Valorization of different organic waste sources for electrochemical applications: Process and life cycle assessment

E. Petri[1], S. El Yamani[2,3], F. Capodarca[1], A. Primante[2,3], A. Contin[2,3], F. Soavi[1,3]*

[1]Dept. of Chemistry "Giacomo Ciamician", University of Bologna, Via Selmi 2, 40126, Bologna, Italy
[2] Dept. of Physics and Astronomy "Augusto Righi", University of Bologna, Viale Berti Pichat 6/2, 40127, Bologna
[3]Centre for the Environment, Energy, and Sea - Interdepartmental Centre for Industrial Research in Renewable Resources, Environment, Sea and Energy (CIRI-FRAME), University of Bologna, Viale Ciro Menotti 48, 48122, Marina di Ravenna, Italy

email: francesca.soavi@unibo.it

Significance and Relevance

In recent years, biochar produced through the pyrolysis and activation of biomass has emerged as a promising material for various electrochemical systems, including fuel cells, redox flow batteries and supercapacitors. Its production lines up with global efforts to move towards sustainable energy solutions by integrating renewable and waste-derived materials into advanced technologies. Moreover, biochar offers the potential to mitigate climate change by sequestering CO_2 and substituting high-emission, fossil-based products, thereby contributing to a more circular economy.

Preferred topic: Green chemistry and biomass transformation, renewable resources conversion
Second choice: Circular economy
Preferred presentation: Oral preferred or Short Oral

Introduction and Motivations

The growing demand for sustainable electrochemical energy storage and conversion systems has driven interest in the valorization of organic waste as a resource for innovative materials. Biomass, such as lignin and vine prunings, represents an abundant and renewable European feedstock for biochar production, which can be tailored for applications in energy storage devices. The optimization of biochar's porosity through pyrolysis and activation processes (e.g., using $KHCO_3$) enhances its electrochemical performance and adds value to the battery value chain. Additionally, valorizing waste-derived materials not only reduces environmental burden but also opens pathways for energy recovery and resource efficiency. Evaluating the environmental impacts of the proposed activated biochar production process through a life cycle assessment (LCA) further supports its viability as a sustainable solution[2].

Materials and Methods

Biochar was produced on a gram scale from organic wastes, such as lignin and vine prunings, via pyrolysis and chemical activation. Pyrolysis conditions were optimized to enhance porosity, with potassium bicarbonate ($KHCO_3$) used as a mild activating agent to increase surface area. The materials were characterized using scanning electron microscope (SEM), thermogravimetric analysis (TGA), nitrogen adsorption, elemental analysis and Raman spectroscopy. Pyrolysis by-products were evaluated for thermal energy potential, while a life cycle assessment (LCA) analyzed the environmental impacts, considering energy and material recovery and the integration of renewable energy.

Results and Discussion

The tailored pyrolysis and activation processes successfully produced biochar with optimized porosity, which is suitable for use in energy storage applications. Preliminary analyses indicate significant improvements in the material's electrochemical properties, making it a viable candidate for ORR and HER in fuel cells (inorganic and biological), as well as in vanadium redox flow batteries, supercapacitors and other energy storage systems. The evaluation of pyrolysis by-products revealed their potential for thermal energy recovery, contributing to the overall sustainability of the process. The life cycle assessment highlighted the environmental benefits of this approach, particularly in terms of CO_2 sequestration, reduced reliance on fossil-based products, and effective waste valorization. These findings underscore the feasibility and ecological advantages of integrating biochar into the energy storage value chain.

References

1. E. Petri, E. Heigl, A. Fasolini, L. Zeilerbauer, M. Giovannucci, Y. Küçükağa, C. Torri, F. Basile, F. Soavi. *Carbon*, **2024**, 226, 119-221.
2. M. Liu, Z. Xiang, H. Deng, K. Wan, Q. Liu, J.Piao, Y. Zheng, Z. Liang. *Journal of The Electrochemical Society,* **2016**, 163 (10), H937-H942.
3. L.J.R. Nunes, A.M. Rodrigues, J.C.O Matias, A.I.Ferraz. Rodrigues. *Agriculture* **2021**, *11*, 489.

Acknowledgements

This work was supported by the MIAMI Project 2022-2025 - Italian Minister for Ecological Transition, MiTE codice proposta CSEAA_00014