


Chapter 7


Advances in Plant-Based Materials for Sustainable Electrochemical Energy Devices

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ABSTRACT

Transitions to circular and sustainable energy systems require the design of innovative material platforms that are safe for the environment and highly resource-use efficient. In this respect, plant-derived biomaterials are increasingly recognized as highly promising alternatives to conventional components in batteries, supercapacitors, and fuel cells. This chapter underlines the role that plant-based materials play in the development of greener and more sustainable energy infrastructures

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by presenting their integration within the above-mentioned energy systems. Major issues such as electrical conductivity, durability, and scalability are comprehensively discussed. The most recent strategies in the realm of material hybridization, system integration, and bioinspiration are reviewed. The fast-developing intersection between natural material science and electrochemical engineering keeps driving innovation to the forefront in this interdisciplinary domain towards next-generation sustainable energy technologies.

1. INTRODUCTION

The transition towards sustainable and circular energy systems is among the major challenges of the 21st century (Asif, 2022), while fossil resources are depleting, demand from both environmental and social perspectives for clean technologies is increasing. In this context the scientific community develops new strategies to meet, in a more intensive way, the energy demand rising globally (Asif, 2024; Kandpal et al., 2024). It is electrochemical energy storage and conversion devices-particularly, batteries and supercapacitors-which are at the frontline of this effort because of their high efficiency and versatility in storing and delivering electrical energy (Shah et al., 2024). However, these systems conventionally have been made with materials mostly sourced from rare or non-renewable sources and usually produced through energy-intensive methods. Their use reveals several long-term sustainability and cost concerns with a high environmental impact (Aazem et al., 2024; Gallo et al., 2022).

In this respect, biobased materials and, mainly, those of plant origin represent a very fascinating option for being an alternative (Chowdhury et al., 2025; Saini et al., 2021; Vinodh et al., 2021), appreciated that with the advancement of material sciences, green chemistry, and biotechnology, they were able to confer unique properties on such materials, among which one could mention renewability, biodegradability, low environmental footprint, tunable physicochemical properties, and several others. For example, as reported by (Chinnappan et al., 2012; L. Zhang et al., 2021) works, the portfolio starting from cellulose, lignin, tannins, polysaccharides, plant-derived oils, and other biomolecules is quite broad in respect of components that can be valorized in an active or functional way within electrochemical systems.

These materials represent not only an ecological and ethical need but also provide technical properties competitive or superior to conventional alternatives quite frequently (Aslan & Altuntaş, 2023; J. Luo & Liu, 2023; Yhobu et al., 2022). Indeed, most biomass precursor-derived activated carbons have shown large specific surface area, hierarchical porosity, and very good charge storage capability, hence appearing as perfect candidates to act as electrodes in supercapacitors (Jain et al., 2021; Sarmah et al., 2024; Srivastava & Yadav, 2023).

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