FINAL REPORT OF THE EXPERT NETWORKING GROUP

Deliverable No.: D7.8

Deliverable Status: Final

Last update: 23rd February 2017

Authors: Clémence Devilliers (Air Liquide); Randy Dey (CCS); Thomas Brachmann, Fredric Barth (Honda); Reinhold Wurster (LBST)

Confidentiality Level: PU

PU – Public | PP = Restricted to other programme participants |RE – Restricted | CO - Confidential

Acknowledgement

This project has received funding from the European Union´s 7th Framework Programme (FP/2007-2013) for the Fuel Cells and Hydrogen Joint Technology Initiative under FCH-2012-1 Grant Agreement Number 325277.

The project partners would like to thank the EU for establishing the fuel cells and hydrogen framework and for supporting this activity.

Disclaimer

The staff of HyTransfer prepared this report.

The views and conclusions expressed in this document are those of the staff of the HyTransfer partners. Neither the HyTransfer partner(s), nor any of their employees, contractors or subcontractors, make any warranty, expressed or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, product, or process enclosed, or represent that its use would not infringe on privately owned rights.

This document only reflects the author´s views. FCH JU and the European Union are not liable for any use that may be made of the information contained herewith.

CONTENTS

1 INTRODUCTION

1.1 Aim of the Expert Networking Group (ENG)

The ENG aims to engage individuals leading the deployment of hydrogen refuelling infrastructure in Europe with experience and understanding of the difficulties that still need to be overcome.

Their input will enrich the analysis of the fuelling process optimization opportunities. They will learn first-hand about the results of the test program and maybe even be able to provide some input into the fuel-system testing. And more importantly, they can help interpret some of the results before dissemination to the stakeholders, which they are a part of.

1.2 Identification of main objectives of the project

The HyTransfer project aims to develop and experimentally validate practical approaches for optimizing the means of temperature control during fast transfers of compressed hydrogen and to provide recommendations for the eventual adaptation in to the relevant Regulation Codes and Standards (RCS).

Temperature control is an essential area of optimization of the hydrogen vehicle refuelling process, as it significantly impacts fuelling duration, energy consumption, investment costs and process reliability.

The following improvement opportunities are being addressed:

- Avoidance of fuelling duration increase as a means of preventing temperature limits from being exceeded, so that fuelling can always be performed in less than 3 minutes;
- Thermal control requirement bearing on cumulated thermodynamic energy input (as reflected by average delivery temperature), rather than on maximum fuel delivery temperature which is quite constraining;
- Reference to material temperature for compliance with temperature limits as reference to gas temperature is often over-conservative;
- Intensity of cooling determined at time of fill based on actual needs using a simple model, rather than preset for all fills and all conditions;

A two-phase experimental approach was applied for investigating these opportunities and validating the resulting improved temperature control approaches:

- A ‘single’ vessel testing program was performed first to validate models for predicting extreme temperatures in the gas and in the material during fast filling and emptying.
    - One of the main objectives here was to translate this prediction capability into a simple model allow to determine conservatively at

the time of fuelling the amount of cooling required to avoid exceeding the specified temperature limits.
The experimental program, involving a total of 88 highly instrumented filling or emptying tests on three different vessels (one Type 3 and two Type 4) by three testing entities has been defined in detail. Experimental test campaign was performed in 2015.

- Improved temperature control criteria and approaches resulting from the above analysis were tested and validated on a tank assembly representative of vehicle fuel systems in a refuelling station environment.
    - The Compressed Hydrogen Storage System (CHSS) like test bench was composed of 5 vessels: four Type 4 and one Type 3, representing a total capacity of 7,4 Kg of hydrogen at 700 bar.

      More than 20 filling and emptying were performed on a station like test facility to test and validate the proposed improved filling protocol.

Finally, a techno-economic analysis was performed to evaluate and quantify the benefits of the new approaches proposed in comparison with the currently applied refuelling protocols, in particular with regards to CAPEX and OPEX.

A preliminary dissemination of HyTransfer outcomes was initiated at the end of the project, mainly through the Expert Networking Group. Efforts need to be continued by industrial partners to bring and support the proposed HyTransfer filling protocol to RCS bodies.

The purpose of this deliverable is to describe the activities done in HyTransfer around the Expert Networking Group (mainly Task T7.3): construction of the ENG, organization of events, feedbacks from experts...

1.3 Overview of the main subjects for the ENG

The following subjects were addressed to the members of the Expert Networking Group:

- HyTransfer New Approach: philosophy behind, optimization opportunities.
- CFD / Modelling
- Experimental setup
- Techno-economic evaluation of the New Approach
    - Pre-cooling impact on market strategy and normalization (cost reduction CAPEX & OPEX, CO2 footprint reduction potential…)
- Proposition of RCS recommendations
- Proposition of Industry recommendations

2 FORMATION OF THE ENG GROUP

2.1 First target group

The first target group was defined on the overall scope of the project, without specific focus on the stage of the project. Experts in the field of hydrogen energy mobility were approached including OEMs, station operators, gas companies, manufacturer of equipment and components, labs and further actors.

Branch	Company	Person to invite

CONFIDENTIAL

2.2 Attempts and formation of a smaller ENG group

An initial attempt to hold the first ENG meeting on March 11th 2014 during the European Hydrogen Energy Conference in Sevilla was not successful.

A flyer and invitations were sent but no expert answered positively, as this event turned out to be too academic and most of the experts approached were not participating in the conference.

A second effort to hold an ENG meeting in Webex format was again not successful on June 6th. Invitations were sent, a brief presentation was prepared but the webex was cancelled due to a lack of external expert participation.

The ENG strategy was modified to consider having a smaller ENG group with a focused effort on engaging individuals interested in the overall advancement of HRS from organizations such as Daimler, Linde, Shell, WEH, Magna and NOW. A letter of invitation was revised to further explain the ENG approach and the benefits of participating. In addition, a letter of support of the FCH JU to the ENG was developed together with the Programme Office for encouraging participation. This letter was eventually received (see Annex A1). A presentation of the fuelling process optimization opportunities has been developed to engage the ENG members. This presentation was completed with attendees' feedbacks.

The ENG strategy was then modified as well as the invitation list for the first ENG meetings. The table underneath shows the individuals personally invited.

Branch	Company	Person to invite

CONFIDENTIAL

3 EVENTS ORGANIZED WITH THE ENG

3.1 First meeting of the ENG

The first face to face meeting of the ENG was done in two parts:

- a first meeting in Hamburg on September 29th 2014, with representatives of Shell and NOW,
- and a second meeting in Stuttgart on October 6th 2014, with representatives of Daimler.

The main objective of the ENG was reached with the presence of main experts selected.

The main opportunities described in the aim of the ENG were addressed.

The main feedbacks from the ENG for HyTransfer were:

- The overall approach is relevant and can improve the fueling station operation and reduce the high energy consumption in the early deployment.
- The techno economics results will be an important factor of success for the new approach of HyTransfer to encourage the industry to launch a development of fueling protocol and shall involve the results already achieved by the industry for example in Germany and H2 Mobility. The early results shall be disseminated widely in the European effort. The established fueling protocol does not focus on efficiency and cost analysis. Capex and Opex evaluation need to be performed to show to the operator the benefit of this approach.
- The qualification program will be developed from the HyTransfer approach, as a fueling protocol will be an important factor of success and shall be addressed sooner than later with a validation program for getting the HRS operating approval by the authorities.

3.2 Second ENG event: Webinar of December 2015

Given the difficulties faced to gather people for ENG meetings, it was decided to organize a webinar during the second year of the project. Webinar is the most efficient way to get people attending the presentation. Indeed, it is very difficult for ENG members to justify travelling costs for such meetings, which has no direct benefits for their companies.

This webinar took place on December 11th, 2015. Around 15 people, out of the HyTransfer project, were attending.

The feedbacks were tracked in the webinar presentation, and listed below:

- The values in HyTransfer for fueling at the hydrogen station will be valid only when the upstream components from break-away to receptacle are

simulated thermally (to understand how much cooling energy is needed to overcome the thermal mass in the startup) – Input for WP5

- The range of tanks sizes and thermal properties used in SAE J2601 represented the "possible" from 8 OEMs represented there. Though the HyTransfer takes into account the three tanks reference. It would be suggested to reference Appendix A of SAE J2601 for simulation of both tanks and station hardware.
- Ensure all vehicle are addressed within the new fueling protocol including new cylinders type such as Type 5 (only composite, no liner) or smaller tank (less than 2kg)
- HyTransfer shall issue a public report with the synthesis of the temperature gradients during the experiment and simulations
  - With a special focus on peak and average temperature of gas, liner and composite.
  - Presentation of the simulation model for gradient estimations and the validity limits of the model including the type of liner and composite investigated in HyTransfer (PA6, PA12? Other)
  - Temperature variations in the time and in the space
- Storage risk analysis of over temperature during refueling
  - Potential degradation (impact for short, average or long exposure of over temperature limits)
  - Potential risks: leak (major/minor), liner degradation
  - Report on experiments with over temperature excess limit on liner degradation on storages
  - Bibliography study and REX of liner/composite over temperature effects
- Proposal for optimal temperature range for materials (vehicle and HRS)
  - Low temperature:-40°c or less
  - High temperature: +85°C or more
  - Realistic extend operating temperature range(-50°c to + 100°c)
- Alternative fueling protocol proposal
  - Guidelines and list of the minimal requirements in terms of:
    - Method (Ramp, State of charges, other)
    - Performance
    - Safety and risk analyses

- Definition of scope: what is included? small storage (< 2 kg), new type of storage (type 5), communication mode with the vehicle, the pressure range of stations , only 70Mpa or 35Mpa/70Mpa

- Level of safety requirement for vehicle communication
- Planning to achieve the alternative protocol of filling at the European level in a term of 2 or 3 years.

➢ Recommendations for the evolution wished by the GTR 13:

- Recommendation of temperature cycling test to have an acceptable safety margin (overpressure risk, 10 tests at to 150 % of the NWP in the GTR to ensure a safety margin)

➢ Hytransfer should answer:

- Which refueling case required -40°C cooling: Type of storage, Dimension, Flow rate, Initial condition
- How many filling are impacted?

3.3 Third ENG event: Seminar of June 2016

The 21st edition of the World Hydrogen Energy Conference took place in Saragossa (Spain) in June 2016 (13th-16th). As this event is very attractive for (more than 900 people around the world in 2016), we thought this was the right place to organize a parallel event for presenting the HyTransfer approach, recent results, upcoming test campaign and preliminary conclusions / recommendations.

Indeed most of companied involved in the Hydrogen Energy sector are present for this worldwide event. As travel was already arranged for WHEC participants, this was the easiest way to gather a maximum of experts.

Around 25 people attended the seminar, among which 9 people of the HyTransfer consortium.

Audience appreciated the work performed in HyTransfer, and an interesting and constructive Question & Answer session took place after the presentation, during more than 1h30. A synthesis of question received and answers brought is given below:

Name	Question / Comment	Answer
CONFIDENTIAL	A flow rate of 8g/s in 3 min represents only1,2 kg of H2...	I suggest adding that the 8 g/s value was chosen because this provides a filling duration of the tested 40 l tank in about 3 min.
	Impact of piping diameter and filter on pressure drop ?	Additional pressure drop increases the amount of cooling required. In our calculations we considered the pressure drop defined for the Hot Case. It is assumed that in any fuel station with any vehicle the pressure drop will be lower. Standards should specify the maximum pressure drop in the fuelling assembly and in the piping (including the on-tank valves).

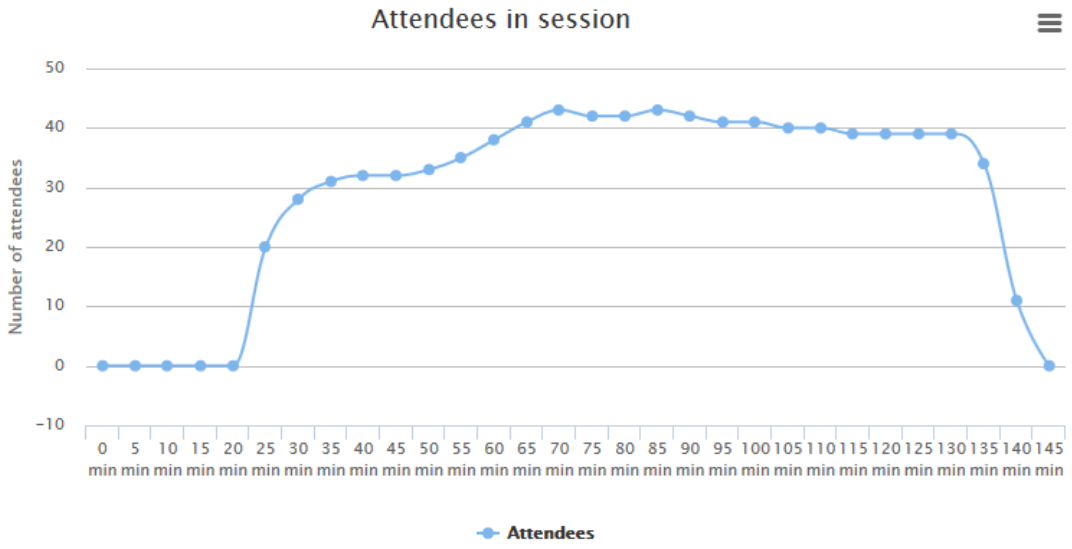
	Difference between T3 and T4?	The temperature increase is lower in Type 3 than in Type 4 tanks. The difference is about 10C for a 40 l tank, and greater for larger tanks.
CONFIDENTIAL	Question about thermal mass of the station? Need to consider exactly the same thermal mass as in SAEJ. Recommend to postpone the tests at ET in order to be exactly representative of SAEJ assumptions. Someone (who?) was interested to join to project and offer more information	Testing of the new protocol using storage systems representative of the Hot Cases and Cold cases defined by industry (one for each of the 3 defined H2 storage system categories) should indeed be considered. In HyTransfer the protocol will be evaluated using Hot Case (HC) and Cold Case (CC) configurations based on components that could be made available by the consortium partners. A first validation of the new protocol will be provided by showing that when it is applied using filling parameters based on these HC and CC configurations; there is no overheating for the HC configuration and no overfilling for this CC configuration.
	The thermocouples included in car tanks right now are very close to the injection. Is it a correct estimation of the temperature inside the tank?	Hytransfer's work has shown that there exist very different flow regimes throughout the filling of a car tank. Some of them lead to very homogeneous temperature fields inside the gas volume, while other can lead to very heterogeneous fields inside the gas volume. We are also able to demonstrate that some SAEJ recommended fillings lead to vertically stratified temperature regimes. (eg. some fillings are made in 15 minutes with 5,5mm injectors). In that case, the temperature field will be heterogeneous, and the thermocouple measurement will not be representative of the maximum gas temperature. It is therefore very clear that the station will stop the filling when the TC measures a temperature of 85°C, and at this moment, the maximum temperature in the gas and in the liner will be over 85°C. Therefore, SAE based filling already lead to wall temperatures over 85°C in the gas and in the material, locally.
	Is the criterion of T@1,5mm from liner surface applicable to other type of cylinders? What about Type 5 cylinders without liner? Should be considered in our recommendations.	The filling conditions are designed for meeting this criterion for the Hot Case, which assumes a liner thickness of 5 mm. With the 1.5 mm criteria, the temperatures exceeds 85°C only temporarily within a surface layer of 1.5 mm maximum and the material temperatures does not exceed 95°C. This temporary exposure is acceptable for the materials used in a Type 4 vessel.

3.4 Final dissemination event: webinar of Dec 2016

As part of outcomes dissemination in the frame of WP7, a final event had to be organized. Unfortunately, no European or worldwide event was organized in November / December 2016. Therefore, the HyTransfer consortium decided to organize a new webinar, at beginning of December. The date of December 7th, 2016 was selected based on our respective agendas. Time was chosen at 16h (CET) so that US people could attend the event.

By chance, a workshop took place the same day at JRC in Petten, and most of experts in hydrogen filling protocol were participating (ISO, SAE). Agenda of the workshop has been slight modified to allow people listening to the HyTransfer webinar.

Invitation was sent by email to the distribution list established during the project. Around 66 registrations were recorded on the HyTransfer website. However, the Webinar software used by LBST recorded up to 40 attendees at the peak audience. In addition, JRC workshop represented maybe 35-40 people. So in total, we assess to 75-80 the number of people attending this dissemination event. Follow is the evolution of audience during the webinar.



During the webinar, people had the possibility to ask question by chat. Unfortunately, no question was raised, showing the low interactivity of such event.

However, very good feedbacks have been received after the event, from different people / companies, on the scientific and technical quality of the work performed in this project.

In conclusion, we can say that the success of this final dissemination event matched up with the quality of the project and the interest showed in this topic.

3.5 Post-project: dissemination to SAE committee on Feb 2017

After the official end of the project (31/12/2016), an opportunity was given to one member of the project (from Air Liquide) to defend and explain again project results and the new filling protocol proposal to the SAE committee members during a quarterly SAE meeting. This meeting took place in Torrance, California on February 9th and10th, 2017. A time slot of one hour was given. Around 30 people were attending the presentation, from different companies:

- **OEMs**: Toyota, Honda, General Motors... but also the Japan Automobile Research Institute (JARI)
- **Labs**: NREL, Powertech, ...
- **HRS manufacturers**: Air Liquide, NEL/H2 Logic, First Element, Powertech, IVYS Energy Solutions, ...
- **Dispenser manufacturers**: Tatsuno
- **Hydrogen associations**: HySUT in Japan (association of Hydrogen Supply and Utilization Technology) , CaFCP in US (California Fuel Cell Partnership)
- **Modelling**: Wenger & associates

The presentation was mainly based on the Webinar presentation, but lightened and presented in a slightly different way, with a focus on the new filling protocol proposal and its rationale. A large part of the SAE members attended the final webinar and were already aware of the project outcomes.

Globally, the presentation has been very well appreciated and a lot of congratulations were received for the quality of work performed in the project (methodology, testing, modeling, techno-economic analysis, etc..).

The presentation was followed by a Q&A session. Following points were raised /discussed:

- Honda suggested to add a curve in Slide 38 : SAE protocol with new assumptions on piping (thermal mass and pressure drop)
- Thermal masses: Two hypothesis in SAE J2601: high thermal mass for Hot Case (S2) and low thermal mass for Cold case (S1). Hypothesis S2 was taken to cover Japan market (higher safety factors). MC method had proposed S1 but was not successfull. Concerns to ensure that a station would use the correct components (e.g. sourcing Japanese components in the US)
- Adjust delivery temperature according to ambient temperature:
  - Wenger & associates mentioned a paper published previously which suggested a similar approach (I will ask him the reference)
  - It has been envisaged at the beginning of SAE (8-10 years ago). But one person thought implementation was not so easy, and it was easier to have a fixed temperature. They did not remember the precise arguments...

- Extended tank temperature limit to 95°C:
  - Risk probability and consequences of temperatures beyond max 85°C during uncontrolled (malfunctioning) fuelling has been discussed lengthily discussed between stakeholders in the past. By now proposing a higher peak temperature, stakeholders will have to revisit the risk, including risk of a malfunctioning at the HRS, which might bring the temperatures higher than 95°C. This might influence on the qualification margins. Automotive makers will require on top of minimum required in RCS, which most likely will be higher than 95°C, or require the test to be done on a number of cylinders to build statistical confidence into the cylinder design, also taking into consideration variation in materials used.
  - Other consideration for the hot temperature is the valve and regulator which have soft polymers which can be affected by the hot temperatures and the JT effect with expansion
  - Arguments given to explain why the max temperature limit of 95°C will not happen at every filling, but only sometimes, when all worst hypothesis are raised. NO: from a safety point of view, if it can happen, a high frequency must be considered in the risk analysis (at each filling) to be conservative.
- Boyd Hydrogen LLC: all fillings performed at hot ambient temperature and stopped at 875 bar, will lead to underfilled tanks (much more important at 95°C)... SoC for these cases need to be quantified. Customer feedbacks on miles/filling are very important, much more than time to fill.
- What are the next steps?
  - Targeting the higher tank temperatures is GTR rev 3. Not the GTR rev 2.
  - Toyota suggested a drastic change to reap the benefit of the efforts required for RCS changes, rather than incremental changes

The most challenging outcome of the HyTransfer project is the necessity to consider a higher temperature limit for Type IV tank (95°C instead of 85°C currently) to get significant savings on the pre-cooler (CAPEX / OPEX). More discussions and clear information about the potential occasion of such temperature level will be needed in the future to convince people about the possibility to accept higher temperature over a thin thickness of the liner in rare exceptional conditions (Hot Case situation) during a short time. Of course, safety concerns need to be followed and taken into account. And we need to explain when it can happen to implement this in a future risk analysis matrix.

4 CONCLUSION

In conclusion, several events were organized during the project to disseminate project results and approach followed. The objective was to involve stakeholders early in the project to consider their comments and follow their advices, based on their experience.

They got the chance to influence project choices (assumptions, test matrix, etc...). Unfortunately, we faced the difficulty to organize specific face-to-face meetings with the right people. The easiest way to have Expert Networking Group meetings was by webinars or parallel seminars during a large hydrogen event (like WHEC).

Globally, the quality of work presented was highlighted by the audience. However, attendees pointed out the most challenging optimization opportunity of the proposed filling protocol, that is to say increasing the high temperature limit of tanks to 95°C to get significant savings on HRS. Next steps are now:

- Either, to demonstrate by testing that tanks as currently designed can withstand without noticeable impact on the level of safety higher gas temperatures over a short period (without changing the design and testing requirements), also taking into considerations malfunctions in the control system of the fill process. To that end, risks and consequences of an overheating must be quantified in a risk analysis. For that, more work is needed on the tank to better understand the impact of exposing the tank to higher peak gas temperatures.
- Or we demonstrate that risks and consequences are not acceptable for current tank designs. In that case, design and/or testing requirements would need to be changed in RCS, with a potentially significant impact on the tank cost. In this case, an overall techno-economic analysis needs to be performed, taking into account a higher cost for the tank (to be quantified), for demonstrating that it is still interesting from an economic point of view to accept higher peak gas temperatures.

A1 SUPPORT LETTER FROM FCH JU

New Energy World JU
fuel cells & hydrogen for sustainability

Brussels, 19 September 2014

Ref.: Invitation to participate in the HyTransfer Project Expert Networking Group

Dear Sir, Madam,

The Fuel Cells and Hydrogen Joint Undertaking is supporting the HyTransfer project that performs pre-normative research on gaseous hydrogen transfer. The aim is to develop an optimized refuelling process which requires less pre-cooling by better understanding the thermodynamics of the refuelling process.

An important component of the project is the Expert Networking Group that will shed strategic light on issues like H2 mobility and standardisation of filling requirements. This Group will also keep the industry informed on the progress of the project and facilitate the dissemination of the project results.

I would like to invite you to join the Expert Networking Group and use the opportunity to meet with the representatives of HyTransfer to jointly bring forward our common interest in fuel cells and hydrogen in Europe and the World.

Yours sincerely,

Nikolaos Lymperopoulos
Project Manager

Fuel Cells Hydrogen Joint Undertaking (FCH JU)
WA, TO-56, 1049 Brussels, Office 04/28, Tel: (32-2) 221 81 39, Fax: (32-2) 221 81 26