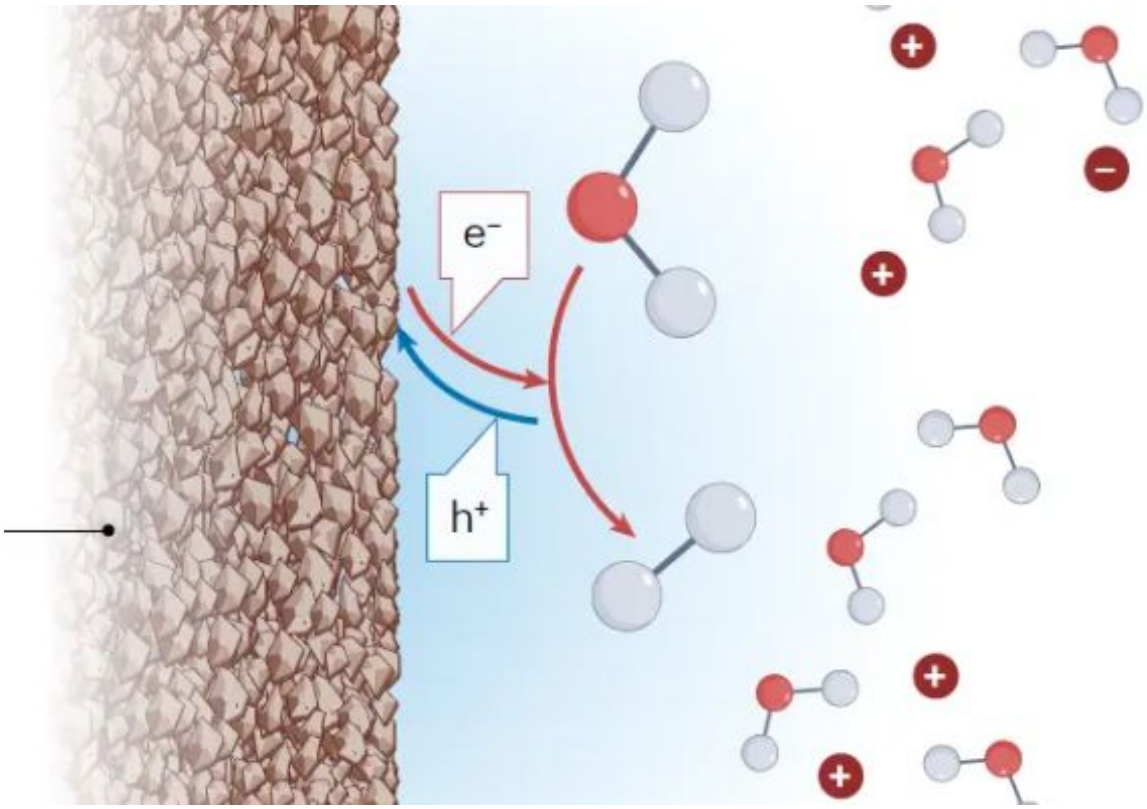

Mapping the landscape of solar fuel technologies

A new article reviews and compares five approaches to converting solar energy into chemical fuels, highlighting common challenges and opportunities.

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In the search for more sustainable ways to produce energy and reduce the environmental impact worldwide, solar fuel technologies have emerged as a promising alternative to fossil fuels. By using sunlight to drive chemical reactions, these technologies enable the synthesis of valuable molecules that can be used as fuels and materials that can be used to produce other chemicals.

Despite their promise, solar fuel technologies are often studied in isolation, making it difficult to identify shared challenges and common design principles. Now, ICFO researchers **Prof. Pelayo Garcia de Arquer, Viktoriia Holovanova,** and **Diksha Mittal** publish a perspective article reviewing and comparing five major solar fuel technologies - photocatalysis, photovoltaic-driven electrolysis, photoelectrochemical, photothermal, and plasmonic catalysis - going over their advantages, limitations, technological maturity, and prospects for

real-world deployment.

Although all solar fuel technologies store energy in chemical bonds, each one of these technologies harvests sunlight and drives reactions in a different way. Photocatalytic and photoelectrochemical systems use semiconductors to absorb light and drive reactions directly; photovoltaic-driven electrolysis separates light harvesting from catalysis; and photothermal and plasmonic catalysis rely on heat dissipation and doped nanoparticles to promote chemical reactions.

A broader perspective

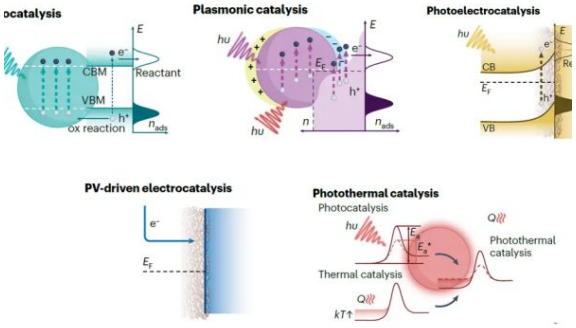
In the perspective article, published in Nature Reviews Clean Technology, the authors analyze the **catalyst design**, **interfaces**, **and environment** in each of these technologies. The team identifies common performance metrics and technological and design trade-offs that are often overlooked when studying these systems separately.

One of the main takeaways is that, despite operating through different mechanisms, solar fuel technologies share **common bottlenecks,** including their dependence on critical materials, energy and heat losses, and the need for stability in challenging environments. Moreover, the article highlights that **sharing key design features** means that improvements in the performance of one of the technologies can improve the efficiency and stability across the other platforms. By offering a unified perspective across technologies, the work provides a roadmap for guiding future research efforts toward more efficient, stable, and scalable solar fuel systems.

i¿½The ideas from this work show that many clean fuel and fertilizer technologies face the same challenges, such as energy losses, material sustainability, and scaling up to real-world conditionsi¿½, says **Viktoriia Holovanova**. By learning from these shared lessons, projects like ICONIC can develop more efficient and robust ways to produce sustainable fertilizers from waste streams, using renewable energy. i¿½We hope this broader perspective supports the transition toward cleaner agricultural inputs while helping restore ecosystems and rebalance the carbon and nitrogen cyclesi¿½, concludes

Reference:

Golovanova, V., Mittal, D. & Garcia de Arquer, F.P. What solar fuel technologies can learn from each other. Nat. Rev. Clean Technol. (2026)
https://doi.org/10.1038/s44359-025-00130-5



Working principles of the five solar fuel technologies