LCRI LOW-CARBON RESOURCES INITIATIVE

EPRI

EXECUTIVE SUMMARY

Quantitative Risk Assessment for Hydrogen Energy Systems—Electrolyzers

Hydrogen technologies are a promising option for decarbonizing key economic sectors such as transportation, energy storage, and chemicals production [1]. Enabling the wider adoption of hydrogen technologies requires rigorous investigation and quantification of associated risks to develop measures to mitigate and prevent failures. Quantitative risk assessment (QRA) is a rigorous methodology used to estimate risks posed by industrial systems or processes to provide information for decision making about system design and operations [2]. Ultimately, QRA aims to determine if system risk is tolerable or if mitigation measures are required to reach a more broadly acceptable level of risk to workers and the public.

The objective of this work was to conduct QRA for a hydrogen electrolyzer and to identify gaps, QRA research needs, and opportunities for these systems. To achieve this objective, we defined a clear method for conducting QRA on electrolyzers (derived from QRA methodologies developed as part of previous work [2],[3]), and ensured the methodology includes all facets of a QRA:

1. Defining the scope of the analysis and gathering relevant information and data, documenting the system being analyzed
2. Identifying hazards and failure modes
3. Causal modeling of risk and root causes
4. Conducting frequency, probability, and consequence analysis

We then applied this method to a PEM electrolyzer. Following the QRA, we identified key gaps by considering both the scientific literature, the current state of the art, and our experience in attempting to complete all steps of a QRA method.

For the QRA study, we surveyed three types of electrolyzers: alkaline, proton exchange membrane (PEM), and solid oxide. For each system, we evaluated the state of the data and tools available to conduct a QRA study. A summary of those findings is presented in Section 1.2.3 Safety and Reliability. Based on this, we decided to conduct a QRA on a small PEM electrolyzer design due to the availability of detailed design information and the anticipated prevalence of PEM electrolyzers within the near-term planned deployments in the U.S. [4].

First, we conducted a failure modes and effects analysis (FMEA) on the selected electrolyzer design to identify potential failure scenarios and their consequences. We identified a total of 133 failure scenarios resulting in three major consequences: hydrogen release, oxygen release, and hydrogen and oxygen mixing. Jet fires or explosions can result if the released hydrogen or collected hydrogen and oxygen gas is ignited. These situations pose significant risk to personnel surrounding the electrolyzer and need to be mitigated. Through analysis of the failure modes and scenarios, we determined that the primary components of concern are the electrolysis stack, the pump supplying water to it, and the non-return valves and backpressure regulators throughout the system. Based on these findings, we propose the following mitigation and prevention measures:

1. Mechanical integrity checks and leak detection of the water pump, process valves and backpressure regulators.
2. Mechanical integrity checks on electrolysis stack membrane.
3. Prevention of flow blockages in valves, backpressure regulators, and piping segments through maintenance and process monitoring activities.

We next developed failure logic models of these scenarios via fault trees (FTs), with the top events being hydrogen release, oxygen release, and hydrogen-oxygen mixing. These FTs were parametrized using reliability data sources: Non-electronic Parts Reliability Database (NPRD) [5], HyRAM+ version 5.0 [6], the Reliability Data for Safety Equipment (PDS) handbook [7], the Offshore and Onshore Reliability Data Handbook (OREDA) [8], and the CCPS Guidelines for Process Equipment Reliability Data [9]. The parametrization exercise allowed us to identify several gaps in the reliability data available, primarily around the electrolyzer stack and failure modes pertaining to flow blockages in valves.

As a next step, we evaluated consequences, focusing primarily on the consequences from hydrogen releases. Thus, we calculated the probability of a hydrogen release from the electrolyzer system and simulated the resulting jet fires and explosions. We found that jet fires (thermal harm) were more likely to occur, but that the main consequence of concern was explosions (overpressure harm) due to the higher potential consequences to the site personnel.

Next, we used component importance measures analysis to identify failure modes and events critical to the electrolyzer’s safety and reliability. The results highlighted the importance of leak detection and mitigation for hydrogen-water separators as well as inspection and maintenance of process valves to prevent flow blockages.

This work shows that QRA can be used to gain insights on electrolyzer failure scenarios, their probabilities, and resulting consequences. However, we also highlight the need to scale up this analysis to larger systems that are more representative of those currently being designed and deployed in the U.S. and around the world. Also, we identified several gaps in the available data for system components and their failure modes. There is a need to collect reliability data that can be used to enhance the quality of the QRA studies and inform future design and deployments.

This report is one of three companion reports. The other two reports cover liquid hydrogen fueling stations [10] and hydrogen transmission pipelines [11].

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THE LOW-CARBON RESOURCES INITIATIVE

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LCRI CONTACT

Alex Gupta
Low-Carbon Fuel Safety Specialist
505.709.5787
algupta@epri.com

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University of Maryland (UMD)
Center for Risk and Reliability
0151 Martin Hall
College Park, MD 20742

Principal Investigator
K. Groth

Contributors
A. Al-Douri
V. Grabovetska
A. Jimenez
S. Mosleh
C. Schaad
S. Wismer

EPRI contributed to the preparation of this report:

Principal Investigator
A. Gupta

Contributors
A. Rohr

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For more information, contact:

EPRI Customer Assistance Center
800.313.3774 • askepri@epri.com

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EPRI
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