Hazard Analysis for Hydrogen Applications CHS Webinar Q&A

Key Words: Hazard Analysis, Risk, Ventilation, Leak, Fire, Explosion, Deflagration, Detonation, Ignition, Electrical Classification, Vent System, Fire Protection, Embrittlement

The information in this document provides answers to the questions that were raised during the Center for Hydrogen Safety June 21, 2021 webinar.

1. At what stage of my project should I be applying this hydrogen combustion risk analysis in order for it to be most effective?

A hydrogen combustion risk analysis needs adequate information such as a preliminary design, P&IDs and other information to be highly valuable. Therefore, implementing the HCRA during either conceptual or functional design stage is likely the most appropriate time during a project lifetime. It can then be revisited at later points in the process as the design changes or different needs arise.

2. What specific background should the analysis team have?

The team should have a variety of backgrounds such as design, pressure vessel, safety, operation, and maintenance, electrical, materials. The HCRA method can be used by design engineers exclusively, although technical diversity is an advantage to capture additional considerations and risks. Therefore, adding participants such as operators and maintenance staff is highly valuable. However, if the goal is to improve the design individually as a design engineer or as a small design engineering group, the HCRA can be used to inform design and prepare for a broader group assessment such as might be done curing a HAZOP.

3. What is the most advantageous/optimum ventilation method for existing plants? Natural ventilation or forced circulation?

The most advantageous/optimum ventilation method for existing plant is specific to the plant/system, with both natural and forced ventilation having disadvantages and advantages. A forced ventilation system often has the advantage of having a higher flow or air exchange rate and is independent of environmental conditions. However, the forced ventilation system is reliant on a power source and therefore the system is at risk if this source power is not 100% reliable. Alternatively, a natural ventilation system has the advantage of no moving parts, eliminates potential ignition sources, and isn't reliant on source power. Natural ventilation systems are generally lower flow rates that vary with environmental conditions and thermal elements in the system. The system that is the most advantageous will be that which meets the safety, cost, performance, and reliability requirements. From a safety perspective, both systems will benefit from complimentary engineering controls such as flow or differential pressure switches, leak detection, and/or flame detection.

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4. Are there some examples of risk analysis that can be shared as a reference?

Most risk analyses are completed for customers and contain proprietary information. However, WHA's hydrogen risk combustion analysis is just one method that can be used, and many other well-established methods can be valuable when assessing hydrogen systems depending on where you are at in the lifetime of the project. The presentation provides an overview of example methods such as What-if, HAZOPs, and FMEA as well as their advantages and disadvantages for hydrogen systems. Since the HCRA method was developed based on NASA's methodology, publicly available hydrogen hazards analysis conducted by NASA will be similar in their approach.

5. Are there special data bases/ collections about hydrogen specific applications for semi- or quantitative analysis-approaches you could share?

Due to the maturing hydrogen market, statistically significant data does not widely exist to drive semi- or quantitative analysis approaches. We recommend that you explore the documentation and data integrated into Sandia National Lab's HyRAM tool.

6. How are the risks of Hydrogen radicals captured as part of the combustion?

Hydrogen radicals enter into the analysis in two areas: First they are part of the detailed combustion chemistry and are therefore treated in the bulk combustion analysis, Second, they are an initiation step in the hydrogen embrittlement process and are therefore treated in the bulk hydrogen embrittlement and materials compatibility analysis.

7. What are the methods you recommend for the detection of hydrogen gas leaks and fires?

Hydrogen gas leaks and fires can be successfully detected a number of different ways and the best methods are dependent on system design including spatial arrangement. Hydrogen gas leaks can be detected through single and multi-point combustible gas and hydrogen specific sensors as well as acoustic sensors, chemo-chromic materials, and other methods being adapted for hydrogen. Fires can be detected through multi-spectrum IR detectors as well as thermal measurement techniques such as thermocouples in some applications. Indirect methods are often also valuable such as leak detection through mass/pressure loss, soap solution applied to fittings, and pressure hold checks. A combination of methods often provides the most robust solution.

8. Could you please provide a proofed source for electrostatic discharges being potential ignition sources?

I am not sure we understand the question adequately. The minimum ignition energy for hydrogen in air is only 0.02mJ, which is an order of magnitude smaller than that of the common hydrocarbon fuels. For this reason, numerous potential ignition mechanisms exist, including electrostatic ignition. Multiple sources exist that discuss hydrogen ignition sources including electrostatic ignition. One example is Chapter 3 of the Biennial Report on Hydrogen Safety provided by HySafe.

9. How can one keep the hazardous zone at **a leak point as small as possible?**

This statement was made in relation to the fact that with any leak of pure hydrogen will transition from 100% H2 at the source to 100% Air at the outer boundary. In between those two regions you will pass through the flammable region which is the combustible volume. Therefore, it is often valuable to keep the combustible volume as small as you can to reduce the overall hazard of the system. For example, the smaller the leak the smaller the combustible volume. At one extreme the leak rate is small enough that you never build a flammable concentration of hydrogen in an appreciable volume if the hydrogen diffuses and buoyantly flows away from the leak faster that the concentration can build to a flammable concentration. Note that ventilation has a direct effect on combustible volume size as well.

10. Is there the possibility to get access to a (kind of) demo version of WHA HCRA (free of charge)??

Unfortunately, the HCRA tool is only available to our customers – either through taking a training course or hazards analysis consulting. However, you can research the basis of the technique in NASA/TM-2003-212059.

11. What are the setback requirements for bulk compressed hydrogen storage versus specific equipment: such as any rotating equipment (compressors), vent stacks, etc.?

Setback distances are contained in code depending on the location of the system. For the United States, the relevant code is NFPA 2.

12. From the safety point of view, is there a preference on using multiple vent points, dedicated to specific areas in a production facility, over using one common venting system for the entire facility?

This is a design specific consideration, as some designs may benefit from multiple vent points while others may benefit from a common vent point. Combining vents from significantly different process pressures may create a hazard to the lower pressure vents in the system. In addition, process and safety vents should have different considerations and it may or may not be advisable to combine these into a common vent. Vent design is an often-overlooked element in hydrogen systems design and has led to multiple catastrophic failures. This is an area that should receive significant attention and the relevant codes and best practices studied to ensure a system is properly designed.

13. Can forced ventilation ever declassify an enclosed room with hydrogen users/equipment or will it always be at least a Class I, Div II, group B area?

Yes, this is the primary method used to declassify a space, and it is a critical strategy for applications where classification is impossible such as fuel cell and electrolyzer enclosures. Ensure that the system conforms to code, meets the ventilation requirements, and ventilation will be maintained in a safety event. In these circumstances, it is critical that the flow dynamics of the system also be evaluated so that you mitigate potential local areas where a flammable mixture could develop, even though bulk flow is theoretically sufficient.

14. Now that USA federal and state governments are working on hydrogen hubs, who in the hydrogen industry is looking at risk? Is it the scientific community, academia, industry, regulators?

All entities listed are evaluating risk and it is and is likely to continue to be an area of active research and development from both private and public funding. Establishing accurate quantitative risk analysis through H2-specific data is a prominent topic of interest ang growth. Risk evaluation is a broad topic, and as the hydrogen market grows, it is critical that this topic remain a priority and advance at or ahead of the pace of hydrogen technologies. It is our opinion that all hydrogen hubs should place emphasis on this topical area.

15. Since it is not possible to eliminate all sources of ignition, how do you assess or claim risk reduction for controls that eliminate some but not all potential ignition sources?

This is considered a statistical reduction in risk in this case and the adequacy of the reduction is dependent on the risk tolerance and judgement of those who are performing the evaluation. Because the data to drive accurate quantitative assessment does not exist yet, it will therefore be a qualitative or semi-quantitative evaluation. Depending on the severity of the consequence, the parties performing the evaluation may or may not deem the reduction sufficient. Ignition source mitigation for hydrogen systems should be secondary in consideration to leak prevention and combustible mixture avoidance strategies.

16. Do the lessons learned examples contain leak detectors? What are the detection limits of hydrogen gas leak detectors today? What is the accuracy? Reliability?

The detection limits and accuracy of hydrogen gas leak detectors vary by manufacturer, application, and detection method. Reliability of detectors are also dependent on application and detection method and can be impacted by process conditions such as installation environment and water condensation.

17. Besides adequate layout spacing, how much can be said about active fire protection for hydrogen applications in terms of effectiveness since hydrogen fire is gaseous and fire mitigation will be after the fact (after LOC)?

Fire response should be customized to the unique aspects of hydrogen combustion, and fire response personnel should be informed and trained to respond appropriately. Improperly managing a hydrogen fire event can exaggerate the situation, with examples being deflagration events when an active hydrogen fire is temporarily put out but the fuel source still exists, and water being applied to cryogenic systems. Isolation of the hydrogen source should be the first step in any hydrogen fire scenario.

18. What sort of design considerations should be made with regards to vehicle traffic flow in and out of fueling stations or loading terminals (e.g., Hydrogen delivery trucks OR consumer vehicles)?

Hydrogen systems should be designed to mitigate the associated risk of vehicle traffic and human interaction. This includes conforming to setback distances for hydrogen components, as well as integration of barriers such as safety bollards and dispenser breakaways. Conforming to requirements and evaluating site specific considerations should appropriately mitigate these risks.

19. How do we limit the leak to stop the spread of the gas if the leak is from a pipeline instead of a storage tank?

This could be mitigated a number of ways depending on the location of the pipeline and the associated risk of the leak. A simple example would be strategically located isolation valves in the pipeline that can be actuated upon the identification of a leak, mitigating the released volume. This is a broad topic and is dependent on pipeline capacity, location, operating conditions, and many other parameters.

20. Do you get into analysis of an electrical hazardous area classification?

Electrical area classification is often a straightforward evaluation based on the classification definitions in code.

21. Do all materials (metals) suffer from hydrogen embrittlement or are there specific metal alloys that do not suffer from embrittlement?

All metals have some propensity to be embrittled by hydrogen, whether to a negligible or severe extent. The extent to which hydrogen embrittlement has an effect on materials is a function of multiple variables, including the material susceptibility, pressure, temperature, hydrogen concentration, etc. Material susceptibility itself depends on the composition of the material, but also the way that it was manufactured, the form of the material, and much more. Therefore, material compatibility is not a yes/no answer for a given material, it depends on application.

22. What are the most critical factors in changing the character of combustion from deflagration to detonation?

There are many factors that influence whether an explosion will be a deflagration, detonation, or transition from deflagration to detonation (DDT). Hydrogen/oxidizer mixture concentrations, supplied ignition energy, and geometric confinement are the main factors. Turbulence will accelerate the flame increasing the likelihood of DDT.

23. Can you speak about the scope of systems that can be covered by the risk analysis process described here?

The HCRA process is focused on evaluation of risks of hydrogen specific systems, capturing the unique attributes and hazards of hydrogen. The HCRA method is applicable to any hydrogen system regardless of size and complexity. However, if hydrogen is only a component in a system such as a more complex renewable fuel synthesis process, then it is recommended that the HCRA be coupled with industry standard risk analysis processes, where the hydrogen subsystem is evaluated with the HCRA. Note that the HCRA is representative of a process and systematic way of evaluating hydrogen based systems, so the underlying approach can be adapted to other risk analysis methods.

24. If we assume risk as likelihood times consequence, how is risk quantified in the HCRA if the probability codes contribute to the likelihood and maybe not to the consequence?

Risk is not explicitly evaluated in the HCRA, however a standardized or company specific risk assessment matrix can be used with the information generated in the HCRA for a formal evaluation. The HCRA process focuses on the assessment of probabilities of scenarios/failures as well as the expected consequence of the associated event. Therefore, all of the information is there to perform an assessment of risk. However, because risk is an individual or company specific evaluation, it is up to the entity using the tool to determine the best way to correlate probability and consequence to acceptable/unacceptable risk.

25. How are you taking into account in your risk analyses the potential of immediate ignitions and jet flames?

Fires and jet flames are covered in equal proportion to delayed ignition and deflagrations as well as detonations in the HCRA method. Explosions and subsequent fire is also covered. These consequences vary by application and failure scenario, so all should be considered.

26. Are there design thresholds related to system capacity to be mindful of that could potentially put you in a more stringent risk category?

Absolutely. A primary means of risk management is to limit the capacity of the hazardous fluid such as hydrogen. These risk categories are often represented in codes such as NFPA 2, where design requirements are a function of hydrogen capacity for the system. However, each system should be evaluated, as overall system capacity is not necessarily representative of a potential leak/failure.

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27. How could this Risk Analysis be applicable for the mobility systems that use H2 as their source?

The HCRA method can evaluate simple or complex hydrogen systems as well as individual component level evaluations. The analysis is applicable to hydrogen-based mobility systems because they share common failure modes and mitigation strategies with all other hydrogen systems. The HCRA method guides the users in assessment of ruptures, leaks, materials compatibility, and many other considerations. The strategy is focused on failure avoidance and development of appropriate mitigation strategies that are applicable to mobility systems.

28. Is artificial or natural ventilation inside an enclosure a sort of mitigation for jet fire?

If designed properly, artificial or natural ventilation can be effective at avoiding a jet fire entirely, especially if used in conjunction with additional controls such as gas detection and fail-safe design. If a jet fire has already been started upon release, ventilation may or may not contribute to the mitigation of the fire itself – this is situation dependent.