TASK 37 – HYDROGEN SAFETY – FINAL REPORT (2021)

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TIMEFRAME: JANUARY 2015 – December 2021

SYNOPSIS

The overarching goal of this Hydrogen Safety Task is to support the acceleration of safe implementation of hydrogen-based technologies and their infrastructures through coordinated international collaborations and hydrogen safety knowledge dissemination.

Under Task 37, Dr. Khalil managed a portfolio of research activities conducted by international hydrogen safety experts. Also, he organized five subtasks under Task 37 as shown in Table 1. Each subtask has assigned subtask Leader(s) and a team of internal hydrogen safety experts.

Table 1. Subtasks leaders in Task 37 (Hydrogen Safety).

SUBTASK	TITLE	SUB-TASK LEADER & Affliation
A	QRA Tool Kit Integration (HyRam)	Prof. Katrina Groth University of Maryland, USA
B	Accident Scenarios Development & Quantification	Prof. Knut Vagsather University of South-Eastern (USN), Norway
C	Physical Effects / Phenomena	Prof. Vladimir Molkov Ulster University, N. Ireland, UK Prof. Jennifer Wen Warwick University, UK
D	Human Reliability Analysis (HRA)	Prof. Frank Markert Technical University of Denmark (DTU), Denmark
E	Materials Compatibility Issues	Prof. Tadahiro Shibutani Yokohama National University (YNU) Yokohama, Japan Prof. Changjian Wang Hefei University of Technology, China

MAIN TASK ACHIEVEMENTS AND RESULTS

One of the key activities of Task 37 was supporting the development and testing of Hydrogen Risk Assessment Model (*HyRam*) toolkit which incorporates numerous H2 behavior models into a user-friendly package designed to address key barriers to H2 infrastructure deployment, including limited access to reliability data and lack of models describing H2 behavior. Other activities of Task 37 included providing quantitative insights (*both physics-based and probabilistic*) to support development of new as well as revised H2 safety C&S (*e.g.*, NFPA2 and ISO standards). Below are selected examples Task 37 deliverables and H2 safety knowledge dissemination.

SELECTED EXAMPLES OF TASK 37 KEY DELIVERABLES AND KNOWLEDGE DISSEMENATION

1. Groth, K.M. (2016). Hydrogen behavior and quantitative risk assessment. *DOE Hydrogen and Fuel Cells Annual Merit Review (AMR)*, Washington, DC, USA.

2. Khalil, Y.F. (2019). Safe use of hydrogen as a promising energy carrier for light-duty vehicles. Invited Presentation, *Center for Global Public Safety Industry Stakeholders' Forum*, Worcester Polytechnic Institute (WPI) Worcester, MA. Source: PowerPoint Presentation (wpi.edu)

3. Khalil, Y.F. (2019). Role of hydrogen in a low-carbon economy: Hydrogen safety considerations for the power-to-gas (P2G) conversion process. Invited Presentation, *Workshop on Hydrogen Production with CCS*, Sponsored by *Électricité de France*, Campus EDF Chatou, 6 Quai Watier, 78400 Chatou, France, November 4-8, 2019.

4. Khalil, Y.F. (2018). Science-based framework for ensuring safe use of hydrogen as an energy carrier and an emission-free transportation fuel. *Journal of Process Safety and Environmental Protection*, 117, 326-340.

5. Khalil, Y.F. (2018). UK Research and Innovation Hydrogen Experts Meeting. *Department of Engineering Science*, University of Oxford, UK

6. Khalil, Y.F. (2017). A probabilistic visual-flowcharting-based model for consequence assessment of fire and explosion events involving leaks of flammable gases. *Journal of Loss Prevention in the Process Industries*, 50, 190–204.

7. Khalil, Y.F. (2016). Experimental determination of dust cloud combustion parameters of α-AlH3 powder in its charged and fully discharged states for H2 storage applications. Journal of Loss Prevention in the Process Industries, 44, 334-346

8. Khalil, Y.F. (2015). Risk quantification framework of hydride-based hydrogen storage systems for light-duty vehicles. *Journal of Loss Prevention in the Process Industries*, 38, 187-198.

9. Khalil, Y.F. (2015). Safe use of hydrogen for on-board light-duty fuel cell vehicles (LD-FCV). *Invited IEA HIA presentation*, Kawasaki Heavy Industries, Ltd, Tokyo, Japan

10. Kodoth, M., Aoyama, S., Sakamoto, J., Kasai, N., Khalil, Y.F., Shibutani, T., Miyake, A. (2020). Leak frequency analysis for hydrogen-based technology using Bayesian and frequentist methods. *Process Safety and Environmental Protection*, 136, 148-156.

11. Kodoth, M., Shibutani, T., Khalil, Y.F., and Miyake, A. (2019). Verification of appropriate life parameters in risk and reliability quantifications of process hazards. *Process Safety and Environmental Protection*, 127, 34-320.

KEY MESSAGES

- Over the six-years duration of Task 37, Dr. Khalil and his internal H2 safety experts continued to provide risk quantitative insights (both physics-based and probabilistic) to support the development of new, as well as revised, hydrogen safety C&S (*e.g.*, NFPA-2 and ISO standards).

- Dr. Khalil emphasizes the importance of expanding the scope of hydrogen safety beyond the fuel-cell-powered light-duty vehicles (LDV) application and H2 refueling stations. In this regard, Dr. Khalil recommends expanding the scope of H2 safety to other applications such as maritime, commercial aviation (hybrid-electric & all-electric aircraft), power-to-gas (P2G), H2 transport in long road tunnels and other confined-spaces such as garages.