PROJECT

COPERNIC

COst & PERformaNces Improvement for Cgh2 composite tanks

Funding: European (7th RTD Framework Programme)
Duration: Jun 2013 - Nov 2016
Status: Complete with results
Total project cost: €3,514,791
EU contribution: €1,984,800

CORDIS RCN : 108778

Objectives:

A certain level of maturity of on-board compressed gaseous storage systems have been demonstrated through large Fuel Cell Electric Vehicle (FCEV) deployment projects like Clean Energy Partnership (100+ FCEVs). In addition, major car companies have confirmed their intent to start production by 2015. Nevertheless, major issues still remain to be addressed:

- VOLUME: Actual CGH2 tank production is far from being capable of feeding the volume requested by the automotive industry.

Therefore, current manufacturing equipment and production strategies are not designed for addressing such a market.

- COSTS: Latest techno-economic analysis (DoE 05/2011) are still forecasting that industrial costs for 700bar CGH2 tanks may remain 4 to 5 times higher than expected targets.

This is particularly critical with respect to a massive deployment of FCEV.

COPERNIC will address the two major targets: performance improvements and cost reduction of 70MPa TypeIV composite vessels for automotive application in order to achieve targets and lead to rapid industrial exploitation owing to the strong contribution of 4 SME and industrial partners in the consortium. It will provide real scale demonstration on a pilot manufacturing line quantitative and technical and economic assessment of strategies including evolution of materials, components, processes and designs.

Therefore, in full consistency with the call Topic, the COPERNIC project will contribute to:

- Increase the maturity and competitiveness of CGH2 manufacturing processes evolving from classical automotive manufacturing technologies or concepts.
- Decrease costs while improving composite quality, manufacturing productivity and using optimized composite design, materials and components.

The scope of work has been defined taking into account past project outcomes (STORHY) and on-going project objectives (HYCOMP). COPERNIC will ensure that the deployment of FCEV is not inhibited by prohibitive high-pressure tanks cost or availability.

Parent Programmes:
FP7-JTI - Specific Programme "Cooperation": Joint Technology Initiatives

Institute type: Public institution
Institute name: European Commission
Funding type: Public (EU)

Lead Organisation:

Commissariat A L Energie Atomique Et Aux Energies Alternatives
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| **Organisation Website:** | [http://www.cea.fr](http://www.cea.fr) |
| **EU Contribution:** | €726,888 |

**Partner Organisations:**

- **Hochdruck Reduziertechnik GmbH**
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- **Optimum Cpv**
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  - **EU Contribution:** €70,709

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### Technologies:

- Alternative fuels
- Fuel storage systems

**Development phase:** Research/Invention

### Key Results:

**Final Report Summary - COPERNIC (COst & PERformaNces Improvement for Cgh2 composite tanks)**

The main objectives of the COPERNIC (Cost & performances improvement for CGH2 composite tanks) project was to improve the CGH2 (Compressed Gaseous Hydrogen) storage system cost and to increase the performance. All expected targets have been reached within the Copernic project...

**Executive Summary:**

The main objectives of the COPERNIC (Cost & performances improvement for CGH2 composite tanks) project was to improve the CGH2 (Compressed Gaseous Hydrogen) storage system cost and to increase the performance.

All expected targets have been reached within the Copernic project duration. For the cost reduction, the target (600 €/H2 kg) is achieved if the composite is optimized (-13 %), the internal volume is higher (from 37L to 61L: -40 %) and the annual production is higher (for 8,000 unit -70 %).

The Improvement of vessel performance for Copernic Storage System is effective. The gravimetric capacity reaches 4.99 % and 0.0221kg/L for the volumetric capacity.

Significant breakthroughs are implemented in the on-tank valve (OTV) (reduction of mass, number of parts, power consumption) and a certification process is on-going.

Thanks to Copernic Process innovations, productivity improvement (27kg of composite) from an initial 120 minutes winding time to a final 70 minutes (with 8 axes robot) is achieved. A new dimensionless number, Vi, was created during Copernic project to evaluate the efficiency of composite structure.
After the end of the project, future steps are planned by Copernic partners. Structural health monitoring (SHM) tests activities remain on-going for manufacturing quality process. A new target for winding time with prepreg is defined to increase the productivity. CEA asked in 2015 for a ComposicaD batch mode that will be available in 2017. Work on alternative designs will be pursued to evaluate the potential of these new prototypes.

An optimized ANLEG On-Tank-Valve with pressure regulation (OTV-R) has been successfully developed and will pass the certification process planned next February 2017.

Copernic video summarizes the overall project results (available here: http://www.project-copernic.com/).

Now, thanks to FCH-JU Copernic project, CEA, RAIGI, OCPV, WRUT and ANLEG are developing an European 61L H2 vessel & storage system to be homologated and commercialized during 2018 (Hiphone project).

Project Context and Objectives:

The main objectives of the COPERNIC (Cost & performances improvement for CGH2 composite tanks) project was to improve the CGH2 (Compressed Gaseous Hydrogen) storage system cost that is actually around 3000 €/kg H2 for the storage system.

For that, COPERNIC provided real scale demonstration on a pilot manufacturing line and quantitative assessment of strategies including evolution of materials, components, processes and designs:

- WP3: Enhanced materials (resins, carbon fibre, inserts).
- WP3: Innovative components (all-in-one on-tank valve, on/off board structural health monitoring).
- WP4: Enhanced composite design (improved geometries).
- WP5: Improved composite quality (tank performance repeatability).
- WP5: Higher manufacturing process and cost evaluation

The expected progresses at the beginning of the project were:

- Performance/cost efficient ratio using hybrid carbon composite.
- Study of polyurethane resins (expected cost reduction: 30%).
- Development of cheaper ways to obtain those parts, such as forging (expected cost reduction: divided by 5).
- Quantification of improvement potential using novel geometries.
- Quantification of ultimate accessible performance on model cylinders to increase carbon fibre translation efficiency.
- Improved composite design based on synergistic material and process optimum (15% weight carbon fibre saving, Energy density 6%m).
- Highly repeatable automated winding process with constant fibre/resin ratio and non-damaging processing of fibre for ultimate performance benefit from the carbon fibre.
- Increase quality, consistency and productivity (winding speed / process throughput +30%).
- Quantify wet winding /prepreg winding performance and cost achievements.
- Innovative all-in-one compact pressure device merging low energy consumption on-tank valve with built-in pressure regulation functionality.
- No high pressure piping, pressure outlet 10bar
- On-tank valve targets: Reduction of weight: from 6 kg down to 3.5 kg; number of used parts from 146 down to 80 power consumption: /10.
- Develop and quantify potential capability and limitations of in composite embedded optical fibre strain transducers to monitor on/off board the integrity of high pressure composite cylinders.
- Contribution to the advancement of relevant test methods by generation of accurate data materials and processes sensitivity to tank performance and safety
And the associated contributions to the program objectives are:

- MAIP: Design/ test criteria for CGH2 tanks (Contribute to advancement of relevant test methods).

- AIP: Development activities on materials (Assess alternative materials to improve performance/cost ratio), Lower cost production processes (Assess manufacturing technology improvement strategies), Improved complete tank systems and components (Reduced weight and volume, Fully integrated OTV).

Project Results:

WP2 Specifications

• WP Overall Assessment and Vision

Several data have been collected based on car integrator and refueling station manufacturer experience, as valuable input for products development, especially in terms of integration requirements and interfaces compatibility. However, we observed that this kind of requirements is difficult to translate to quantitative targets at component level to be directly linked to DoW targets and WP5.

It is to be noted that economic data were difficult to obtain and compare due to huge variations depending on the quotation date, purchase volume etc.

• Task 2.1: Market survey / State-of-the-art

The survey has been completed and includes key industrial players description, main known commercial products characteristics, with cost data that have been obtained through various RFQ or market study, both for tanks and pressure components. Main drivers of storage system costs are discussed. A literature database has been aggregated including patents, and publications with respect to tank components and manufacturing processes.

• Task 2.2: Performances and durability specifications

Analyses of the normative requirements including test description at material, component or system level, and the state-of-the-art. Identification of additional requirements with respect to car manufacturer or integrators.

• Task 2.3: Integration and cost specifications

The specifications related to on-board integration have been defined:

5 kg H2 onboard for a full power vehicle / 1,5-2 kg for a range extender

- Storage system configuration: Single tank if specific car is built (cheaper tank), multiple tanks if integration a posteriori (easier to integrate with smaller diameter)

- EC79 compliance required

- With respect to pressure component: Separate line for inlet and outlet, non-return valve at the inlet, good mechanical integration of pressure regulator and pressure relief valve to the bottle head (protected in case of crash)

- Refuelling station compatibility: optimize pressure component in order to avoid pressure oscillations during refuelling and reduce ΔP (nozzle/tank) to be able to fill up to 350 or 700 bar with good efficiency.

- Connectors and IR compatible with SAE J2601 (not mandatory)

- Specifications of requirements for high pressure hydrogen storage at HRS’s has been conducted and assessment on the potential for use of 70MPa storage vessels at Hydrogen Refuelling Stations (HRS).

• WP Conclusion

Hydrogen tanks and pressure components market is a quickly moving market as identified during a continuous market survey even after the end of WP2. Indeed, within the duration of Copernic project, several new players have emerged:

• Tanks

- Emergency of X-perion, then bought by Hexagon

- European entry of Iljin

- Worthington Industries
- Bottle valves
  - Activity stopped at GHR, then took over by Anleg
  - Emergency of OMB

We also observed in the market a move towards more integration as recommended in our deliverables:
- Pressure regulator integrated in bottle valve: ex OMB
- Partnership between tank provider and bottle valve manufacturer: ex Hexagon, Luxfer...

Continuous RCS watch appeared to be of key importance:
- Today tanks with less than 2kg onboard are out of SAE J2601 (standard for refueling stations)
- Involvement in ISO TC197 WG24 to make the standards compatible with developed product

The output of this work is an update planned end of 2016 where low volume threshold will be set to 50L which is equivalent to 1,2 kg at 350 bar and 2 kg at 700 bar.

WP3 Materials & Components development

- WP Overall Assessment and Vision:

  The goal of the study of enhanced materials is to conduct material development and characterization to assess potential benefits in terms of cost reduction and/or performances improvement. Innovative components task consists in developing and/or optimizing new fully integrated on-tank valve with built-in pressure regulation and related pressure ancillary pressure equipment to demonstrate volume, weight and cost reduction and/or performance or functionality improvement. In parallel, the definition of on/off board structural health monitoring is engaged to provide integrity level, ageing status, post incident residual performances related to on-board CGH2 storage system integrity.

- Task 3.1 Enhanced materials

  The task 3.1 dealt with the study of enhanced materials (metal for boss, resin, fibers) with the objectives to reduce the cost and to improve the performances. Several materials have been studied in each category. They have been purchased, processed, characterized in similar conditions that the ones representative of the manufacturing of the vessel or of its use in automotive. At the end, a reference has been defined for each category and used in the COPERNIC vessel.

  Concerning the metal for the boss, two materials have been selected and studied. In this part, it is more the process of manufacturing of the boss which has been studied than the material itself. With the objective to reduce the cost of manufacturing, bosses have manufactured thank to an industrial process. They have been used in several vessels. Concerning materials, both alloys have been characterized. Their corrosion resistance and their tensile behavior at different temperatures have been studied.

  Concerning the resins, eight systems have been fully studied (viscosity, pot-life, resistance in hot water, tensile...). The characterizations have been carried out step by step according to priorities we had defined. As soon as we obtained results, the selection was refined and the number of resins to study decreased. At the end, 3 resins have been selected and classified according to criteria (processability, performances and cost). They have been evaluated on vessels at the scale one.

  Concerning the fibers, five fibers have been fully studied, characterized and used for the manufacturing of vessels. The characterizations enable to evaluate their mechanical performance and to compare the data provided by the suppliers. The manufacturing of vessels has two objectives: to study the behavior of the fiber during the process and to evaluate the performances of similar vessels manufactured in the same conditions but with different fibers.

  Thanks to this study, two alternative fibers have been selected at the end of the COPERNIC project. During the 42 months of the project, a lot of materials have been studied from a technical point of view with keeping in mind the cost aspect.

- Task 3.2 Improved Pressure components

  At the beginning of the project, standard proprietary on-tank valve (on/off) and separate pressure regulators coupled with high pressure piping was the state of the art. The aim of this task was to develop an innovative all-in-one compact pressure device (OTV-R) merging low energy consumption on tank valve with built-in pressure regulation functionality, no high pressure piping, pressure outlet 10bar. The targets for the OTV-R (On tank Valve with pressure Regulation) are: Reduction of weight from 6 kg down to 3.5 kg, number of used parts from 146 down to 80, power consumption divided by 10.
Copernic partner has defined, designed and produced a completely new OTV integrating the pressure regulator, reducing the quantities of components to below 100 and reducing the weight 0,9 kg and dimensions total length outside the bottle 39 mm.

Anleg is currently the only OTV manufacturer with an integrated pressure reducer. This simplify the complete H2 line inside the vehicle and allows to use non EC 79 certified components (O

Over the duration of the two different development phases, Anleg has built up test benches to perform internal validation tests. Anleg is now able to identify very quickly and find solution on identified technical issues before sending the material to certification bodies.

• Task 3.3 On/off board diagnosis, development of Structural Health Monitoring for high pressure vessels

The aim of this task was a development of Structural Health Monitoring system for integrity monitoring of a high-pressure composite vessel, designated for storing pressurized gas fuels (i.e. hydrogen). It was expected that the SHM system should provide for continuous and reliable monitoring of the structure and gather the most relevant data from the vessel regarding quality, design specifications, behavior during its manufacturing, proof testing and longtime operation. It was also expected that system shall enable estimation of degradation level of the composite structure, and by that determination of its safe operation period. An important part of work was description of an efficient “monitoring strategy”. This one was used for detection of damages in the composite pressure vessel during its lifetime. It was expected that applied SHM system should register degradation of composites structure and thus determine the time of safe operation without needs for disassembling the system and increasing the pressure above the service conditions.

General conclusions for the strategy of COPV monitoring:

- The most efficient strategy for Structural Health Monitoring of the high pressure vessels integrity is continuous measurement (i.e. during manufacturing, proof test, refueling phase, daily use) of selected parameters. This approach is at the same time the most expensive one. It is necessary to install on-board all system components (sensors integrated with COPV, reading units, data analysis).
- SHM strategy for COPV is based on: strain field measurements (using optical fiber sensors; i.e. FBG ones), internal temperature and pressure (sensors integrated in on-tank valve), hydrogen gas detectors.
- The project propose to integrate Copernic SHM with hydrogen fueling protocols without interfering into current standards (i.e. SAE J2601).
- Continuous monitoring allows for early detection of defects which are critical for the structure and constant monitoring of them.
- In order to evaluate integrity of COPV an adequate algorithm for measured data analysis is obligatory. For this purpose, it was proposed to compare a real data registered from the COPV (strain field distribution and its changes) with its numerical model (definition of threshold level). FEM analysis can be also used for optimization of sensors arrangement (localization of “hot spots”).

The FBG based SHM system is composed of the short gage sensors but in form of quasi-distributed (network of sensors). It allowed for registering the strain field distribution at the COPV surface and inside composite and evaluate residuals strains after production processes, control during winding (tune the manufacturing process), identify the areas without pre-tensioned reinforcement (with internal defects), check the repeatability of the production process and its control at structural level. Data collected by SHM system (in form of a strain field distribution) was also used to benchmark different numerical simulations regarding their relevance for failure mechanisms prediction, architecture analysis and optimization (WP4). The validation of applicability of proposed SHM system was made during hydraulic tests (WP5).

• WP conclusion:

Alternative materials (liner, metallic boss, matrix, carbon fiber) have been identified, selected and characterized for H2 CPV 700 bar on-board application to improve performance and decrease cost. Except carbon fiber price, the Copernic targets are reached. Innovative component like fully On-tank valve has been developed. The certification step is in progress (01/2017). The volume, the number of parts and the cost have been reduced to reach the 2020 FCH-JU targets for the storage system. Innovative non destructive SHM strategy has been defined and evaluated on Copernic vessels. Identification of abnormal behavior of vessel before leak is defined. In particular, an update on protocol SAE J2601 HRS filling protocol has been defined to increase safety during the filling phase. Thanks to Copernic, Hiphone project (KIC) is engaged with CEA, WRUT, SSA and RAIGI: The goal is to define, manufacture and commercialize 62 H2 700 bar CPV for on-board application using for example ANLEG
OTV.

WP4 Optimization of processes and designs

• WP Overall Assessment and Vision:

One objective is to optimize the winding lay-up at higher speed of the robot and validate performance of vessel. The composite design optimization consists in increasing the gravimetric capacity. New numerical models will be developed and validated. In parallel, ComposiCad interface developments improve filament winding program.

• Task 4.1 Improved manufacturing process

Compared to the state of the art (2 hours for 27kg of composite on a 37L vessel), the winding time was reduced by 18% with wet winding by improving path, by 41% with prepreg (improving path, new ComposiCad version, new eye motor). With a new robot evolution perspectives and interpolation, the reduction winding time can reach 64% for 27 kg of composite. With the new patented (in progress) delivery system, interpolation to 1750 bar burst pressure 37LCopernic optimized vessel will be wound in 54 minutes. During the project, all the liners has been manufactured by CEA. SSA and CEA have manufactured the composite part.

• Task 4.2 Design optimization

For bottle geometry, isotensoidal dome contour is very important. Slight deviations from this contour can result in a significant performance loss. Structural efficiency was increased with approx. 25% due to optimal design, FEA calculations and process optimizations.

For new geometries, trials have proven that the structural efficiency of special shaped pressure vessels can be as high as 85% of the max achievable. Calculation (FEA) has shown that special shaped pressure vessels have the potential to have a structural efficiency of as high as 90% of the maximum achievable.

A new dimensionless number, Vi, was created during Copernic project to evaluate the composite efficiency of a type IV&V Composite Pressure Vessel. This number can be also adapted for type III vessel.

• Task 4.3 Multiscale modelling of composite lay-ups

The homogenization model shows good correlation with tests of composite samples. Thanks to CEA previous experience (French ANR OSIRHYS IV project), a seamless interface between the ComposiCad winding simulation and the FEA analysis was developed and tested (ANSYS). The time for a design verification was reduced to 30 min (initially 1 day). An automatic optimization routine was programmed to supply the lay-up for the radial reinforcement of the final design of the cylinder. The calculations were validated by (burst) testing of cylinders.

• Task 4.4 Numerical interfaces and winding control optimization

The FEA interfaces have been successfully tested at CEA (ABAQUS), WRUT (ANSYS) and OCPV (ESACOMP). The interfaces allowed to verify the behaviour of the composite very efficiently. One iteration step could be completed in less than 30 min, where previously an entire day was needed. The machine motion control was tested successfully tested at CEA and allowed to increase the winding speed by up to 50%. The new Composicad functionalities have already been integrated in the commercial software package. Licences have been granted to some of the world-wide leading tank manufactures in Europe, USA, Japan and Korea.

• WP conclusion:

With the robot solution, enhanced material and Composicad development, the winding time was reduced by 2. Thanks to Copernic project, ComposiCad numerical interface program has been improved with the filament productivity of the robot. Today, a mean winding speed of 40 m/min is achieved and the next step in progress targets more than 50 m/min mean speed. During Copernic project, a new dimensionless number, Vi, was created to evaluate the composite efficiency of a Composite Pressure Vessel.

WP5 Evaluation

• WP Overall Assessment and Vision:

The main objectives of WP5 was evaluation of the newly designed and optimized in WP3 and WP4 system for compressed gas storage in automotive application. The COPERNIC vessel is a type IV tank designed to store compressed gaseous hydrogen (CGH2). It is composed of a plastic liner, metallic inserts (end-bosses) and a composite shell with carbon fibre and thermoset resin (CFRC). The targeted
service pressure is 700 bar. The newly designed vessel must be compatible with current European
depulations, codes and standards (ie. EC79/2009).

• Task 5.1 Test protocols and evaluation criteria

The goal of the task was to define the tools which can be used to evaluate the improvement of the
tanks. Two kinds of objectives were defined: performance and economic targets. The first one was
based on the test conditions and the criteria to measure improvement of the performances of hydrogen
storage system, based on the current standard (EC406/2010). The aim was not to homologate the
prototypes but to measure the evolution between the beginning of the COPERNIC project (reference
tanks) and the improved ones. Moreover, the developed prototypes were compared to external products
described in the state of the art from an economic and technical point of view. So, for this purpose, a
test protocol was established to define an order of priority. In a first step, tests were the simplest (burst
test) and gradually, the level of the required performances increased (ambient and extreme
temperature pressure cycling and accelerated stress rupture tests). Concerning the cost evaluation, the
targets were defined and presented. The evaluation can be made by parts or for the container
(performance/cost ratio in €/kg system). The evaluation of the tank improvement was managed by a
milestone at the mid-term of the project and a final deliverable to assess the progress.

• Task 5.2 Validation of high pressure vessels durability

The aim of this task was validation of operational performance of the optimized vessels in real test
conditions. The series of hydraulic test for determining operational properties of the COPERNIC vessels
in accordance with Commission Regulation No 406/2010 were realized. The main goal was to determine
short and long term properties of the newly developed vessels and compare them to reference tank and
State-of-the-art.

The test program consisted of the following tests:

Ambient temperature pressure cycle test, burst test, Chemical exposure test, Accelerated stress rupture
test, Extreme temperature pressure cycle test.

The validation procedure was focused on evaluation of modified composite designs (CFRC architecture
made by filament winding method), different materials (liner, matrix and fiber) as well as the end-boss
(both: material and design). Results of the hydraulic tests were compared with numerical
simulation/modelling. For this purpose, an external instrumentation during the selected tests was used.
Such parameters like: pressure, radial and axial displacement or strains were registered and compared
with modelling results. This allowed for validation of applied numerical models of COPV and provided
feedback for further improvement or optimization of vessel.

For the project the nominal working pressure (NWP) of COPV was fixed as 700 bar (70 MPa) and the
number of filling cycles equalled to 5000 load cycles (LCs).

During the tests, it was proven that 37L vessels with PA6 liner are not able to reach the target for
extreme temperature cycle. Therefore, a new liner material, has been chosen. The new liner
demonstrated (105L liner) robust behavior during pressure cycle test. With the new liner geometry, the
composite architecture for 37L tank was evaluated by calculations, and next manufactured and burst
tested at a pressure higher than 1775 bar. During the project ~60 Copernic vessels were manufactured
and burst tested.

The final Copernic vessel obtained after burst test campaign was:

- Liner: 34L liner
- Fiber: carbon fibers selected
- Matrix: thermoset matrix selected
- Mass of carbon composite: around 19,5 kg for 1750 burst pressure value
- Total mass of the empty vessel (with rings, without pressure components) :24,5 kg
- Gravimetric ratio: 5,23%
- Vi number = 22% (composite efficiency)

The last study shows a strong dependency of the burst pressure to process parameters. So, it is still
possible to increase the performance and decrease the cost of the vessel.

Within the task several types of long term test were also carried out. The main effort was focused on
ambient and extreme temperature pressure cycling test (together ~20 COPV were investigated).
Moreover, the accelerated stress rupture test for 4 vessels was performed.

The long term test results confirm that the optimized vessel, give very promising results. It was proven that the tested vessels from the final batch has successfully passed selected tests according to EC requirements. The tests which were chosen to confirm their performance are as follows: burst test, ambient temperature pressure cycling, extreme temperature pressure cycling, accelerated stress rupture and chemical exposure. Due to the time constrains and late delivery of the final vessels to the testing facility at WRUT it was not possible to perform the other tests. However, selected tests were chosen as the most representative ones to confirm and measure the performances of tanks in relation with their costs. The test results are described in detail in Copernic deliverables.

• Task 5.3 Validation of Structural Health Monitoring system

The aim of this task was experimental validation of the Structural Health Monitoring (SHM) system and strategy for integrity monitoring of the high-pressure composite vessel. The investigations were focusing on the monitoring of the COPV manufacturing process and a proof of an on-board SHM solution (including data analysis algorithm) during vessel normal operation. An effectiveness of the proposed solution was checked during static and cyclic tests of COPV in accordance with EC 406/2010.

The proposed SHM system was based on strain field measurements done by optical fibre sensors (so called Fiber Bragg Gratings, FBGs) during the whole time of exploitation (testing). FBG technology offers the possibility of implementing “nervous systems” for pressure vessels that allow its health and damage assessment. Within the first part of the task it was proven, that integration of OFS inside composite structure during COPV manufacturing is possible and can be used for improvement of the production process itself (winding, curing, hydraulic test). The registered data was used to measure its influence on the final product and work out the COPV manufacturing rules which led to the improvement of COPV quality in terms of its short and long term behaviour. The manufacturing parameters that can be controlled and tuned.

Measurements of selected components of the strain field of highly stressed composite layer can be used for the evaluation of the degradation level during its use, and thus can determine its safe lifetime. Therefore, the second part of the task was dedicated to a proof of an on-board monitoring system and monitoring strategy during vessels regular. The goal was to confirm if the system and data analysis algorithm are able to detect critical defects in the COPV structure. The hydraulic tests have showed that the surface integrated and embedded inside the composite material FBG sensors can be used for “on-line” monitoring of the COPV. Continuous monitoring allows for early detection of defects which are critical for the structure.

In order to evaluate integrity of COPV an adequate algorithm for measured data analysis was developed and validated. The most useful solution was based on correlation of the strain changes (ABS parameter) registered in different locations. For a stable growth of defects (continuous degradation) in composite structure, the correlation between two points shall be linear. In case of any unexpected behaviour (defects like flaw or delamination), the linear dependence will be lost. An effectiveness of the proposed solution (defects detection, prediction of the safety operation time) was proven during hydraulic pressure cyclic tests of fully instrumented vessels with and without programmed defects in accordance with EC 406/2010.

The SHM system and strategy which was developed during COPERNIC project and checked for small vessels can be implemented for other high pressure storage systems (ie. stationary applications and/or filling stations, chemical industry, etc.). SHM solution which was used for manufacturing process monitoring can be applied for another R&D projects in a field of composite structures.

• Task 5.4 Cost and performance improvement assessment

Hydrogen storage tank represents an important share in H2 vehicle investment cost. So the need of new designs, new materials and improved manufacturing processes is necessary in order to reduce the cost of these systems. The objectives of this cost study are to provide a reference manufacturing cost of high pressure vessels at industrial production scale (starting point at the beginning of the project), and to quantify the cost reductions that can be reached thanks to COPERNIC technical innovations.

6 tank designs have been studied. All the steps of manufacturing process are taken into account and are implemented in a cost model. The considered cost factors are divided in two categories: fixed costs and variable costs. Few cost factors are excluded from the analyse like “Material and final product storage”, “SHM sensors”, taxes and warrant.

Cost reduction compared to reference product, is achieved through: Improved composite designs (~13%), Increased inner tank volume (~40%), Higher annual production rates (~70% cumulated cost reduction; OTV cost reduction included).

The main cost drivers at low production rates are Material, Process and OTV costs and at high
The results show that 600€/kg syst. target (2020 FCH target) appears to be achievable for high inner volume tanks and production rates above 8,000 - 10,000 tanks/year.

The comparison with DOE cost study gives similar results.

WP conclusion

• Cost study:

The FCH JU 2020 target (600€/H2Kg) is realistic and feasible according to actual Copernic result. For high manufacturing rates, the results from Copernic cost study are similar to the DOE costs estimations for high production volume and 149L storage system.

• Improve vessel performance:

The operational durability and performance in real test conditions of the Copernic optimized vessels (ca. 80pcs of COPVs were pressure tested) were validated with successful completion of the most critical hydraulic test (burst, ambient/extreme T pressure cycling, accelerated stress rupture, etc. for optimized vessels). All of the tests were made in accordance with Commission Regulation No 406/2010.

Copernic H2 storage system Gravimetric capacity: 4.99%. This ratio is in line with expected FCH JU 2020 target (5%). Copernic H2 Volumetric capacity: 0.0221kg/L. This value is also in line with FCH JU target 2017 (0.022Kg/L).

• SHM:

An OFS embedding method during COPV manufacturing was developed. Experimental validation of SHM system applicability during vessel manufacturing has been conducted with optimization of manufacturing parameters. Experimental validation of SHM system and strategy for COPV lifetime monitoring has been tested with detection of critical behaviour/failures.

The SHM system and strategy which was developed during COPERNIC project and checked can be implemented for another high pressure storage. SHM solution which was used for manufacturing process monitoring can be applied for another R&D projects in a field of composite structures.

WP6 Dissemination and IPR

• WP Overall Assessment and Vision:

The industrial partners developed a significant improvement in internal skills and product delivery and they start to manage a real business development. Academics partners improved the knowledge and achieve a higher position in the H2 network. Dissemination activity & the Users’ workshop were successful for the targeted audience (worldwide key actors of the H2 community). Today, there is a continuation of the project with the Hiphone project (CEA, OPTIMUM CPV, WRUT and RAIGI) and the use of ANLEG OTV-R can be planned to propose a 700 bar storage system to Symbio FCell for example.

• Task 6.1 Dissemination and outreach activities

Over the duration of the project, the COPERNIC project was presented at different exhibitions like:

- Hannover fair, Fuel Cell Expo at Tokyo, JEC, CAMX
- Different Speeches at ZBT-Duisburg, Brennstoffzellen Forum Hessen ect....

The COPERNIC project was also presented by CEA and WRUT at several events and scientific conferences:

- International Conference (CPVS 2013,2014,2015,2016&2017), Smart Energy Conversion & Storage,
- WHEC 2016,
- KOMPOZYT-EXPO® 2015, Kraków, Poland - composite exhibition.
- FDFC 2017: Stuttgart organized by DLR

• COPERNIC posters:
**Cost & Performances Improvement for Cgh2 Composite Tanks.**

**Structural Health Monitoring of COPV**


- **COPERNIC video:**
  
  A video has been realized to promote the FCH-JU Copernic project and results. The video was shown during the 2016 PRD meeting organized by the FCH-JU in Brussels last November 2016. This video was very appreciated by the audience (Video delivered to FCH-JU and free access on the Copernic web site).

- **Task 6.2 Users Workshop**
  
  The Copernic user workshop called “Phase Convention” has been organised in May 2016. It was a real success and the next Phase convention will take place at Hasselt in May 2017. [https://phase-convention.com/](https://phase-convention.com/)

- **Task 6.3 IP and exploitation management**
  
  Three patents have been filled thanks to Copernic results:
  
  - Boss treatment, April 2015, CEA
  - Boss – Head, CEA – ANLEG, ongoing
  - New Delivery system for the robot, CEA, ongoing

  Industrial partners are starting exploiting Copernic results and already work on next opportunities.

  **CEA:**
  
  - Patents exploitation;
  - Implement a 61L tank CEA design with best Copernic solutions (Automotive Type IV 70MPa) for a certification (EC 79/2009) planned in 2018 (Hiphone project – KIC Innoenergy innovation project with RAIGI, OCPV, WRUT);
  - Preparing New European projects to improve and homologate the H2 pressure vessels for automotive, aeronautic and boat applications;
  - Promote European H2 pressure vessels and storage systems.

  **Raigi:**
  
  - Implement results (resin and boss characterisation) in a tank (Automotive Type IV 70MPa) for a certification (EC 79/2009) planned in 2018 (Hiphone project – KIC Innoenergy innovation project);
  - Investment realised on a rotomoulding machine to manufacture the Hiphone liner (200k€);
  - Associated results with:
    - Symbio FCell: commercial agreement to replace the Iljin vessel (used actually in the Kangoo car) with the Hiphone one.
    - Discussions on going with car manufacturers & first rank suppliers (French & German).

  **Optimum CPV:**
  
  - The project allows Optimum CPV to extend their skills regarding development, manufacturing and testing of Composite Pressure Vessels (CPV’s) for high pressure applications (mainly related to H2 storage). Furthermore, a broader view has been provided regarding the use of different materials and improved laminate architecture applies to other high pressure cylinders (e.g. CNG).
  
  - Investments were made to acquire high pressure equipment for testing, which has already successfully been used for other industrial development projects. The equipment includes a high flow cycle pump to test cylinders with a storage capacity of up to 2000 L at 550 bar. For high pressure hydrogen application, a second installation was configured to allow cycle tests at 1100 bar. Additionally, a burst pump and safety chamber was built to perform burst tests at up to 2500 bar. An amount of 300,000 EUR was invested to acquire these equipments.
  
  - Updates of COMPOSICAD (with improved numerical interfaces) have already been granted to several customers. It has become the leading software tool to design CPV’s in Europe, the US and Asia,
including leading OEM’s of the automotive industry.

- During the past 2 years, Optimum CPV hired 4 people to face the growing market demands. The turnover was increased by 50%. To enhance international business, Optimum CPV has finalized marketing/representation agreements in the US, South- America, Japan, Korea and China. The European business is handled by the headquarters in Belgium.

- Optimum CPV has become a world leader in CPV development. Its competence is combining Design, Manufacturing, Testing and Training of CPV’s, which is unique in the industry.

ANLEG:

- The Copernic project allowed Anleg to develop a complete new OTV-R;
- The homologation should be obtained by next February 2017.
- Anleg has already started the production of the Copernic OTV-R. Over 50 valves have been sold the last 3 months (November 2016);
- A new Business unit (within Anleg) “B-Branch” has been created to produce/manufacture and deliver dedicated valves and H2 storage systems to customers like Airbus, Zodiac Aerospace, DLR Linde.
- Due to the increase of turnover and strong interest from end users, 3 new jobs have been created and new business has been generated and launched within the aerospace industry and car manufacturers;
- Anleg invested approx. 100.000€ in hydrogen infrastructure, production, testing facility for this OTV-R business branch. In order to meet the quality requests from the aeronautical customers, Anleg is currently ongoing the EN 9100 certification;
- With the Copernic project, Anleg has become a worldwide known company as OTV manufacturer (or other valves dedicated to gases), especially on the hydrogen applications. Today, current negotiations are ongoing and very promising on maritime and avionics aspects.

• WP6 conclusion

A large number of dissemination activities have been performed over the project duration, about 50 among which 6 publications, 1 international workshop, 1 videos and an active website. The Copernic Video was very appreciated during FCH-JU Program Review Days meeting last November 2016. This is a good promoting way for all partners and & FCH-JU.

CEA, Optimum CPV, WRUT and RAIGI are now involved in other project called Hiphone in the H2 topic, thanks to their notoriety, partly due to Copernic technical results known through dissemination achieved.

The Phase convention has been a fantastic conference meeting, with a great number of international attendees. All partners had the opportunity to present their results. The new Phase convention is schedule during spring 2017 in Hasselt.

CEA has concluded a IP transfer with RAIGI. Each partner shall now conclude what they have to do in term of IP.

The project has good results from a technical point of view, and the communication around these results allows industrial partners to develop/gain a significant leadership position within the H2 community.

The impact of such results within the community is high: quantitative and qualitative assessments of strategies including evolution of materials, components, processes and designs have already been transferred and used within industrial H2 project deployments. Some partners are also working on next generation solution (tank, valve...) and technical conclusions should bring new opportunities.

Copernic Conclusion

All expected targets have been reached within the Copernic project duration.

- For the cost reduction, the target (600 €/H2 kg) is achieved if the composite is optimized (-13 %), the internal volume is higher (from 37L to 61L: -40 %) and the annual production is higher (for 8,000 unit - 70 %).
- The Improvement of vessel performance for Copernic Storage System is effective. The gravimetric capacity reaches 4.99 % and 0.0221kg/L for the volumetric capacity.
- Significant breakthroughs are implemented in the on-tank valve (OTV) (reduction of mass, number of
parts, power consumption) and a certification process is on-going.

- Thanks to Copernic Process innovations, productivity improvement (27kg of composite) from an initial 120 minutes winding time to a final 70 minutes (with 8 axes robot) is achieved. A new dimensionless number, Vi, was created during Copernic project to evaluate the efficiency of composite structure.

The realised Copernic video summarizes the project results (available on Copernic website).

After the end of the project, future steps are planned by Copernic partners. Structural health monitoring (SHM) tests activities remain on-going for manufacturing quality process. A new target for winding time with prepreg is defined to increase the productivity. CEA asked in 2015 for a ComposicaD batch mode that will be available in 2017. Work on alternative designs will be pursued to evaluate the potential of these new prototypes.

An optimized ANLEG On-Tank-Valve with pressure regulation (OTV-R) has been successfully developed and will pass the certification process planned next February 2017.

Now, thanks to FCH-JU Copernic project, CEA, RAIGI, OCPV, WRUT and ANLEG are developing an European 61L H2 vessel & storage system to be homologated and commercialized during 2018 (Hiphone project).

Potential Impact:

Potential impact:

The potential impacts are the following:

- Decrease the cost of H2 pressure vessel
- Extend innovations to other volume
- Extend innovations to other on-board applications (aeronautic, boats)
- Extend innovations to stationary or transportable applications
- Increase the car safety with SHM by technology transfer

Dissemination activities:

Conferences & Publications:

COPERNIC partners presented the project and results to several conferences and events over the duration of the project. The impact is both on the academic and industrial sides (papers, publication, business developments). Copernic has been presented to 31 identified events. Details have been provided in the dissemination deliverable.

4 Publications are in progress

Publication 1:

- Title / Copernic Project
- Main author : CEA
- Title of the periodical or the series: International Journal of Hydrogen Energy
- Publisher: Hydrogen Energy Publications, LLC. Published by Elsevier Ltd.
- Date of publication 2017
- Is open access provided to this publication? No
- Type: peer reviewed

Publication 2:

- Title / A dimensionless number to measure the mechanical performance of the composite structure for a high-pressure tank: application for on-board storage of hydrogen gas at 700 bar
- Main author : CEA
• Title of the periodical or the series: International Journal of Hydrogen Energy
• Publisher: Hydrogen Energy Publications, LLC. Published by Elsevier Ltd.
• Date of publication 2017
• Is open access provided to this publication? No
• Type: peer reviewed

Publication 3:
• Title / SHM for on-board storage of hydrogen gas at 700 bar
• Main author : WRUT
• Title of the periodical or the series: International Journal of Hydrogen Energy
• Publisher: Hydrogen Energy Publications, LLC. Published by Elsevier Ltd.
• Date of publication 2017
• Is open access provided to this publication? No
• Type: peer reviewed

Publication 4:
• Title / Multiscale Modeling for on-board storage of hydrogen gas at 700 bar
• Main author : WRUT
• Title of the periodical or the series: International Journal of Hydrogen Energy
• Publisher: Hydrogen Energy Publications, LLC. Published by Elsevier Ltd.
• Date of publication 2017
• Is open access provided to this publication? No
• Type: peer reviewed

Patent:
Three patents have been initiated by Copernic:
• Boss – Head, CEA – ANLEG, ongoing
• New Delivery system for the robot, CEA, ongoing

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STRIA Roadmaps: Low-emission alternative energy for transport, Other
Transport mode: Multimodal transport
Transport sectors: Passenger transport, Freight transport
Transport policies: Other specified
Geo-spatial type: Other