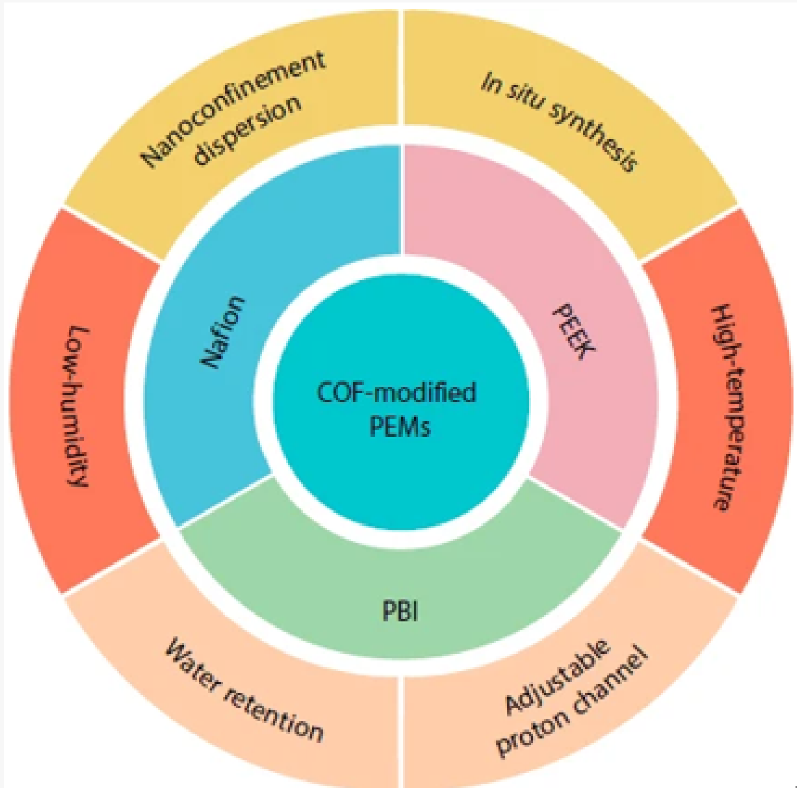
Covalent organic frameworks unlock next-generation proton exchange membranes for fuel cells

FAYETTEVILLE, GA, UNITED STATES, May 19, 2026 /EINPresswire.com/ -- Hydrogen fuel cells offer a clean and efficient path to sustainable energy, but their real-world performance is often held back by a key component: the proton exchange membrane (PEM). These membranes must efficiently conduct protons while blocking fuel crossover, yet conventional materials struggle under hot, dry conditions. A new review brings together recent strategies to enhance PEMs by incorporating covalent organic frameworks (COFs) — porous, designable structures that create ordered proton pathways inside polymer matrices. The work highlights how COF-modified membranes can maintain high conductivity even at low humidity and elevated temperatures, addressing long-standing limitations in fuel cell technology.



Engineering “proton highways” with covalent organic frameworks for next-generation fuel cells.

Conventional PEMs such as Nafion rely heavily on water to transport protons, which makes them prone to performance loss above 80°C or under low relative humidity. At higher temperatures, water evaporates too quickly, and alternative membranes like phosphoric acid-doped polybenzimidazole (PBI) suffer from mechanical weakening and acid leakage. Covalent organic frameworks (COFs) offer ordered nanochannels and tunable chemistry, but integrating them into flexible membranes has proven challenging due to poor interfacial compatibility, particle clumping, and uncertain long-term stability. Based on these challenges, there is an urgent need for in-depth research into COF-polymer interfacial design, scalable fabrication, and durability testing under realistic operating conditions.

On April 16, 2026, researchers from Northwestern Polytechnical University, the Northwest Research Institute of Chemical Industry Co., Ltd., and Xi’an Jiaotong University published (DOI: 10.1007/s10118-026-3638-1) a comprehensive review in Chinese Journal of Polymer Science. The team systematically analyzed strategies for designing COF-modified proton exchange membranes (PEMs) using Nafion, sulfonated polyetheretherketone (SPEEK), and PBI as base polymers. Their work focuses on how COFs can create continuous "proton highways" inside membranes, improving conductivity under low-humidity and high-temperature conditions while suppressing fuel crossover.

The review highlights two main fabrication routes: nanoconfinement dispersion, which shrinks COF particles below 100 nm to improve mixing, and in situ synthesis, where COFs grow directly inside the polymer solution for better interfacial bonding. For low-humidity operation, sulfonic-acid-functionalized COFs in Nafion or SPEEK matrices help retain water and form stable proton pathways. One example shows that adding just 0.6 wt% sulfonated covalent organic nanosheets (SCONs) to Nafion boosted performance in methanol fuel cells by 44%. For high-temperature operation (100–200 °C), COFs reinforced PBI membranes. A striking design used phosphoric acid as both solvent and proton source in a PBI-COF gel, achieving anhydrous proton conductivity of 0.168 $S\cdot cm^{-1}$ at 180 °C — among the highest reported. Another study showed that tuning COF pore size above 2.1 nm switches proton transport from a slow vehicle mechanism to fast hopping, exponentially boosting conductivity. The authors also stress that in situ growth and covalent grafting can resolve interfacial defects, while long-term tests (e.g., 15 days in water with minimal conductivity loss) suggest real-world potential.

The authors said that the real breakthrough lies in how COFs reshape the inner architecture of conventional membranes. They explained that instead of just adding a filler, the goal is to build connected, molecule-level pathways that let protons move quickly even when water is scarce. The team added that the most exciting progress comes from in situ synthesis, where COFs grow directly inside the polymer — this solves the clumping problem and creates a tight, stable interface. They emphasized that moving forward, precise pore engineering and smart functional group design will be key to making these membranes reliable enough for commercial fuel cells.

These advances could accelerate the adoption of hydrogen fuel cells in electric vehicles, backup power systems, and portable generators — especially in environments where heat or low humidity would cripple current membranes. High-temperature proton exchange membrane fuel cells (HT-PEMFCs) operating above 100 °C also tolerate carbon monoxide better, allowing the use of reformate hydrogen from natural gas or biofuels. COF-modified membranes reduce fuel crossover, which improves safety and efficiency. With continued work on scalable roll-to-roll coating and machine learning to predict optimal COF structures, the path toward industrial use is becoming clearer. The review provides a roadmap for designing tough, conductive, and durable membranes that could finally close the gap between laboratory innovation and real-world clean energy infrastructure.

References
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