Krakow, 9th May 2008

Hydrogen Energy and its storage

Overview on the activity of the Laboratory of Applied Mechanics in this field of research

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Context

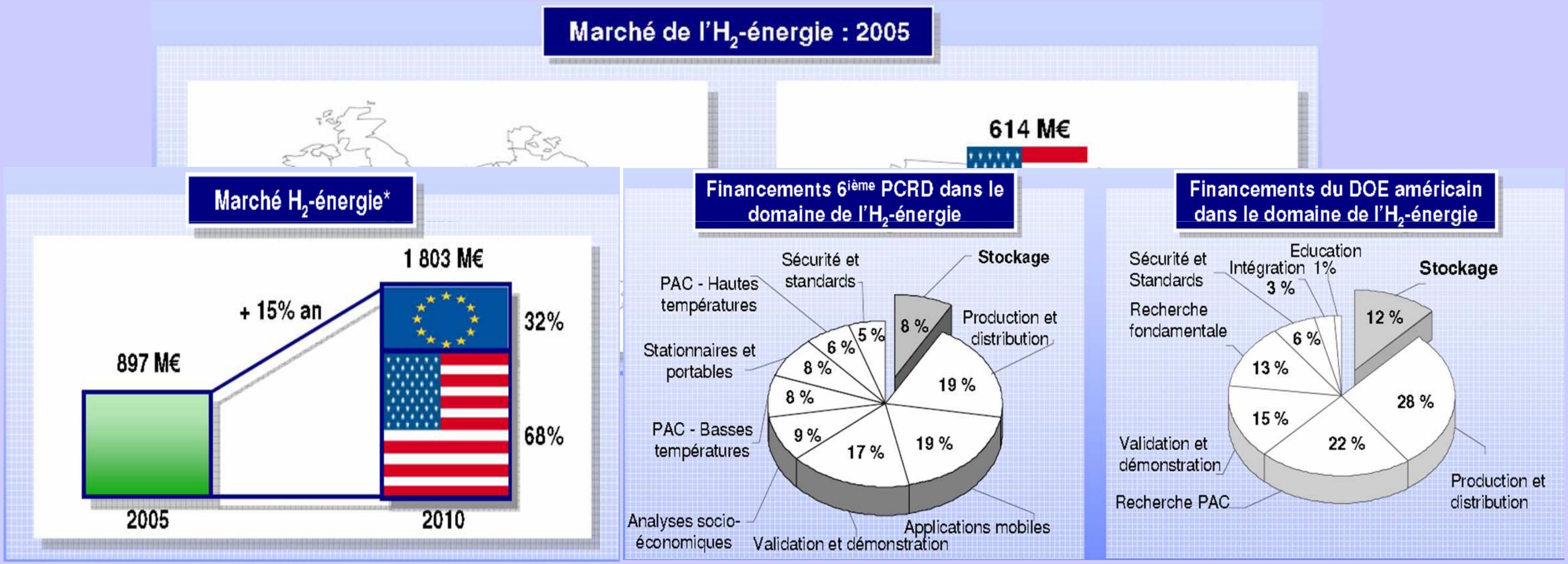
A worrying situation???

- pollution by emission of green-house effect gas

- a scheduled collapse of fossil fuel energy

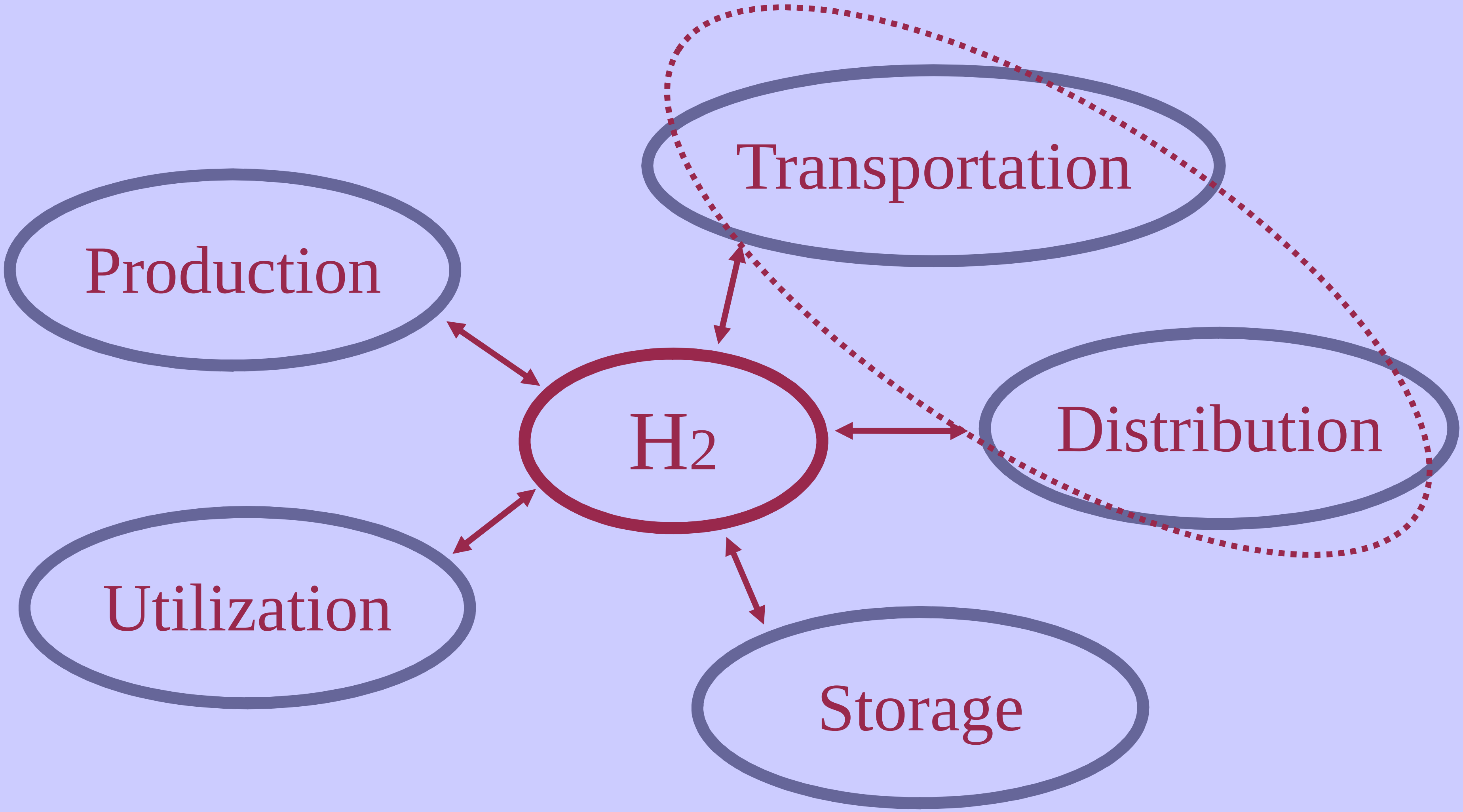
… renewable energy carriers

and hydrogen is a promising one!!



2005 Hydrogen Market, Hydrogen R&D and Commercial Implication in The U.S. and E.U.
Fuji-Keizai USA, Inc., May 2005

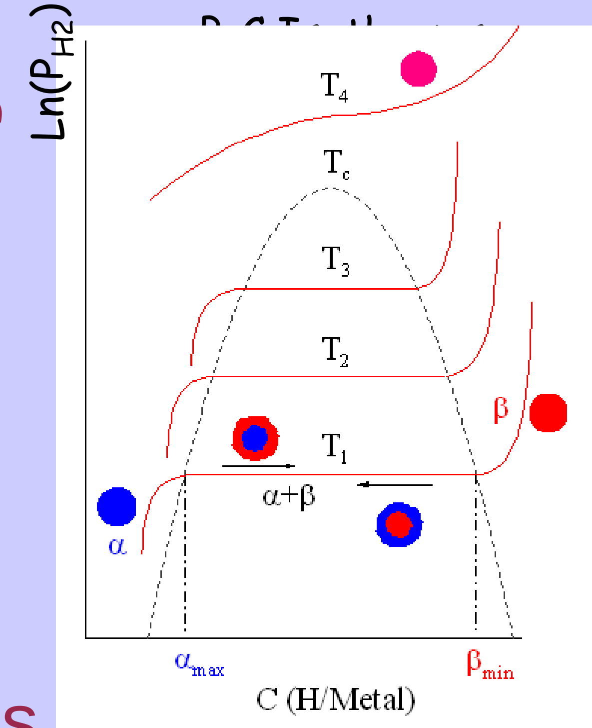
Hydrogen set of problems



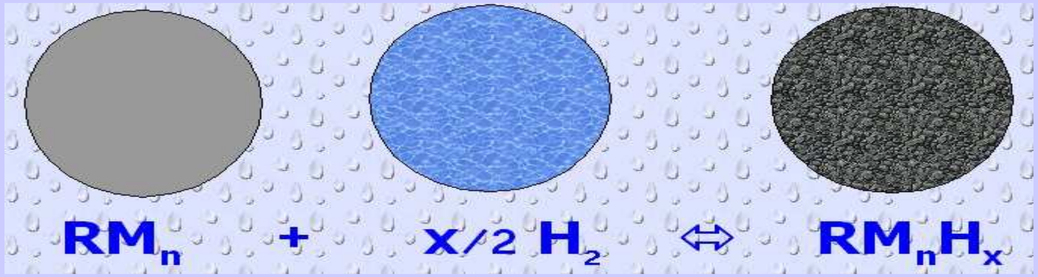
Hydrogen storage carriers

Solid...	Material-based storage
Liquid...	very low temperature
Gaseous...	high pressure

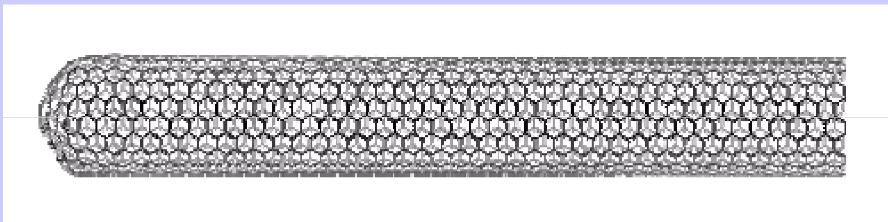
Materials-based hydrogen storage



Absorption: metal hydrides



Adsorption : active coal, carbon nanotubes or nanofibers



Chemical reaction:

Hydrolysis : $NaBH_4 + 2\ H_2O \leftrightarrow NaBO_2 + 2\ H_2$ (*Sodiumhydridoborate*)

Hydrogenation : $C_{10}H_{18} \leftrightarrow C_{10}H_8 + 5\ H_2$ (*Dimethyl Propylmethane*)

Materials-based hydrogen storage

Advantages : - safety (low pressure and temperature)

- stability

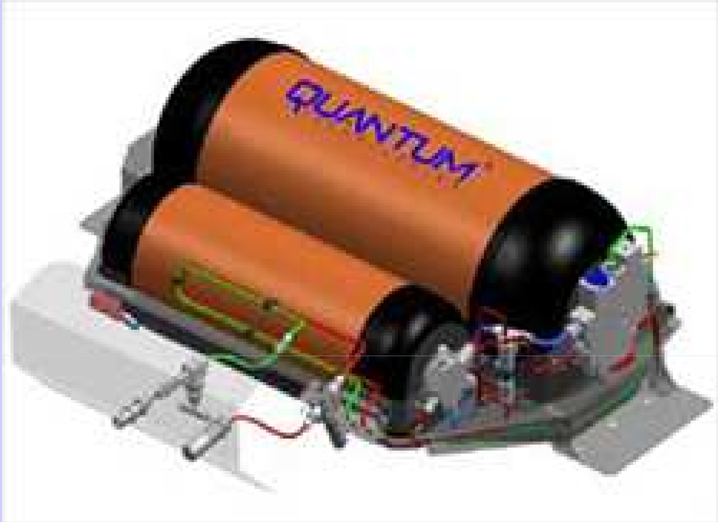
Drawbacks : - cost (rare components, catalyst)

- technological breakthrough

- weight (hydrides)

- off-board regeneration

Gaseous hydrogen storage



Method : gas is compressed
5000-10000 PSI

Advantages : - a well-known technology

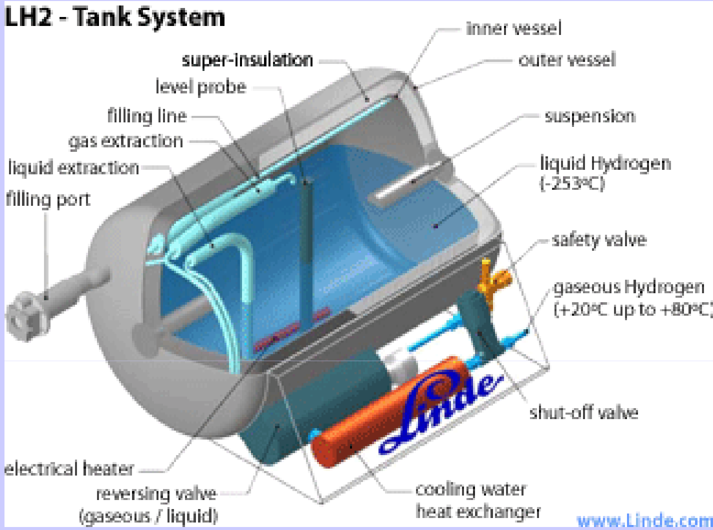
- acceptable refueling time

Drawbacks : - low volumetric density

- HP requires specific equipements

- 10% heating power

Cryogenic hydrogen storage



Method : hydrogen is liquefied
20 K

Advantages : - a good volumetric density

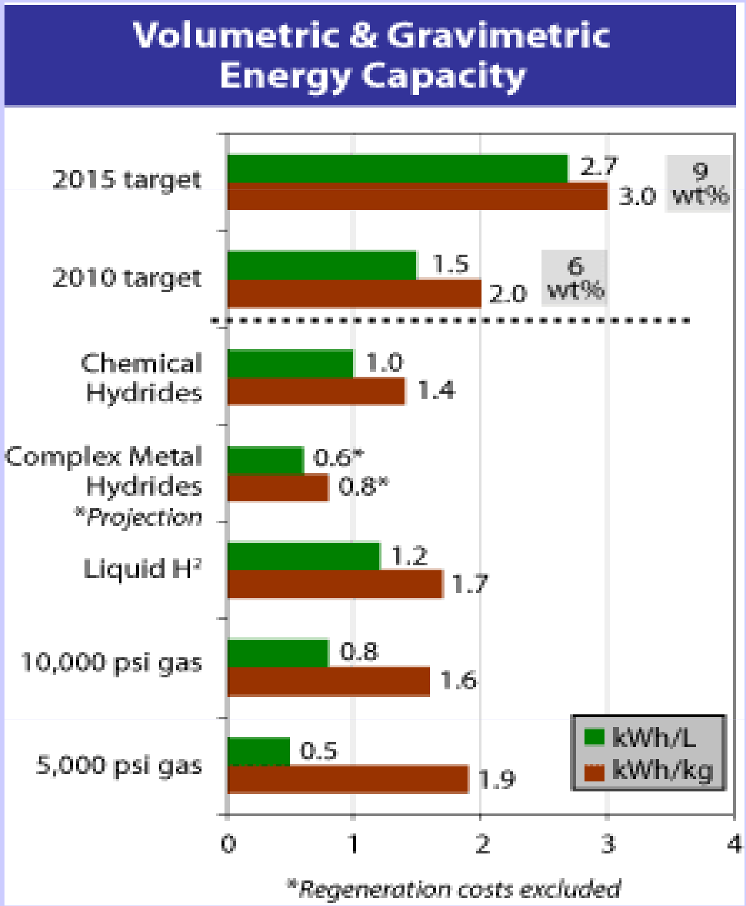
- refueling technology is acquired

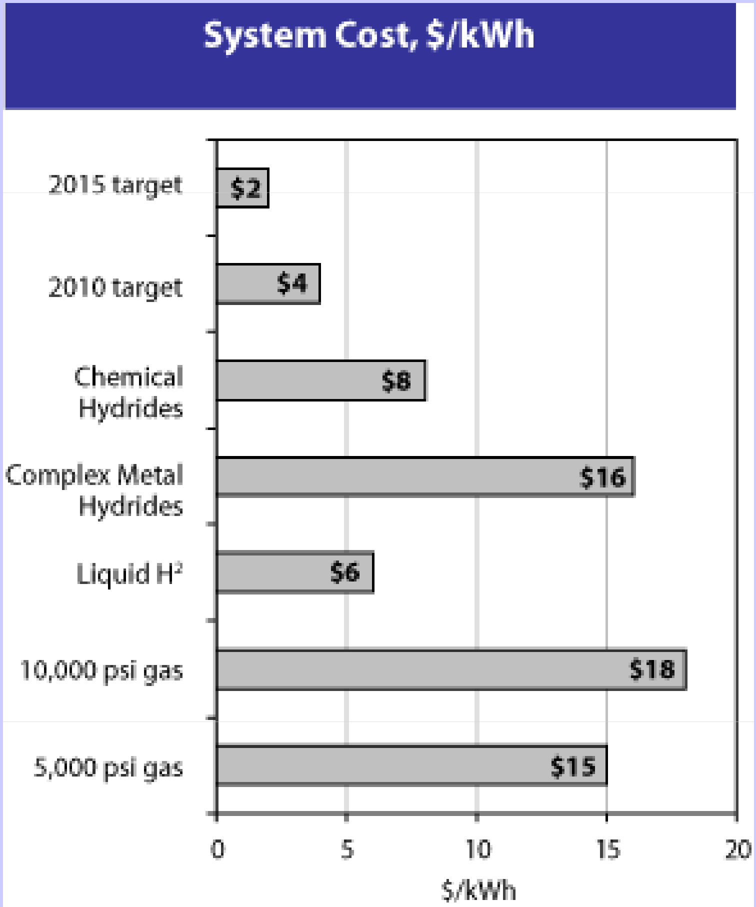
Drawbacks : - boil-off phenomenon (1%/day)

- Cryogeny requires specific equipements

- 30% heating power

Storage carriers comparison





<u>Unreachable target ??!!</u>

Hydrogen storage challenges

For transportation... 500 km requires 5 kg H_2

Weight and volume...	to be reduced
Efficiency...	to be increased
Durability...	lifetime of 1500 cycles
Refueling time...	less than three minutes
Cost...	cheaper materials and compounds
Codes and standards...	must be established

Analysis of the full life-cycle is missing

Research activity examples

Optimization of a Type III hydrogen storage vessel (1)

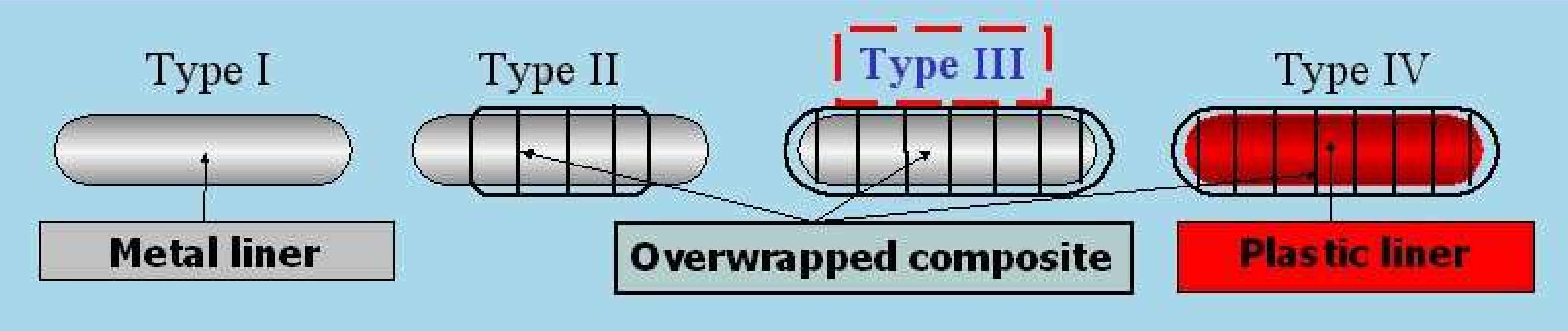
Design of a hybrid storage tank (2)

…

LMARC, Institut FEMTO ST
P2M departement
D. Chapelle, D. Perreux, F. Thiébaud...

Research activity examples (1)

What is a type III hydrogen storage vessel?



Metal liner

Polymeric liner

10 cm

Samtech

Research activity examples (1)

What is the goal?

Development of a tank reinforced by composite

- in use pressure : 10000 PSI (70 Mpa)
- gravimetric density : 6%
- metal liner : stainless steel or aluminium alloy
- burst pressure : 23500-30000 PSI

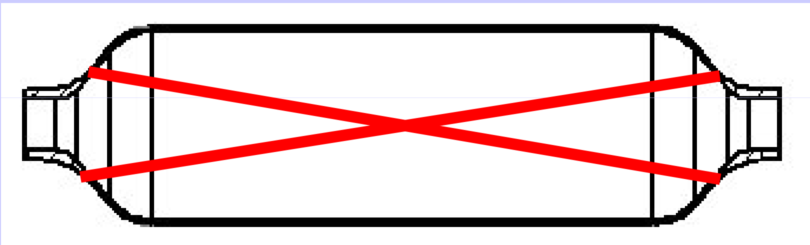
Research activity examples (1)

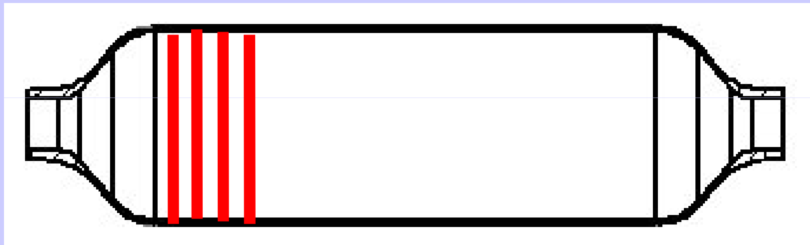
The industrial approach

is based on time considerations

Polar winding

Circumferencial winding





The winding angle depends on the liner geometry

AXIAL LOADING

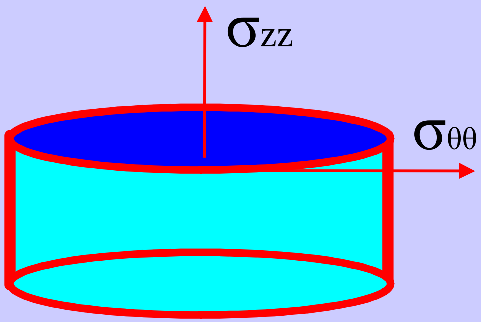
HOOP LOADING

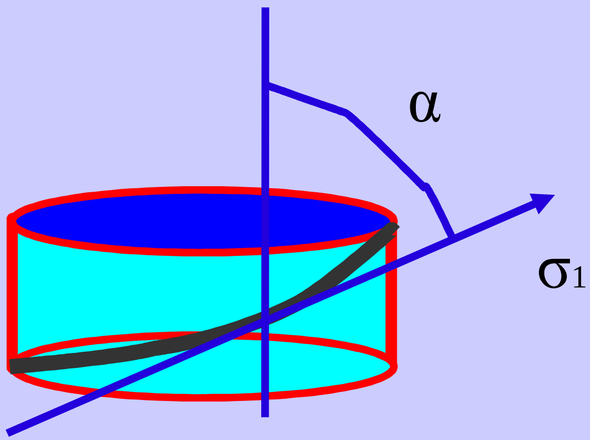
Research activity examples (1)

Simple mechanical analysis

Optimal winding angle is 55°

Thin shell under internal
pressure with close-end effect





Strength equilibrium: $(\sigma_{\theta\theta} / \sigma_{zz}) = 2$

$\sigma_{\theta\theta}$ = Pressure . Radius / thickness

σ_{zz} = Pressure . Radius / (2 . thickness)

$\sigma_{zz} = \sigma_1 \cos^2 \alpha$

$\sigma_{\theta\theta} = \sigma_1 \sin^2 \alpha$

It means… $\tan^2 \alpha = 2$

Research activity examples (1)

First objective

Develop experimental techniques

- to get Type III pressure storage vessel

- to test these prototypes under internal pressures

↓

Comparison with numerical tools

Research activity examples (1)

Manufacturing process (1)

Type III gas storage vessel

Seamless metal barrier

Deep drawing of cylindrical plate

Tubes spinning

Hydroforming

reinforced by

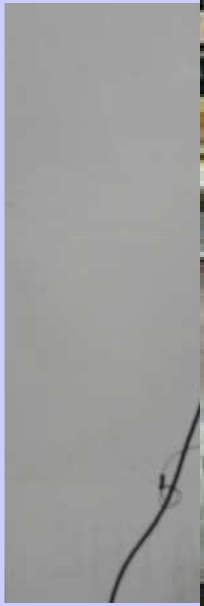
Filament winding

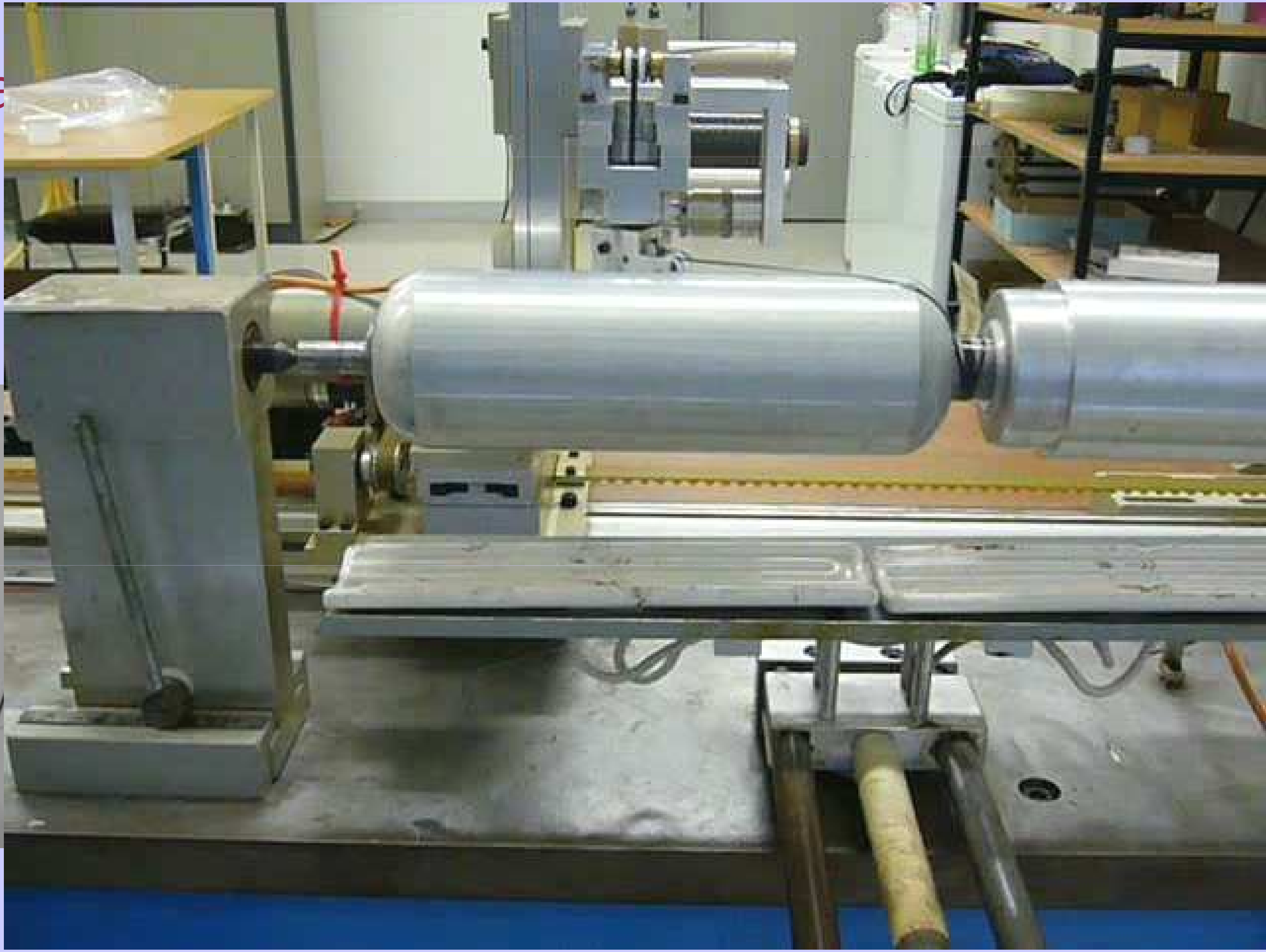
(carbon, glass fibre…)

Composite

Research activity examples (1)

Ma



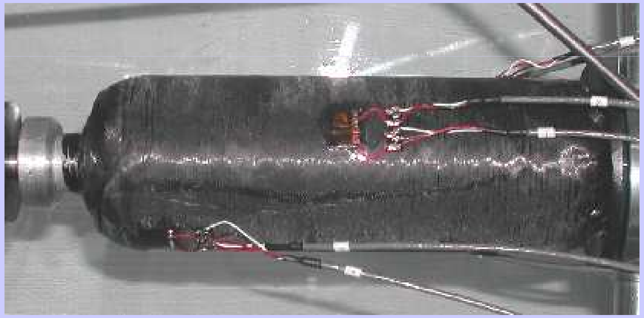


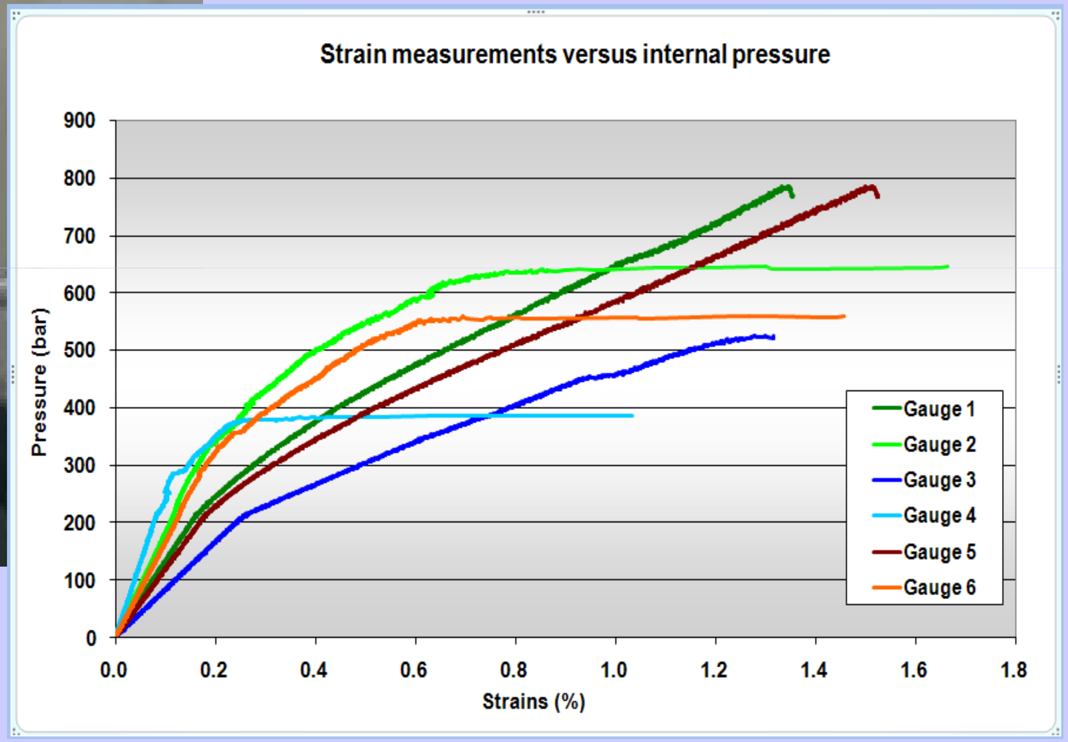
Research activity examples (1)

Some results

Gauges

Axial strain	2	4	6
Hoop strain	1	3	5





9 carbon layer composite on an aluminum liner
Burst pressure: 780 bars
Volume 0.8 litre

Research activity examples (1)

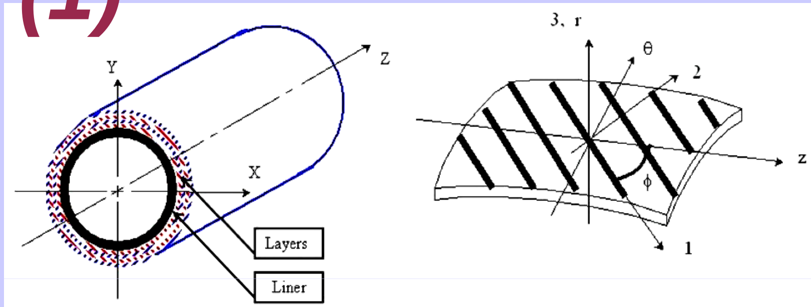
Second objective

Analytic modelling of the cylindrical section of a high pressure gas storage for thermomechanical loading

Numeric tool to design vessel structures combining a metal liner and a composite laminate (stiffness)

(Type III hydrogen storage tank)

Research activity examples (1)



Mechanical analysis (1)

Structure parameters

- liner inner radius R_0, thickness e

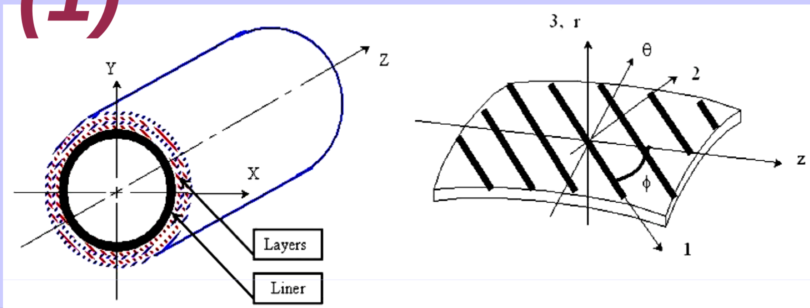
- layers n_s, k^{th} layer thickness $ep(k)$, the stacking sequence

Mechanical behaviour

- liner : elastic-plastic material (von Mises)

- composite : CLT, damageable, Tsai-Wu failure

Research activity examples (1)



Mechanical analysis (2)

Specific displacement field:

- $u=u(r)$, $v=v(r,z)$, $w=w(z)$
- constant axial strain along radial direction
- no dependency of $\varepsilon_{z\theta}$ with z coordinate

Boundaries conditions

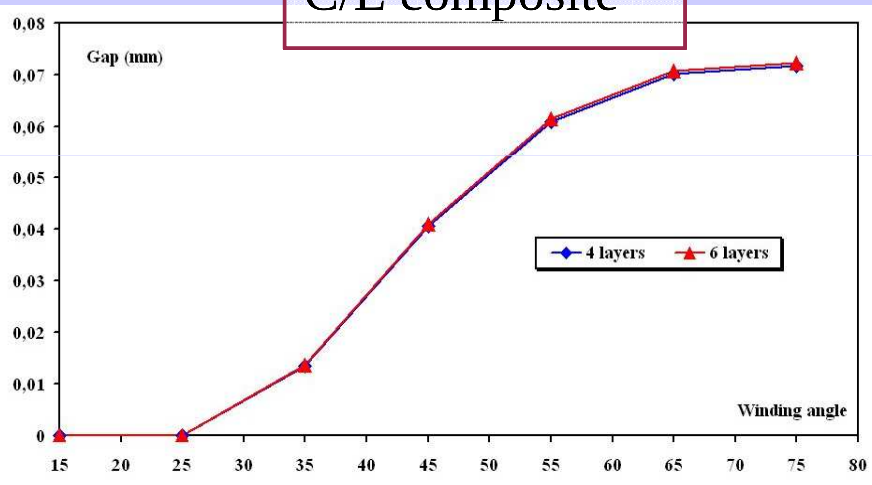
- radial displacement and stress continuity
- internal pressure with close-end effect

Linear problem

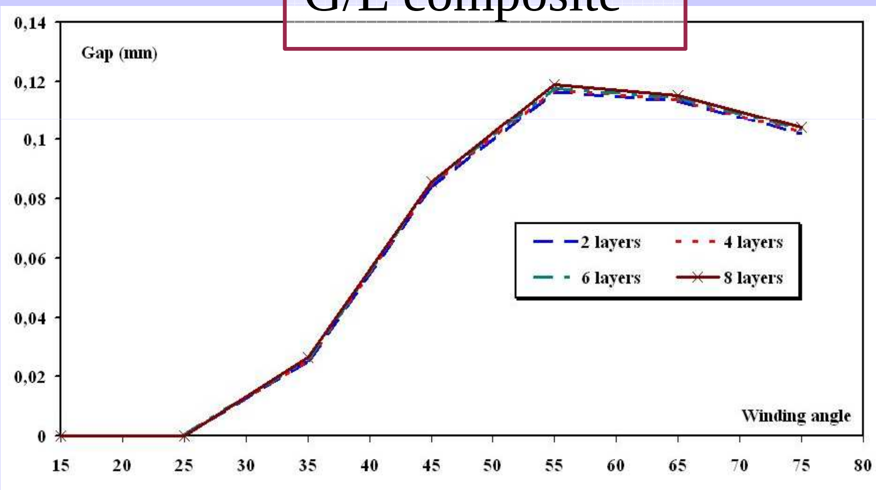
$$A.X = B$$

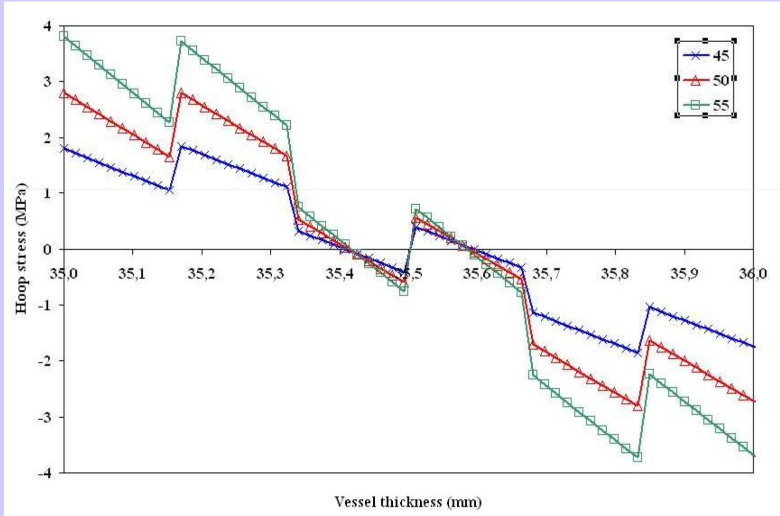
Research activity examples (1)

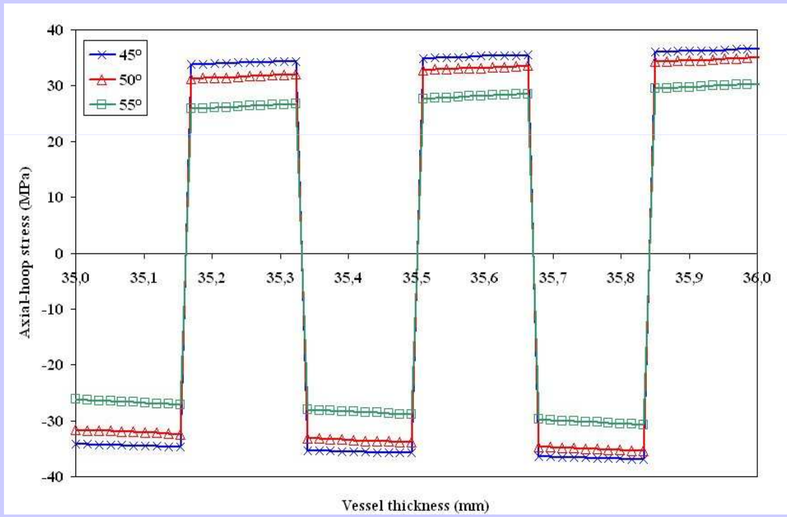
C/E composite



G/E composite

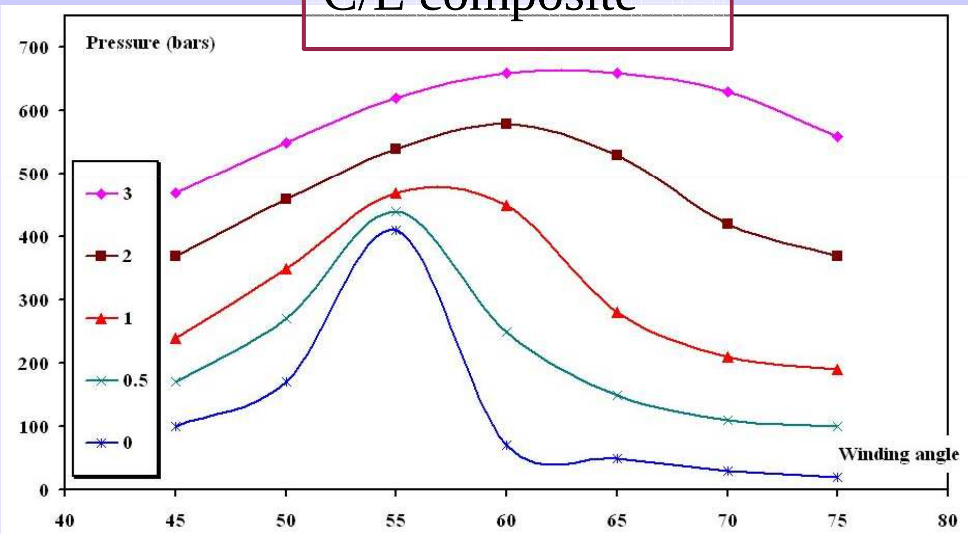




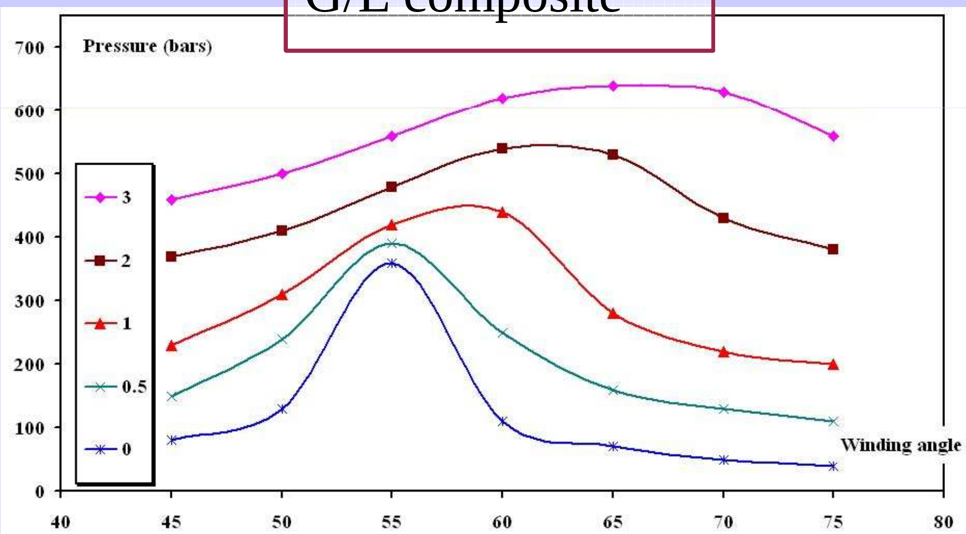


Research activity examples (1)

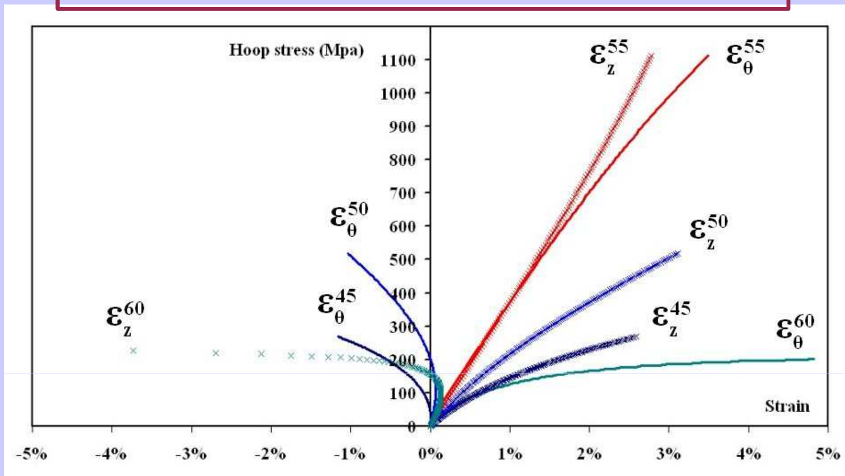
C/E composite



G/E composite



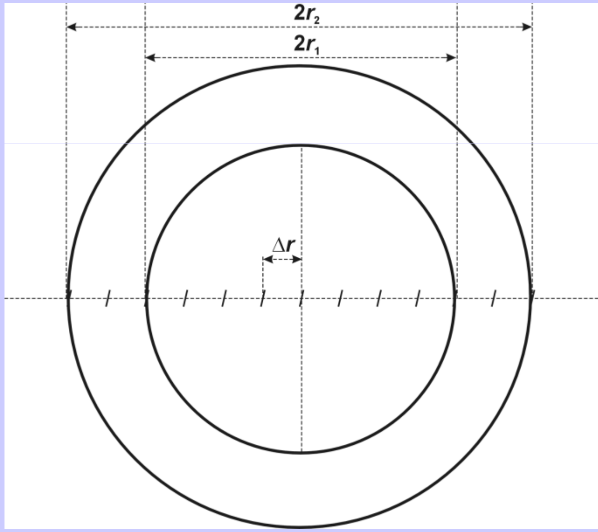
Strain-stress evolution



Research activity examples (2)

Design of a hydride storage tank

Pr. Figiel, N.B. Selvaraj



$$\frac{\partial^2 \theta}{\partial r^2} + \frac{1}{r}\left(\frac{\partial \theta}{\partial r}\right) + \frac{g}{k} - \lambda\,\frac{\partial \theta}{\partial t} = 0$$

Θ	Temperature, °C	
C_p	Heat capacity, J kg^{-1} K^{-1}	
h	Heat transfer coefficient	W m^{-2} K^{-1}
t	Time, sec	
ρ	Material density	
λ	Thermal conductivity	
g	Heat sources	

$$k = \frac{\rho C_P}{\lambda}$$

Explicit resolution

$$\theta_{i,j+1} = \frac{\Delta t}{\lambda_1 \Delta r^2}\left(\theta_{i+1,j} + \theta_{i-1,j} - 2\theta_{i,j} + \frac{\Delta r}{r_i}\left(\theta_{i+1,j} - \theta_{i,j}\right) + \Delta r^2 \frac{g}{k_1}\right) + \theta_{i,j}$$

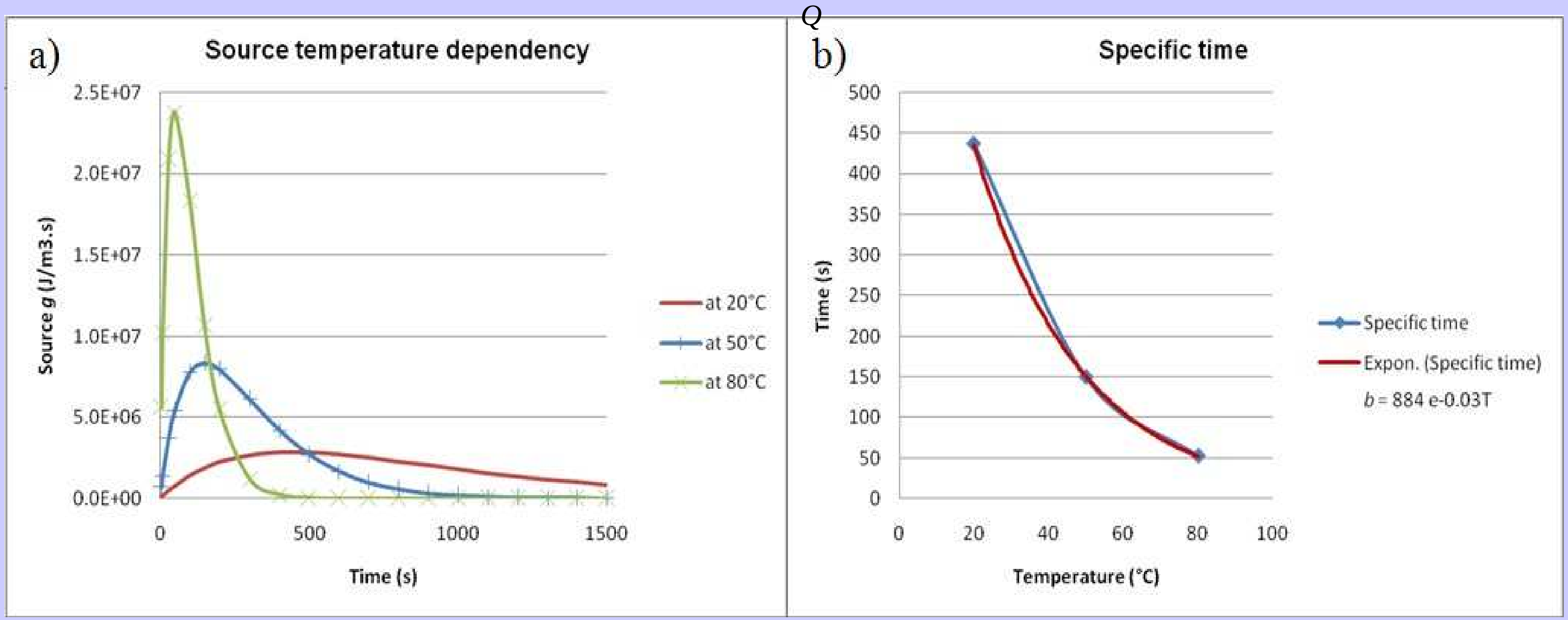
Research activity examples (2)

From experimental data of absorption at 20, 50 and 80˚C… **$LaNi_{4.78}Sn_{0.22}$**
Heat sources are assumed under the form…

$$g = \left(Q / b^2 \right) t \exp\left(- t / b \right)$$

$LaNi_{4.78}Sn_{0.22} + nH_2 \rightarrow LaNi_{4.78}Sn_{0.22}H_{2n} + Q$

$$Q = 3.4 \times 10^9 \quad J / m^3$$

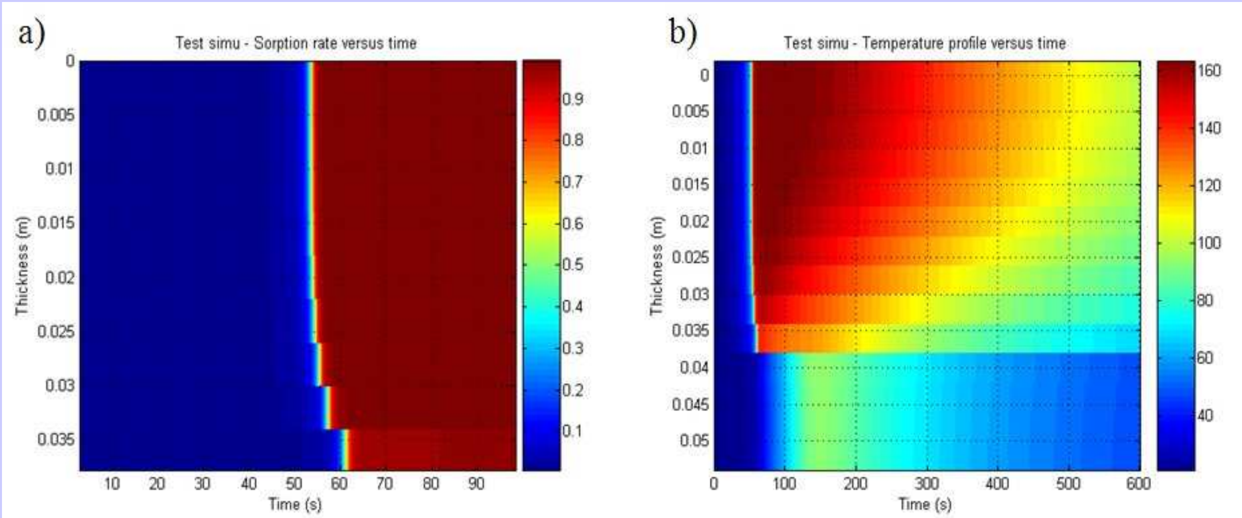


Profiles of heat produced during absorption.
a) Temperature dependence, b) Temperature dependency of *b* coefficient.

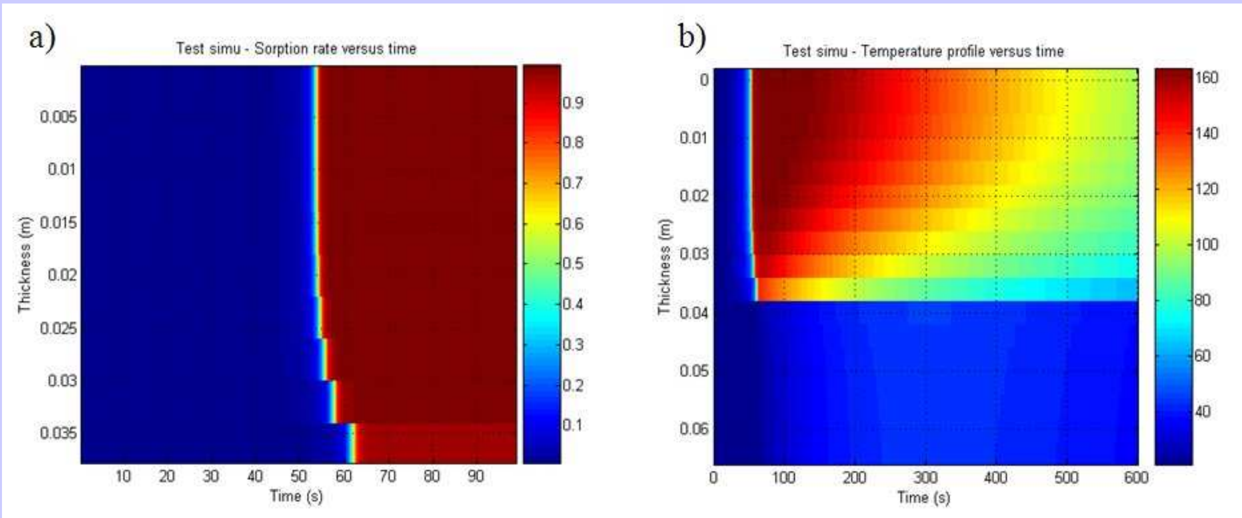
Research activity examples (2)

Simulation of $LaNi_{4.78}Sn_{0.22}$ absorption for a radius bed of 40 mm and a thickness tank of T mm
a) Absorption rate versus time, b) Temperature profile versus time

T = 12 mm



T = 24 mm



Research activity examples (2)

Experimental investigations on various geometry of tank
Temperature measurements on the external surface

Hydride tank Hydrogen bottle Seivert apparatus in the LMARC

Research activity examples (3)

Conception d’un réservoir hybride de stockage intégrant les technologies de stockage solide et gazeux

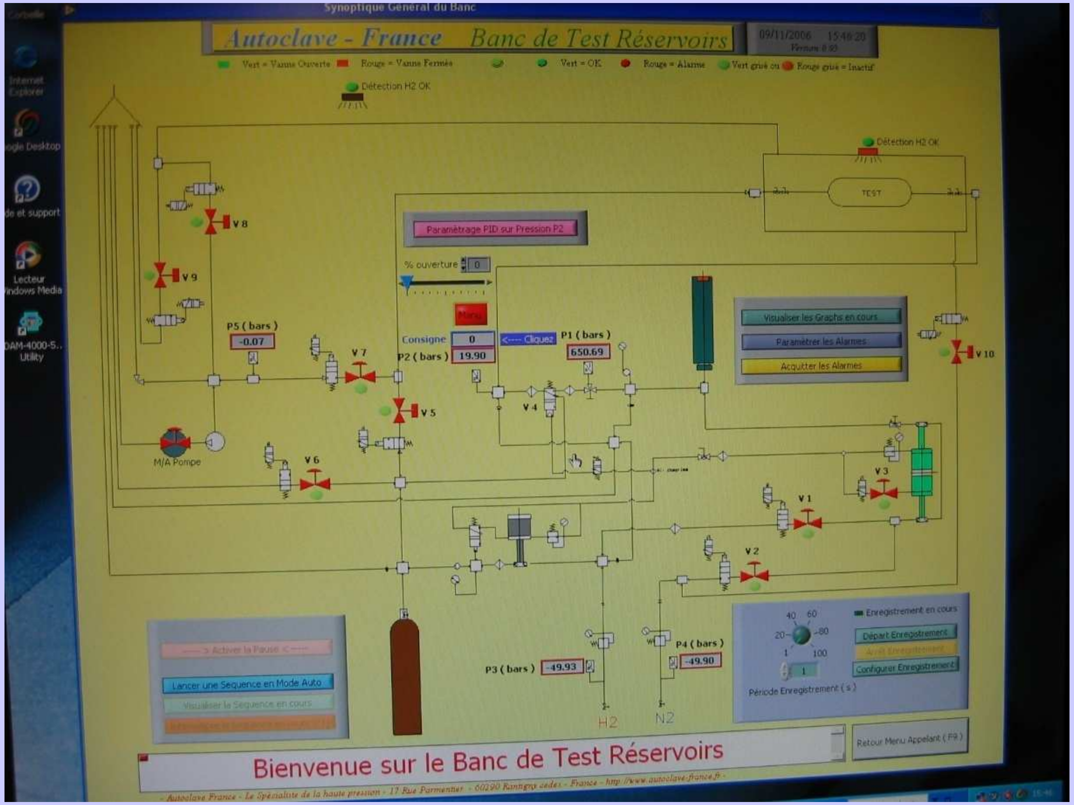
Thesis Marko Feldic, HyTrain program
CNR Florence, M. Zoppi
CEA Grenoble, O. Gillia

Modélisation thermodynamique et cinétiques d’absorption d’hydrogène associées aux transformations de phase

Thesis Germain Gondor
Pr. Christian Lexcellent

Original equipments

High pressure hydrogen equipment : 800 bars



Conclusions

- not only one energy carrier, not only one way to store hydrogen

- many improvements (almost on materials)

- solutions for future will depend on the investments

http://www.hydrogennow.org
http://www.hydrogenus.com/
http://www.imr.salford.ac.uk/hytrain/
http://www.eere.energy.gov/
http://www.storhy.net/
http://www.afh2.org
http://www.h2eco.org/

Thank you for your attention!!