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Hydrogen systems for a circular and low-carbon economy

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Hydrogen continues to emerge as a cornerstone of the global energy transition, offering pathways to decarbonize hard-to-abate sectors and enable circular resource use. It is our pleasure to introduce this themed collection of hydrogen research, inspired by the vibrant discussions and groundbreaking contributions presented at the 2024 Munich Hydrogen Symposium (MH2S) and beyond. Held in Garching (Munich), the MH2S brought together leading researchers, industry experts, and stakeholders to explore the future of hydrogen technologies. This collection builds on the momentum of two visionary initiatives – the International Future Lab REDEFINE H2E and the H2 Living Lab Burghausen – and reflects the symposium's commitment to fostering collaboration and innovation in the hydrogen context.

This themed collection brings together cutting-edge research that spans the hydrogen value chain, from feedstock innovation and process intensification to environmental assessment and end-use applications. The selected studies reflect the diversity and vitality of hydrogen science, with a particular emphasis on two particularly pressing issues: sustainable feedstock utilization as well as electrified and enhanced conversion processes.

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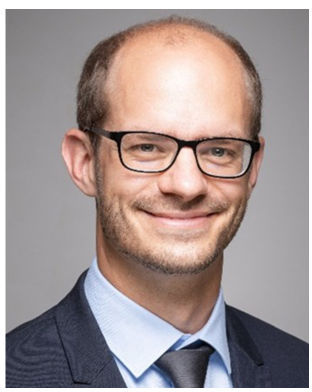
Kentaro Umeki

Kentaro Umeki has been a full professor in Energy Engineering at Luleå University of Technology (LTU) since 2019 and was a guest professor at the Chair of Energy Systems at the Technical University of Munich (TUM) during 2023 and 2024. Umeki studied Mechanical Engineering (BEng) and Environmental Science and Technology (MEng and PhD) at the Tokyo Institute of Technology. His research group is developing gasification-based biofuel production technologies, pyrolysis technologies for high-quality biocarbon and liquid production, and electrification of high-temperature process heating. Umeki has co-authored around 80 scientific articles in renowned international journals.



Sebastian Fendt

Sebastian Fendt studied Chemical Engineering at the Technical University of Munich (TUM) and the University of California, Berkeley. After finishing his studies, he did his PhD at the Chair of Energy Systems at TUM. Since 2015, he has headed a research group working on carbon-conversion technologies, focusing on efficient conversion of biogenic and waste-derived carbon feedstock into sustainable chemicals and fuels, as well as the electrification of high-temperature processes within the Chair of Energy Systems at TUM. Furthermore, he is the coordinator of the interdisciplinary network TUM.Hydrogen and PtX. Sebastian Fendt has authored and co-authored around 90 publications in various renowned scientific journals.

Sustainable feedstock and circular carbon

Plastic waste, often viewed as an environmental burden, is reimagined by Bashir *et al.*[1] Their work explores the thermochemical conversion of plastic waste into hydrogen, offering a dual benefit of waste mitigation and clean hydrogen generation, while at the same time also enabling the recycling of additives and contaminants, such as zinc. In a similar context, Weiland *et al.*[2] show a great potential of thermochemical conversion to produce hydrogen-rich gas from plastic waste. Complementing this, Mandal *et al.*[3] investigate the use of floral biomass in photochemical hydrogen production, highlighting the potential of organic waste streams in renewable hydrogen pathways.

Electrified and enhanced conversion processes

Electrification of hydrogen production and conversion processes is a key strategy for integrating renewable electricity and reducing carbon intensity. A novel electrified, sorption-enhanced reforming process by Mostafa *et al.*[4] introduces a hybrid approach that combines sorption-enhanced reforming with electrification of sorbent regeneration, significantly improving CO_2 capture and process efficiency. Singh *et al.*[5] investigate interface-engineering strategies for enhanced electrocatalytic hydrogen-evolution reaction, providing an overview of how interface-engineering strategies in transition-metal-based nanomaterial electrocatalysts can enhance hydrogen-evolution-reaction performance. Meanwhile, the study of Hauth *et al.*[6] investigates the design-parameter optimization of a membrane reactor for methanol synthesis using a sophisticated CFD model.

These studies underscore the role of advanced reactor design and electrified systems in scaling low-carbon hydrogen technologies. With rapidly accelerating technical development, it is important to analyse various technologies in a holistic manner. Our recent review on the electrification of gasification-based biomass-to-X (BtX) processes assesses the technological maturity, performance, feasibility, and research needs for direct and indirect electrification options to enhance carbon efficiency, product yields, and sustainability in biomass conversion.[7] In more detail, Bastek *et al.*[8] provide a critical assessment of how using steam plasma in entrained-flow gasification could enable much cleaner, more efficient conversion of low-quality biomass and waste into hydrogen-rich syngas.

Together, all these publications reflect the multifaceted nature of hydrogen research in a circular-economy context and its potential to transform energy systems. From leveraging waste and biogenic feedstock as a resource to emerging fields of electrification and novel reactor design, the studies in this collection offer valuable insights and innovations. As hydrogen continues to evolve from a concept to a cornerstone of clean-energy strategies, interdisciplinary collaboration and systems thinking will be essential. We hope this collection inspires further exploration and integration of hydrogen technologies across sectors and scales.

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