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Hydrogen in Electricity's Future: Enabling Scalable, Flexible, and Low-Carbon Energy Systems

By
Ahmed F. Zobaa
Brunel University of London. United Kingdom

Abstract
The global energy landscape is undergoing a profound transformation driven by the urgent need to decarbonize while maintaining reliability, affordability, and resilience. Although renewable electricity generation continues to expand rapidly, significant challenges remain in addressing variability, long-duration storage, and the decarbonization of hard-to-abate sectors. Hydrogen is emerging as a critical enabler in this transition, offering a flexible energy vector that can bridge gaps across power systems, industry, transport, and heating.

This plenary talk presents a comprehensive and forward-looking perspective on the role of hydrogen in electricity's future. It examines the current state of hydrogen production, where the majority is still derived from fossil fuels, and evaluates the pathways toward scaling low-carbon hydrogen through electrolysis and carbon-managed processes. The discussion highlights the technical, economic, and environmental trade-offs associated with green and blue hydrogen, including their dependencies on renewable energy expansion, carbon capture technologies, and global supply chains.

The talk further explores hydrogen's potential to transform electricity systems through long-duration energy storage, dispatchable low-carbon generation, and enhanced system flexibility. It addresses how hydrogen can enable sector coupling, linking electricity with industrial processes, transportation networks, and building energy systems. Real-world developments and emerging applications are used to illustrate how hydrogen is transitioning from concept to deployment.

At the same time, the plenary provides a critical assessment of the challenges that must be addressed to unlock hydrogen's full potential. These include efficiency losses across the hydrogen value chain, infrastructure requirements for storage and transport, safety considerations, regulatory frameworks, and competition with alternative decarbonization pathways such as direct electrification and battery storage.

The talk concludes by outlining strategic priorities for research, policy, and investment, emphasizing the importance of international collaboration and integrated energy system planning. It provides a balanced and evidence-based perspective that moves beyond expectations toward actionable pathways for implementing hydrogen at scale.

Key Contributions of the Plenary

- Provides a holistic, systems-level perspective on hydrogen in future electricity networks
- Bridges technical innovation with policy and infrastructure considerations
- Identifies realistic pathways for scaling low-carbon hydrogen
- Offers critical insight into risks, trade-offs, and competing technologies
- Connects global trends with practical implementation strategies

Main Topics Covered

- The evolving role of hydrogen in the global energy transition
- Hydrogen production pathways: green, blue, and emerging alternatives
- Infrastructure challenges: storage, transmission, and distribution
- Hydrogen for long-duration energy storage and grid flexibility
- Sector coupling: integration with industry, transport, and buildings
- Economic, environmental, and geopolitical implications
- Key barriers, risks, and research opportunities

Relevance to the Conference

This plenary aligns strongly with conference themes related to sustainable energy, decarbonization, smart grids, and emerging energy technologies. It offers both depth and breadth, making it suitable for a diverse audience and setting the stage for subsequent technical sessions and discussions.

*Short biography of **Dr. Ahmed F. Zobaa***

Dr. Ahmed F. Zobaa is a Reader in Electrical and Power Engineering at Brunel University London and a member of the Brunel Interdisciplinary Power Systems Research Centre. He is a Senior Member of IEEE and an internationally recognized authority in power systems, renewable energy, and smart grid technologies.

He received his B.Sc. (Hons.), M.Sc., and Ph.D. degrees in Electrical Power and Machines from Cairo University, Egypt, and was awarded the Doctor of Science degree from Brunel University London in 2017. He also holds a Postgraduate Certificate in Academic Practice from the University of Exeter.

Over the course of his career, Dr. Zobaa has held academic positions at Cairo University, the University of Exeter, and Brunel University London, where he has made significant contributions to research, education, and academic leadership. His work focuses on power quality, marine and renewable energy systems, smart grids, energy efficiency, and sustainable energy applications.

Dr. Zobaa is a Chartered Engineer, Chartered Energy Engineer, European Engineer, and International Professional Engineer. He is a Fellow of the African Academy of Sciences (FAAS) and serves as Chair of the Scientific Advisory Committee of the African Research Initiative for Scientific Excellence (ARISE), playing a key role in advancing research capacity and scientific leadership across Africa.

He is also a Principal Fellow of the Higher Education Academy in the United Kingdom and a Fellow of several prestigious professional institutions, including the Institution of Engineering and Technology, the Energy Institute, the Chartered Institution of Building Services Engineers, the Institution of Mechanical Engineers, and the Royal Society of Arts.

In addition to his academic achievements, Dr. Zobaa is widely recognized for his leadership in scholarly publishing. He serves as the Managing Editor of the *Journal of Engineering and Applied Science* and contributes to numerous international journals as an editor, associate editor, and editorial board member.