LCRI LOW-CARBON RESOURCES INITIATIVE EPRI GTI ENERGY

EXECUTIVE SUMMARY

SAFETY CONSIDERATIONS IN ELECTROLYZER OPERATION FOR HYDROGEN PRODUCTION

The global focus on sustainability necessitates advancements in technology and investments in energy infrastructure to decarbonize the economy. Challenges associated with renewable energy technologies, such as temporal inflexibility and non-portability, create a need for alternative energy carriers (AECs) to transfer energy from generation to the point of use. Hydrogen is a promising AEC, particularly for some "hard-to-decarbonize" applications like transportation and off-grid power generation. However, most hydrogen is currently derived from fossil fuels. Electrolysis, employing an electric current to split water into hydrogen and oxygen, is a potential emission-free alternative when powered by renewable energy sources. This report aims to provide a comprehensive overview of the safety considerations associated with electrolysis.

During normal electrolyzer operations, some product gas inevitably crosses through the electrolytic cell separator, even though the separator is designed to prevent this. Under certain conditions, gas crossover can result in the undesired internal accumulation of gases beyond the lower flammability limit, which can lead to explosion, property damage, and/or loss of life. Accumulation of hydrogen on the oxygen side of the cell (anodic hydrogen) is particularly problematic. The anodic concentration of hydrogen can reach dangerous levels at low current densities (that is, low power/reaction rate), at which the product oxygen flux is insufficient to dilute hydrogen that has crossed the separator. The operating temperature, cathode pressure, and cell design can also affect internal gas mixing. Strategies to mitigate this risk include establishing turndown limits for electrolyzer power, monitoring operating parameters, and implementing various control strategies.

Internal flammable gas mixtures may also form due to device failure. Various factors such as internal impurities, catalyst deactivation, and component degradation can compromise the cell separator and lead to product gas intermixing. It is incumbent upon the manufacturer to thoroughly anticipate possible degradation modes, stress test their products to validate these assumptions, and provide thorough guidance pertaining to operating parameters and device lifetime. On the other hand, electrolyzer users need to understand their devices on a mechanistic level, monitor operational data for early signs of problems, and be prepared to safely stop work and/or intervene quickly when problems arise.

The following additional hazards are associated with electrolyzers:

- Industrial-scale electrolyzers require a large electrical current, and precautions should be taken to prevent electrical accidents. Residual hydrogen and oxygen in the system can create an electric potential even when the device is de-energized, posing a risk to personnel during service and maintenance.
- High operating temperatures and moving parts present thermal and mechanical hazards, respectively, which need to be addressed.
- Pressurized gasses within an electrolyzer system present risks. Separator perforation, mechanical failure of pressurized equipment, and loss of gas containment are potential dangers that can be controlled through appropriate design, installation, and operation of equipment. System pressure should be included in monitored parameters, and pressure relief devices should be implemented.
- Exposure to the electrolyte within an alkaline electrolyzer can cause symptoms including chemical burns, eye damage, and/or respiratory irritation. Adherence to safety-focused procedures and the use of personal protective equipment (PPE) are essential to prevent exposure.

- Hydrogen leaks are hazardous due to the high flammability of hydrogen. On the other hand, oxygen leaks may increase the flammability of nearby combustibles. Vented hydrogen should be adequately diluted. Components containing pressurized hydrogen or oxygen should be comprised of appropriate materials, configured safely, and regularly inspected and maintained. Hydrogen detectors should be used to indicate leaks, and their placement should account for factors such as airflow, concentration levels, and obstructions.
- Freezing of water within the electrolyzer can obstruct mass transport, cause mechanical stresses, and slow the reaction. Electrolyzers should be operated within the specified ambient temperature range, and climate control or direct heating solutions should be considered depending on local conditions.

Real-world electrolyzer installations provide examples of how to safely integrate electrolyzers into a variety of facilities and settings:

- A hydrogen-based energy storage system called the *Greenergy Box* was planned for installation in a public building in France.[1] The project managers successfully addressed public opinion and regulatory challenges to bring this effort to fruition.
- A demonstration plant in Latin America utilizes electrolysis to produce hydrogen from wind turbine energy.[2] Safety measures include atmospheric monitoring, alarms, restricted access zones, compliance with industry standards, and proper documentation.
- A hydrogen energy system was implemented in Japan to explore building decarbonization.[3] Safety measures include temperature regulation, stainless steel pipelines, safe venting of hydrogen, and an emergency management system.
- A pilot photovoltaic (PV)-alkaline electrolyzer-fuel cell installation provides heating for an experimental greenhouse in Italy.[4] Safety considerations include process design to prevent gas intermixing, secondary containment, sensors, electrical grounding, pressure relief devices, and a robust emergency stop system.

Several incidents involving electrolysis have been reported. Common features of these incidents include material degradation, gas leaks, and separator failure caused by negligence, material incompatibility, and/or improper system configuration. From these incidents, several best practices can be inferred, including:

- Select electrolyzer systems based upon suitability for the intended end-use environment.
- Test prospective solutions in controlled settings when encountering safety questions.
- Follow thoroughly reviewed standard procedures for operations and maintenance.
- Continuously monitor process lines with interlocked gas sensors, and periodically sample and test product gases.
- Conduct regular inspections and maintenance, and continuously monitor operational data for abnormalities.
- Wear appropriate PPE when working with electrolyzers.
- Promptly address recurring electrolyzer issues or "quirks."

[1] F. Verbecke, B. Vesy, "Safety strategy for the first deployment of a hydrogen-based green public building in France," *International Journal of Hydrogen Energy*. Vol. 38, No. 19, pp. 8053–8060 (2013). https://doi.org/10.1016/j.ijhydene.2013.03.019.

[2] J.L. Aprea, "Hydrogen energy demonstration plant in Patagonia: Description and safety issues," *International Journal of Hydrogen Energy*. Vol. 34, No. 10, pp. 4684–4691 (2009). https://doi.org/10.1016/j.ijhydene.2008.08.044.

[3] N. Endo, E. Shimoda, K. Goshome, T. Yamane, T. Nozu, T. Maeda, "Construction and operation of hydrogen energy utilization system for a zero emission building," *International Journal of Hydrogen Energy*. Vol. 44, No. 29, pp. 14596–14604 (2019). https://doi.org/10.1016/j.ijhydene.2019.04.107.

[4] S. Pascuzzi, I. Blanco, A.S. Anifantis, G. Scarascia-Mugnozza, "Hazards assessment and technical actions due to the production of pressured hydrogen within a pilot photovoltaic-electrolyser-fuel cell power system for agricultural," *Journal of Agricultural Engineering*. Vol. 47, No. 2, pp. 88–93 (2016). https://doi.org/10.4081/jae.2016.507.

- Maintain a strong safety culture, and encourage questioning attitudes among personnel.
- Document and gain approval for modifications or deviations from specifications.
- Employ multiple redundant safety controls and independent verification.

The following codes and standards are specific to electrolytic hydrogen production:

- Underwriters Laboratories (UL) 2264A, *Outline of Investigation for Water Electrolysis Type Hydrogen Generators*[5] outlines requirements for various electrolyzer technologies and maps various component requirements to other applicable standards such as National Fire Protection Association (NFPA) 70[6] and NFPA 2.[7]
- International Organization for Standardization (ISO) 22734, *Hydrogen Generators Using Water Electrolysis – Industrial, Commercial, and Residential Applications*[8] establishes construction, safety, and performance requirements for electrolyzers.
- NFPA 2, *Hydrogen Technologies Code*[7] includes requirements for hydrogen generation systems. Chapter 13 specifically addresses electrolyzers.

When planning an electrolysis project, consult UL 2264A to identify relevant codes and standards. ISO 22734 guides manufacturers in product design, quality control, and documentation, while UL 2264A adds requirements in areas like mechanical and electrical aspects. NFPA 2 is primarily for end users, providing guidelines for safe integration of electrolyzers into facilities and processes. Facility and process engineers should refer to NFPA 2 for installation and consider all three standards when developing procedures.

Existing educational resources cover electrolysis safety, system operation, and compliance with codes and standards. The Center for Hydrogen Safety offers a webinar on electrolysis safety,[9] while EPRI's H_2EDGE curriculum focuses on hydrogen workforce development in key technical areas.[10] World Hydrogen Leaders provides a course on electrolysis technologies,[11] and Hydrogen Tools offers a best practices manual.[12] The Hydrogen Safety Panel has published guides to safety planning[13] and equipment certification,[14] while WHA International offers a course on flammable gas safety geared towards electrolyzers.[15] The Center for Hydrogen Safety provides a fundamental hydrogen safety certification program.[16]

[5] *Outline of Investigation for Water Electrolysis Type Hydrogen Generators,* Underwriters Laboratories UL 2264A, 2017. https://www.shopulstandards.com/ProductDetail.aspx?UniqueKey=40988.

[6] National Electrical Code®, National Fire Protection Association NFPA 70®, 2023. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70.

[7] *Hydrogen Technologies Code,* National Fire Protection Association NFPA 2,2023. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=2.

[8] *CSA/ANSI B22734:23 Hydrogen generators using water electrolysis - Industrial, commercial, and residential applications,* CSA Group (ISO 22734:2019, MOD), 2019. https://www.csagroup.org/store/product/2705341/.

[9] L. Moulthrop, "Safety of Water Electrolysis," Center for Hydrogen Safety webinar, 2021. https://www.aiche.org/ili/academy/webinars/safety-water-electrolysis.

[10] EPRI, "H_2EDGE: Hydrogen Education for a Decarbonized Global Economy," EPRI.com. https://grided.epri.com/H2EDGE.html.

[11] World Hydrogen Leaders, website home page, WorldHydrogenLeaders.com. https://www.worldhydrogenleaders.com/.

[12] Department of Energy, Pacific Northwest National Laboratory, "HydrogenTools: Best Practices Overview," H2Tools.org. https://h2tools.org/bestpractices/best-practices-overview.

[13] Department of Energy, Pacific Northwest National Laboratory, "Safety Planning for Hydrogen and Fuel Cell Projects," Hydrogen Safety Panel, 2017. https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-November2017_0.pdf.

[14] *Hydrogen Equipment Certification Guide,* Hydrogen Safety Panel, 2017. https://h2tools.org/sites/default/files/Hydrogen%20Equipment%20Certification%20Guide_Jan2017.pdf.

[15] WHA International, Inc., "Training: H2/O2 Safety for Electrolysis Systems," WHA-International.com. https://wha-international.com/course/hydrogen-and-oxygen-safety-for-electrolyzers/.

[16] AIChE Institute for Learning & Innovation, "Explore Academy: Fundamental Hydrogen Safety Credential," AIChE.org. https://www.aiche.org/ili/academy/courses/elp200/fundamental-hydrogen-safety-credential.

The safety challenges associated with electrolyzers need to be fully understood and addressed through regulatory frameworks, risk analyses, and scientific knowledge applied to commercial systems. Incidents involving water electrolysis have highlighted the potential for catastrophic failures, emphasizing the importance of training programs and control measures. Improved reporting and cataloging of operational experiences are necessary to enhance industry expertise. While there are specific codes and standards for electrolysis systems, further guidance is needed to ensure consistent application of general industry codes and standards. The scientific understanding of electrolysis technologies is more advanced for some systems than others. The development of quantitative models to predict risk levels would be valuable.

The full report is available here.

The Low-Carbon Resources Initiative

This report was published under the Low-Carbon Resources Initiative (LCRI), a joint effort of the EPRI and GTI Energy addressing the need to accelerate development and deployment of low- and zero-carbon energy technologies. The LCRI is targeting advances in the production, distribution, and application of low-carbon energy carriers and the cross-cutting technologies that enable their integration at scale. These energy carriers, which include hydrogen, ammonia, synthetic fuels, and biofuels, are needed to enable affordable pathways to economy-wide decarbonization by mid-century. For more information, visit www.LowCarbonLCRI.com.

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