Hydrogel electrolytes for electrochemical energy storage and conversion systems: Structure–property relationships and performance trade-offs

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Abstract

Hydrogel electrolytes have emerged as promising soft ionic media for sustainable electrochemical energy storage and conversion systems due to their high water content, tunable polymer networks, and mechanical flexibility. Compared with conventional liquid and solid electrolytes, hydrogels offer improved safety, interfacial adaptability, and suitability for flexible devices. However, structure–property–performance relationships remain fragmented across batteries, fuel cells, supercapacitors, and hybrid systems. This review critically examines recent advances in hydrogel electrolytes, emphasizing the relationships among synthesis strategies, network architecture, physicochemical properties, ion transport mechanisms, and application-specific electrochemical performance. Key transport mechanisms, including Grotthuss hopping, vehicular transport, polymer segmental motion, and ion–water–polymer interactions, are comparatively discussed. The review further evaluates multifunctional strategies involving double-network structures, zwitterionic systems, nanocomposites, and water-in-salt hydrogels, while highlighting critical challenges associated with durability, scalability, interfacial stability, and commercialization pathways for next-generation energy technologies. (139

Author keywords

Conversion systems; Electrochemical; Electrolytes; Energy storage; Hydrogel

Indexed keywords

Engineering controlled terms

Data mining; Digital storage; Distributed computer systems; Fuel cells; Hybrid systems; Network architecture; Physicochemical properties; Solid electrolytes

Engineering uncontrolled terms

Conversion systems; Electrochemical energy conversions; Electrochemical energy storage; Electrochemicals; Energy; Energy storage and conversions; Hydrogel electrolytes; Storage systems; Structure-properties relationships; Systems Structure

Engineering main heading

Economic and social effects; Energy storage; Hydrogels

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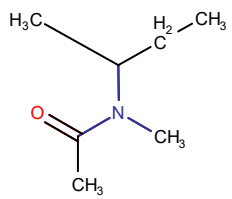

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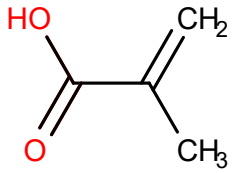

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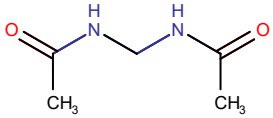

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