# Laying stones on the path to K-ion batteries: crafting greener cell components


# Abstract

The growing penetration of renewable energy sources in modern grids has exposed the urgent need for reliable, safe, and sustainable stationary storage systems. In this scenario, potassium-ion batteries (KIBs) represent a promising alternative to lithium-based technologies, combining lower cost, wide raw material availability, and comparable electrochemical potential. However, the large ionic size and high chemical reactivity of potassium introduce distinctive challenges related to electrode stability, electrolyte compatibility, and interfacial control.

This Thesis aims to deepen the understanding of potassium electrochemistry and to propose materials capable of both exploiting its potential and overcoming its intrinsic limitations. A critical and integrated approach was adopted, encompassing the development and characterization of electrodes, electrolytes, and interfaces, as well as characterization techniques. The goal was to highlight how each component contributes to the overall performance and how their mutual interactions define the behaviour of K-based systems.

The first part focuses on the study of metallic potassium and carbon-based anodes, where the interfacial evolution and ion-storage mechanisms were investigated by combining electrochemical and morphological analyses. The insights gained guided the design of bio-derived lignin-activated carbon, structurally controlled, and conceived to improve both ion diffusion and structural integrity during cycling.

Subsequently, the research addressed the formulation of new gel polymer electrolytes (GPEs) designed to enhance stability and mechanical robustness while maintaining high ionic mobility. Particular attention was devoted to the use of lignin-based materials, aiming at developing greener and safer electrolytes for stationary applications, while proving mechanical strength and enhancing ionic conductivity.

Finally, the Thesis explores the potential of organic redox-active cathodes based on anthraquinone, TEMPO, and carbonyl compounds, as sustainable alternatives to conventional inorganic materials. These systems were designed and their performance compared with lithium counterparts to clarify the role of molecular structure, polymer architecture, and electrolyte interaction in governing the electrochemical response of organic electrodes in potassium cells.

Overall, this PhD work tries to contribute in building a coherent framework for the rational design of KIBs, emphasizing a chemistry-specific rather than lithium-analogous approach. The materials and strategies proposed were conceived to harness the advantages of potassium while addressing its limitations, aiming at contributing to the development of efficient, safe, and environmentally responsible KIB technologies