



第 126 回定例研究会 資料VI

# The Research and development on Hydrogen Energy in France


Jean-Marc Olive



九州大学  
KYUSHU UNIVERSITY



HYDROGENIUS





NATIONAL INSTITUTE OF  
ADVANCED INDUSTRIAL SCIENCE  
AND TECHNOLOGY (AIST)

To Hélène David

## Outline

- Industry of Hydrogen : activity and R&D
- French Research Networks and Program:
  - Pan-H: a national program on Hydrogen (ANR: National Research Agency)-CEA
  - BioH2: CNRS Research Network on BioHydrogene
  - PACTE: CNRS Research Network on Fuel cells
- Few examples of research activity of laboratories CNRS, Universities and CEA

## AIR LIQUIDE Hydrogen activity


- 1967: Air Liquide builds the first liquid hydrogen production unit geared to the space industry.
- 1973: Start-up of the first unit for hydrogen production by steam methane reforming (SMR) in Isbergues, France, and the first hydrogen pipeline (20 km).
- 1979: First launch of Ariane 1 with a tank of liquid hydrogen
- 1985: Extension of the pipeline from Isbergues to Zeebrugge in Belgium, thereby creating a multi-source international network, for different customers. Network length approximately 140 km.
- 1987: Air Liquide builds Europe's largest hydrogen liquefying unit in Waziers (France) and supplies hydrogen to Ariane. Start-up of a hydrogen liquefier in Resoult (Canada), then in Japan in 1988.
- 1988: First launch of Ariane 4. Establishment of Cryospace.
- 1991: Start-up of the first high capacity hydrogen unit (10,000 Nm<sup>3</sup>/hr) and extension of the hydrogen network to a third country, the Netherlands.

35 years of experience feedback on hydrogen pipeline.


1902

G. Claude and P. Delorme  
Innovation in gas separation  
And liquefaction

2006: 200 MEuros in R&D  
850 scientists  
10,000 patents

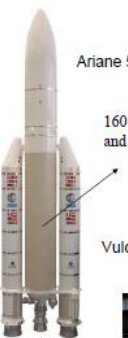


Unité de production d'hydrogène




Principaux gaz produits : hydrogène (H<sub>2</sub>)

- 2005: Start-up of a large SMR in Caoping near Shanghai (China). Air Liquide hydrogen sales reach 600 million euros for a volume of 5 billion m<sup>3</sup>.
- 2006: Construction of a second 100,000 Nm<sup>3</sup>/hr capacity hydrogen unit in Antwerp.
- 2008: Air Liquide hydrogen sales forecast should reach 1 billion euros.



Ariane 5

160 tonnes of liquid hydrogène and oxygène at -253 °C



Vulcan II (cryogenic engine)







Figure: Air Liquide's 180-bar gaseous hydrogen supply pipeline grid covering France, Benelux and Germany.



Stationary and mobile power sources from hydrogen.

Comin Pac™ Base

## H2E : A French project starting 2008 for 7 years

- H2E: Horizon Hydrogène Energie
- Leader: Air Liquide 
- 15 partners
- 77 M€ from the french state
- Objective: develop hydrogen-fuel cell industrial applications through high value-added products (long term transport market)



## French nuclear industry

  
AREVA  
the world leader in nuclear power



HELION, part of AREVA, is specialised in the design, development and manufacture of PEM (Proton Exchange Membrane) type fuel cell systems and electrolysers for applications combining availability, safety and reliability. On the basis of its shared R&D plan and its road map for access to precursory markets, HELION is claiming a key position as a supplier of ready to go solutions addressing high value markets such as decentralised stationary energy, the naval industry and urban transport.

HELION-Fuel Cell maker

### History and key figures

- Company set up in March 2001.
- Recognised success, with over 40 employees and a growth dynamic with an average of over 50% per year continuous increase in activities.
- A matured technology and application roadmap:
  - 2001: 1st French fuel cell of 2 kW.
  - 2002: 10 kW test bench fitted with a 5 kW/e stack.
  - 2003: European HELIOS project for a 5 kW/e backup power system.
  - 2004: implementation of purely H<sub>2</sub>/O<sub>2</sub> stacks, with nominal power 20 kW/e.
  - 2005: backup power system S'VAPAC20 with net power 20 kW/e.
  - 2006: 50 kW/e power obtained by the HyStar stack developed in the context of transport applications; installation of HELION 50 kW/e industrial fuel cell backup power system in real operating conditions at the customer's site; Evaluation of a 4.8 MW<sub>el</sub> and 5 MW<sub>th</sub> COFEPAC cogeneration systems including a fuel cell module and a natural gas reformer with a purification membrane; Realisation of a new generation high pressure PEM electrolyser stack, successfully tested ISO 9001 and ISO 14001 certification for the whole company activities.
  - January 2007: HELION joins the newly created AREVA Renewable Energies Business Unit.



## French automotive industry.



> 150 years



Fuel Cell Concept car 207 PEUGEOT  
Fuel cell 20 kW + Lithium-ion battery  
5 HP tanks (15 l) 700 bars  
Driving range: 350 km  
Speed max: 130 km/h

In 1860, Etienne Lenoir of France invented the 1-cylinder, 2-stroke Hippomobile.  
The Lenoir Hippomobile was so named because it received its fuel by electrolyzing water and running the hydrogen through the small horizontal engine.  
Around 350 of the Lenoir gas motors were built and sold.

Mass production !



- QUARK
- PAC 1,5kW + batterie NiMH
- Bouteille H<sub>2</sub> 700 bars **plug & drive**

## French natural gaz industry GDF-SUEZ

Demonstration of buses fuelled with natural gas and hydrogen in Dunkirk and Toulouse  
A first step towards the hydrogen economy

Coordinator :  
Gaz de France, R&D

  
Althyte



The project Althyte aims to test the operation of buses fuelled with a blend of natural gas and hydrogen in the cities of Dunkirk and Toulouse. It is a question of testing on real site this new clean fuel and of evaluating the technical and economic interest of it.

Hythane® : mixture of natural gas and hydrogen – 80% NG + 20% H<sub>2</sub>.



Réservoirs composite-aluminium Dynetek

- 8 réservoirs de 155 litres
- Autonomie de 300-400 km

<http://www.althyde.info/docs.htm>

## ANR (French Research Agency)

A funding agency for research projects  
Budget in 2007: 825 M Euros (for 3 or 4 years projects)

Department of Sustainable Energy and Environment

National Action Plan on Hydrogen and Fuel Cells (PAN-H) 22% : CEA and ANR

Call for proposal <http://www-anr-panh.cea.fr/>

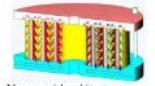
Axe thématique	Number of projects				Number of funding				Funding by ANR (M Euros)			
	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008
Production												
Transport					2	5	4	-	3.1	7.4	3.86	-
Fuel cell					7	5	2	-	6.3	3.4	2.70	-
Activités transverses					15	11	5	-	19.8	17.1	6.64	-
					1	1	1	-	0.4	1.0	0.36	-
	75	72	32	56	25	22	12	-	25.6	28.9	13.7	-
Total											72.23	-

Nombre de partenaires en moyenne : 6



## PROD-HYGE Project :

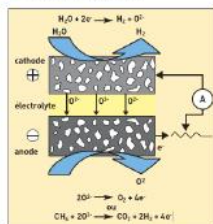
- Objective : Validation of an innovative architecture for high temperature electrolyser for hydrogen production
- leadership : CEA - french atomic energy commission
- Partners : CEA, AREVA, Arcelor-Mital, SPCTS, LMP
- 3 years long, started in september 2007
- Budget : 4,1 M€



New coaxial architecture :  
- Patents E.N. 04/52495 & E.N. 04/52496




### Reversed SOFC



**PRODHYGE ANR**

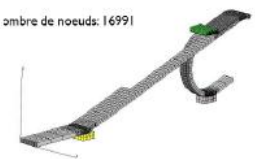
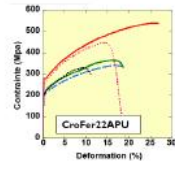
**LMP's Tasks:**




High Temperature creep test with environmental effect

- Up to 900°C
- pure H<sub>2</sub>, pure Moisture, inert gaz. mixture

ombre de noeuds: 16991

CroFer12APU



Bending relaxation fixture in TGA

**BioH<sub>2</sub> Group of Research BioHydrogène**

Biological and Biomimicking Ways of Synthesis and Use of Hydrogen

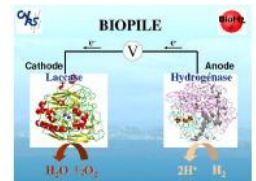
The Group of Research "Biological and Biomimicking Ways of Synthesis and Use of Hydrogen" was created in 2006 with the objective of promoting hydrogen of biological origin as a source of energy.

44 Groups from 22 Laboratories

CNRS, CEA, INRA, IRD, INRIA, INSA, INPT, BRGM

Universities: Marseille, Montpellier, Toulouse, Nice, Grenoble, Clermont-Ferrand, Nantes, Orsay, Brest, Lille

**BIOPILE**



**Fermentation**

Substrats → Glucose → H<sub>2</sub>

**Photosynthesis**

Solar Energy → Green Algae → H<sub>2</sub>

[http://www.bioh2.cnrs-mrs.fr/gb\\_index.php](http://www.bioh2.cnrs-mrs.fr/gb_index.php)

**Groupements de Recherches du CNRS "Piles A Combustible Tout Electrolyte" PACTE**

**Fuel Cell French Research Network of CNRS**

Contact: [grenier@icmcb-bordeaux.cnrs.fr](mailto:grenier@icmcb-bordeaux.cnrs.fr)

**Main research fields :**

- \* **PEMFC** : Proton Exchange Membrane Fuel Cells
- \* **DMFC**, Direct Methanol Fuel Cells
- \* **ITSOFC**, Intermediate Temperature Solid Oxide Fuel Cells,
- \* **PCFC**, Proton Ceramic Fuel Cells
- \* **HTE**, High Temperature Electrolysers
- \* **Systems and modelling**

**48 Academic research teams**

C.E.A., ADEME

**10 Industrial partners**

**Web site:**

<http://www.qdr-pacte.cnrs.fr/>

**Saclay**

**Hydrogen-deformation interactions in Fe and Ni base alloys. Consequences on hydrogen-assisted cracking**

**Main current research programs**

- ✓ **H-plasticity interactions in fcc materials (Ni base alloys, stainless steels) related with stress corrosion cracking mechanisms .**
- ✓ **Mechanisms of intergranular SCC of Ni base alloys in Pressurized Water Reactors**
- ✓ **Mechanisms of SCC of Fe-Mn ferr steels**
- ✓ **Role of H in the mechanism of Irradiation Assisted SCC**
- ✓ **Interactions H-microstructure-deformation in ferritic steels**
- ✓ **Role of H in the SCC of ferritic steels for long term storage of nuclear waste**
- ✓ **Improvement of the HE resistance of new ferritic steel for H transport**
- ✓ **Interactions <sup>3</sup>H/<sup>2</sup>He/irradiation induced defects in W for ITER divertor**
- ✓ **Interactions deuterium/tritium-microstructure in Fe and Ni base alloys**
- ✓ **Management of tritiated waste**
- ✓ **Development of techniques for the isotopic tracing of H**
- ✓ **Role of H in the oxydation mechanisms of Zr alloys**

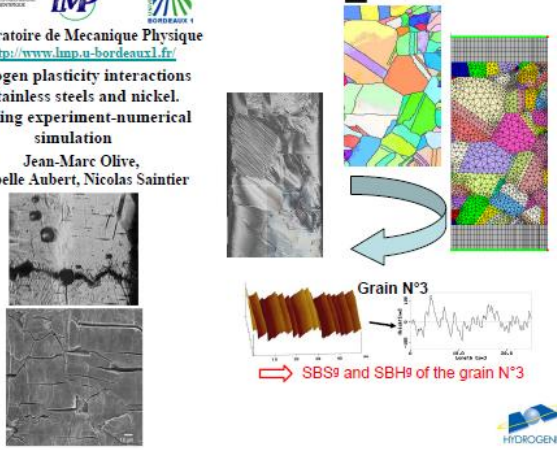
**Jacques CHÉNE**  
CNRS/CEA, UMR 8587, Laboratoire d Etude de la Corrosion Aqueuse, CEA Saclay, F91191 Gif sur Yvette, France  
[jacques.chene@cea.fr](mailto:jacques.chene@cea.fr)

**Laboratoire de Mécanique Physique**

<http://www.lmp.u-bordeaux1.fr/>

**Hydrogen plasticity interactions on stainless steels and nickel. Coupling experiment-numerical simulation**

Jean-Marc Olive, Isabelle Aubert, Nicolas Saintier



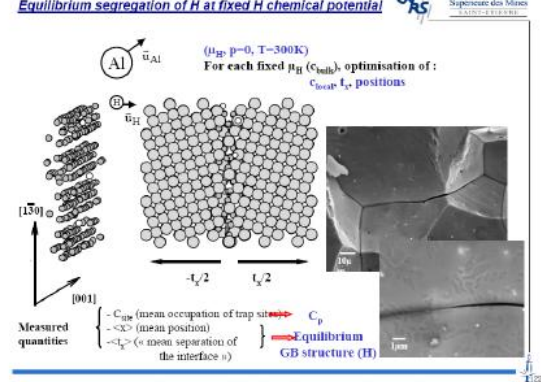
Grain N°3

SBS<sub>g</sub> and SBH<sub>g</sub> of the grain N°3

**Equilibrium segregation of H at fixed H chemical potential**

$(\mu_H, p=0, T=300K)$

For each fixed  $\mu_H$  ( $C_{\text{total}}$ ), optimisation of :  $C_{\text{total}}, t_1, t_2$  positions



Measured quantities

- $C_{\text{tr}}^{\text{GB}}$  (mean occupation of trap sites)
- $\langle x \rangle$  (mean position)
- $\langle t_1 \rangle$  (« mean separation of the interface »)

Equilibrium GB structure (H)

D. Tanguy, N. Pauze, D. Delalosse  
UMR CNRS 5146, LPECM <http://www.emse.fr/index.php>  
Ecole des Mines de Saint-Etienne

**L.E.M.M.A.**  
Laboratoire d'Études des Matériaux en Milieux Agressifs  
<http://www.univ-lr.fr/labo/lemma/>

**Influence of plastic deformation on the hydrogen reduction**  
Pr. Xavier FEAUGAS  
[xavier.feugas@univ-lr.fr](mailto:xavier.feugas@univ-lr.fr)

Monocrystalline pure nickel

**EADS COMPOSITES AQUITAINE**

**Hydrogen tanks 700 bars**  
Research program: 2008-2011

**AIR LIQUIDE**

**IMP** **BORDEAUX 1** **lym²**

**OXAS** CENTRE NATIONAL DE LA RECHERCHE AERONAUTIQUE

◦ Liner/composite adhesion ageing

Pr. Martin Shanahan  
[m.shanahan@imp.u-bordeaux1.fr](mailto:m.shanahan@imp.u-bordeaux1.fr)

**HYDROGENUS**

**IMP** **NDE of hydrogen tanks** Pr. Bernard HOSTEN  
[b.hosten@imp.u-bordeaux1.fr](mailto:b.hosten@imp.u-bordeaux1.fr)

Through-thickness view

High pressure composite tank

High pressure composite tank

Experiments

Result