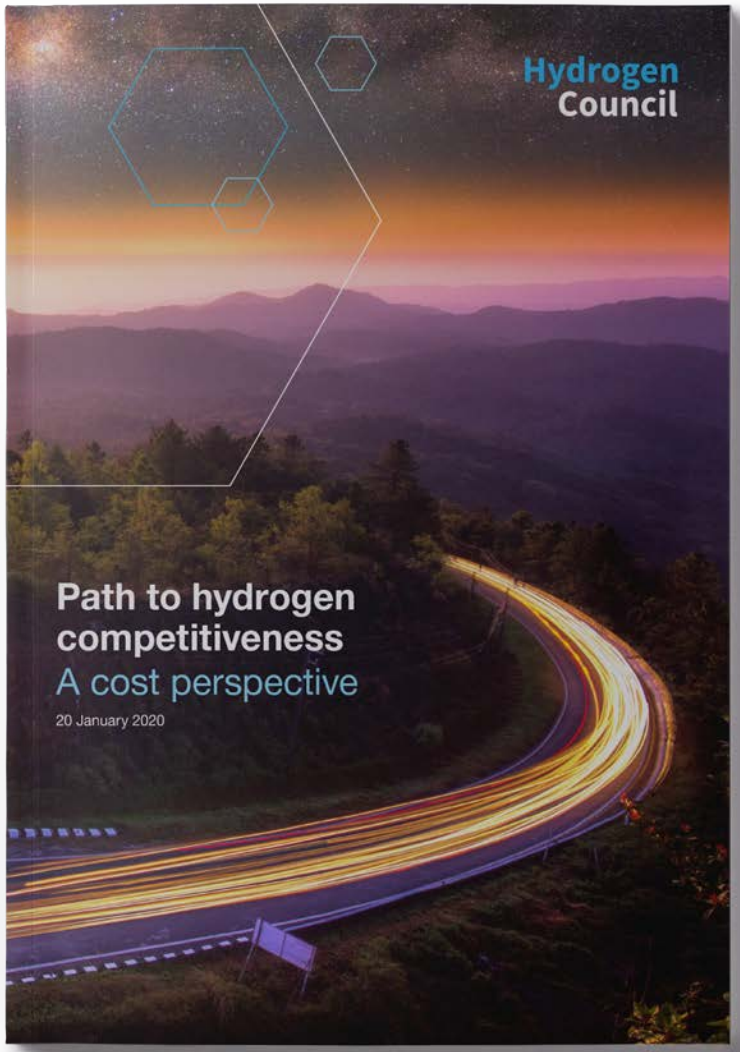


Jan. 2020



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Hydrogen by 2050:
a quantified vision of its key role in the energy transition

18%
of final energy demand

30 million
jobs created

6 Gt
annual CO_2 abatement

$2 500 Bn
annual sales
(hydrogen & equipment)

Source: McKinsey & Hydrogen Council 2017

Hydrogen mobility markets:

Ready to scale TODAY

Ferries
1 T/day

Cruise ships
10 T/day

Material handling vehicles
100 kg/day per site

Trucks
100 kg/day per truck

Buses
20 kg/day per bus

Trains
150 kg/day per train

Individual cars
100-200 kg/day per station

Drones

Airplanes Applications

Bicycles & scooters

Air Liquide worldwide hydrogen Operations

H_2: 545 km

2 bn€ Sales

15 bn m3/year

Key Figures

- **200** H2 plants.
- **55** Hydrogen / CO Units
- **23** H_2 Purification Units
- Global H_2 Capacity > **1.3 million Nm^3/h**
- More than **1,850 km** H_2 pipeline

H_2: 40 km

H_2: 950 km

OTF: Over the Fence supply, Air Liquide owns and operates plants

AL's assets for H_2 supply:

- H_2 Production Unit for OTF supply of H_2
- H_2 Purification Unit – OTF Supply of H_2
- H_2/CO Production Unit (SMR / POX)

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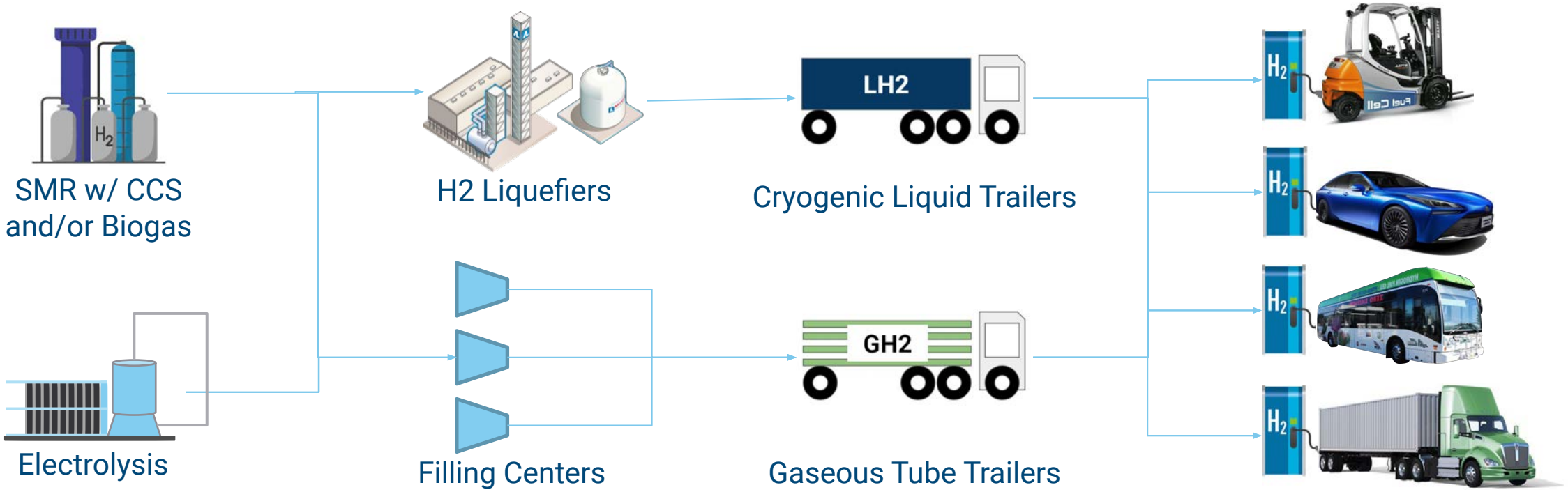
Air Liquide: A catalyst for new markets, to enable the development of core activities



H2 Production	H2 Conditioning	H2 Distribution	Dispensing and Retail
Build – Own - Operate			Minority Stake

Technology / Know-how / Expertise

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Air Liquide

A

H2 production

"Avoided CO2 emissions"
A new driver for H2 production costs?

Sources	Production	Storage

Biogas

+

Fossil Feed
E.g Natural Gas

+

Water + Renewable Electricity

+

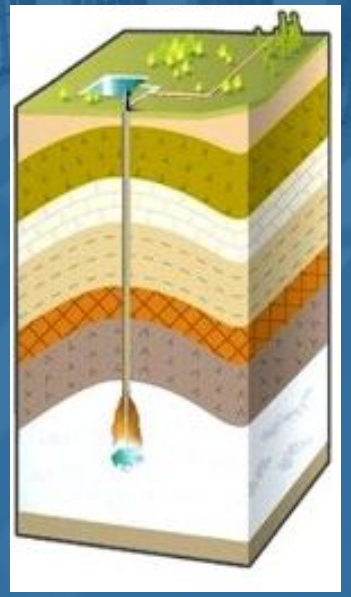
Steam Reforming

CCS*

Electrolysis

→

BLUE HYDROGEN
Clean energy solutions



Air Liquide operates the world's largest hydrogen storage facility in the Gulf Coast area
- 1,500 meters deep and nearly 70 meters in diameter
- 30 days of a large SMR production

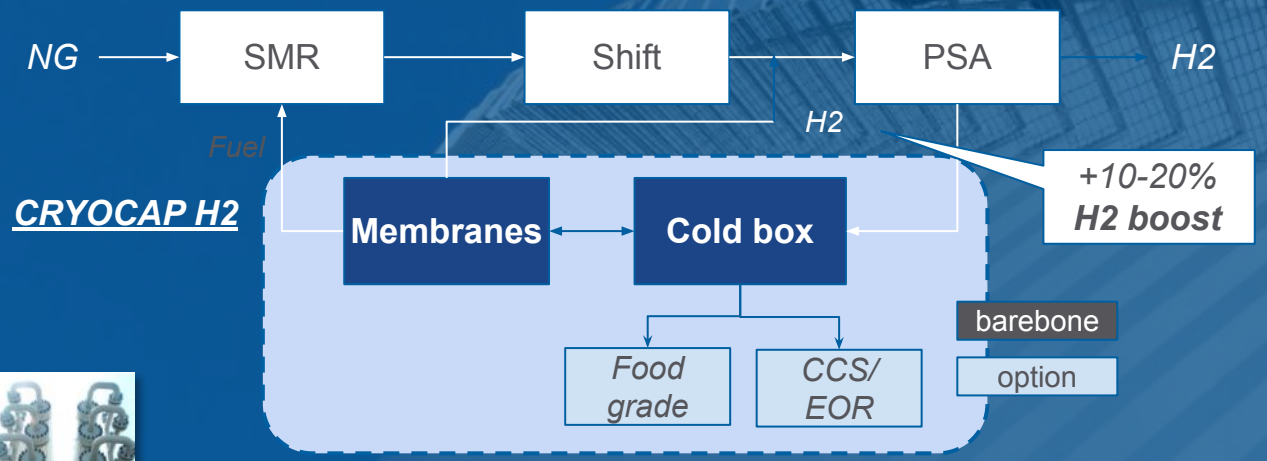
***CCS: Carbon Capture & Storage**

Air Liquide

Cryocap H2: Syngas CO2-capture on SMR

CO2 -60%

Best technology for low power/natural gas price geographies



- Unique combination of proprietary Cryogenics and Membranes technologies (MEDAL™)
- ~35% lower capture costs compared to aMDEA
- Retrofit possible
- Plug-in add-ons:
  - *Food grade CO2*
  - *HP compression for EOR*

World only referenced cryogenic solution at industrial scale

Port-Jerôme

- Built, owned & operated by Air Liquide in France
- Start up in H1 2015
- Retrofit on existing SMR : 50,000 Nm3/h H2
- PSA off gas treated: 17,000 m3/h
- Liquid CO2 production: 300 tons/day
- Industrial Food Grade CO2 sales

Increase H2 production by 10-20% or eq. NG saved

AL next step - Electrolyser scaling up

Scale up to 100 MW +
Preparing the next step

HYBALANCE 1.25 MW
One of largest PEM
In operation

< 2017

more than 45 electrolyzers in operation **worldwide**
usual range: **50 - 100** $Nm^3/h\ H_2$
Mainly Alkaline technology
ONSITE

2018

BECANCOUR 20 MW
Largest PEM project
Under execution

Air Liquide invests in the world's largest membrane-based electrolyzer to develop its carbon-free hydrogen production

2019

gasworld

Hydrogenics announces $20.5m private placement and technology partnership with Air Liquide

By Joanna Sampson | 2 January 2019

Air Liquide

HyGreen Provence

Air Liquide, DLVA and ENGIE are entering into an ambitious partnership to produce green hydrogen on an industrial scale

News | Wednesday, November 13, 2019

Air Liquide signs long-term power purchase agreement for renewable electricity

Press release | Friday, November 30, 2018

- Design and build Group's industrial gas production units
  - Solution oriented towards our gas customers
  - Plant life-cycle optimization
  - Supporting operations

Air Liquide

B

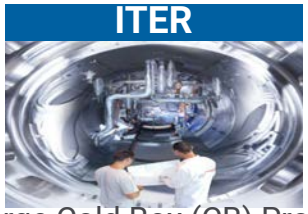
H2 Liquefaction, Transport & Storage

Air Liquide worldwide technology leader in cryogenics

F	-44	-69	-126	-260	-297	-301	-312	-321	-423	-452
°C	-42	-56	-88	-162	-183	-185	-191	-196	-253	-269
	C_3H_8	CO_2	C_2H_6	CH_4	O_2	Ar	CO	N_2	H_2	He
	Cryocap™		NGL	LNG	NRU/NWU	ASU		SPU	LH_2	HRU
	Carbon Purification		Natural Gas Liquids	Natural Gas Liquefier	Nitrogen Rejection/Wash	Air Separation		Syngas Purification	Hydrogen Liquefaction	Helium Recovery

Air Liquide is the technology leader for all cryogenic products

H2 liquefaction expertise



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

AL hydrogen liquefiers come from decades of

- Development & Design capitalization → Large Science Projects & LH2 references
  - LH2 plants → 8 plants (4 references in China)
  - Science Projects → ITER & CERN
- Operation experience and capitalization of LHe & LH2 plants (5)

Waziers, France → 10 tpd

Kourou, Guyana→ 2.5 tpd

Becancour, Canada → 10 tpd

Key equipments mastered & core to AL

- Proprietary turbo-expanders with gas bearing technology : high efficiency, maintenance-free and reliable (MTBF>150 000 hours)
- Cold box design and manufacture
- Plate-fin heat exchanger and catalyst basic design
- Multi-Layer Insulation
- Cryogenic transfer lines design and manufacture
- Boil-off optimization

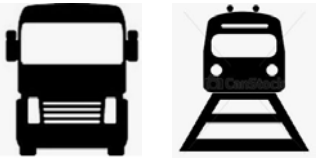
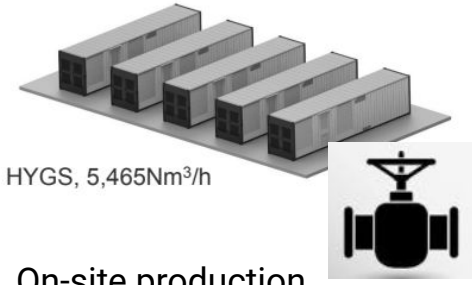
AL Proprietary gas bearing turbine

ITER 1 out of 3, World's Largest CB ever manufactured
Equivalent to a 50 tpd H2 Cold Box !

Air Liquide

Designed by DAVYTOPIOL – Crédits photos : Thinkstock

H2 Supply chain: Matching solutions with market demand

<40kg/day	>40 kg/day <250 kg/day	>250 kg/day <1000 kg/day	>1000 kg/day <4000 kg/day	>4000 kg/day
Forklifts - small HRS Cars-demo HRS	Forklifts -medium & large HRS Cars - small HRS Buses - demo HRS	Forklifts - very large HRS Cars - medium HRS Buses - small & medium HRS Truck - small HRS	Cars - large & very large HRS Buses - large HRS Truck - medium HRS Train - small HRS	Buses - very large HRS Truck - large & very large HRS Train - medium & large & very large HRS
 55 forklifts 80 cars 13 taxis	 350 forklifts 500 cars 83 taxis 8 buses	 2000 cars 333 taxis 33 buses 12 trucks	 8000 cars 1333 taxis 133 bus 50 trucks	 >50 trucks > 16 trains
 200 bar H2 Bundles 10kg payload Deliveries of 4 bundles	 Steel 200 bar trailers 300kg payload	 Composite 300 bar trailers 900 kg payload	 Liquid Hydrogen Trailer max 4 tons payload	 On-site production & new pipeline

Composite technology for increased payload and working pressure

State of the art

Existing supply chain (“200 bar”) is quickly limited when HRS are loaded because of limited payload

With composite

1. High capacity: 300 bar range -> logistic optimum (up to 680 kg H_2 usable)
2. High capacity/High Pressure: 500-700 bar range

- But in reality
  - Regulatory constraints, suppliers product range leads to different trailers depending on your geography.
- Good news
  - Regulation are relaxing and new suppliers become active.

Typical “200 bar” tube trailer

Composite tube trailer

450 bar trailer in the USA

300 bar trailer

Liquid Hydrogen distribution

- Liquid Hydrogen is ultra pure
- Payload is typically from 2700 to 4000 kg depending of package type and regulation
- Logistic loop can induce a net loss of product of up to 14% by evaporation ⇒ Boil off recovery must be done
- Holding time (OWTT) can vary from 180 hours to 50 days, normal evaporation rate usually below 1% /day
- Only a few manufacturers (including Air LIquide CRYOLOR)
- Very safe (transport pressure lower than 10 bar, double wall enveloppe, good resistance to fire ...).

US trailer - 4000 kg net capacity

ISO40' container - 2700 kg net capacity

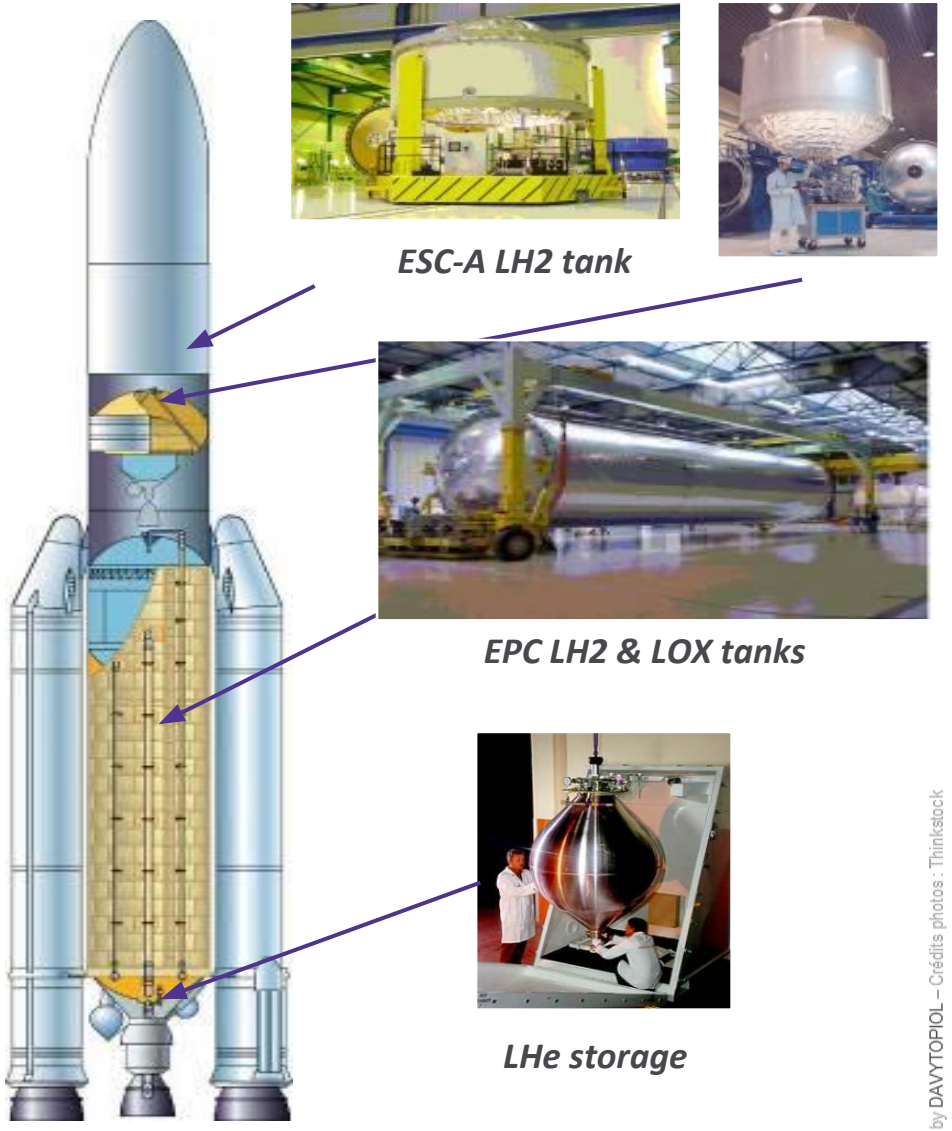
EU trailer - 3000 kg net capacity

Designed by DAVYTOPIOL – Crédits photos : Thinkstock

H2 Storage

AL Hydrogen Storage come from decades of

- Development & Design capitalization → ARIANE & LH2 Cryolor references
  - ARIANE 5 → More than 65 storages manufactured
- Operation experience and capitalization LH2 storages



ARIANE 5 Launcher ; AL Cryo Storage Scope

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C

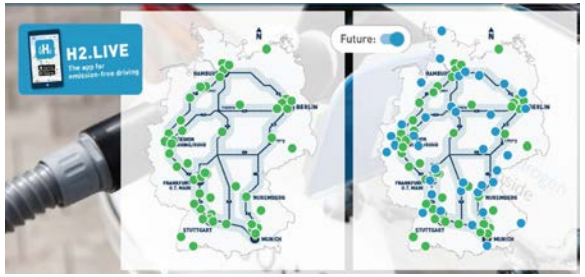
H2 Stations

H2 Stations

- > 120 H2 stations installed worldwide
- > 50 H2 stations operated by Air Liquide
- Station products for forklifts, cars, bus, trucks, trains
- Design & construction teams in France, Germany, US, Japan, China, Korea
- Strategic partnership in the US with First Element
- Strategic partnership in China with Houpu
- Leader member in several HRS consortiums

H2 MOBILITY FUELLING HYDROGEN

JAPAN H2 MOBILITY JHyM



D

Safety & Regulations

Our Skills

Manage hazards to provide safe applications

Phenomenon

Examples of mitigation

Means to study and assess

Release & Leak

Flow restrictor
Specific fittings
Appropriate materials

ALDEA
DRHyS test facility
CFD

Dispersion

Natural & forced ventilation
Smart detection

ALDEA
DRHyS & CEA test facilities
CFD

Ignition

Zoning
Ex-equipments
Strategic location of e^- devices

Literature studies

Explosion

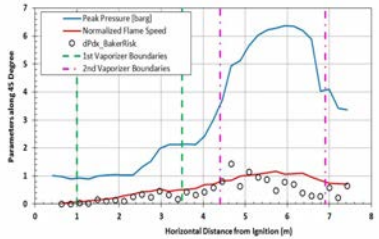
Low strength surfaces
Gaseous build-up limitation

ALDEA
INERIS/KIT/HSL test facilities
CFD

Integrity loss & Burst

Safety distances
Pressure relief devices

ALDEA
GEXCON test facility
CFD



CertifHy

www.certifhy.eu

Guarantee of Origin

Stakeholder Platform

Design the 1st EU-wide Green Hydrogen Guarantee of Origin system

Transparency

Label

- Label the origin of a product
- Provides information to customers

Market for low carbon H_2

New market for low carbon or Green H_2

Allowing EU-wide transferability and consumption of valuable low carbon or green H_2

Pilot "Guarantee of origin platform" on four H_2 production plants:

24th November 2017

Water electrolysis	colruyt	H_2 mobility	uniper — Power to Gas
Chlor Alkali	AkzoNobel	Industry	
SMR + CCU	Air Liquide	Industry	

... able to provide "**Green** " (= Renewable AND low Carbon) or "**low carbon**" Guarantees of Origin for H_2 in EU

E

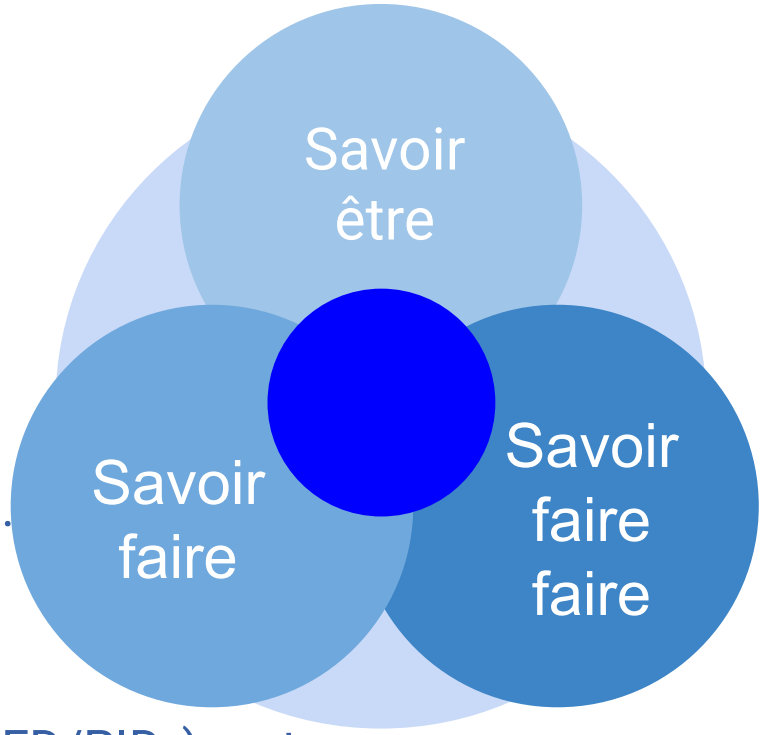
Required Competencies

Compétences nécessaires dans l'Hydrogène Energie

- Il ne s'agit pas de tout apprendre sur l'hydrogène pendant sa formation !
- La chaîne d'approvisionnement de l'hydrogène requiert des compétences spécifiques par brique technologique très variées
- Les compétences nécessaires en fonction des phases de vie d'un même système sont aussi spécifiques

Phase	Technical competence	Gaseous use (incl GH2)	Cryogenic use (incl LH2)
CONCEPTION	Solution Product Development	Electrolyzer, GH2 HP trailer , GHRS,..	LHRS, LH2 trailer, Liquefier, CCS, sea terminal,..
	Experimental Set-up and Methodology	Compressor, storage/connection	pumps , turbine
BASIC &DETAILED DESIGN / MANUFACTURING	Technology & processes (incl process control)	GH2 Process (ex: filling protocol)	LH2 process (ex: boill off)
	Electricty	Transfo electrolyzer	
	instrumentation, piping, component , fitting	pipeline, HP valve, cylinder,	coupling, break away
	storage (fixed & mobile)	pressure vessel, H2 buffer	LH2 tank, LH2 trailer
	proprietary equipment design	Electrolyzer, GH2 trailer	pumps, vaporizer
	rotative & reciprocating machine	Compressor	pumps , turbine
OPERATION	Primary production	plant operation HyCO / Electrolyzer	Liquefier (Turbo- Brayton)
	Supply chain / filling center	filling center trailer HP	
	Supply chain / transportation	transportation trailer HP,	transportation trailer HP,
	H2 Refuelling Stations	Gaseous HRS	Liquid HRS

Compétences nécessaires dans l'Hydrogène Energie



- Savoir Faire
  - Connaissance des fluides
  - Process lié aux fluides
    - Type adsorption, purification, liquéfaction, etc…
    - Thermodynamique, mécanique des fluides pour le calcul, …
  - Connaissances liés aux solutions & application technologies
  - Pipeline distribution
  - Compression, pompe,...
  - Instrumentation - automatisme (process control, niveau de fiabilité,...
  - Matériau & métallurgie (compatibilité, corrosion …)
  - Génie civil, structure
  - Electricité (puissance transfo) & électrochimie,
  - Méthodes , processus ingénierie (plan mécanique, chaudronnerie , PFD/PID,) ou transverse (sécurité, fiabilité, qualité)
- Savoir Être
  - Compétences linguistiques, comportementales, la curiosité, l'ouverture d'esprit, la flexibilité, l'intégrité, le positivisme, le professionnalisme, le sens des responsabilités, l'esprit d'équipe, l' éthique, la communication, la courtoisie, …. qui font la différence entre un ingénieur et un bon ingénieur!
- Savoir Faire Faire

F

Conclusion

Conclusions

- HYDROGEN TECHNOLOGIES ARE READY FOR SCALE UP

↓

- VOLUME WILL BRING COST DOWN

↓

- REGULATIONS WILL BRING VOLUME

↓

- URGENCY FOR ENERGY TRANSITION AND ITS INVESTMENT POTENTIAL SHALL CAUSE REGULATIONS TO COME