Fuel cells and hydrogen
Joint undertaking

Programme Review Day 2013

Brussels, 11& 12 November 2013

New Energy World JU
fuel cells & hydrogen for sustainability

Project name

HyCOMP
Enhanced Design Requirements and Testing Procedures for Composite Cylinders intended for the Safe Storage of Hydrogen

(Grant Agreement N° 256671)

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HyCOMP

Project & Partnership description

- HyCOMP is a Pre-Normative Research (**PNR**) project on composite storage tank
- Launched in January 2011, will finish in March 2014 (**39 months**)
- Budget: **3 802 542 €** of which **1 380 728 €** (36 %) is funded by FCH JU
- Partnership:

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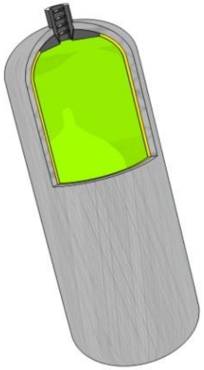
Project presentation (1/4)

- Context:
  - Hydrogen storage is a key issue for the extensive use of H_2 as an energy vector & for success of the whole hydrogen value chain

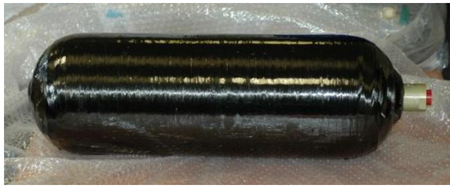
Production → Storage → Distribution → Storage → Public use

- Need to support market deployment of hydrogen energy: 2015-2020
  - Different technologies for H2 storage:
    - *In a cryo-compressed form, or solid storage in metal hydrid materials, etc…*
  - But the most mature technology for storing hydrogen is in compressed form in **composite pressure cylinders**



Fully wrapped composite cylinders are made of:

1. A metallic boss
2. A liner: load sharing (type III) or non load sharing (type IV)
3. A filament wound composite wrapping (most often carbon fibers and epoxy resin)



9L cylinder especially designed for HyCOMP

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Project presentation (2/4)

- Need to improve the performance of storage vessels
  - Performance objectives in terms of cost efficiency, safety and improved logistics (high quantity transported and low compacity)
    - Gravimetric storage capacity = m_{H2} / (m_{system}+m_{H2}) (in wt.% hydrogen) **≥ 4,8 %**
    - Volumetric storage capacity = m_{H2} / V_{system} (in g_{H2}/L) **≥ 23 g_{H2}/L**

Targets fixed by the FCH-JU by 2015-2016

- Strong need to have composite pressure vessels that are:
  - **Reliable & safe** (in any circumstances in normal service conditions) AND **cost competitive**

↗ m_{H2}, ↘ m_{system}, ↘ V_{system} → ↗ NWP (Nominal Working Pressure) → ↗ Composite thickness (i.e. carbon fiber quantity) → ↗ Cylinder price

Safety factor SF

$$SF = \frac{\text{Minimal Burst Pressure}}{\text{Design Pressure}}$$

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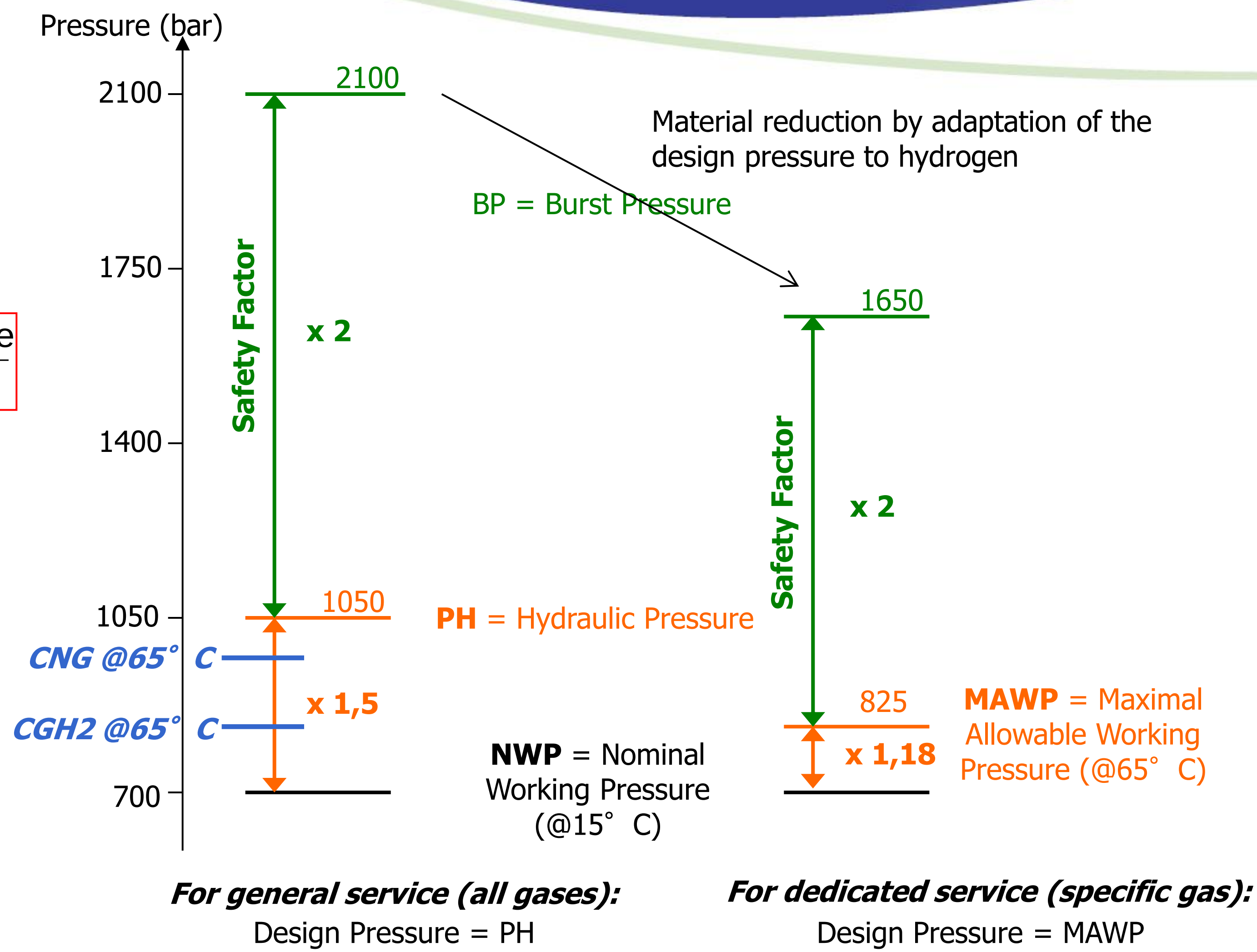
Project presentation (3/4)

- Example of Transportable cylinders @700 bars

$$SF = \frac{MinimalBurstPressure}{DesignPressure}$$



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Project presentation (4/4)

- Key issues and needs
  - Current regulations and standards do not allow one to exploit the full potential of CF materials
  - No scientific rationale for cylinder design and qualification testing
  - **Need to improve standards** to better address <u>structural integrity of composite cylinders</u> throughout their service life

→ An evolution of Regulation, Codes and Standards will most likely not be possible without a better **understanding of damage accumulation mechanisms & kinetics** under typical loads in service (static and cyclic loads)

- Goals & expected outcomes:
  - Quantify the damage accumulation rate in composite materials, in order to preserve structural integrity of CPV
  - Improve **design requirements** (*including acceptable stress ratios for carbon fibres*) and **testing procedures** for type approval, manufacturing quality assurance and in-service inspection
  - Disseminate project **recommendations** through industrials (cylinder manufacturer, OEMs, etc.) and RCS

Experimental and modeling results: Achieved

Recommendations under construction
(Will be proposed in Q1 2014)

Dissemination workshop organized in Q1 2014

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Alignment to the MAIP / AIP

- HyCOMP addresses different objectives of the MAIP in different application areas:

Transport & refueling infrastructure

✓ "Research and technological development to show the **application readiness of on-board high capacity hydrogen storage**" *(Page 12 of the revised MAIP)*

✓ "Pre-normative research will complement the RTD in this application area , in particular […] **design and test criteria for high pressure composite storage tank**" *(Page 13 of the revised MAIP)*

Hydrogen production & distribution

✓ "**Safe, efficient and reliable hydrogen distribution** and refueling infrastructure" *(Page 14 of the revised MAIP)*

- Development of **reliable & cost competitive** H_2 storage tanks is of high importance for the 4 application areas

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Main achievements (1/4)

1. Characterization of CPV service life

- Review of accidents of composite cylinders:
  - No reports from field service **over more than 15 years** that failure is caused by lack or degradation of carbon fiber based composite cylinders
  - **High level of safety** of composite cylinders manufactured according to current regulations

- Characterization of operational loads:
  - **Automotive application**: Cylinders used for storing hydrogen or accumulation sufficient high hydrogen pressure for quick transfer (fill of vehicles) are identified as one of the most severe load conditions a cylinder can be exposed.
  - **Stationary application**: Characteristic load is high average load in combination with high number of pressure cycles. One refueling of a vehicle will represent one pressure cycles. In a larger hydrogen refueling station in the future, it is expected that number of refuelings can be more than 10^6 over the lifetime of the cylinders
  - **Transport application**: Combination of loads described above

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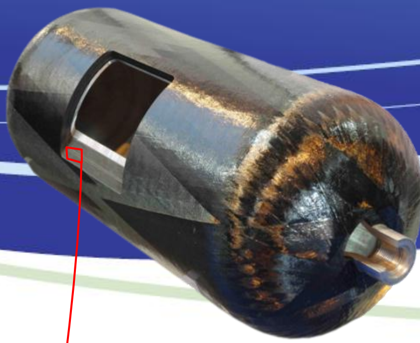
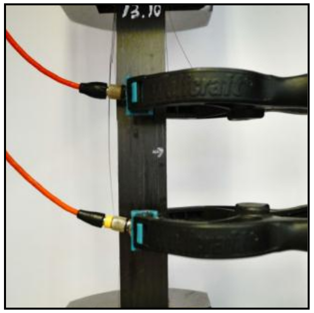
Main achievements (2/4)

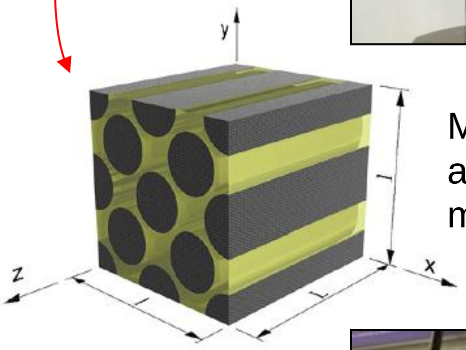


2. Damage accumulation rate at a material scale
   - Understand and quantify the damage accumulation mechanisms due to operational loads
     - Effect of loads: static, cyclic, etc.
     - Effect of environmental conditions: temperature, humidity
   - Development of a predictive model able to account for the composite damage kinetics
   - Definition of an intrinsic Safety Factor (iSF) based on both experimental and numerical results, covering intrinsic material properties only

⇨ Considerable amount of samples tested

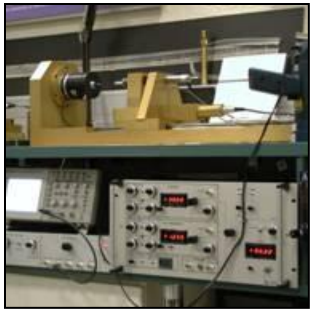
Acoustic **E**mission





Multi-scale approach and modeling

Probabilistic description of the failure mechanisms at the material scale



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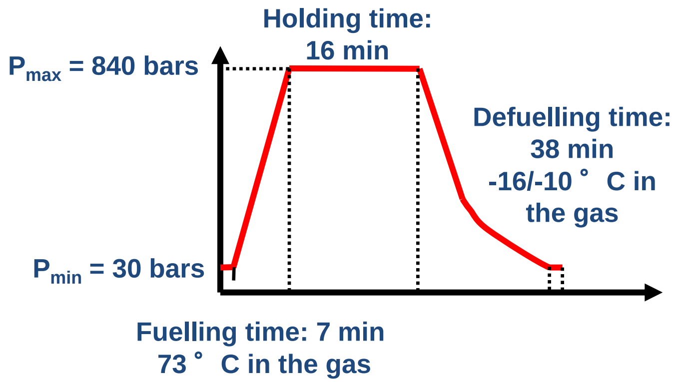
Main achievements (3/4)

3. Damage accumulation rate at a cylinder scale (type 3 & type 4 cylinders)
   - *T3 cylinders*: Identification and experimental verification parameters leading to premature liner failure
     - Influence of **autofrettage process parameters** on fatigue resistance
     - Influence of **service conditions (temperature)** on the cycle fatigue behavior
     - Development of new test procedures / methodologies in order to evaluate the current state of damage of pressure cylinders, addressing **probabilistic aspects of test results and influence on reliability**
   - *T4 cylinders*: Evaluation of acoustic emission (AE) methodology to characterize the state of damage after cycling test
     - Influence of cycling conditions (mean cycle pressure, effect of amplitude, etc.) on the mechanical resistance
   - *T3 & T4 cylinders*: Effect of gaseous load cycle process on the mechanical behavior of the cylinder wrapping compared to hydraulic load cycle process



⇨ Considerable amount of cylinders tested

Highly instrumented H2 cycling test at the **JRC-IET reference laboratory** on own funding

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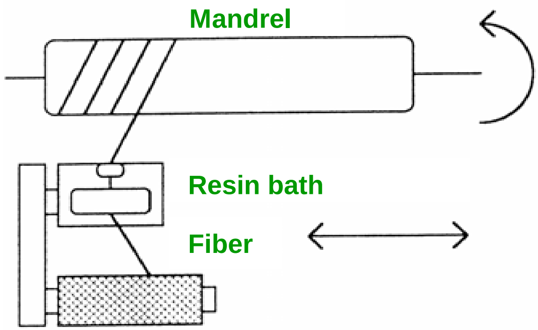
Main achievements (4/4)

4. Manufacturing Quality Assurance

- Objective: Define requirements for ensuring that manufactured cylinders will behave as observed under type approval
- Characterization of cylinder performance due to variations in manufacturing parameters



Parameters studied:

Pattern and placement of the fibres	Modify the offset during winding by 1 bandwidth
Resin mix	Increase the quantity of hardener by 20%
Resin curing	Curing at room temperature
Fibre type	Use T300 instead of T700 to simulate a picking error *(same linear mass, same Young modulus, but lower UTS)*

- Characterization of initial strength (burst) and long term properties (pre-conditioning + cycling)
- **Curing of the matrix** has shown to have the greater influence

- Evaluation of non-destructive examination (NDE) methods for production monitoring:
  - **Acoustic Emission** testing based on the analysis of the energy curve
  - The method **can detect most failures by a deviation from the reference**
  - Further work is needed for demonstrating the procedure at a manufacturer

120 cylinders tested

Cross-cutting issues

- Regulations, Codes & Standards (RCS)

Cross-cutting activities

✓ "…will aim to support and enable the other application areas at program level. […] These activities mainly include: **RCS** and **PNR**" *(Page 17 of the revised MAIP)*

- Review of existing published and draft RCS documents (e.g. ISO, ADR, TPED)
- Provide a path that will define how the project findings can be integrated into ongoing or new RCS activities
- **Dissemination of project recommendations** concerning the safe storage of hydrogen, to **support RCS initiatives** at the international level (cylinder tests & design criteria)
  - Organization of a workshop in conjunction with ISO/TC58/WG24 and WG 35 meetings in February/March 2014
  - Organization of a meeting with OEMs to present HyCOMP results

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Relationship to other projects

- Earlier projects:
  - **StorHy** (European project, finalized in 2008): similar intention as HyCOMP on the way to design cheaper cylinders by a more intelligent approval approach.

- Current projects:
  - **HyCube** (KIC, 2012-2014): dedicated exchanges of test results and its statistical assessment

  - **DeliverHy** (FCH-JU, 2012-2013): strong collaboration with DeliverHy project whose objective is to optimize transport solutions for compressed hydrogen, because:
    - Decrease of the safety factor is an option to improve the capacity of transport solutions (exchanges on an alternative approach to justify a SF value);
    - Adapted testing procedures for the approval of large cylinders are required.

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Post-project activities

- End of HyCOMP in March 2014, thereafter:
  - Confirm some drafted conclusions with further testing
  - Continue the dissemination of results in the Hydrogen and Fuel Cell community
  - Continue the work in standardization working groups to implement changes (long time needed)

Thank you for your attention

Any questions ?

http://hycomp.eu

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