

# Porous Organic Materials, such as Covalent Organic Frameworks (COFs), and Their Application in Energy Storage

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Porous organic materials with precisely controlled structures are attracting increasing attention for applications in energy storage, catalysis, and molecular transport. Among them, especially, covalent organic frameworks (COFs) are crystalline porous polymers constructed from light elements and have emerged as a promising class of materials for energy and environmental applications. Their periodic structures, high surface areas, and tunable pore environments enable precise control of molecular interactions and charge transport. In this lecture, we present our recent progress in the molecular design of functional COFs for electrochemical energy storage and proton conduction. By incorporating conjugated building blocks and heteroatom-rich functional groups, we have developed highly ordered porous frameworks with enhanced electronic and ionic transport properties. These COFs exhibit excellent performance as electrode materials for supercapacitors and as proton-conducting membranes under humid conditions. These results highlight the potential of rationally designed COFs as versatile platforms for next-generation energy materials. In this lecture, we present our recent advances in the design and synthesis of functional COFs with tailored electronic and ionic transport properties. By integrating heteroatom-rich building blocks and conjugated linkages, we developed highly ordered porous frameworks capable of facilitating proton transport and charge storage.

Prof. Dr. Atsushi Nagai is a distinguished Japanese scientist and academic, primarily recognized for his extensive work in polymer chemistry, organic synthesis, and next-generation energy systems. Since early 2022, he has served as a **Group Leader** for the Next-Generation Energy Systems group at ENSEMBLE<sup>3</sup> (Centre of Excellence) in Warsaw, Poland.

Below is an overview of his academic journey and scientific contributions.

- Kyoto University (2008–2010): Served as a Project Assistant Professor, focusing on functional materials like conjugated polymers.
- Institute for Molecular Science (2010–2017): Held the position of Assistant Professor, where he led projects in chemical and optical polymer synthesis.
- University of Texas Southwestern Medical Center (2014–2015): Served as a Visiting Professor in the Department of Biochemistry, developing cancer imaging probes and bio-electronic polymers.
- Delft University of Technology (2017–2020): Appointed as an Associate Professor in the Department of Aerospace Engineering in the Netherlands.
- Toyohashi University of Technology (2021–2022): Served as an Associate Professor in the Department of Electrical and Electronic Information Engineering.

He is particularly known for developing porous organic materials, functional polymers, carbon-based materials, and ion-conductive systems, with an emphasis on understanding and controlling structure–property relationships. His materials are explored for applications in energy storage, electrochemical systems, proton and ion conduction, and environmentally responsive technologies, contributing to clean energy solutions and resource-efficient materials engineering.