



Knowledge gaps: industry perspectives

HySafe Research Priorities Workshop

BAM - Berlin – 16-17 October 2012 | RUBAN Sidonie | CRCD Material Science – Operational Safety

Air Liquide and Hydrogen

World leader in Gases for Industry, Health and the Environment



- A long experience in hydrogen
 - More than 40 years in H2
 - 10 years in fuel cells

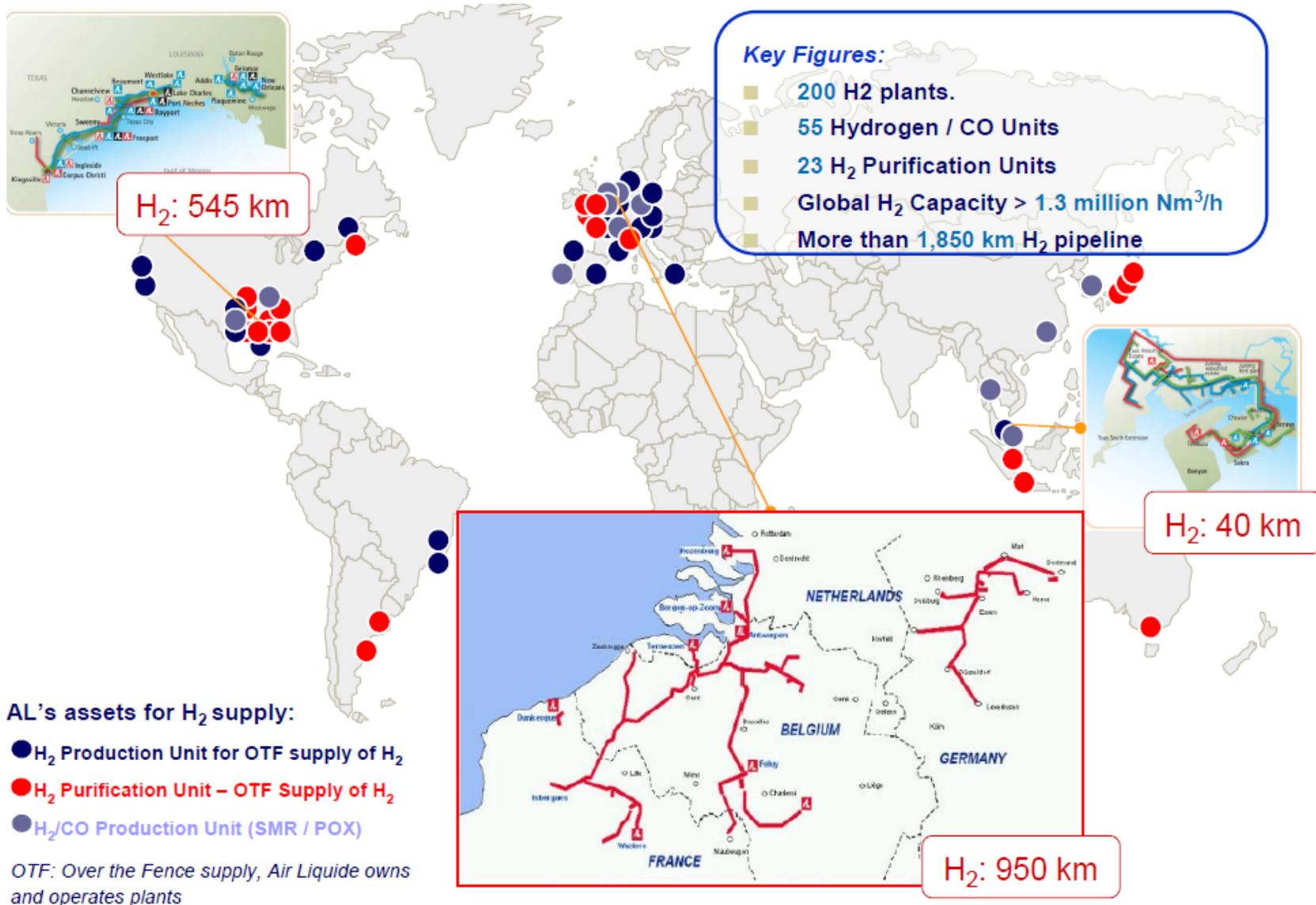
- A strong expertise in the “hydrogen chain”
 - Production, storage, distribution
 - High technologies (H2 stations, ...)

- A worldwide hydrogen infrastructure
 - More than 200 H2 production units
 - Broad range of H2 distribution modes: pipelines (> 1800 km), trucks, cylinders

- Key figures
 - Global H2 Capacity: 9 Billions Nm³ in 2010
 - 55 H2 stations



Air Liquide Worldwide Hydrogen Operations



This document contains confidential information of Air Liquide that cannot be communicated without its prior agreement.

Committed to Hydrogen Energy

Early markets



Forklifts

Mobility



Isolated sites



Telecommunication antennae

Niche markets



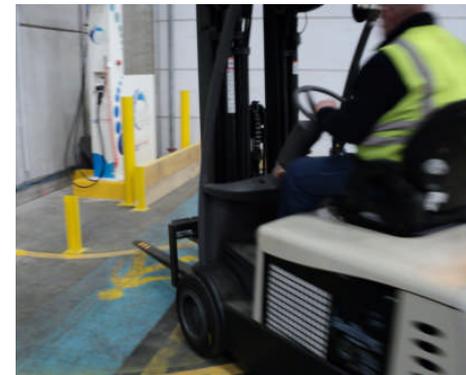
Mobile generator



This document contains information that cannot be communicated without its prior agreement.

Who are the early customers ?

- Ready to buy and use a H2E system or service
- Stationnary markets
 - ▣ Supply to isolated sites
 - ▣ Back-up systems
 - ▣ Small mobile generators
 - ▣ Balance fluctuations of the grid coupled to intermittent renewables
- Mobile markets
 - ▣ Fleets of industrial vehicles (forklifts)
 - ▣ City buses



To meet customers 'expectations, high-reliability systems are being developed with competitive TCO targets

ment



1st Focus: Electricity for Cell towers

- Stationary fuel cell with an average electric power of **0.1- 3kW**
- In substitution of Diesel Generators
 - Power supply to off-grid sites in countries with developed grid
 - Power Backup in countries with low reliability grids
- H2 advantages
 - Power reliability
 - Clean at point of use
 - No noise, no vibrations
 - Low maintenance
 - **Competitive Total Cost Of Ownership**
- H2 gas supplied and stored with cylinder bundles
 - Gaseous H2 @ 200 to 700 bar
 - Logistics based on “full – empty exchange”
- **Full service** including telemonitoring, maintenance and H2 storage management



France



India

contains confidential information of Air Liquide that cannot be communicated without its prior agreement.

Reliability & total cost objectives within easy reach
Review of Market size in Europe & Asia on going

2nd focus: H2 to store and deliver electricity on the right time, at the right place



BACKUP

Fuel cell-based backup power system

for uninterruptible power supply needs of data centers & critical industrial systems



**Back Up
100 kW**

HYDROGEN PRODUCTION

PEM electrolyser for Industrial Applications for Energy Applications



10 – 100 Nm³/h

DECENTRALIZED ENERGY STORAGE ENERGY MANAGEMENT

Hydrogen-based storage system

to address renewable energy sources intermittency, power distribution networks support, especially in developing countries

Currently undergoing market exploration



Greenergy Box™ 70kW

Built-in modularity

Fuel cell

Electrolyser

Fuel cell + Electrolyzer

HELION's Core expertise
Designing and manufacturing electrolysis and fuel cell stacks
Integration into complete self standing systems



3rd focus: H2E for electric forklifts

- **Captive fleet** operations around a local H2 filling station
- A range of FC systems 1.5kW - 10kW
- Market
 - ~ 3000 systems deployed in North Am
 - > 1000 large sites in Europe
- H2 & Fuel Cell advantages
 - Greater autonomy than battery forklifts (X2)
 - Quick refill (3 to 5 mn)
- H2 produced on site or delivered through H2 gaseous trucks
 - H2 trucks (200 bar - 700 bar) from large existing H2 plant
 - Regional production from natural gas or biogas
 - On-site water electrolyzer



Productivity gains and flexibility of warehouse fleet

CO₂ reduction depends on grid electricity carbon footprint

Life Cycle Analysis in progress



On the road to sustainable mobility with Hydrogen – Need for a dedicated infrastructure

Production

- Clean/renewable technologies (CO2 free/neutral)
- Centralized/decentralized
- Cost competitive

Storage

- High capacity
- Ergonomic packaging
- Cost competitive



Conversion in Fuel Cell

- Fuel quality
- Performance
- Durability
- Cost competitive

Transport & Distribution

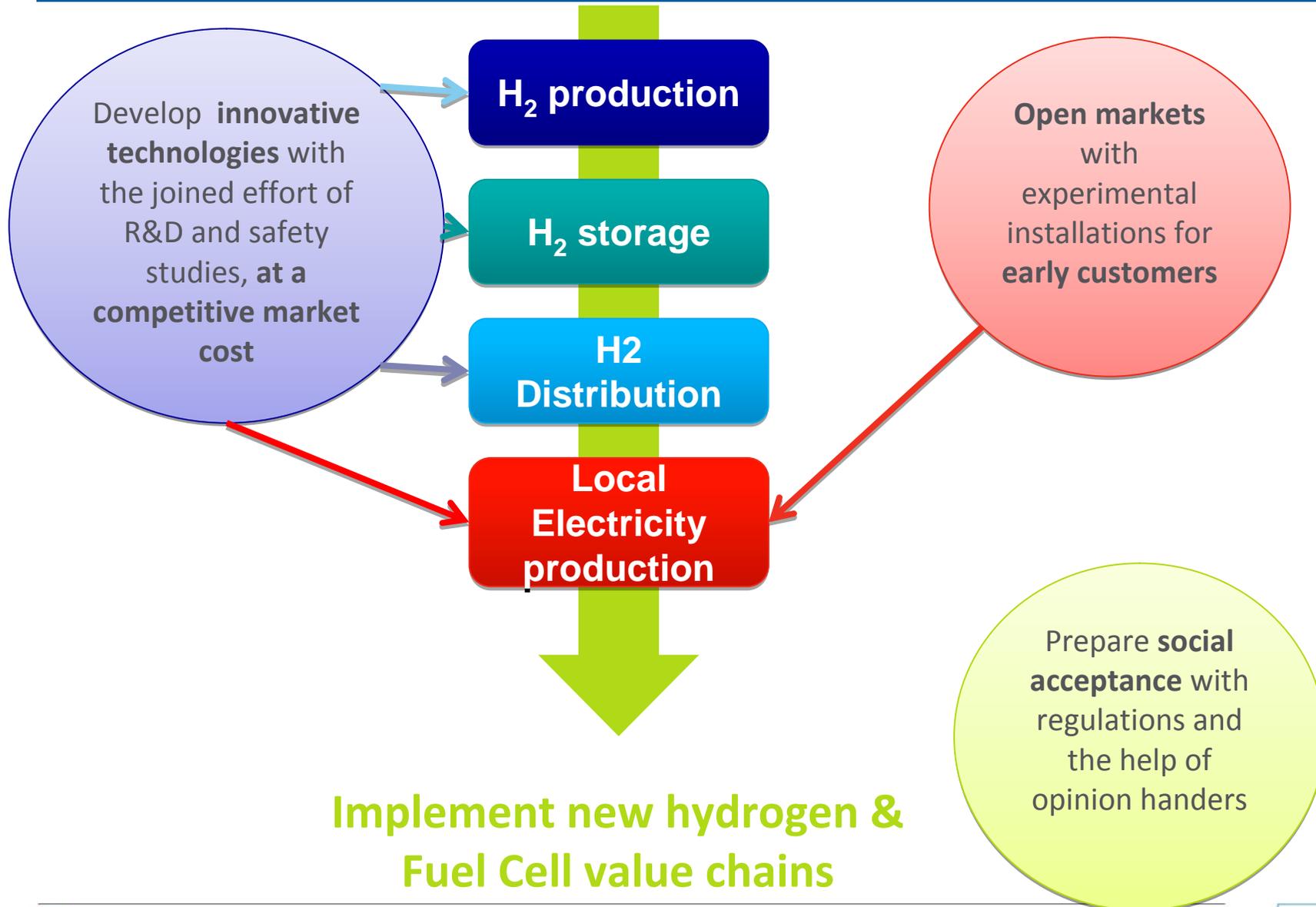
- Efficiency
- Optimized logistics options
- Cost competitive

Social acceptance

- Shared safety knowledge
- Adoption of codes & standards

This document contains confidential information of Air Liquide that cannot be communicated without its prior agreement.

Complete & optimal supply chains



This document contains confidential information of Air Liquide that cannot be communicated without its prior agreement.

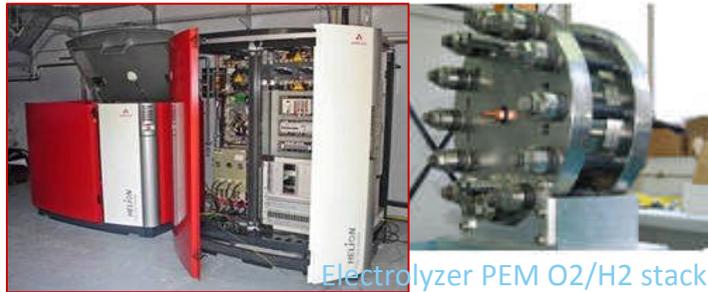
From prototypes to competitive products

Air PEM Fuel Cells



Evopac based Mobile generator 2 kW

O2 PEM Fuel Cells



30 kVA back-up system

PEM Electrolyzer

H2 Distribution



Hydrogen delivery system
2,4 l 500 bar composite cylinders

r Liquide that cannot be communicated without its prior agreement.



16/10/2012



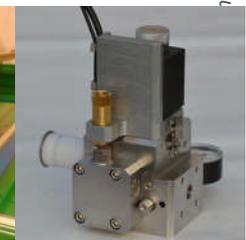
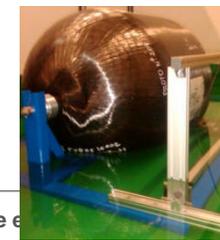
IA HySafe Workshop



Air Liquide, world leader



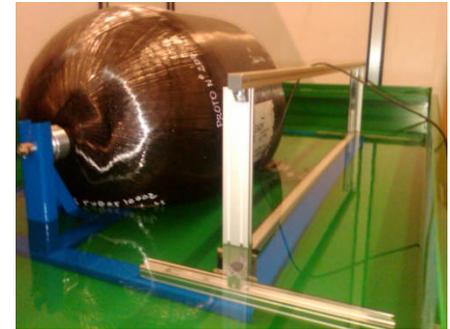
and the e



Confidential infor

H₂ high pressure mobile storage system

- H₂ logistics based on high pressure gas storage in composite fiber cylinder (525 – 700 bar)

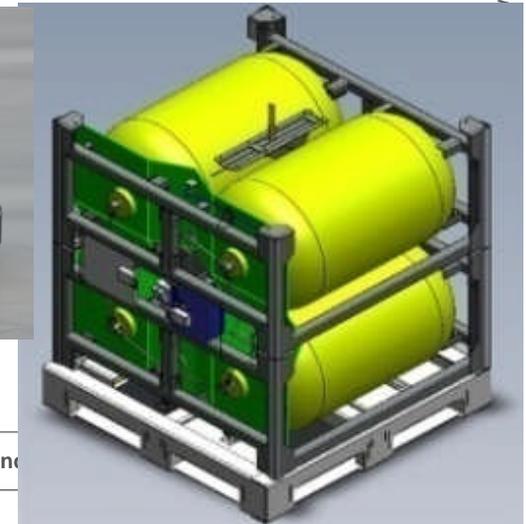
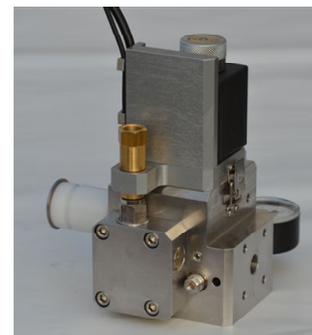


- Composite fiber cylinders development (Type IV)

- ✓ 142L at 525 bar
- ✓ Design
- ✓ Qualification methods
- ✓ Long term behaviour
- ✓ Inspection methods (non destructive)
- ✓ Safety (fire, impact ...)



- Cylinder interface with intelligent depressurizing tap: HyDeAL
- Wireless pressure transmitting device HIPI



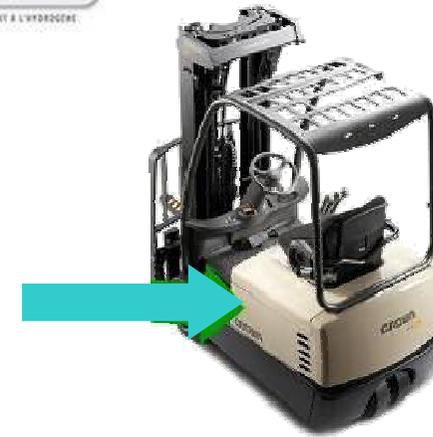
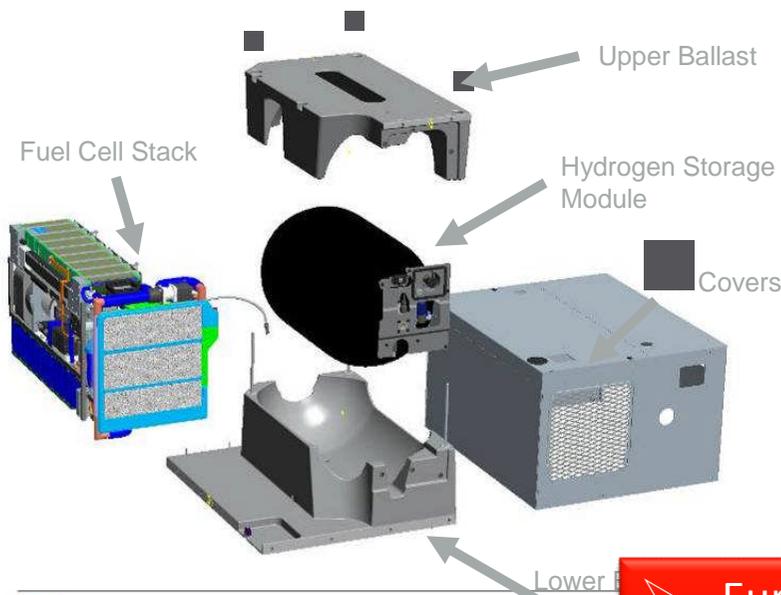
- Homologation planned for mid 2013
- Large scale distribution in 2014

Systems for forklifts market

- Air Liquide 350 bar filling station
 - ▣ New customer interface deployment in 2012
 - ▣ Industrialized standard 100 kg / day by 2015



- Integrated offer for fuel cell forklifts with Hypulsion pack including fuel cell stack and storage module
 - ▣ New complete European Offer for 2014



➤ European certification of 7 key systems by mid 2013

H₂E achievements so far

2009

- Creation of Air Liquide Hydrogen Energy
- 17 systems deployed
- 5 invention declared
- 136 000 € turnover

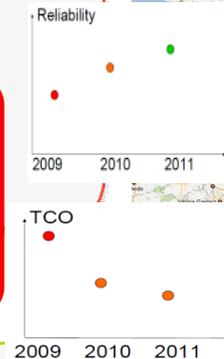
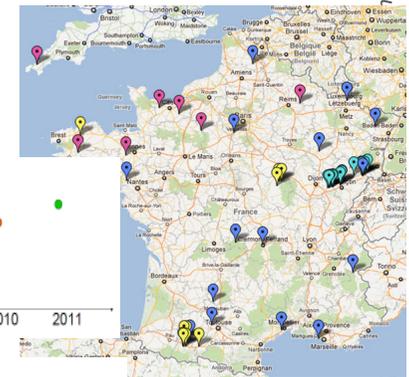
2009-2010 :
Targets definition, detailed study of markets, expression of the various needs.



2010

- Prototypes for cylinders and electrolysis
- 18 systems deployed
- 14 patent requests
- 200 000 € turnover

2010-2011 :
Gain in systems reliability on installations from **91,2%** to **99,2%** and TCO reduction



2011

- Project in Vatry (forklifts), HyES development, prototypes for interface solutions
- 62 systems deployed
- 16 patent requests, 38 invention declarations
- 4 842 000 € turnover

2011-2013 :
Generation 1 developed, certified and deployed



Next Steps

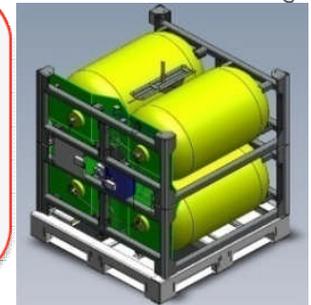
2012

- HyPulsion JV created
- First forklift customers
- 8 000 hours running time reached on the field with a PEM FC
- Electrolyser & H2/O2 Fuel Cell in operation for solar energy storage
- French norm for H2E system installation released



2013

- Homologation of 525 bar composite cylinders
- Agreement for 525 bar cylinder filling station
- New Axane modular Fuel Cell on market in Europe & Asia
- Deployment of Helion back up systems for critical equipment



2014

- 525 bar cylinder-based logistics in operation (France, Spain, Italy)
- Cost reduction target met on stationnary off-grid market
- Stationnary systems deployed in East Europe & Asia
- Cost reduction target for H2 distribution station confirmed
- Projet launched for Blue hydrogen produced through a PEM electrolyzer

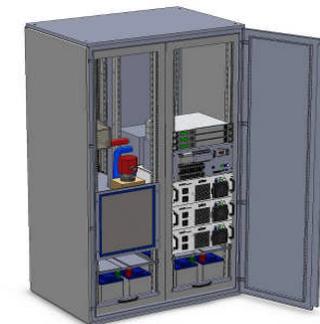


New safety challenges

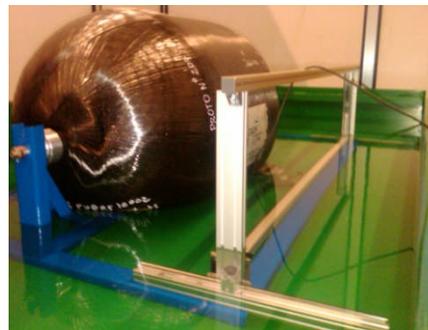
- High pressure and specific mechanical loading
 - ▣ Leak tightness
 - ▣ Material compatibility (hydrogen embrittlement)
 - ▣ Intelligent depressurizing tap



- “Indoor” use
 - ▣ Natural ventilation
 - ▣ Structure strength



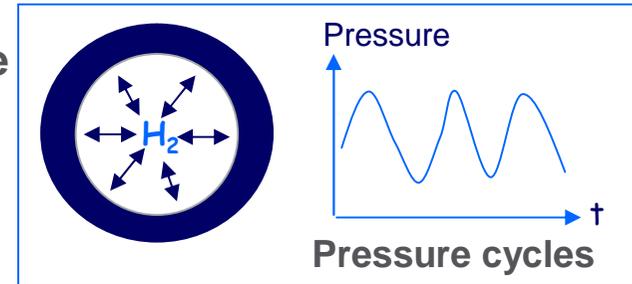
- High capacity for H2 mobile composite storages
 - ▣ Failure mechanisms
 - ▣ Resistance to fire



This document contains confidential information of Air Liquide that cannot be communicated without its prior agreement.

Hydrogen safety: what have we learned? (examples)

- Considering **pipeline steels microstructure** and **fatigue enhanced embrittlement** in addition to **material composition** ⁽¹⁾
- **Sizing release flow-rate for fire protection of H₂ composite cylinder** ⁽²⁾
 - Pressure peaking effect
 - Flame effect
 - Storage leak and no burst phenomena
- **Sizing openings** for an efficient natural ventilation of enclosures
 - Parameters such as openings size, position have a strong influence on dispersion regimes



- (1) D. Stalheim and L. Hayden, Metallurgical considerations for commercial steels used for hydrogen service. Proceedings of the 2008 Hydrogen Conference, Somerday, Sofronis and Jones, Eds.
- (2) S. Ruban and al., Fire Risk on high-pressure full composite cylinders for automotive applications, International Conference on Hydrogen Safety 4, San Francisco (2011)

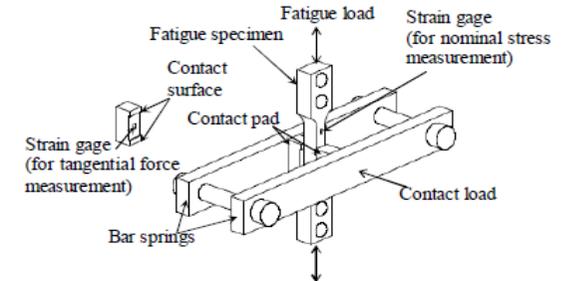
What do we need?

- **Mechanisms of hydrogen embrittlement**
 - remain a topic of actuality and need further research efforts
- ➔ **We need a testing method** that allows to generate data useful for complete service life and reliable data under **hydrogen high pressure service conditions**
- ➔ **Specific materials manufactured** for hydrogen use
- ➔ **A consensus** for testing method

- **Mechanism of ruin of composite storage under fire**
 - Is a new topic and need further research efforts
- ➔ **We need a testing method** that allows to assess the capacity of the storage to sustain pressure and fire and **size protections**
- ➔ We need **predictive models**
- ➔ **A consensus** for testing method

- **Dispersion regimes for hydrogen indoors**
- **Deflagration of localized / stratified / lean mixtures**

- ➔ **We need simple engineering tools to size and localize openings** for safe and natural ventilation and effective overpressure venting, whatever the **size of the enclosure**, for a number of **leak rates** and type of **leak source** (from pipe rupture to fittings leaking)
- ➔ **Validate methods to get rid of wind influence**



This document contains confidential information of Air Liquide that cannot be communicated with

Improving knowledge

- Focusing research and prioritizing knowledge gaps
- Working also with academic & research partners to increase knowledge and focus research on industrial needs
- Towards international standardization and shared guidelines





End of presentation
Thank you for your attention

Sidonie.ruban@airliquide.com

