Hydrogen as the Nexus of Future Sustainable Transport and Energy Systems

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Education

2021 - PhD, Electrical Engineering, University of Bath, UK

(Low-Carbon Energy Systems)

2017 - BA, Electrical Engineering, 华电 & University of Bath, UK

Work Experience

2021-2024, Chinese Academy of Sciences (Institute of Automation),

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2024-2025, Systems Engineering, Cornell University,

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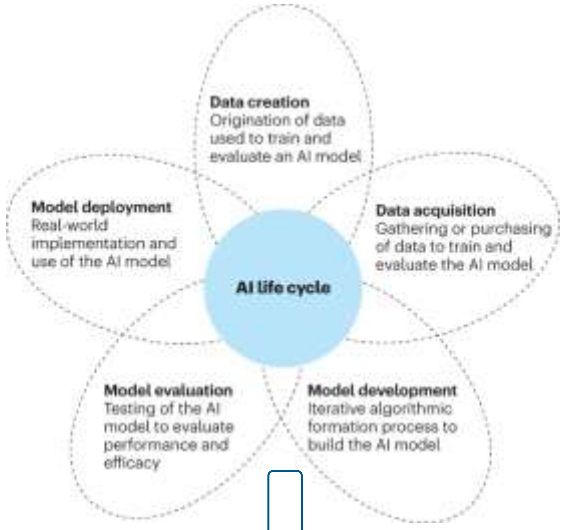
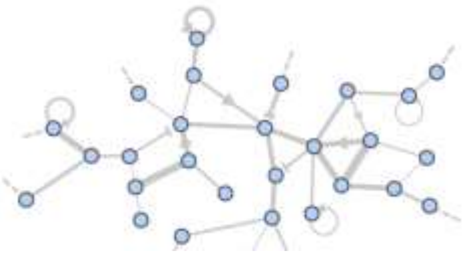
Research Interests

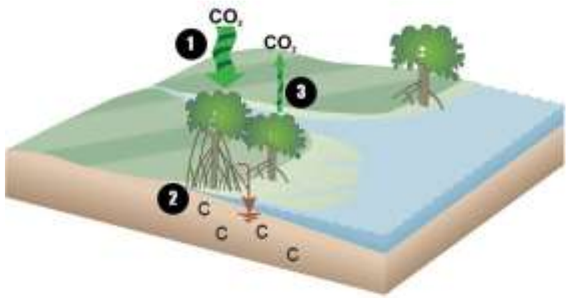
AI + OR





Water-Energy-Carbon Nexus

Optimizing water and energy use to minimize emissions and foster sustainable resource management.



Low-Carbon Energy Systems

Exploring the potential of energy systems, including renewable energy and carbon capture integration, to achieve large-scale carbon reduction targets.

Psychology-Based Modelling

It integrates behavioral and cognitive insights into energy system design, aiming to align technical control with human decision-making patterns.

Guess Who Can't Find a Gas Station?

Let's start with a question...

❓
What's the most common element in the universe… but still struggling to find a gas station?

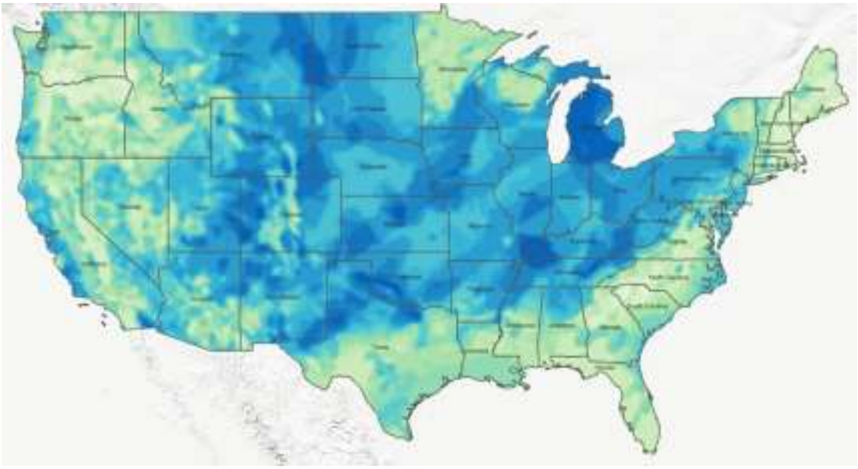
👉
A. Oxygen
B. Nitrogen
C. Hydrogen
D. Elon Musk 🕶

C. Hydrogen!

Hydrogen makes up ~75% of all baryonic matter... but in most cities, it's easier to find bubble tea than a hydrogen pump!

Motivation & Background

Why hydrogen? Why now?



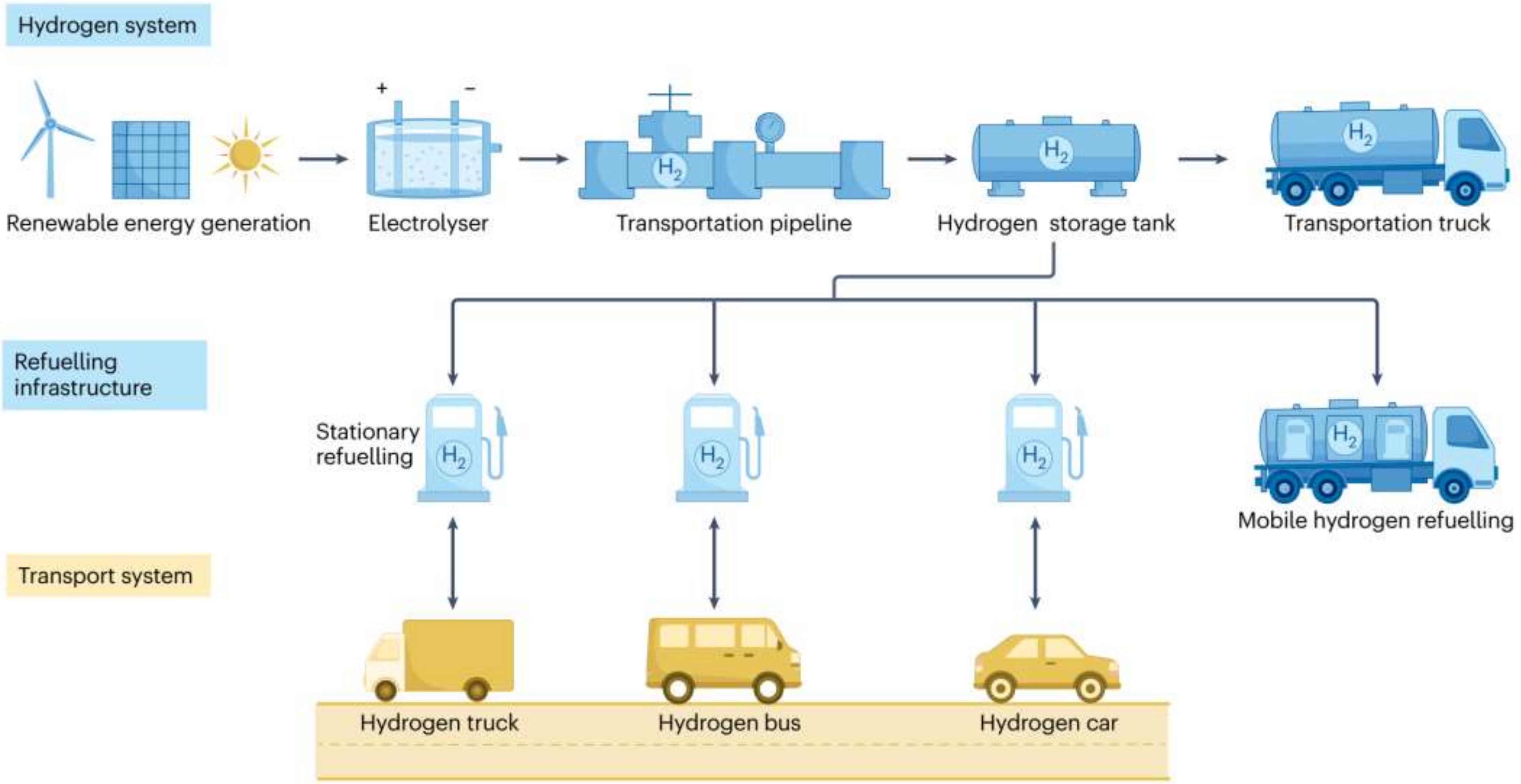
- In 2022, transportation was responsible for 22% of global energy-related CO_2 emissions, making it a critical sector for decarbonization.

- Hydrogen Fuel Cell Vehicles (HFCVs) offer fast refueling (<3 minutes), long driving ranges (>500 km), and zero tailpipe emissions, making them ideal for long-haul and high-utilization applications.

- Unlike battery electric vehicles (BEVs), HFCVs provide greater operational flexibility and are particularly effective in regions or use cases where charging infrastructure or grid capacity is limited.

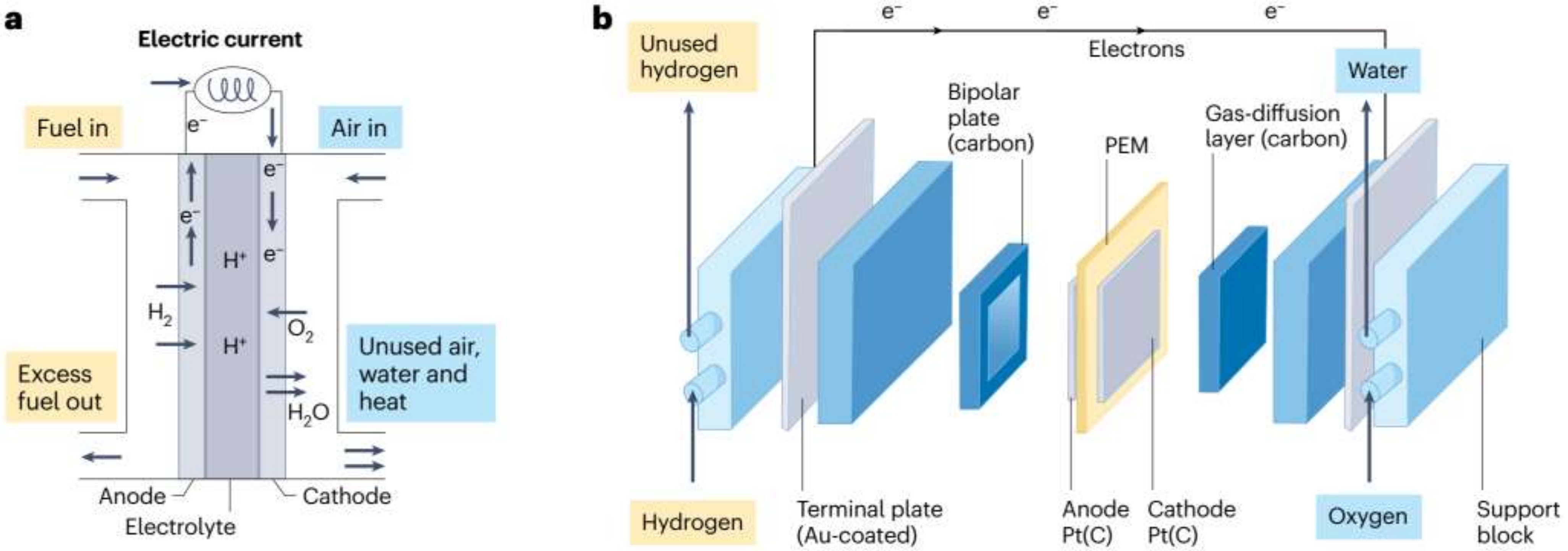
System Architecture of Hydrogen Mobility

How hydrogen integrates energy and transport infrastructure



PEM Fuel Cell Technology & Performance

Technical foundations of PEM fuel cells powering HFCVs

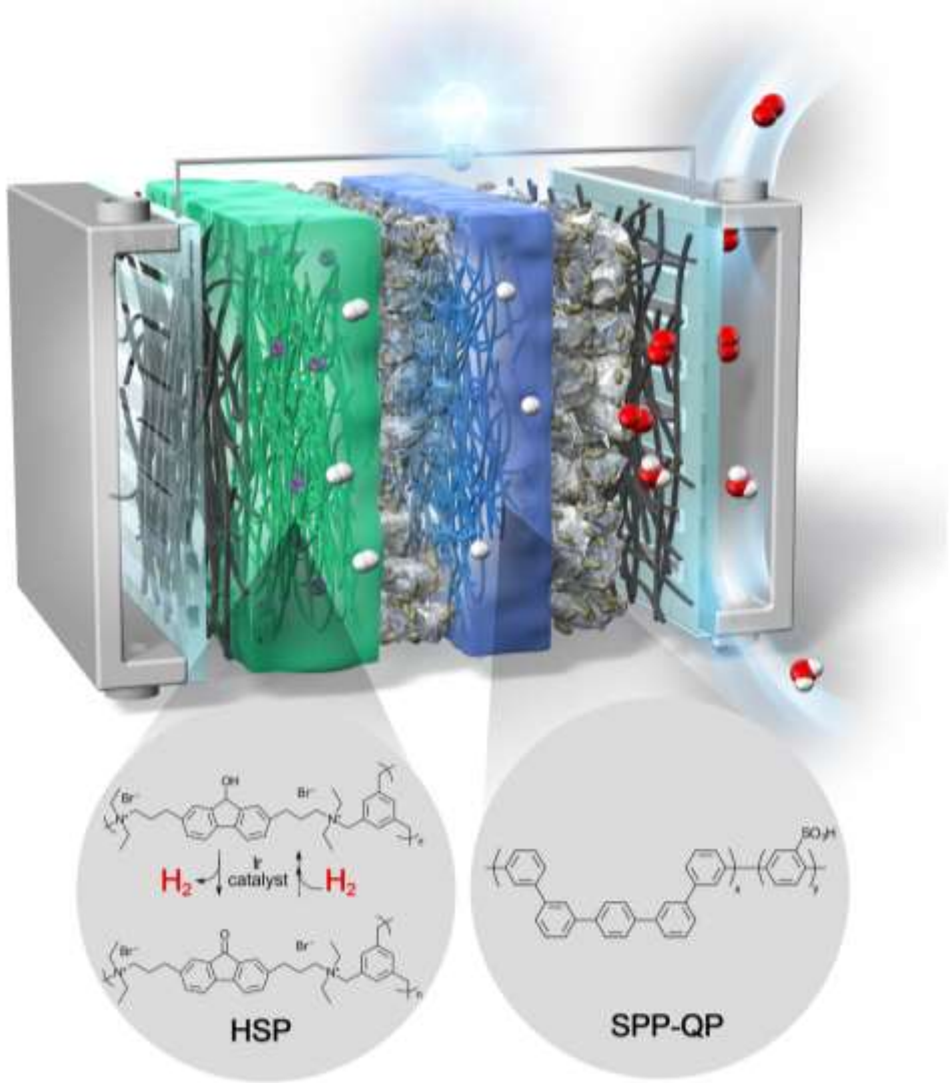


Under optimal conditions, modern PEMFCs achieve up to 60% system efficiency, more than double that of traditional combustion engines (~30%).

Technologies like thin-film membranes, nanocage catalysts, and non-precious metal catalysts (NPMCs) have significantly improved power density and reduced platinum use.

Durability & Safety of PEM Fuel Cells

Long-term performance and real-time fault management



Long-term performance of PEMFCs is hindered by degradation mechanisms: catalyst dissolution, carbon support oxidation, and membrane thinning.

Monitoring technologies (e.g., SEM imaging, EIS analysis, polarization testing) help diagnose wear patterns and predict component failure.

Hybrid methods that combine physical models with machine learning — such as digital twin + transfer learning frameworks — improve real-time fault prediction.

Safety systems detect hydrogen leaks, thermal hotspots, and mechanical faults using smart sensors and adaptive controllers.

Standards like ISO 14687 ensure hydrogen purity, while control systems mitigate risks like thermal runaway and over-pressurization.

Miyake, J., Ogawa, Y., Tanaka, T. et al. Rechargeable proton exchange membrane fuel cell containing an intrinsic hydrogen storage polymer. Commun Chem 3, 138 (2020). https://doi.org/10.1038/s42004-020-00384-z

Refueling Infrastructure Typology

Station types, deployment challenges, and mobility logistics

Hydrogen refueling stations are categorized into regular, rapid, and mobile formats:

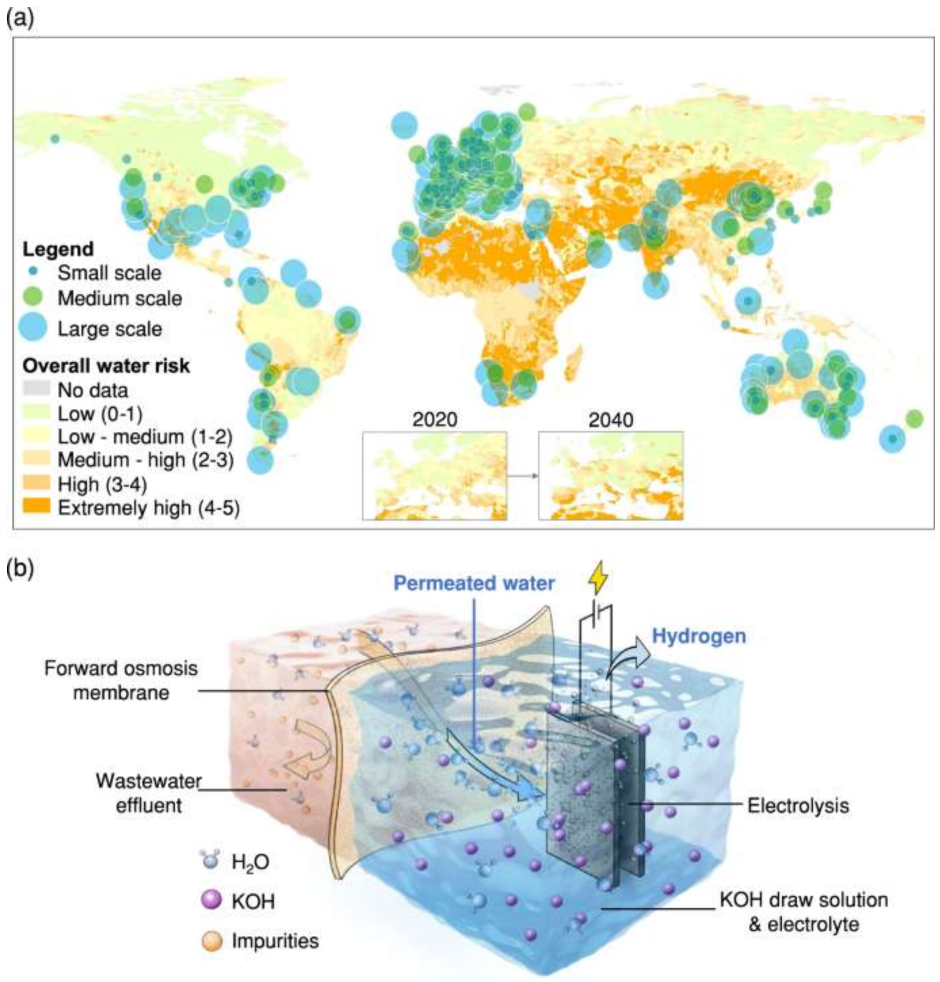
- Regular stations (1–10 kg/day) serve residential use with long refill times.
- Rapid stations (>100 kg/day) deliver 3–10 minute refueling, ideal for buses/trucks.
- Mobile stations provide on-demand service in remote or pilot areas.

The core challenge is building out high-throughput, geographically distributed infrastructure that ensures reliability, affordability, and hydrogen purity.

Emerging technologies include 700-bar dispensers, cryogenic storage, and even solid-state hydrogen storage solutions.

Challenges in Scaling Green Hydrogen

Barriers and breakthroughs in electrolytic hydrogen production



- Only 5–6% of global hydrogen is currently green, mostly produced via water electrolysis.

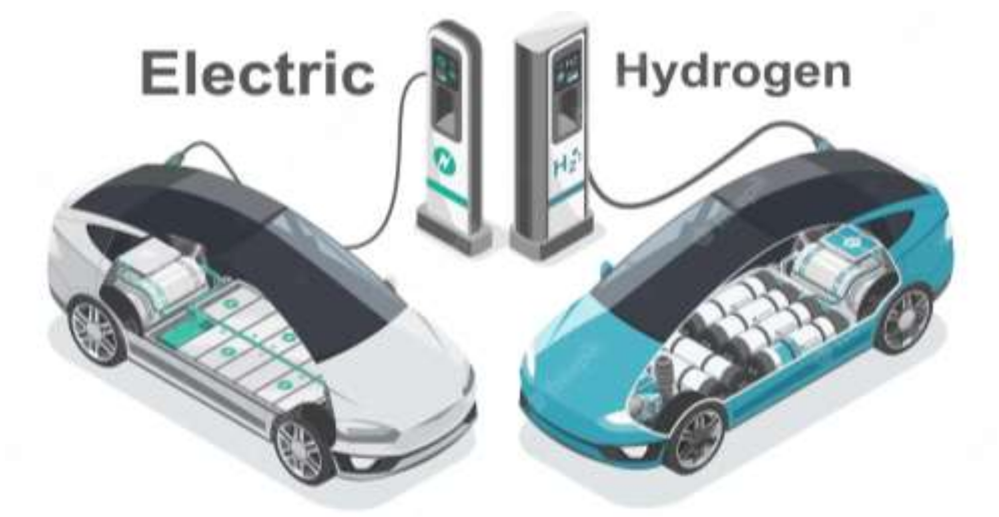
- The major barriers are high capital cost of electrolysers, operational inefficiency, and water demand (~9 liters per kg of hydrogen).Solutions include co-location with renewable energy sites (e.g., Japan's FH2R with a 10-MW solar-powered electrolyser) and use of desalinated or recycled water.

- Modular electrolysers, automated operation, and dynamic scheduling enable better synchronization with renewable availability.

- Achieving cost parity with grey hydrogen is projected by ~2030 in regions with high solar/wind resources.

Smart Integration & Roadmap

From AI-driven refueling to V2G and grid services



- Smart hydrogen refueling leverages IoT and AI to forecast demand, monitor station health, and dynamically control electrolysis.
- Example: Toshiba's IoT-equipped stations reduced downtime by 30%.
- HFCVs can become mobile green hydrogen virtual power plants (GHVPPs), participating in ancillary grid services like frequency regulation and reserve provision.

Conclusion & Outlook

HFCVs as a nexus for the future clean energy transition

- Hydrogen Fuel Cell Vehicles are not just transport assets; they are mobile energy storage units, enabling grid stability and renewable integration.
- With advances in PEMFC technology, infrastructure design, AI-based operations, and green hydrogen production, the vision of a hydrogen-driven mobility system is becoming realizable.
- Remaining challenges include ensuring safety, reducing production costs, harmonizing standards, and scaling infrastructure.
- Nonetheless, HFCVs represent a foundational pillar in the transition toward a decarbonized, flexible, and resilient energy ecosystem.

Nature Reviews Electrical Engineering

Yayyy!

nature reviews electrical engineering https://doi.org/10.1038/s44287-025-00178-2

Review article

Check for updates

Hydrogen as the nexus of future sustainable transport and energy systems

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Abstract

Serving as a clean energy carrier, green hydrogen – hydrogen produced by the electrolysis of water – enables low-carbon transportation and facilitates the large-scale integration of intermittent renewable energy sources into the power grid, thereby enhancing system flexibility and decarbonization. Hydrogen fuel cell vehicles (HFCVs) are key to the integration of green hydrogen into the energy and transport systems. The adoption of HFCVs is being supported by advances in hydrogen production and fuel cell technologies, coupled with the development of hydrogen refuelling infrastructure. However, technological, economic and regulatory barriers to the growth of the hydrogen economy remain. This Review examines the progress and challenges in the integration of HFCVs into the energy and transport systems. We also consider challenges in scaling green hydrogen production using renewable energy and highlight the role of HFCVs in facilitating the integration of green hydrogen and renewable energy into the energy and transport systems. Finally, we provide a roadmap that outlines directions for research, policy and investment to overcome the obstacles to growing the hydrogen economy and harnessing hydrogen as a cornerstone of sustainable energy and transport systems.

Sections

Introduction
Fuel cell technology and operation
Infrastructure for HFCV refuelling
Scaling green hydrogen
Roadmap to HFCV integration
Outlook

nature reviews electrical engineering https://doi.org/10.1038/s44287-025-00181-7

Review article

Check for updates

Integrating solar-powered electric vehicles into sustainable energy systems

Thomas Tongxin Li, Alexis Pengfei Zhao, Yuchuan Wang, Shuangqi Li, Jiaqiang Fei, Zhaoyu Wang & Yue Xiang

Abstract

The integration of solar electric vehicles (solar EVs) into energy systems offers a promising solution to achieving sustainable mobility and reducing CO_2 emissions. This emerging field leverages advances in photovoltaic technology, EV design, battery innovations and energy management strategies. In this Review, we explore the potential of solar EVs to enhance energy efficiency, promote renewable energy use and contribute to the decarbonization of the power and transport sectors. We discuss the benefits of incorporating photovoltaic systems into EVs, such as reduced grid dependency and increased vehicle autonomy, and examine strategies for optimizing integration, including advancements in battery technology. The Review also addresses the challenges of grid adaptation, policy development and the need for supportive infrastructure, highlighting the importance of interdisciplinary research and technological innovation. A roadmap for the sustainable integration of solar EVs into energy systems is presented, offering insights into the future of energy-efficient and decarbonized transportation.

Sections

Introduction
Optimizing solar EV integration through advanced battery technology
Solar EV infrastructure for PV integration
Grid harmonization of PV electric vehicle charging
Environmental aspects of solar EV integration
Sustainable solar EV integration
Outlook

Thank You! 😄 Questions are welcome.

Feel free to collaborate with us!

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