

УДК:661.96

SAFETY ISSUES AND RISK MANAGEMENT IN HYDROGEN ENERGY SYSTEMS

ВОПРОСЫ БЕЗОПАСНОСТИ И УПРАВЛЕНИЕ РИСКАМИ В ВОДОРОДНЫХ ЭНЕРГЕТИЧЕСКИХ СИСТЕМАХ

VODOROD ENERGETIKASI TIZIMLARIDA XAVFSIZLIK MASALALARI VA RISKLARNI BOSHQARISH

Omonov Baxtiyor Muxidin o‘g‘li

Email: Bakhtiyor.omonov@gmail.com

<https://orcid.org/0009-0005-2251-4242>

*Institute of Materials Science, Academy of Sciences of the Republic of Uzbekistan,
Tashkent, 100095 Uzbekistan*

*Turin Polytechnic University in Tashkent, Little Ring Road 17, Almazar district,
100095, Tashkent city, Uzbekistan*

Keywords:

Hydrogen energy systems

- *Safety management*
- *Risk management*
- *Hydrogen hazards*
- *Explosion and fire risk*
- *Hydrogen storage and transportation*
- *Accident prevention*
- *Safety protocols*
- *Hydrogen leak detection*
- *Digital twin technology*
- *Human factors analysis*
- *Industrial safety training*
- *Sustainable energy transition*
- *Hydrogen infrastructure*
- *Operational risk assessment*

Ключевые слова:

Водородные энергетические системы

- *Управление безопасностью*
- *Управление рисками*
- *Опасности водорода*
- *Риск взрыва и пожара*
- *Хранение и транспортировка водорода*

- *Предотвращение аварий*
- *Протоколы безопасности*
- *Обнаружение утечек водорода*
- *Технология цифрового двойника*
- *Анализ человеческого фактора*
- *Промышленная безопасность*
- *Переход к устойчивой энергетике*
- *Водородная инфраструктура*
- *Оценка операционных рисков*

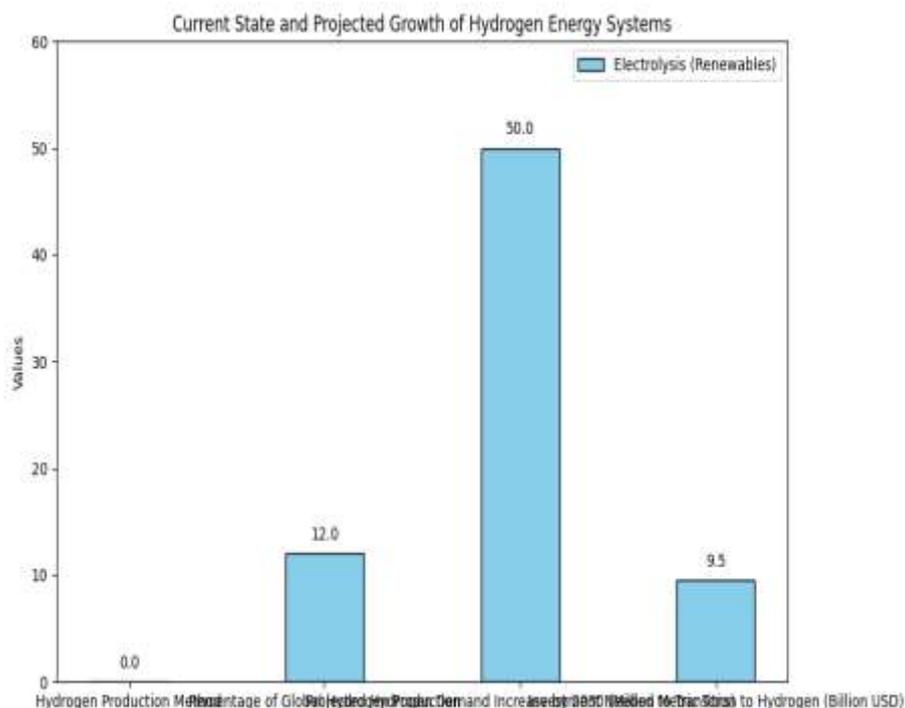
Kalit so‘zlar:

- *Vodorod energetika tizimlari*
- *Xavfsizlik boshqaruvi*
- *Risklarni boshqarish*
- *Vodorod xavflari*
- *Portlash va yong‘in xavfi*
- *Vodorodni saqlash va tashish*
- *Favqulodda holatlarning oldini olish*
- *Xavfsizlik protokollari*
- *Vodorod sizib chiqishini aniqlash*
- *Raqamli egizak texnologiyasi*
- *Inson omili tahlili*
- *Sanoat xavfsizligi*
- *Barqaror energiyaga o‘tish*
- *Vodorod infratuzilmasi*
- *Operatsion risklarni baholash*

As the quest for clean energy intensifies, hydrogen energy systems have emerged as a promising avenue for achieving sustainable energy goals. However, the adoption of hydrogen technology is accompanied by significant safety issues that warrant meticulous risk management. Hydrogen, being highly flammable and exhibiting unique properties, raises concerns regarding storage, transportation, and utilization, necessitating rigorous safety protocols to mitigate potential hazards. The integration of robust safety measures is crucial for fostering public confidence and encouraging wider acceptance of hydrogen as a viable energy source. Furthermore, the complexity of hydrogen systems requires a multi-faceted approach to risk management, addressing not only technological challenges but also human factors and operational processes. Visualization tools, such as that represented in, can play an essential role in enhancing safety awareness, providing frameworks for training and implementation of safety protocols. Thus, an informed and comprehensive approach to risk management in hydrogen energy systems is imperative for ensuring a safe transition to this innovative energy source.

Overview of hydrogen energy systems and their growing importance

The evolution of hydrogen energy systems represents a critical shift toward sustainable energy solutions, highlighting their growing importance in a world striving for lower carbon emissions. As nations increasingly seek alternatives to fossil fuels, hydrogen emerges as a key player in various applications, notably in transportation and industrial sectors, potentially decarbonizing processes pivotal to economic growth. Recent advancements in hydrogen production methods, such as electrolysis from renewable sources, underscore its potential to integrate into modern energy grids, thereby enhancing grid stability and energy security (Akpasi SO et al., 2025). However, alongside its promise, the development of hydrogen systems raises substantial safety concerns that necessitate diligent risk management strategies. Effective oversight and innovative technological frameworks are required to address the inherent risks associated with hydrogen utilization, thus ensuring its safe adoption in the global energy landscape (Bibri SE et al., 2024).



The chart illustrates the current state and projected growth of hydrogen energy systems. It highlights the significant role of electrolysis from renewable sources in global hydrogen production, with a notable demand increase anticipated by 2030. Additionally, it underlines the necessary investment required to transition to hydrogen energy.

Safety issues in hydrogen energy systems

The implementation of hydrogen energy systems presents notable safety challenges that must be addressed to ensure their successful integration into the energy landscape. Incidents in hydrogen use, highlighted by data from the Hydrogen Incident and Accident Database (HIAD), reveal that human factors and management failures are predominant causes of accidents, often overshadowing technical issues (A Khanal et al., 2024). This underscores the necessity for robust safety protocols that incorporate comprehensive risk assessments and proactive management strategies. Furthermore, evolving energy storage

solutions, as discussed in recent literature, are pivotal in mitigating the risks associated with hydrogens volatility and aiding in grid stability during fluctuations of renewable energy supply (George G Njema et al., 2024) . By embracing such strategies and fostering a culture of safety awareness, stakeholders can enhance the reliability and acceptance of hydrogen technologies, ultimately promoting a more sustainable energy future. The illustration of safety practices in industrial environments can be seen in , emphasizing the importance of structured safety training.

Common hazards and potential accidents

In exploring the safety issues associated with hydrogen energy systems, it is crucial to identify common hazards and potential accidents that may arise during operation. Hydrogen, while a promising fuel source, is highly flammable and can form explosive mixtures with air, which underscores the need for stringent safety protocols. Accidents can occur due to leaks, improper handling, or equipment failure, leading to catastrophic consequences such as explosions or fires. The need for effective risk management strategies is highlighted in various contexts, including the design of safety systems and the implementation of training programs for personnel. As illustrated in the educational visualization of warehouse safety topics, comprehensive safety training can significantly mitigate risks associated with hazardous environments . Furthermore, specialized monitoring technologies enhance the ability to detect and address potential hazards proactively (Mostafa M El-Sheekh et al., 2025) (Menye JS et al., 2025) .

Risk management strategies

In the dynamic field of hydrogen energy systems, implementing effective risk management strategies is paramount to ensuring safety and mitigating hazardous incidents. Comprehensive safety protocols, including rigorous risk assessment models, can identify potential hazards associated with hydrogen utilization, thereby guiding the development of preventive measures. For instance, employing methodologies such as the Human Error Assessment and Reduction Technique (HEART) and the Human Factor Analysis and Classification System (HFACS) can significantly contribute to addressing human-induced risk factors that are often overlooked. Furthermore, understanding the intricacies of energy storage systems, especially their capabilities to manage intermittency in renewable sources, presents an opportunity for enhanced safety through advanced monitoring and control technologies (A Khanal et al., 2024) (George G Njema et al., 2024) . The visual representation of warehouse safety practices provides a pertinent analogy, illustrating the critical need for structured safety management in environments where hydrogen systems operate, reinforcing the commitment to accident prevention.

Techniques and technologies to mitigate safety risks

In addressing safety risks inherent in hydrogen energy systems, robust techniques and technologies are essential for effective risk management. Innovations such as advanced monitoring sensors, which capture real-time data on system conditions, are becoming

increasingly prevalent. These sensors enhance predictive maintenance, allowing for timely interventions that can prevent accidents before they occur (George G Njema et al., 2024) . Additionally, the integration of digital twin technology enables the simulation of various operational scenarios, facilitating the optimization of safety protocols and system designs. Collaborative models that combine these technologies with human oversight can further mitigate risks, ensuring that safety is prioritized throughout operations. These advancements underscore the importance of a multifaceted approach in improving the safety landscape of hydrogen energy systems, as captured in educational materials highlighting warehouse safety practices .

Conclusion

In conclusion, addressing safety issues and risk management in hydrogen energy systems is paramount for the successful integration of this promising energy source into our existing infrastructure. As highlighted in recent studies, including advancements in hydrogen production technologies and the importance of robust safety protocols, it is evident that an interdisciplinary approach is necessary to mitigate potential hazards and enhance public acceptance of hydrogen as a viable energy alternative (Akpasi SO et al., 2025) . Furthermore, the integration of emerging technologies such as artificial intelligence can improve data-driven planning and operational safety, solidifying hydrogens role in sustainable energy systems within smart urban environments (Bibri SE et al., 2024) . The necessity for comprehensive policies, rigorous training, and continuous improvement in safety practices cannot be overstated, ultimately ensuring that hydrogen energy systems contribute positively to environmental sustainability while minimizing risks associated with their deployment. Additionally, the visual representation of essential warehouse safety topics further underscores the importance of fostering a culture of safety across all operational dimensions.



Image1: Key Warehouse Safety Topics for Accident Prevention

Summary of key points and future directions in safety and risk management

In summarizing the key points and future directions in safety and risk management within hydrogen energy systems, it is essential to highlight the ongoing technological advancements alongside emerging regulatory frameworks. As the sector evolves, comprehensive risk assessments become paramount, particularly in areas such as production, storage, and transportation of hydrogen. Significant advancements in production technologies, as noted in recent reviews (Akpasi SO et al., 2025), underline the necessity of sustainable practices to minimize environmental impacts. Moreover, understanding the organizational and policy dimensions of hydrogen adoption can mitigate operational risks, as explored in various studies of electric vehicles (Zaino R et al., 2024). To visualize these safety practices further, the warehouse safety topics, such as those depicted in , emphasize the importance of operational protocols that ensure a secure working environment. By integrating these aspects, future research can better address the complex challenges of hydrogen energy systems.

REFERENCES:

- Bhutada Sarita, Dahikar Samadhan, Md Zakir Hassan, Elena G. Kovaleva (2025). A comprehensive review of probiotics and human health-current prospective and applications. Volume(15), 1487641-1487641. Frontiers in Microbiology. <https://doi.org/10.3389/fmicb.2024.1487641>
- George G. Njema, Russel Ben O. Ouma, Joshua K. Kibet (2024). A Review on the Recent Advances in Battery Development and Energy Storage Technologies. Volume(2024), 1-35. Journal of Renewable Energy. <https://doi.org/10.1155/2024/2329261>
- Stephen Okiemute Akpasi, Ifeanyi Michael Smarte Anekwe, Emmanuel Kweinor Tetteh, Ubani Oluwaseun Amune, Sherif Ishola Mustapha, Sammy Lewis Kiambi (2025). Hydrogen as a clean energy carrier: advancements, challenges, and its role in a sustainable energy future. Volume(9), 52-88. Clean Energy. <https://doi.org/10.1093/ce/zkae112>
- Simon Elias Bibri, Jeffrey Huang, Senthil Kumar Jagatheesaperumal, John Krogstie (2024). The synergistic interplay of artificial intelligence and digital twin in environmentally planning sustainable smart cities: A comprehensive systematic review. Volume(20), 100433-100433. Environmental Science and Ecotechnology. <https://doi.org/10.1016/j.ese.2024.100433>
- A. Khanal, Neil K. Chaudhary, Bishwajeet Pandey, Biraj Singh Thapa (2024). Review of Hydrogen-Related Accidents: Root Causes, Mitigation Strategies, and Recommendations for secure utilization.. Volume(1385), 012022-012022. IOP Conference Series Earth and Environmental Science. <https://doi.org/10.1088/1755-1315/1385/1/012022>
- Rami Zaino, Vian Ahmed, Ahmed Mohamed Alhammadi, Mohamad Alghoush (2024). Electric Vehicle Adoption: A Comprehensive Systematic Review of Technological, Environmental, Organizational and Policy Impacts. Volume(15), 375-375. World Electric Vehicle Journal. <https://doi.org/10.3390/wevj15080375>

25-Yanvar, 2026-yil

- Mostafa M. El-Sheekh, Hala Y. El-Kassas, Sameh S. Ali (2025). Microalgae-based bioremediation of refractory pollutants: an approach towards environmental sustainability. Volume(24), 19-19. Microbial Cell Factories. <https://doi.org/10.1186/s12934-024-02638-0>
- Joselyn Stephane Menye, Mamadou Baïlo Camara, Brayima Dakyo (2025). Lithium Battery Degradation and Failure Mechanisms: A State-of-the-Art Review. Volume(18), 342-342. Energies. <https://doi.org/10.3390/en18020342>

IMAGE REFERENCES:

- Key Warehouse Safety Topics for Accident Prevention [Image]. (2026). Retrieved from <https://dropinblog.net/34249688/files/featured/10-warehouse-safety-topics-to-prevent-accidents1.png>