

Development of H₂ Safety Expert Groups and due diligence tools for public awareness and trust in hydrogen technologies and applications



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Authors:**Andrea Rausa (CiaoTech – PNO)**

Silvia Colella (CiaoTech – PNO)

With contributions from:

Lourdes F. Vega (MATGAS, Carburos Metálicos-Air Products Group)

Patricia Ruiz (MATGAS)

Maria del Mar Arxer Ribas (Carburos Metálicos-Air Products Group)

Ismael Aso (McPhy)

Stefano Campanari (Politecnico di Milano)

Daniele Facchi (Solvay Specialty Polymers)

Maurizio Rea (SOL s.p.a.)

Fausto Gallucci (TU Eindhoven)

Marieke Reijalt (European Hydrogen Association/FAST)

Ahmed Essam Aly (FAST)

Giorgio Tagliabue (FAST)

Note: Author printed in bold is the contact person for this document.

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1 Introduction

This Deliverable is specifically aiming at describing the **H₂ due diligence safety risk assessment tool** that has been prepared by the H₂TRUST Consortium and made available online on the project portal.

As stated in Deliverable D 5.1, the on-line tool is part of a series of advanced features developed by the H₂TRUST consortium in order to:

- i) facilitate access for the user to relevant information related to H₂ safety,
- ii) give the user guidance on the methodological framework, the main parameters involved and the steps needed to perform a risk assessment related to H₂ technologies,
- iii) create a forum of experts able to respond to questions and remarks on safety of hydrogen.

As explained already in D 5.1, the **H₂ due diligence safety risk assessment tool** is based on the H₂TRUST FCH stakeholders and analyses model as well as the reference benchmark for production-storage-distribution technologies (result from Task 5.2) and has been made available for whoever wants to use it to assess its safety readiness/adequacy.

It has to be noted that the tool is not intended to be an exhaustive tool for risk assessment, but more a “guiding instrument” in the hands of users. To this end, the main parameters involved, the mathematical and physical models that regulate the different hazard situation and potential consequences have been addressed for several case studies, as well as how these are calculated and treated to evaluate the risk associated to a certain technology, process, plant, involving Hydrogen.

The tool is based on a series of assumptions in order to be user-friendly and show them as well as the formulas used for the calculation, in a step-by-step flavour designed to be very handy for users.

In the following paragraph, we explain the basic methodological framework of the tool, as well as the various steps that guide the user in performing a simulated risk assessment, based on relevant assumptions.

2 Methodological basis and logical steps

In the following sections, the online tool is presented with screenshots; the tool is based on the risk assessment methodology described in more details in the Deliverable D4.2 by TU/e. This tool is available at the project website (<http://h2trust.eu>).

The aim of the tool is to give a quick indication to the user about the level of risk for each possible hazardous event. In particular, the aim is to calculate, for each possible event, the frequency of occurrence and the outcome in terms of fatalities (consequence). With these two numbers the risk is identified and compared with a risk Matrix like the one reported in Table 1.

Table 1: "Risk Matrix" presentation.

		Probability Level (per year)				
		A (<0.001)	B (0.01-0.001)	C (0.1-0.01)	D (1-0.1)	E (10-1)
Consequence severity Level	1 (Disastrous)	H	H	H	H	H
	2 (Very major)	M	H	H	H	H
	3 (Major)	M	M	M	H	H
	4 (Serious)	L	L	M	M	H
	5 (Moderate)	L	L	L	L	M

The letters H, M and L denote risk levels “High”, “Medium” and “Low” respectively. The descriptions of the risk levels are given in the **Table 2**.

Table 2: Description of risk levels: High, Medium and Low.

LEVEL	LEVEL NAME	DESCRIPTION
H	High	High risk, not acceptable. Further analysis should be performed to give a better estimate of the risk. If this analysis still shows unacceptable or medium risk, redesign or other changes should be introduced to reduce the criticality.
M	Medium	The risk may be acceptable but redesign or other changes should be considered if reasonably practical. Further analysis should be performed to give a better estimate of the risk. When assessing the need of remedial actions, the number of events falling into this risk level should be taken into consideration to assure that the risk is as low as reasonable practical (ALARP)
L	Low	The risk is low and further risk reducing measures are not necessary.

If the risk is “High” or “Medium” the user is invited to scan the Hazard table for the identification of mitigation measures to reduce the risk to a “Low” level (acceptable risk).

The algorithm at the basis of the online tool goes through the following few steps:

1. calculation of the event frequency (Number to be used in the risk table),
2. calculation of the hydrogen release,
3. calculation of the radiation release,
4. calculation of the probability function,
5. calculation of the number of Fatalities (Number to be used in the risk table).

In the following sections the calculation scheme and equations used in the online tool are reported for a typical case. Some of the data required for the calculations are inputs of the user (such as pressures on the tubes, length of the tubes, population density etc.). The rest of the data have been taken from literature or databases (see deliverable 2.3), which is the main limitation of the tool at the moment. It is important to note that, as many data are missing, only few particular cases can be really calculated. Hence, the tool is just to give an example of calculation to the user, who should therefore conduct a more detailed safety assessment with more comprehensive available tools.

3 Overview

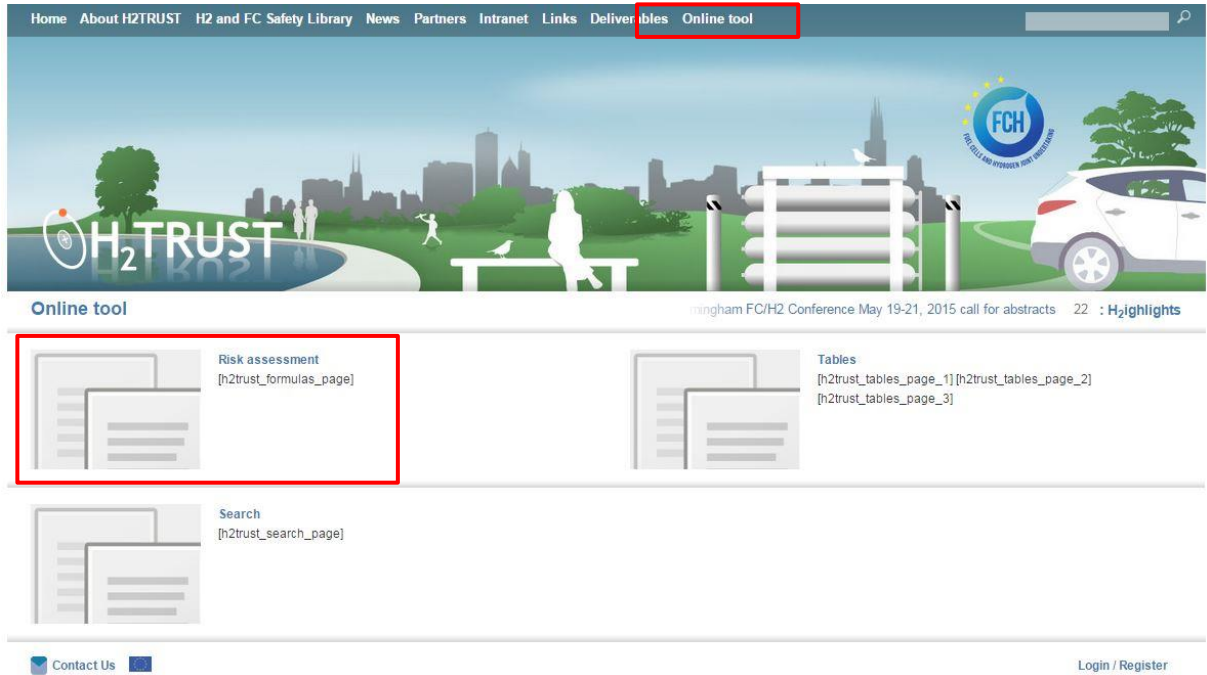


Figure 1. Online tool.

4 Interfaces

4.1 Risk Assessment

The risk assessment tool starts with a Disclaimer, explaining to the user the “demonstrative” nature of the tool, its main assumptions and basics instructions as a guide for subsequent steps.



Figure 2. Risk assessment and disclaimer.

4.1.1 Release Frequency

This is the first step of the calculation. For the release frequency, the release through a tube is considered. Similar formula are available for releases from vessels, container etc. However, data from failure rate are required in all the cases. Since this data for release through tubes is well documented, this case has been selected as the representative example.

Release frequency
 $F = F_p \cdot L_s \cdot E$

F: Expected frequency of hydrogen release from GH 2 pipeline (1/yr)
 F_p: Failure rates of gas pipeline (1/km.yr)
 L_s: Length of route segments (km)
 E: Exposure factors for the route segments

Insert Length of route segments value

Choose size

Choose Causes of pipe failure

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Figure 3. Release Frequency.

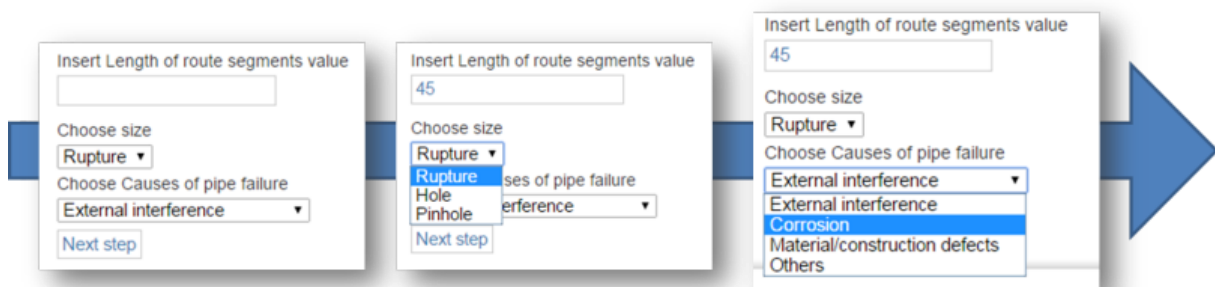


Figure 4. Menus of the frequency calculation page.

4.1.2 Discharge Rate

The discharge rate depends on the type of hydrogen considered (i.e. gas phase or liquid phase). Although they are similar, the two formulas for the two cases require different input data. For our example, we have considered the model for gas phase hydrogen.

Release frequency: 0.00084

Discharge rate

$$\dot{m} = C_D A P_1 \sqrt{\frac{2g_c M}{R_g T_1} \frac{k}{k-1} \left[\left(\frac{P_2}{P_1}\right)^{2/k} - \left(\frac{P_2}{P_1}\right)^{k+1/k} \right]}$$

C_D : Discharge coefficient (=0.86)
 A : The area of the discharge (m²)
 P_1 : The pressure upstream of the hole (N/m²)
 g_c : The acceleration of gravitation constant (9.80 m/s²)
 R_g : The universal gas constant (=8314 J/kmol/K)
 T_1 : The initial upstream temperature of the gas (K)
 k : The heat capacity ratio, Cp/Cv (=1.41 for H₂)
 P_2 : The downstream pressure (=101325 N/m²)
 M : The molecular weight of hydrogen (=kg/kmol)

The pressure upstream of the hole (N/m²)

The initial upstream temperature of the gas (K)

[Next step](#)

Figure 5. Discharge Rate

The pressure upstream of the hole (N/m²)

The initial upstream temperature of the gas (K)

[Next step](#)

Figure 6. Fill-in boxes for the discharge rate calculation.

4.1.3 Thermal radiation

The thermal radiation depends on the type of event occurring once the release of hydrogen occurred. We could have a flame, an explosion, etc. For our example, we illustrate the calculation in the case of flame. Similar models are available for the other cases such as explosion (see D 4.2 for more details on other models).

Discharge rate: 299.34625727374

Thermal radiation

Surface Emissive Power [W/m²]:

$$SEP = \frac{F_{rad} \cdot m_o \cdot \Delta H}{A}$$

F_{rad}: fraction of heat radiated (=0.17)
 ΔH: the heat of combustion (J/kg) (=119,930 kJ/kg)
 A: total surface area of the flame (m²)

Heat Flux [W/m²]:

$$I = SEP \cdot F_{view} \cdot \tau_{\alpha}$$

SEP: the surface emissive power [W/m²]
 F_{view}: the view factor (emissivity) (=0.023)
 τ_α: the atmospheric transmissivity (=1)

Total surface area of the flame (m²)

Next step

Figure 7. Thermal Radiation.

Total surface area of the flame (m²)

Next step

Figure 8. Request field for the thermal radiation calculation.

4.1.4 Probit Equation (consequence calculation)

The probit equation is used to calculate the possible number of fatalities once the thermal radiation associated to the hydrogen release is known. Once the time of exposure is inputted by the user, the probit equation can be solved.

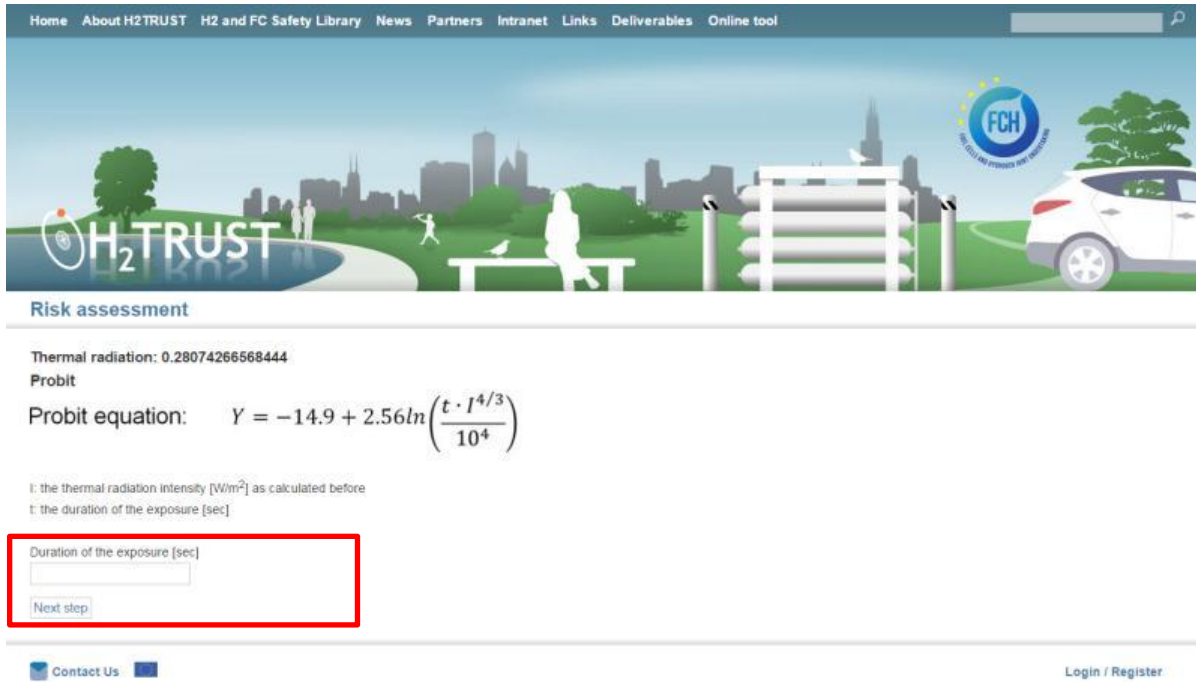


Figure 9. Probit equation.

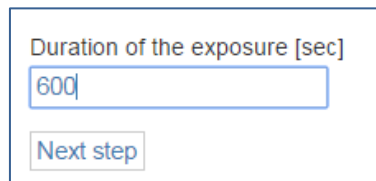


Figure 10. Request field for the probit equation.

4.1.5 Number of people affected

Finally, the number of fatalities can be calculated once the user inputs the population density where the accident occurs.

Probit equation: -26.438346145396

Number of people affected

$$p_{f,i} = 50 \left[1 + \frac{Y - 5}{|Y - 5|} \operatorname{erf} \left(\frac{|Y - 5|}{\sqrt{2}} \right) \right]$$

$$\operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

The number of people (N) affected:

$$N = A \cdot D \cdot p_{f,i}$$

where

- A : the fatal effect area of the outcome [m²]
- D : the population density [Pop./m²]
- p_{f,i} : the fatality level (%)

The population density [Pop./m²]

[Next step](#)

Figure 11. Number of people affected.

The population density [Pop./m²]

[Next step](#)

Figure 12. Input box for the calculation of people affected.

5 Conclusions

At the end of the above-mentioned calculation, the tool delivers two values: (1) number of fatalities and (2) the frequency of the event. With these two numbers we can evaluate the event against the risk matrix, where if the number of fatalities or the frequency is below a certain value the risk is acceptable.

As an example, in the calculation, we achieved a very high frequency but the event does not report any fatalities (see Figure 13), so the risk is of “Medium level”. In such a case the user is invited to review the tables of events and see which measures can be used to decrease the risk (mitigation measures). In this particular case, only the frequency can be decreased by possibly changing the material of the tube to avoid corrosion/rupture.



Figure 13. Results of the calculation and comparison with Risk Matrix.

It should be again stressed that **this online tool is only demonstrative** of the calculations, therefore, a user has to perform himself for the real risk calculations. The result is only representative of the selection we made of the frequencies and materials.