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Waste-Energy-Water Nexus: Materials & Processes

Italy
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2025

Book of Abstracts

WASTE-ENERGY-WATER NEXUS: MATERIALS & PROCESSES

1st edition

15th July 2025 - Rimini, Italy

16th July 2025 - Marina di Ravenna, Italy

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12:10 – 12:30 **Invited Lecture.** **Osvalda Senneca** (STEMS-CNR, P.le Tecchio 80, 80125 Napoli, Italia), Cerciello F., Chagtmi R., Coppola A., Chirone R., Fabozzi A., Freisenwinkel E., Narin O., Scherer V., Schiemann M., Schmitt S., Yannakis C. *"Thermochemical reactions of iron and biomass within the H_2, energy, water nexus"*

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12:50 – 13:05 **Regular oral.** **Luca Bottoni** (School of Science and Technology, Chemistry Division, University of Camerino 62032, Camerino, Italy), Darjazi H., Sbrascini L, Staffolani A., Pastore G., Minnetti L., Verdicchio F., Gabrielli S., Catorci A., Nobili F. *"A sustainable anode for Na-ion batteries based on holm oak waste-derived hard carbon and lignin binder"*

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POSTER PRESENTATIONS

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KEYNOTE LECTURES

Chemical and Electrochemical Extraction of Transition Metals from LiB Leachates for MOF-Based Supercapacitor Electrodes

Manyala N.[1], Rutavi G.[1], Mutshaeni F.B.[2], Kirui J. K.[2], Soavi F.[3]

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[2]Department of Chemistry, University of Venda, Thohoyandou 0950, South Africa
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Electrodeposition and chemical precipitation methods were used to extract transition metals from Li-ion battery (LIB) leachate for MOF-based supercapacitor electrodes fabrication. In the electrodeposition, MOFs were directly deposited on carbon cloth (CC) using electrical energy. A high-performance Co/Ni-MOF electrode was fabricated on CC at pH 3 producing agglomerated nanoflower-like structures, achieving a specific capacity of 102 mAh g^{-1} at 1 A g^{-1} and retaining 81% capacity after 10,000 charge–discharge cycles at 5 A g^{-1} in 3 M KOH. In chemical precipitation p-tert-Octylphenoxy-acetic (POOA) was used in separating transition metals from lithium to form insoluble salts for Ni/Mn-MOF electrode synthesis. The optimised Ni/Mn-MOF-48 h sample synthesized using a Ni–Mn-MOF electrode 48 hours delivered a specific capacity of 20.7 mAh g^{-1} at 1 A g^{-1} in 3 M KOH, with a coulombic efficiency of 99.2% and 40% capacity retention after 5,000 cycles at 5 A g^{-1}. These findings demonstrate promising potential for sustainable transition of metal recovery and future lithium reintegration into battery manufacturing.

Valorizing biomass waste into multifunctional aerogels for solar energy harvesting and water remediation

Wang S.[1,2], **Ding S.**[1]

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Converting biomass waste into multifunctional aerogels via carbonization offers a sustainable pathway to address interconnected challenges in waste management and energy utilization. This work presents two biomass-derived carbonized aerogels—starch/carbon nanotube-based and chitosan-based—engineered respectively for solar-thermal energy conversion and storage, and efficient solar-assisted oil-water separation. The first approach transforms starch aerogel into carbon-nanotube-enhanced aerogel via template carbonization. The obtained carbonized aerogel serves as a photothermal scaffold for phase change material infiltration. The resulting composite feature tunable porosity (26.7%–85.6%) and dual-function performance: high solar absorption (>90%) and robust latent heat storage (melting enthalpy up to 182.1 J g-1). The sample attains a stable surface temperature of 86 °C under 1 sun. Nanoconfinement within aerogel pores stabilizes metastable PCM polymorphs, broadening temperature ranges (60-85 °C) for thermal management. Thermal insulation of composites ($\lambda \approx 0.112$ W m-1 K-1) further supports energy retention. The composite maintains structural integrity over 10 solar cycles with zero leakage, demonstrating robust solar energy regulation. Additionally, carbonized chitosan/citric acid aerogels were developed through freeze-drying and low-temperature carbonization for oil–water separation. These carbonized aerogels exhibit exceptional oil/organic solvent uptake (40-125 g g-1) with >99% separation efficiency across extreme conditions (pH < 2, pH > 12, temperature was 4 or 65 °C). Their compressible macroporous network enables 90% shape recovery after 10 compression cycles, facilitating mechanical oil recovery. The carbonized aerogels possess surface photothermal conversion performance, with the surface temperature raising above 80 °C under 1 sun. In a simulated seawater environment (4 °C), the saturated absorption time of aerogels for crude oil is reduced from four days to 10 minutes under 1 sun, while achieving an absorption of 56 g g-1. These synthetic biomass aerogel materials provide modular,scalable strategies for circular waste valorization, solar energy utilization, and clean water access.

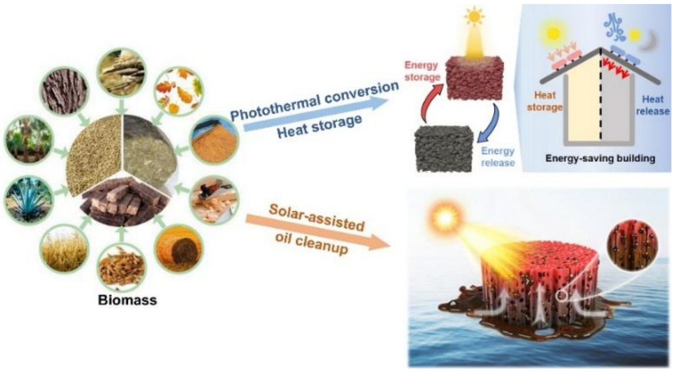

Figure 1: *Biomass-derived carbonized aerogels for photothermal conversion and storage, and solar-assisted oil spill cleanup*

Renewable energy driven biomass conversion for H_2 and biochar

Yang H.[1], Hu Q.[1], Zeng K.[1], Yingquan C.[1], Xiong Z.[1], Yang Y.[1], Xianhua W.[1], Jingai S.[1], Qing Y.[1], Hanping C.[1]

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Biomass as the only carbon contained renewable resources, it not only can substitute fossil fuel for power, it also shows the possibility for high value chemicals and materials, it is very important to energy, chemistry, environment, etc. various field. Also, when with carbon capture or carbon utilization was combined, it is carbon negative, and play a significant role for the carbon neutral target. It is the future of green energy. Thermochemical conversion can convert biomass to H2 rich gas fuel, liquid oil, carbon contained materials, and chemicals. It is the most promising technology of biomass utilization. In this Presentation, the thermochemical conversion process was introduced respected to hydrogen and high value carbon materials production, also some new technologies were showed, especially with the development of new energy and in combination with new heating method, such as solar power, molten salt energy storage, and joule heating, etc. Also, the prospective was elaborated with the point view of carbon negative utilization of biomass.

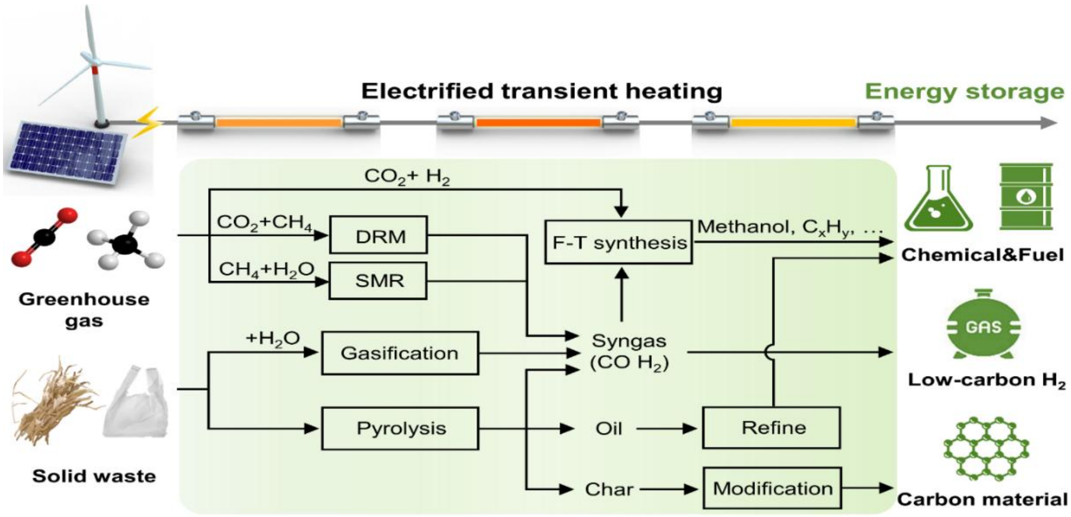

Figure 1: *Renewable Energy-Driven Resource Recycling of Greenhouse Gases and Solid Waste*

INVITED LECTURE

Integrated valorization of meat residues for biomethane and hydrochar production

<u>Conversano A.</u>[1], Sogni D.[2], Zatti M.[2], Di Bona D.[2]

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[2]LEAP s.c.a r.l. – Laboratorio Energia e Ambiente Piacenza, via Nino Bixio 27/C – 29121 (PC) Italy

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The REPowerEU plan aims to reach a biomethane production target of 35 billion cubic meters (bcm) annually by 2030, up from the current 4 bcm in 2023 [1]. This goal is designed to decrease the European Union's reliance on imported natural gas and is expected to require an investment of approximately 37 billion euros. To achieve this target, several strategies need to be implemented, among which the valorization of food waste and residues may cover a relevant role due to the high level of homogeneity of the selected streams. In Emilia-Romagna Region, the food industry produces more than 450 kt/y of waste from the food and beverage sector, which is equal to more than 3% of the total regional industrial waste produced, and more than 13% of the national waste from the food and beverage sector with reference to 2019 [2]. The NACE 10.1 group is dedicated to processing and preserving of meat and production of meat products, and it is associated to a regional value added equal to more than 1 G€ (2017 data) [3]. The recent increase in production costs has led to reduced profit margins, exposing the sector to new challenges in meeting the energy and environmental targets imposed by emerging European regulations. Meat processing generates residues amounting to approximately 25–55% of the live weight of the original animal, resulting in high management and disposal costs. This underscores the need to identify more cost-effective reuse strategies compared to current practices, such as use in pet food production or incineration for energy recovery. Within this context, the MEAT-ICO project funded by Emilia-Romagna PR-FESR is evaluating new opportunities for the valorization of processing residues within a circular economy framework. The work aims at discussing the recent results of the conceptual design of alternative valorization processes based on a combination of anaerobic digestion and hydrothermal carbonization in order to produce biomethane and char from fat-rich trimmings produced by the meat industry.

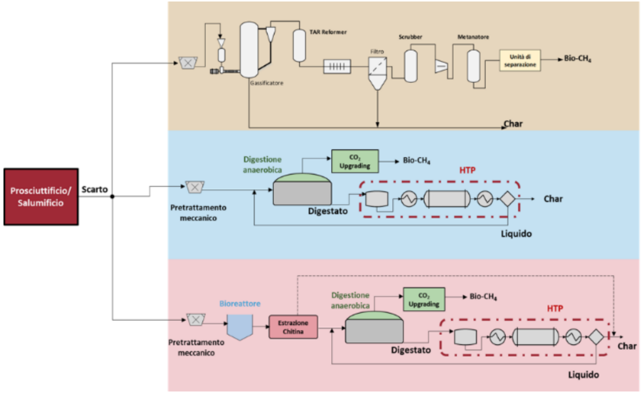

Figure 1: *3 processes investigated in the MEAT-ICO project.*

References

[1] Guidehouse and European Biogas Association (EBA), "Biogases towards 2040 and beyond - A realistic and resilient path to climate neutrality," 2024.

[2] ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale, "Catasto Rifiuti - Sezione Nazionale," 2024. https://www.catasto-rifiuti.isprambiente.it/index.php (accessed Dec. 11, 2024).

[3] Regione Emilia-Romagna e ART-ER - Attrattività Ricerca Territorio Emilia Romagna, "Analisi del sistema agricolo, agroindustriale e del territorio rurale dell'Emilia-Romagna," 2021. [Online]. Available: https://agricoltura.regione.emilia-romagna.it/pac-2023-2027/documenti/analisi-del-sistema/analisi-contesto.pdf

Influence of heating rate and residence time on biochar properties across pyrolysis regimes

Giudicianni P.[1], **Grottola C.M.**[1], **Amato D.**[1], **Fabozzi G.**[1], **Troiano M.**[2], **Solimene R.**[1]

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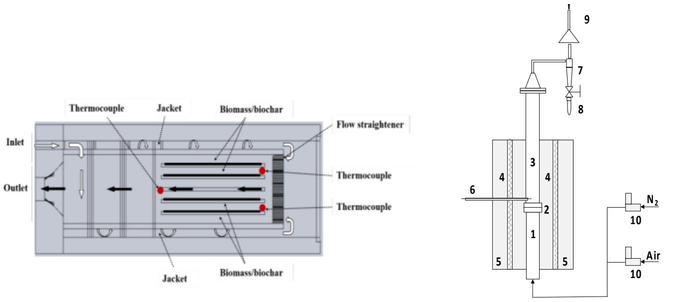
Biochar Carbon Removal (BCR) has emerged as a promising and technologically advanced approach for carbon sequestration. The long-term stability of biochar in the environment has been experimentally confirmed, and its durability in soil is commonly evaluated using well-established chemical and physical indicators, such as the hydrogen-to-organic carbon ratio (H/C_org), random reflectance, and the ratio of volatile matter to fixed carbon [1]. While the influence of pyrolysis temperature on biochar's properties has been widely studied, the roles of heating rate (HR) and residence time (τ) at a given temperature (T) have received comparatively less attention [2]. HR, defined as the time derivative of temperature (T(t)), characterizes the thermal evolution of biomass during its transformation into biochar, assuming a known initial temperature. During temperature transients, HR is critical, whereas the residence time τ becomes particularly important under isothermal conditions, where HR equals zero. This study explores the combined influence of heating rate (HR) and residence time (τ) at different final temperatures under both slow (~0.1–1 °C/s) and fast (~100–1000 °C/s) pyrolysis conditions [3] on the chemical and physical characteristics of biochar using a thermogravimetric analyzer coupled with Fourier Transform Infrared Spectroscopy (FTIR), as well as bench-scale batch reactors. Particular attention is given to the hydrogen-to-carbon (H/C) ratio, the volatiles-to-fixed carbon ratio, and porosity. A range of biomass feedstocks—representative of forestry, agricultural, and industrial residues—were selected based on their varying organic and ash content. The biomass samples were subjected to pyrolysis under different thermal histories (HR and τ), mimicking typical operating conditions for slow and fast pyrolysis in the 500–800 °C temperature range.



(**1**) Gas pre-heating section; (**2**) Gas distributor; (**3**) Fluidization column; (**4**) Electrical heaters; (**5**) Ceramic insulator; (**6**) Thermocouple; (**7**) Cyclone; (**8**) Char collection; (**9**) Stack; (**10**) Digital mass flow meters.

Figure 1: *Reactors for (a) slow and (b) fast pyrolysis tests*

References

[1] H. Sanei et al., « Assessing biochar's permanence: An inertinite benchmark». *Int. J. Coal Geol.*, *281* (2024), 104409.
[2] M. Bartoli et al., « Effect of heating rate and feedstock nature on electrical conductivity of biochar and biochar-based composites». *Appl. Energy Combust. Sci.*, *12* (2022), 100089.
[3] P. Giudicianni et al., « Inherent metal elements in biomass pyrolysis: a review». *Energy fuels, 35* (2020), 5407-5478.

Thermochemical reactions of iron and biomass within the H_2, energy, water nexus

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For the success of hydrogen economy in Europe, the most accredited scenarios assume that hydrogen will be produced from water electrolysis with the renewable energy of windmills or photovoltaic plants, or alternatively from biomass through thermochemical conversion processes such as gasification. Hydrogen shall then be transported in gaseous or liquid state through ships and pipelines. For long distances conversion to ammonia and shipping in cooled vessels appears the most feasible option so far.

However, a new alternative path is emerging recently for the long distance transport of hydrogen [1]. This is based on the use of metal carriers. Accordingly, green hydrogen produced in Africa or South Asia would be used to reduce iron oxides ($3Fe_2O_3+9H_2 \dashrightarrow 6Fe+9H_2O$). The reduced iron can be, later on, re-oxidized with H2O to produce hydrogen ($6Fe+9H_2O \dashrightarrow 3Fe_2O_3+9H_2$). Notably, iron powder is stable at room temperature and suitable for transport by ships and trucks. By this means, hydrogen can be carried over long distances in the form of a safe and stable solid (reduced iron), without the need for expensive pipelines or shipping infrastructure. In terms of energy-water nexus, this approach is also quite interesting, because at the hydrogen production site the combination of the iron ore reduction with water electrolysis leads to virtually zero water consumption, with significant benefit in dry regions.

Reduced iron is also a very interesting perspective fuel for the retrofitting of coal burners for carbon neutral power generation. Research along this path is facing an increasing momentum across the globe. As for reduced iron, so far, this is mostly produced, especially in countries like Australia, through reaction of iron ores with coke and, more in general, with carbon of fossil origin. The use of biomass as alternative reducing agent is an interesting low carbon option, but the mechanisms and kinetics of this reaction are not well established.

Reduction of iron ore with hydrogen and biomass are both interesting heterogenous reactions from the thermodynamic and kinetic point of view [2,3]. The role of structural changes and internal mass transfer add complexity to these reactions. Moreover, structure and reactivity can change over repeated cycles of operation. The present work will provide an overview of these aspects, addressing the perspectives and research gaps associated with the mentioned thermochemical conversion routes.

References

[1] NV report.number https://www.stiftung-klima.de/app/uploads/2024/10/DNV-Securing-Green-Hydrogen-for-the-German-Power-Sector_final-report.pdf

[2] Fabozzi, A., Cerciello, F., Senneca, O. Direct reduction of iron ore using biomass biochar: Reduction rate, microstructural and morphological analysis. Fuel, 383 (2025) 133976.

[3] Cerciello, F., Fabozzi, A., Yannakis, C., Schmitt, S., Narin, O., Scherer, V., Senneca, O. Kinetics of iron reduction upon reduction/oxidation cycles. International Journal of Hydrogen Energy 65 (2024) 337-347

How long-term research is supporting battery recycling: the Horizon Europe REMOVATE project

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It has been estimated that 400 GWh of EoL Li ion batteries (including scraps) will be available for recycling by 2040 [1]. Considering that worldwide governments are investing in electric vehicles these capacities are inevitably expected to grow. This trend makes ever more urgent the boosting of battery recycling for several reasons, e.g., the safe management of a huge amount of wastes including many toxic components, and the securing of healthy supply chains. Additionally, recycling will play a crucial role in developing a circular economy, by reducing the demand for virgin materials and the Europe's dependence from third countries. Indeed, one of the main strategies to remedy the uneven distribution of raw materials and the future supply issues is the development of effective and economical recycling strategies, the so-called urban mining, which is going to be forced by EU regulation [2, 3]. There are many obstacles in the way of the nascent LIB recycling industry, among which the most important are: 1) challenging recycling and recovery targets required by the Regulation; 2) low collection rate and poorly regulated collection strategies; 3) heterogeneity in input feedstock due the presence of different LIB chemistries; 4) lack of knowledge of LIB chemistry from producers due to IPR protection; 5) low selectivity of mechanical treatments; 6) poor global efficiency (up to now plastic and organic components are completely lost) and high cost of chemical processes [4]. There is evidence that recycling cannot be separated from reuse, which implies a strong effort toward materials/cell/battery pack redesign [4]. Similarly, to go towards a zero-waste recycling, non-metallic elements (such as electrolyte, solvents, salts and polymers) must be recycled back to use.

The Horizon Europe RENOVATE project aims at developing and demonstrating new circular economy solutions for the European battery value-chain, targeting the re-use of ~100% (95+%) of in-specification cell fractions (e.g. metallic foil, graphite, electrolyte, fluorinated compounds and cathode active materials) within the battery production chain, fostering a closed-loop circular approach (including direct recycling) that would reduce battery material waste going to landfill, increase the availability of battery precursors in the European battery eco-system, and demonstrate new added-value business cases for recyclers and battery materials users. All recycled materials are recovered over all potential streams (pre-customer scraps and EoL products). The goal is to support the green and digital transformation of the European battery industry to increase its competitiveness and promote its just growth path.

References

[1] Lithium-ion batteries recycling: market and innovation trends for a green future. Deloitte & CAS (2025).
[2] Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC (Text with EEA relevance). http://data.europa.eu/eli/reg/2023/1542/oj
[3] Batteries Europe Research & Innovation Roadmap (2025). https://batterieseurope.eu/.
[4] X. Zhang et al., *Chem. Soc. Rev.* ***2018****, 47, 7239.*

REGULAR ORAL

Insights on the effects of Pb speciation and contamination type on lignocellulosic biomass pyrolysis

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In the context of renewable energy and alternative fuels, "unconventional" lignocellulosic biomass is attracting great interest. An example of this biomass is represented by heavy metals contaminated biomass that comes from polluted sites (i.e. marginal lands). Pyrolysis is a promising thermochemical valorization treatment for contaminated biomass [1]; however, the presence of heavy metals raises environmental concerns related to both their release during the process [2] and the utilization of the contaminated pyrolysis products. Moreover, the presence of heavy metals can modify the pyrolysis mechanisms and, consequently, the properties of the pyrolysis products. However, the observed effects of heavy metals are correlated to their absolute concentration, disregarding any possible influence of their chemical speciation or of the contamination nature, which is an indication of the kind of bonding between the heavy metal and the biomass tissues [3].

This work investigates the transformations of lead (Pb), one of the most common soil contaminants, during pyrolysis of poplar biomass in a wide range of pyrolysis temperatures (400-800 °C) to study Pb distribution into the different pyrolysis products and its possible effects on the pyrolysis mechanisms. In particular, the effects of different Pb chemical forms typically found in the soil and of different mechanisms responsible for biomass contamination are investigated. Various aspects are considered: from the Pb behavior in terms of recovery in the biochar and its stability and speciation to the possible effects on biochar, bio-oil, and pyrolysis gas yield and composition.

Poplar biomass was doped focusing on two aspects: first, three different doping procedures with lead acetate ($Pb(CH_3COO)_2$) were applied to study the effect of Pb bonding type with the biomass structure. Then, poplar biomass was doped with two Pb salts (lead acetate and lead nitrate ($Pb(NO_3)_2$)) to investigate the effect of Pb chemical speciation. The treated and untreated feedstocks were treated under slow pyrolysis conditions at different temperatures (465, 600, and 800°C), and the resulting products were analyzed through different techniques monitoring Pb fate and products' properties variations.

The results show that Pb displacement among pyrolysis products, Pb chemical transformations and stability in the biochar are affected both by initial Pb speciation and Pb bonding with biomass tissues.

On the other hand, while the different Pb speciation results in different products' composition and properties, the simulation of different contamination types does not result in great variability among the analyzed samples.

In conclusion, when treating heavy metal contaminated biomass through pyrolysis, more importance should be given to the identification of the actual chemical speciation of the contaminants and their binding with biomass tissues, since these are two parameters that affect both heavy metal displacement and pyrolysis products' characteristics.

References

[1] M. Vocciante et al., « Enhancements in phytoremediation technology: Environmental assessment including different options of biomass disposal and comparison with a consolidated approach. », *J Environ Manage* (237), 560–568.

[2] C.M. Grottola et al., « Steam assisted slow pyrolysis of contaminated biomasses: Effect of plant parts and process temperature on heavy metals fate. » *Waste Management* (85), 232–241.

[3] S. Vassilev et a., « An overview of the chemical composition of biomass. » *Fuel* (89), 913–933.

A sustainable anode for Na-ion batteries based on holm oak waste-derived hard carbon and lignin binder

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Sodium-ion batteries (SIBs) represent one of the key-enabling technology for the ongoing energy transition. However, the economic success of SIBs relies on sustainable and low-cost electrode materials such as the bio-derived ones. Particularly, it is important to find an environmentally friendly alternative to the commercial binder polyvinylidene fluoride, which currently poses several concerns, as for the other perfluorinated alkylated substances (PFAS), in terms of high environmental impact. In this context, a holm oak waste biomass was used both for the production of hard carbon and as a source of lignin, a natural binder currently poorly valorized (Figure 1). A one-step pyrolysis of holm-oak waste followed by acid leaching were performed to obtain a hard carbon with low amount of impurities, good interlayer spacing and well-developed microporosity and surface area.[1] On the other hand, lignin has been extracted from holm oak waste feedstock through an organosolv process with a binary mixture of γ-valerolactone and water, obtaining a lignin with high level of purity. The obtained materials were combined to prepare a bio-based anode materials for SIBs, exhibiting around 200 mAh g-1 reversible capacity in Na half-cells cycled at 300 mA g-1, with promising rate capability and long cycling stability even at high current rates. The electrochemical results combined with the interfacial and post-mortem SEM analysis demonstrated the ability of lignin binder to ensure longstanding adhesion with hard carbon substrate, reflecting into electrodes with long cycle life and capacity retention.

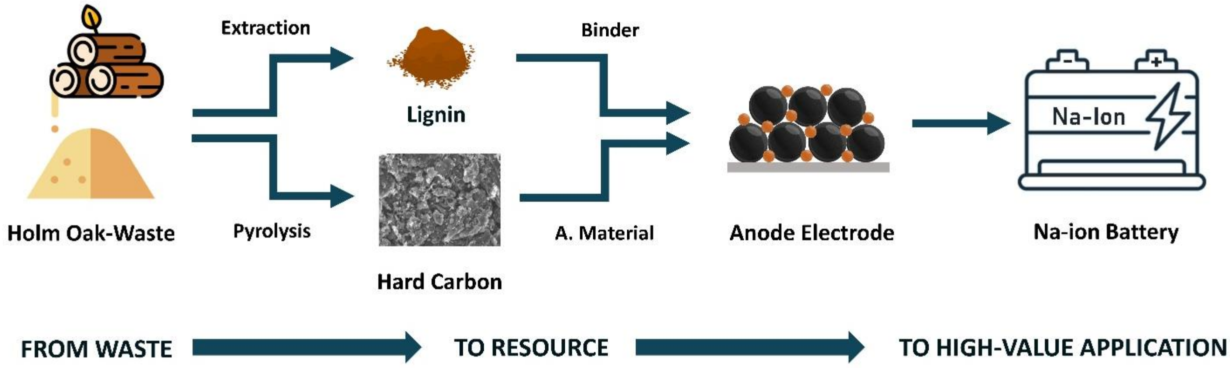

Figure 1: *Schematic representation of the holm oak-waste workflow*

References

[1] L. Bottoni, «Electrochemical Characterization of Charge Storage at Anodes for Sodium-Ion Batteries Based on Corncob Waste-Derived Hard Carbon and Binder», *ChemElectroChem, 10* (2023) e202201117

Understanding pH Effects on Nickel-Graphene Catalysts to Optimize the Oxygen Evolution Reaction

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Electrolytic water splitting to generate hydrogen and oxygen is one of the most promising ways to harness intermittent renewable power sources, store the provided energy as a clean-burning and sustainable fuel and mitigate greenhouse gas emissions. However, in the water splitting reaction, constituted by the hydrogen evolution reaction (HER) at the cathode and the oxygen evolution reaction (OER) at the anode, the HER rate is often limited by that of OER due to the more sluggish kinetics and the large overpotential of the latter, which lowers the overall energy conversion efficiency [1].

The OER typically proceeds via a four-electron proton-coupled electron transfer (PCET) mechanism, which may follow either a concerted or stepwise pathways, depending on factors such as the nature of the catalyst and the reaction conditions. [2].

IrO2 and RuO2 stands out as the best catalyst, though its scarcity, poor stability and high cost pose significant challenges. In this context, earth-abundant, non-noble metals are promising candidates to replace noble-metal catalysts, offering more cost-effective alternatives for large-scale applications.[3].

In this work we focused on the study and characterization of nanostructured electrocatalysts for the OER, based on non-precious metals such as Ni, Co, at different pH values. These materials, developed in collaboration with Dr. Penicaud and Dr. Hof at the CNRS Materials Science Laboratories in Bordeaux, were studied to assess the dependence of the OER mechanism on the electrolyte pH, as a mean to not only increase the overall performances but also to gain mechanistics insights into the role of alkalinity on the electron transfer process.

An actual dependence of OER activity on alkalinity was observed, with an increase in anodic current as the pH increased for each catalysts studied. This finding suggests a possible decoupling of electron and proton transfer, through the addition of a OH and/or OOH deprotonation step, thus separating and decoupling proton transfer from electron transfer and giving rise to pH-dependent behavior.

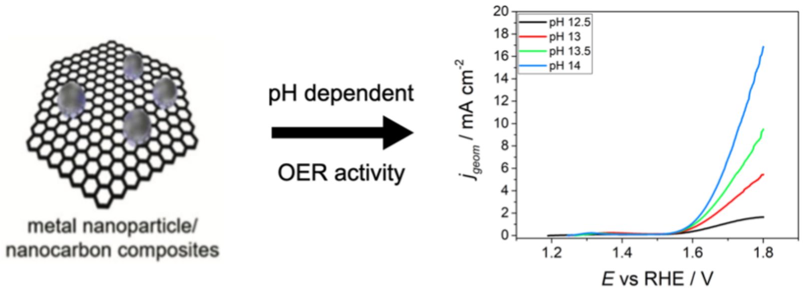

Figure 1: *Representation of nanostructured catalysts and the observed pH-dependent OER activity*

References

[1] Wang, Z., Goddard, W.A., and Xiao, H. « Potential-dependent transition of reaction mechanisms for oxygen evolution on layered double hydroxides. » *Nat Commun*, **14** (2023), 1

[2] Giordano, L., Han, B., Risch, M., Hong, W.T., Rao, R.R., Stoerzinger, K.A., and Shao-Horn, Y. « PH dependence of OER activity of oxides: Current and future perspectives. » *Catal Today*, **262**, (2016), 2–10

[3] Hof, F., and Pénicaud, A. « Graphenide Solutions: A Chemical Platform for Nanoparticle–Nanocarbon Composites.» *Chemistry - A European Journal*, **24** (61), (2018), 16246–16250

Influence of temperature and atmospheric conditions on heavy metal behaviour during biomass pyrolysis

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A comprehensive analysis of biochar production from the pyrolysis of contaminated lignocellulosic biomass is presented, with a focus on the influence of key process parameters—namely, temperature and reaction atmosphere (inert vs. reactive)—on biochar yield, chemical composition, and heavy metal behavior. Experiments were conducted under controlled conditions using inert (nitrogen) and reactive (CO_2 and steam) atmospheres, across a temperature range of 300°C to 700°C.

The results indicate that increasing pyrolysis temperature generally reduces biochar yield while promoting the formation of gaseous and liquid products, due to enhanced devolatilization and secondary cracking. Under inert conditions, higher temperatures produce biochar with increased aromaticity, elevated carbon content, and reduced oxygen levels—attributes desirable for long-term carbon sequestration and soil amendment.

As expected, reactive atmospheres further decrease biochar yield through gasification reactions, while enriching the gas phase with CO and H_2 [1]. The speciation and transformation of heavy metals during pyrolysis follow distinct pathways, influenced by temperature and atmosphere, which ultimately affect their distribution across pyrolysis products.

The nature of the carrier gas significantly impacts product yields and the behavior of lead (Pb) in the resulting biochar. Pyrolysis in CO_2 consistently yields more biochar than in steam (H_2O) or mixed atmospheres across all temperatures. At higher temperatures, CO_2 reacts with inorganic species, increasing the ash content in the resulting biochar. Conversely, steam promotes extensive volatile release and gasification, leading to lower biochar yields.

Pb recovery in biochar is reduced under steam-containing atmospheres (H_2O and Mix) compared to inert conditions, and both steam environments exhibit similar trends with temperature. These results highlight the dominant influence of H_2O in the mixed gas environment. In contrast, pyrolysis under CO_2 at low and intermediate temperatures maintains high Pb retention in the biochar, suggesting that pyrolysis in a CO_2 atmosphere favors the production of PTE-free (potentially toxic element-free) fuel vapors.

According to the sequential extraction protocol proposed by the Community Bureau of Reference (BCR) [2], pyrolysis transforms Pb into more stable chemical forms across all atmospheres, regardless of temperature. At lower temperatures, Pb tends to be stabilized (likely as silicates), following the trend $N_2 > CO_2 > \text{Mix} > H_2O$. At higher temperatures, this trend is reversed.

Overall, the interplay of pyrolysis temperature and atmosphere critically affects the efficiency and selectivity of the process for treating Pb-contaminated biomass, influencing both product distribution and heavy metal stabilization.

References

[1] C. M. Grottola et al., « Steam assisted slow pyrolysis of contaminated biomasses: Effect of plant parts and process temperature on heavy metals fate Title », *Waste Management Journal,* 85 (2019) 232-241

[2] G. Rauret, et al., « Improvement of the BCR three-step sequential extraction procedure prior to the certification of new sediment and soil reference materials« . *Journal of environmental monitoring*, 1(1) (1999), 57-61

Molten salt assisted algae pyrolysis for H_2 and capacitive carbon production

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Algae are competitive in terms of sustainable raw material supply and green energy production due to their rapid growth and rich composition of various elements. Molten salt opens up a new path for efficient thermochemical conversion of biomass by virtue of its unique liquid environment, high thermal conductivity and catalytic properties. This study investigates the feasibility of converting algae into capacitive carbon and hydrogen by using molten salts. In the presence of molten carbonates, the activated carbon obtained from algae possesses a high specific surface area of 2009.26 m2/g, a hierarchical porous structure and abundant oxygen- and nitrogen-containing functional groups. As a result, a high specific capacitance of 230.2 F/g is obtained. Besides, co-pyrolysis of algae and lignocellulosic biomass has been proved to increase the yield and capacitance of capacitive carbon. In the presence of alkaline molten salts, a stable hydrogen yield of 71.48 mmol/g-algae (86.10 vol.%) with minimal CO/CO_2 emissions (< 0.5 vol.%) can be achieved from algae. In addition, the hydrogen production mechanism and the influence of algae ashes are also analyzed through simulation and experiments. This study is expected to provide a scientific reference for the high-value conversion of algae.

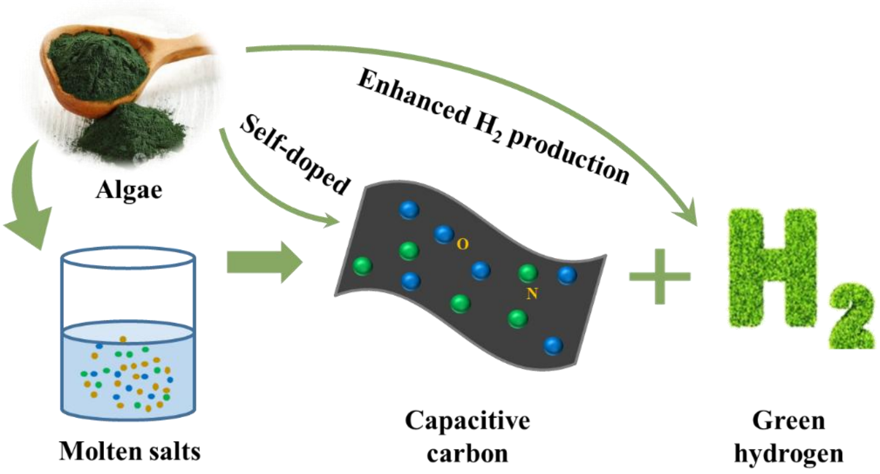

Figure 1: *Molten salt assisted algae pyrolysis for H2 and capacitive carbon production*

Bio-based molecules and dynamic covalent bonds for the development of recyclable and self-healing thermosets and coatings

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Growing environmental concerns and the depletion of fossil resources demand sustainable strategies for developing thermosetting polymers aligned with circular economy principles. Unlike thermoplastics, which are relatively easy to recycle, thermosets have long been considered non-recyclable due to their permanent crosslinked structures.

In this contribution, a vanillin-based photocurable resin was designed for circularity by incorporation of imine functionalities through a Schiff-base reaction between the aldehyde function of vanillin and amino groups of a diamine. Due to the crosslinked structure and imine linkages, the free-standing covalent adaptable network expressed self-healing and thermal reprocessability.

Furthermore, it could be chemically recycled by immersing in a diamine solution, which activated transimination. The obtained oligomeric product with amine-terminal groups could be utilized for production of new thermoset films [1]. The synthesized resins were employed for the development of composite vitrimeric coatings by incorporating functionalized silica nanoparticles at 2%, 5%, and 10% w/w relative to the monomer content. The formulations were applied onto different substrates, i.e. glass, wood and steel, and then cured through UV irradiation and thermal treatment to achieve crosslinking. The resulting coatings were evaluated for adhesion, anti-scratch and self-healing behaviour. The results demonstrated a strong adhesion of the coatings to the steel. Scratch resistance was assessed on glass substrates according with the Standard Test Method for Film Hardness by Pencil Test (ASTM D3363-22). The inclusion of silica nanoparticles embedded significantly enhanced the hardness of the coatings, effectively preventing the scratch formation compared to the coating without silica nanoparticles.

The self-healing and multiple-time self-healing properties of the coating were assessed by manually inducing surface scratches and evaluating their closure after thermal heating in a temperature range between 80°C and 120°C for few minutes. Results demonstrated that all coatings exhibited thermal self-healing behavior regardless of the substrate, with the most effective scratch recovery observed at silica nanoparticle loadings of 2% w/w and 5% w/w.

Finally, the possibility to remove the coatings from the substrate under specific conditions, thanks to the reversible nature of imine bonds, was also demonstrated supporting their reuse and sustainable end-of-life management.

References

[1] A. Liguori et al, «Photocurable extended vanillin-based resin for mechanically and chemically recyclable, self-healable and digital light processing 3D printable thermosets », *European Polymer Journal, 178* (2022) 111489

Electrochemistry as a polyvalent tool in the design of an industrially relevant process for recycling of spent lithium-ion batteries

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Lithium-Ion Batteries (LIBs) are ubiquitous electrochemical devices, from portable electronics to electric vehicles. The tight dependence of this technology from some critical materials is forcing the scientific and industrial community to find out effective strategies to recover such materials from the constantly increasing numbers of spent LIBs. Looking at the EU area, to achieve the stringent recovery rate defined by EU regulation for the coming years recyclers still need efficient hydrometallurgical recovery processes.

Despite the relatively simple working principle, plenty of specific features of LIB technologies (crafting process, plenty of cathode chemistries, shapes and dimensions) combined with the lack of standards in manufacturing, entail challenges for the recycling processes. Thus, the development of a robust multi-step process capable of working with batteries, of any types, is up to date the most plausible solution. Besides pre-treatment stage, which may include mechanical and separation steps together with chemicals ones aimed at recovering solvent and/or lithium electrolyte, binders, etc., the core of any hydrometallurgical recycling process employs the dissolution of metal oxides from positive electrode (i.e., leaching stage) and the recovery of the dissolved metals (i.e., precipitation, separation, refining).

In the present applied research project, carried out through a joint collaboration with an engineering company part of the Consortium of the European Battery Innovation project (IPCEI Batterie 2), we are contributing to develop an industrially relevant closed-loop process for LIBs recycling. In particular, after presenting the general flowsheet of the ongoing process, the speech will be focused on discussing the potential of electrochemistry in supporting the technological challenge.

In particular, case studies will be presented demonstrating application of electrochemistry to face at both analytical and synthetic practical issues. The discussion will be focused on:

- development of a in operando electrochemical protocols for the on-line monitoring of both i) leaching stage and ii) metal recovery stage;
- waste-stream recovery through a DoE study of an electrodialysis cell operating at intermediate scale between benchtop and pilot-scale one.

Acknowledgments

Mirko Magni thanks FSE-REACT-EU PON “RICERCA E INNOVAZIONE” 2014-2020 and Engitec Technologies SpA for co-funding his past researcher position and for supporting research period of the collaborators.

From Waste to Bioimaging: Fluorescent Carbon Dots Derived from Food Industry Residues

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Nowadays, research focusing on the control and use of nanomaterials in various fields, including life sciences, has become a key driver of innovation. In this context, the UNAT project focuses on the development of ultra-small (~10 nm), multifunctional carbon-based nanohybrids (NHs), functionalized with metal atoms for applications in cancer diagnostics and therapy. A key innovation lies in the sustainable synthesis of these nanomaterials from food industry wastes, aligning with circular economy principles by converting biomass into high-value photoluminescent materials. Carbon dots (CDs) are a class of carbon-based nanomaterials known for their strong luminescence, excellent water dispersibility, low toxicity, and high biocompatibility - making them attractive for biomedical applications including drug delivery and bioimaging. In this work, CDs were produced from food industry by-products, in particular chestnut and peanut shells. These lignocellulosic biomasses, rich in cellulose (25–30%), hemicellulose (22–28%), and lignin (30–40%), represent a naturally abundant and promising raw carbon source for photoluminescent nanomaterials. Three main approaches were explored for synthesizing CDs and tuning their chemical and photophysical properties, namely a controlled combustion reaction, a microwave-assisted carbonization and a basic hydrolysis for lignin and hemicellulose extraction from the nut shells. CDs were initially produced by thermal treatment in air of milled nut shells, followed by purification of the CD dispersion. As-synthesized CDs possessed excellent water dispersibility thanks to their abundant negatively charged surface groups, good luminescence properties, and were successfully applied for in vitro cell imaging. Indeed, CDs were not cytotoxic to fibroblasts up to 0.5 µg/µL and retained a good luminescence after cellular internalization [1]. In addition, the as-produced CDs showed a pH-dependent luminescence and may, therefore, serve as cellular pH sensors. In a second instance, gadolinium-doped CDs (Gd-CDs) -to be used as contrast agents in magnetic resonance imaging (MRI)- were produced via a microwave-assisted synthesis, followed by multistep purification. The longitudinal relaxation time (T1) of Gd-CDs was measured to assess the success of the synthesis and to check whether the gadolinium was sufficiently strongly complexed within the carbon structure [2]. The efficacy of Gd-CDs in MRI scanners was then evaluated using a mouse phantom model that is transparent to magnetic radiation. Gd-CDs showed a good potential for use as positive contrast agents, as a significant contrast enhancement was observed in the MRI scans, particularly at 11.7 T. As both of the above methods resulted in blue-emitting CDs with limited quantum yield, a different approach based on the extraction of lignin from the nut shells was subsequently used to 1) obtain CDs with improved quantum yield and 2) tune their emission in the red region to achieve deeper tissue penetration than blue-emitting CDs. Basic hydrolysis of the milled nut shells resulted in the cleavage of cell walls, leaving the cellulose as solid residue and lignin and hemicellulose as mother liquor. Subsequently, p-phenylenediamine (p-PD) was added to the mother liquor to red-shift the emission of the CDs and the solution was microwaved. This treatment produced CDs with a wavelength-dependent emission and a marked red emission at 282 nm. Our study proves that fluorescent CDs can be synthesised in several ways from food industry by-products, thus giving waste materials a second life. By adjusting synthesis parameters, CDs with tunable physicochemical and photophysical properties can be developed for diverse biomedical applications, including imaging and diagnostics.

References

[1] F. Mancini *et al.*, ‘Fluorescent Carbon Dots from Food Industry By-Products for Cell Imaging’, *J. Funct. Biomater.*, 2023

[2] K. Paliienko *et al.*, ‘Green Synthesis of biocompatible Gd^{3+}-doped Ultrasmall Carbon-based Nanohybrids from Coffee Wastes’, *Carbon Resour. Convers.*, 2023

Hydrothermal liquefaction of mixed plastic waste: Conversion and resource recovery

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Handling plastic wastes and improving their management have become major concerns of our time, especially due to current global environmental issues. The possibility to produce oil and chemicals from waste can significantly reduce the volume of waste plastics ending up in landfills, enabling its valorization and thereby lowering waste emissions. Up to now, only 30% of plastics is recycled globally, primarily through mechanical processes, highlighting the need to improve the recycling processes and move toward a more circular economy for plastics[1]. Hydrothermal liquefaction (HTL) is a thermochemical process than can convert many typologies of polymers into chemicals and monomers using water as solvent. In HTL environment, plastics are broken down into smaller oligomers and monomers via hydrolysis. This is followed by dehydration, decarboxylation, and deamination, generating reactive intermediates that recombine to form final products[2]. This work investigates the use of mixed plastic waste as HTL feedstock at subcritical conditions. Mixed plastic waste is the residue of the sorting process to select plastic suitable for mechanical recycling; it consists of a heterogeneous mixture of plastics and may contain other materials such as paper, glass and organics residues. FTIR analysis revealed the presence of different typologies of polymers (e.g., PE, PP, PET, PS, PU, PVC) and paper. Goal is to investigate if sub-critical HTL could decompose polymers containing heteroatoms to recover valuable compounds (i.e. monomers) and to obtain a solid phase composed only by polyolefins (PP and PE) which could be processed to produce renewable fuels.The HTL experiments were performed in a 20 mL stainless-steal reactor at different temperatures (280, 300, 330°C) and reaction times (10 and 30 minutes). Additionally, the influence of feedstock particle size will be analyzed, as this aspect is crucial in determining the cost of the pretreatment processes required before HTL. The percentage yields of the products showed approximately 82,9% solid, 4,5% aqueous phase, 5,5 % bio-oil, and the gas phase, including losses, was calculated by subtraction, resulting in around 7.1% at 300°C. Under subcritical conditions, the obtained solid product is expected to consist of decomposition products from organics and plastic materials such as paper, PET, PU, and PVC, and plastics that do not decompose (e.g., PE, PP, and PS). Undecomposed plastics were separated and terephthalic acid (TPA) was recovered from solid fraction. Mixed plastic waste exhibited varying amounts of undecomposed plastics depending on granulometry. The coarse granulometry (>1cm) showed the highest presence of undecomposed plastics, around 80%, with a very low TPA recovery rate of approximately 20% under all operating conditions. The lowest amount of undecomposed plastics was observed in the medium granulometry waste (1-0.335 cm), which also had the highest TPA recovery, accounting for 50% of HTL feedstock. These results suggest a high PET content in the feedstock, which was confirmed by GC-MS analysis of the aqueous phase. The analysis revealed that, in all operating conditions, the mixed plastic waste with medium granulometry contained approximately 80% ethylene glycol.

Mixed plastic waste is shown to be a viable feedstock for HTL under subcritical conditions, with particle size significantly affecting plastic decomposition and TPA recovery, while polyolefins remain largely undecomposed. Further valorization could be achieved through a second HTL step under supercritical conditions.

References

[1] M. G. Zaman *et al.*, "Biofuel Production Boosted by Plastic Waste: Co-Hydrothermal Liquefaction of Plastic and Biomass toward Sustainable Energy," 29, 2025, *American Chemical Society*. doi: 10.1021/acs.iecr.4c03663

[2] E. Tito, et al. "Multilayer plastic film chemical recycling via sequential hydrothermal liquefaction," *Resour Conserv Recycl*, 197, 2023, doi: 10.1016/j.resconrec.2023.107067

Quasi-solid electrolytes/membranes based on zeolite A for safer batteries

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Rechargeable batteries are an important pillar toward electrification, which is essential to reduce the greenhouse emission and achieve a greener future. Despite the remarkable advance on lithium-ion batteries (LIBs), this class of storage energy device cannot support alone the stablished goals regarding fossil fuel use diminution, due to lithium availability for example. Therefore, other technologies must be developed as well, like redox flow batteries, sodium-, zinc-, potassium-, calcium-based batteries and so on [1]. Another important topic regarding LIBs is safety, that as produced today with organic liquid electrolytes remains with some risks associated with thermal, electric or mechanical runaway [2]. On the other hand, aqueous electrolytes are safer, but the electrochemical stability window is much more limited. Therefore, gel, solid and quasi-solid electrolytes can combine safety with a wider voltage, being the low ionic conductivity the main drawback to develop. Lu and col have demonstrated that water confined inside a metal organic framework (MOF) do not react with alkali-metal allowing remarkable stability and energy density for water-based rechargeable batteries [3].

In the present work we used zeolite a (LTA) as water confinement agent (Structure and morphology shown at Fig. 1a and 1c) instead of a MOF to produce membranes with several polymers (PVDF, PEO, Chitin, Chitosan) as binders, looking for cheaper and more sustainable formulations with satisfactory electrochemical performance. Different formulation and protocols were employed to improve mechanical properties like some flexibility achieved with PEO (Fig. 1b) and permeability/microporosity with PVDF (Fig 1d). Initial electrochemical test with lithium in anode-free (Fig 1e) and symmetric configurations show that the water present is properly trapped inside the LTA pores and good stability was achieved over 300 h with 1 mA cm-2 of current density. Continuous improvement with lithium systems will be later applied for other metal-based batteries.

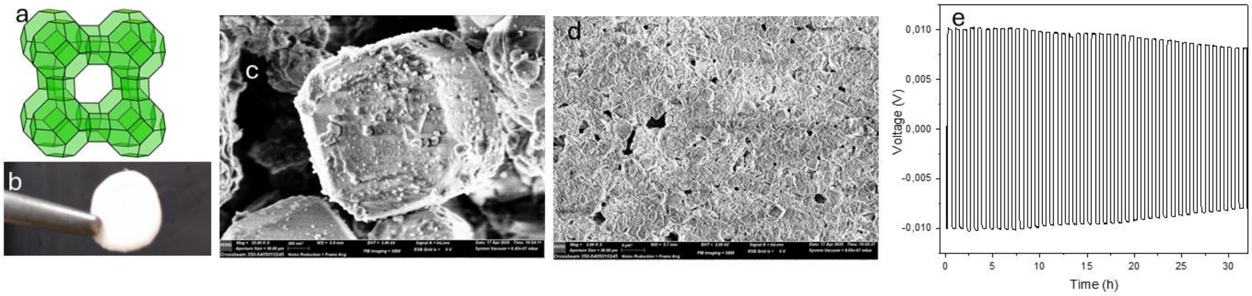

Figure 1: *LTA structure (a), LTA:PEO 9:1 photo (b), LTA micrography (c), LTA:PVDF 9:1 micrography (d), Galvanostatic charge-discharge first cycles profile for Cu //Li after 2 mAh cm-2 deposition with current density of 1 mA cm-2 and energy density of 0.4 mAh cm-2 with LTA:PVDF 4:1 membrane wetted with 1M LiPF6 in PC/DEC*

Acknowledgments

This work is supported by National Recovery and Resilience Plan (NRRP), Mission 04 Component 2, Investment 1.5—Next Generation EU, PE2 NEST—Network 4, Energy Sustainable Transition, Spoke 6 Energy Storage.

References

[1] H. Sun, et al., Rational design and construction of aqueous multivalent metal ion battery systems, *J. Mater. Chem. A*,13 (2025) 17159-17196
[2] S. Li, et al. Development and current status of electrochemical energy storage materials, *J. Phys. Chem. Solids*, 207 (2025) 112917
[3] X. Yi, et al., Quasi-Solid Aqueous Electrolytes for Low-Cost Sustainable Alkali-Metal Batteries, *Adv.Mater.* 35 (2023) 2302280

Pyrolysis of polyolefins: Kinetic and experimental study

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Plastic waste (PW) has become one of the major environmental challenges in recent decades, contributing significantly to pollution and landfill saturation. Recycling and enhancing the circularity of plastic waste are key strategies to address the issues related to the end-of-life management of these materials. When plastic waste consists of a single polymer, mechanical recycling is the most effective approach to recover the material and reuse it in new products. However, mechanical recycling cannot achieve complete recyclability, as it leads to the deterioration of the material's physical properties. Consequently, only 20–40% of a product is typically made from recycled material. In such cases—and particularly when plastic waste is composed of mixed polymers—chemical recycling represents a viable alternative. Chemical recycling consist in converting end-of-life plastic materials into chemicals that can be used as a feedstock for the production of new petrochemicals and plastics and into fuels [1]. Among chemical recycling processes, pyrolysis decomposes organic macromolecules into smaller molecules in inert atmosphere and in a wide range of temperature (400-1000 °C). Aim of this work is to study secondary gas-phase reactions occurring during the pyrolysis of High Density Polyethylene (HDPE) by coupling a newly designed lab-scale apparatus and detailed kinetic modeling. The experimental tests have been conducted using a tubular quartz reactor 40 cm long with a 1 cm of internal diameter heated by an electrical resistance of 25 cm located in the middle of the reactor. Ar is used as carrier gas. When it reaches an isothermal condition an amount of 0,25 g of HDPE is inserted into the heated zone of the reactor. The influence of temperature (700-800 °C) and residence time on the products was evaluated. Gas phase was analyzed by Quantitative Mass Spectrometer and the vapor, such as benzene and toluene, after being trapped in n-decane, are analyzed with GC-MS. The model consists of two communicating frameworks, a primary degradation mechanism [2] occurring in melted phase, and a secondary gas-phase reaction model describing the evolution of a surrogate mixture resembling the primary fragmentation products. The experimental setup is approximated using a simplified network composed of a semibatch reactor for the first degradation step in melted phase and a homogeneous plug flow reactor (PFR) resembling the gas-phase secondary cracking.
Preliminary results in Fig.1 show a comparison between model and experimental data demonstrating a good agreement between model and experimental data when in the model a dilution of only 5 % of the products with Ar is considered, a sensitivity analysis for this parameter was conducted.

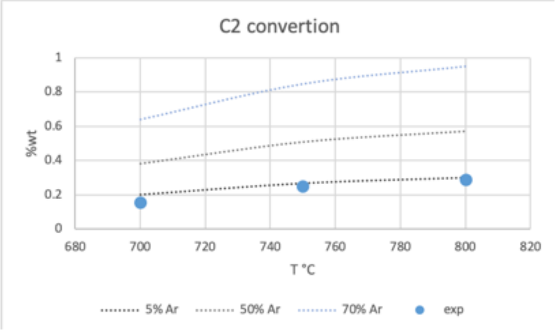

***Figure 1**: Total conversion of C2 species: comparison between experimental data and model.*

Reference

[1] O. Dogu, M. Pelucchi, et al. 'The chemistry of chemical recycling of solid plastic waste via pyrolysis and gasification: State-of-the-art, challenges, and future directions', *Progress in Energy and Combustion Science,* 2021, 84, 100901.

[2] Locaspi, Andrea, et al. "Towards a lumped approach for solid plastic waste gasification: Polyethylene and polypropylene pyrolysis.", *Waste Management*, 2023, 156, 107-117.

Selective recovery and valorization of permanent magnet content from end-of-life electric motors

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The demand for NdFeB permanent magnets is rapidly increasing due to their essential role in clean energy technologies. However, their production is heavily dependent on rare earth elements (REEs), whose extraction and processing are largely concentrated in a few regions, resulting in geopolitical vulnerabilities [1]. Recycling offers a promising alternative to reduce reliance on these limited sources, but the development of a dedicated recovery infrastructure remains limited [2]. Moreover, REE-containing materials are often dispersed within ferrous waste streams, making effective recovery challenging due to their dilution [3].

This study investigates the recovery of NdFeB magnet fractions from end-of-life electric motors through a combined thermal and mechanical treatment approach. The motors were thermally treated to eliminate permanent magnetization, induce thermal stress and facilitate mechanical disintegration. Subsequently, the motors were shredded and processed using magnetic separation in an authorized treatment facility. Additional laboratory procedures and elemental analyses were performed to assess the distribution of magnetic material across various waste fractions.

The results showed that part of the magnetic material was not captured by the drum magnet separator and remained embedded within the non-ferrous waste matrix. This material was later subjected to a magnetic screening step, which proved effective in capturing finer ferromagnetic particles, ultimately yielding a magnet-enriched fraction.

In addition to material recovery, the study also included energy-related assessments of the overall process. These evaluations provided insights into the energy demand associated with each processing step, supporting the identification of potential optimizations for improving energy efficiency.

Overall, the findings highlight the potential for refining pretreatment and separation strategies to enhance NdFeB recovery and separation efficiency, contributing to the development of more sustainable and energy-conscious magnet recycling systems.

References

[1] IEA. *Global Critical Minerals Outlook 2024*; 2024
[2] IEA. Recycling of Critical Minerals. 2024
[3] Bandara, H. M. D.; Darcy, J. W.; Apelian, D.; Emmert, M. H. Value Analysis of Neodymium Content in Shredder Feed: Toward Enabling the Feasibility of Rare Earth Magnet Recycling. *Environ. Sci. Technol.* 2014, *48* (12), 6553–6560

Hydrothermal liquefaction as a valorization pathway for biomass and plastic wastes

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The production of advanced biofuels from waste biomass has attracted significant interest as a potential solution to the pressing issue of global warming. Among the various technologies, hydrothermal liquefaction (HTL) has demonstrated compelling performance for the energy exploitation of organic waste. HTL operates in an aqueous environment at subcritical temperatures (250–374 °C) and pressures (4–25 MPa) sufficient to prevent feed vaporization, with a solid-to-water ratio of up to 30 wt%. Typically, the target product of HTL is an oil phase (biocrude) that, after upgrading, can be used as a substitute for fossil fuels. The process also yields a hydrochar, a gas phase rich in CO2, and an aqueous phase containing residual organics.

This presentation provides an overview of recent advancements in HTL. While thermochemical processes using waste aim for feedstock flexibility, it is well established that the distribution and characteristics of HTL products are heavily influenced by feedstock composition [1]. In particular, biocrude yield has been shown to be increased following the trend lipids > proteins > carbohydrates present in the feedstock. Moreover, strong interactions between biochemical constituents can lead to synergistic or antagonistic effects, especially when proteins and carbohydrates are present in comparable amounts [2]. Far less is known about the effects of inorganics present in the feedstock. A broad screening of the most common metal cations (Na, K, Mg, Ca) in different inorganic forms has shown that even in limited concentrations, inorganic salts can significantly affect biocrude production and residual solid yields. Specifically, sodium and potassium, particularly in their more basic forms, tend to enhance solid conversion and increase biocrude production.

In terms of applications, HTL offers a significant advantage over dry thermochemical technologies such as pyrolysis and gasification for processing high-moisture waste streams. These conventional methods require energy-intensive drying pretreatments, whereas HTL can directly process wet biomass. One illustrative example is the valorization of digestate, a diluted slurry byproduct of anaerobic digestion. Converting digestate via HTL can reduce disposal burdens, increase fixed carbon retention in the hydrochar, and enable the co-production of biocrude, which holds economic value [3].

Finally, recent research has explored the use of HTL for valorizing plastic waste. Due to the ionic nature of subcritical HTL, it is possible to selectively convert condensation polymers—which contain heteroatoms in their structure—into monomers that can be used to produce virgin polymers. This process enables the selective chemical recovery of condensation polymers (e.g., PET, PA) from multi-polymer materials that are unsuitable for mechanical recycling [4]. Additionally, controlled dechlorination of difficult-to-valorize PVC can be achieved via subcritical HTL, resulting in an almost fully dechlorinated solid [5].

References

[1] ARK Gollakota et al. «A review on hydrothermal liquefaction of biomass», *Renew Sustainable Energy Rev, 81* (2018) 1378-92

[2] E. Tito et al., «Exploring HTL pathways in carbohydrate–protein mixture: a study on glucose–glycine interaction», *Biomass Convers Biorefin, 13* (2023), 16385-16404

[3] E. Tito et al., «Hydrothermal liquefaction of digestate from the organic fraction of municipal solid waste: Optimization of operating parameters», *Energy Convers Manag, 336* (2025), 119881

[4] E. Tito et al., «Multilayer plastic film chemical recycling via sequential hydrothermal liquefaction», *Resour Conserv Recycl, 197* (2023), 107067

[5] E. Tito et al., «Sequential hydrothermal dechlorination and liquefaction of PVC», *Energy Convers Manag, 304* (2024), 118228

Preliminary investigation on pyrolysis-anaerobic digestion integration for the safe exploitation of digestate

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Digestate is the ultimate unavoidable waste of biorefining and, more in general, anaerobic digestion (AD). This material, which is a Mton resource, is not anymore suitable for biological conversion but still retains a significant amount of nutrients/carbon/energy content. Due to chemical proprieties of digestate, there is still no technical solution for small scale thermochemical conversion of digestate into a drop in energy carrier. Py-AD concept depolymerises digestate with pyrolysis, thus providing water-soluble pyrolysis products (WS) and pyrolysis gases to anaerobic digestion (performed in the presence of biochar co-product), to obtain additional biomethane. Digestate was subjected to slow pyrolysis (at 400°C and 550°C) followed by gasification in CO_2/H_2O atmosphere at 900°C. Pyrolysis/gasification products were quantified and characterized providing a detailed mass, energy, carbon and nitrogen balance of the process. WS was analysed in detail for the first time, characterizing a satisfactory (45%) amount of WS on a molecular basis. To address the challenges related to AD of WS and gases AD, a novel pyrolysis-anaerobic digestion (PyAD) concept was investigated. The developed system uses a continuously stirred tank reactor (CSTR, for WS) connected to a Char-Based Sparger reactor (CBSR, for gases). The CSTR receives char from the gasification stage and both WS and gases. In this reactor, to address the ammonia issue, a lab-tested approach, namely cyclic aeration of biochar (which partially nitrifies and/or strips ammonia) is used. This method exploits an important feature of AD-activated biochar, it acts as a weak acid exchange resin and concentrates a significant amount of ammonia on the solid. In practice, a portion of the biochar is withdrawn from the bottom of the CSTR, exposed to air and/or stripped and put back into the CSTR, with an extremely simple procedure that stabilizes the aqueous ammonia concentration below 3000 mgNH$_3$-N/L even when processing WS with 14 000 mgNH$_3$-N/L and C/N lower than 10. The developed system allowed o process up to 5 gCOD/L d of WS and syngas, delivering biogas and an interesting nutrient enriched biochar. Overall digestate to biomethane conversion yield was 50% and AD-treated biochar showed interesting chemical features (pH<8.2, low PAHs content) that suggests a significant agronomic value.

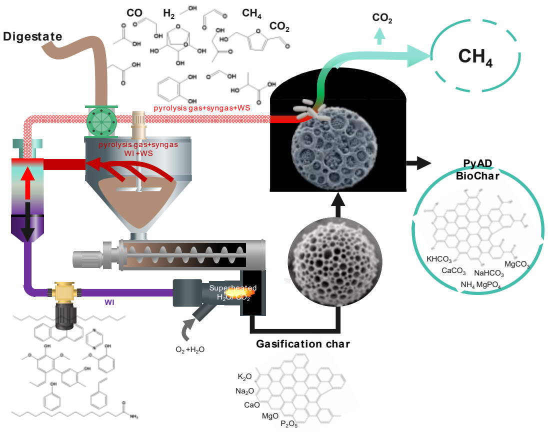

Figure 1: *Graphical description of PyAD concept for digestate valorisation*

Improve Renewable Energy Integration through Pumped Hydro Storage: STORE2HYDRO Project

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In response to the unprecedented decline in global natural resource endowments, the nexus framework is gaining increasing influence on resource management practices. [1] In particular, numerous recent studies have focused on understanding the existing interrelationships and interdependencies between water and energy, including Life Cycle Assessment (LCA) analysis to support strategies designed to reduce their depletion. [2] In this context, the STORE2HYDRO project aims to increase Europe's electricity storage capacity for non-dispatchable renewables through Pumped Hydroelectric Systems (PHS). PHS works by pumping water to higher reservoirs with surplus energy and releasing it to generate electricity when needed, enhancing the connection between renewable sources, utilities and the electrical grid. The main operational principle is to guarantee the satisfaction of the utility electricity demand, giving priority to energy directly sourced by renewables, followed by the PHS, and finally the grid. Complementarily, LCA is applied to compare the environmental performances (e.g., climate change and water depletion) associated with the different water and energy flows occurring in Scenario 1, which involves the presence of the PHS plant, against a Scenario 0, where the PHS plant is not present. The PHS's performance' , yielding all energy and water flows as depicted in Figure 1a, is based on a mathematical model, coded with Python. The LCA study adopts a cradle-to-grave approach and covers the entire lifetime of the PHS system (100 years). The selected functional unit is 1 kWh consumed by the utility. According to Figure 1b, by moving from Scenario 0 to Scenario 1, it emerges a saving of 0.124 kgCO$_2$ eq/kWh, demonstrating the advantages associated with the penetration of non-dispatchable renewable energy sources. Future developments of the presented work will extend the evaluation to a wider spectrum of environmental categories, including water consumption. Nexus analysis confirmed to be crucial for understanding resource relationships and predicting flow changes. In particular, its combination with LCA offers a broader view, allowing to quantify the reduction of environmental impacts and resource depletion.

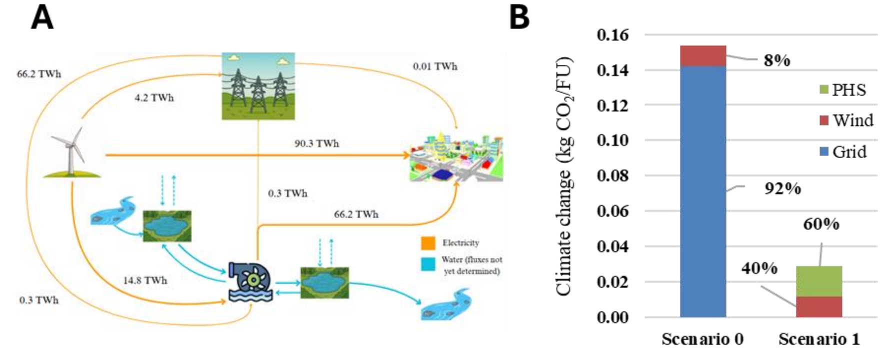

Figure 1: *A)Energy and water flows of Scenario 1, B)Results of climate change impact from the two scenarios.*

References

[1] Font Vivanco D. et al. (2019). J. Ind. Ecol. (2019) 23:241–52. https://doi.org/10.1111/jiec.12704
[2] Arfelli F, et al., (2022). Resour. conserv. recycl.185. https://doi.

POSTER PRESENTATIONS

Biomass pyrolysis for MILD combustion and dry reforming feedstocks production

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Pyrolysis is an established process for biomass thermal treatment. However, the potential use of the different pyrolysis products is still being widely investigated due to their complexity and to the great variability of their properties depending on many parameters (e.g. operational parameters of the process, feedstock biomass characteristics, pre- and post-treatments). In the framework of the project MINICOR - MILD Combustion with Nitrogen and Carbon Dioxide Reforming (Figure 1), funded by the European Innovation Council, biomass residues are processed through pyrolysis to form different products: permanent gases, bio-oil and biochar. Biochar is designed for nitrogen adsorption from several sources, while the other products can be converted through combustion or dry-reforming under MILD conditions for energy or bio-fuel production, given its high fuel flexibility, high efficiency and low environmental impact. Straw, hardwood (poplar) and softwood (mixed residues) have been selected as biomass feedstock. Temperatures 360, 450, and 600 °C and a heating rate of 10 °C/min were selected for the experimental tests of the selected biomasses. Moreover, the effect of solid holding time at 0 and 1 h was considered. The permanent gases produced during pyrolysis were analyzed online via micro-Gas Chromatography, and the corresponding heating value was subsequently calculated. The bio-oil was collected and analyzed offline with different analytical techniques, such as Gas Chromatography coupled with Mass Spectroscopy (GC-MS) for oxygenated compounds identification and quantification, and Karl Fisher Titration for water content determination. The gas composition analysis shows that for pyrolysis temperatures higher than 450 °C, all the combinations of feedstocks, temperatures and solid holding times result in a gas mixture suitable for MILD combustion. The bio-oil composition gives fundamental information on how to create surrogates (as single species or as a mixture) to gain insight into the reaction mechanism and the optimal operating condition for the non-catalytic dry reforming of such complex feedstock.

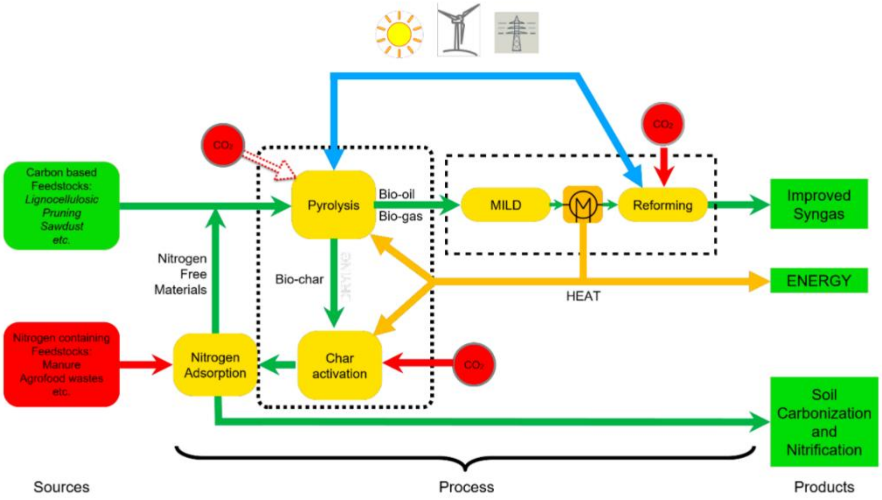

Figure 1: *MINICOR flow diagram*

Oligothiophene and oligoselenophene based Zirconium MIXMOFs for water quality control

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Metal-organic frameworks (MOFs) have garnered significant attention in recent years for a variety of applications, including gas storage and release, energy systems, catalysis, chemical sensing, and removal of water pollutants[1]. A key advantage of MOFs lies in the ability to finely tune their properties, which depends on the nature of both the metal centers and the organic linkers which are factors that govern their porosity, chemical stability, and adaptability[2].

Notably, zirconium-based MOFs (Zr-MOFs) offer enhanced resistance to aqueous environments, thanks to the strong coordination between Zr^{4+} ions and the oxygen atoms of carboxylate-functionalized linkers commonly used in their synthesis, this making them suitable for water treatment [3].

Here, focusing on the development of innovative materials for the adsorption and sensing of emerging contaminants from drinking water[4], we introduce a new class of Zr-MOFs based on oligothiophene and oligoselenophenes linkers. A class of fluorescent trimers bearing carboxylic groups at the oligomer edges, was synthesized by Stille cross coupling reaction[5] and then used for the preparation of Zr-MOFs. The so obtained MOFs were studied as sorbent of different classes of emerging contaminants including perfluoroalkyl substance (PFAS), pharmaceuticals, antibiotics and endocrine disruptors. Adsorption performance in relation to the MOF structure will be discussed.

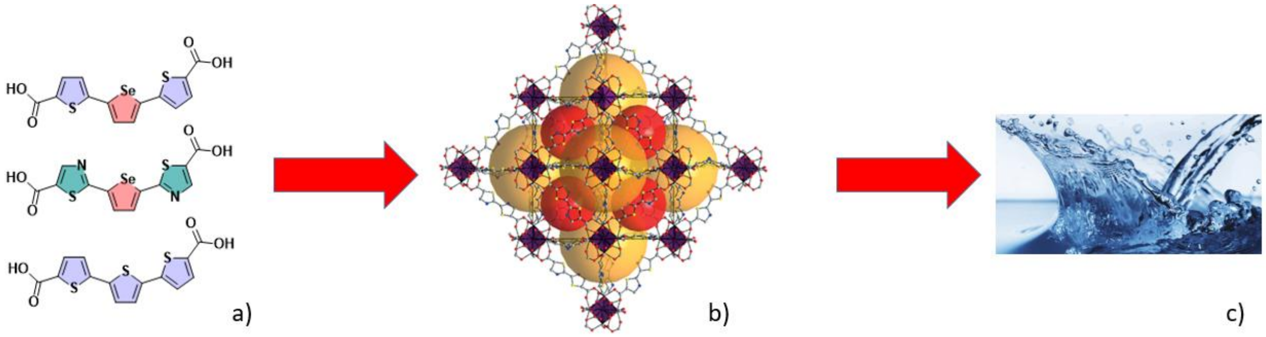

***Figure 1**: a) Synthesis of thiophene and selenophene based linkers; b) Zr-MOF preparation and characterization; c) targeted application: water remediation*

References

[1] V.F. Yusuf et al. ACS Omega 2022, 7, 44507
[2] A.E. Baumann, D.A. Burns, B. Liu & S. Thoi, Communications Chemistry 2019, 2, 86
[3] G. Provinciali et al, ACS EST Water 2024, 4, 2339
[4] M. Melucci et al Nature Water 2025, 3, 369
[5] A. Trifoglio et al, J. Mater. Chem. A, 2025, 13, 4587

Transformation of argan shell bio-waste into high-performance carbon materials for supercapacitor applications

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This presentation explores the transformation of Argan shell bio-waste into high-performance carbon materials for supercapacitor applications, with particular focus on evaluating different electrolyte systems. Using a controlled carbonization and activation process, we fabricated porous carbon electrodes with tailored porosity and high surface area to enhance charge storage capabilities.

The study systematically investigates the electrochemical performance of Argan-derived carbon across multiple electrolyte systems, including aqueous, organic, ionic liquid, and water-in-salt electrolytes. Our comprehensive analysis reveals how electrolyte selection critically influences three key performance parameters: capacitance, energy density, and cycling stability.

Key findings show that while aqueous electrolytes deliver high capacitance, they exhibit a limited voltage window. In contrast, both organic and ionic liquid electrolytes enable higher energy density through their wider operational voltage ranges. The water-in-salt electrolyte system emerges as a balanced solution, offering both competitive performance and enhanced safety features.

This work demonstrates the versatility of Argan shell-derived carbon as an efficient, low-cost, and renewable electrode material. The results provide valuable insights for electrolyte optimization in next-generation supercapacitor development, while simultaneously promoting sustainable waste-to-energy solutions.

References

[1] T. Chafik, « Nanoporous carbonated materials prepared from the shell of the argan fruit » 1–14, 2012
[2] O. Boujibar, A. Souikny, F. Ghamouss, O. Achak, M. Dahbi, T. Chafik, « CO2 capture using N-containing nanoporous activated carbon obtained from argan fruit shells», Journal of Environmental Chemical Engineering, 6 (2) 1995-2002
[3] M. Dahbi, M. Kiso, K. Kubota, T. Horiba, T. Chafik, K. Chafik, T. Matsuyama, S. Komaba, «Synthesis of hard carbon from argan shells for Na-ion batteries», *Journal of Materials Chemistry A*, 5(20) 9917-28.
[4] L. Suo, O. Borodin, T. Gao, M. Gao, J. Ho, X. Fan, C. Luo, C. Luo, K. Xu « Water-in-salt" electrolyte enables high voltage aqueous lithium-ion chemistries », Science, 350(6263) 938-43
[5] M.S. El Halimi, F. Poli, N. Mancuso, A. Olivieri, E.J. Olivieri, M. Calvaresi, T. Chafik, A. Zanelli, F. Zanelli, « Circumneutral concentrated ammonium acetate solution as water-in-salt electrolyte » *Electrochimica Acta*, 389, 138653.
[6] El Halimi, M.S. El Halimi, A. Zanelli, F. Soavi, T. Chafik, « Building towards supercapacitors with safer electrolytes and carbon electrodes from natural resources », *World*, *4*, 431-449

Eutectic solvents and microwave heating for a sustainable lignin extraction and fractionation from biomass

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In the last years, the interest in lignin has risen thanks to its potential valorization into materials, industrial building blocks, and lignin-based polymers. Eutectic solvents (ES) are sustainable, economic, and safe solvents that can extract and solubilize lignin under mild conditions[1]. After the extraction, fractional antisolvent precipitation can be used to narrow the lignin polydispersity and increase its suitability for numerous applications[2]. A detailed characterization of ES-lignins is necessary to determine its suitability for different valorization strategies. Analytical pyrolysis-based techniques can provide a variety of information on ES-lignins[3], but very little information is available in the literature on this topic. In addition, no result is available on the properties of ES-lignins obtained with fractional precipitation. In this study, we extracted lignin from four different substrates (fir, oak, giant reed, Neptune grass) using ES and microwave-assisted heating. Fractional antisolvent precipitation of the extracts was then performed and the procedure was optimized. The different lignin fractions were characterized by analytical pyrolysis coupled to GC/MS (Py-GC/MS) and evolved gas analysis by mass spectrometry (EGA-MS), to obtain information about structure, purity and thermal stability. Semi-quantitative parameters were calculated from the experimental results to evaluate the efficiency of the extraction method, and the properties of the resulting lignin. This study highlights the ability of analytical pyrolysis-based techniques in providing in-depth information on isolated lignins and provides a first report of the fractional antisolvent precipitation of ES-lignin.

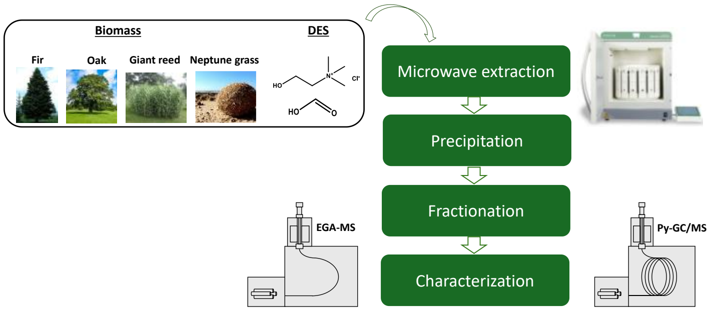

Figure 1: *Procedure for lignin extraction, fractional precipitation and characterization*

References

[1] M. Zhou, O. A. Fakayode, A. E. G. Ahmed Yagoub, Q. Ji, and C. Zhou, “Lignin fractionation from lignocellulosic biomass using deep eutectic solvents and its valorization,” Mar. 01, 2022, *Elsevier Ltd*. doi: 10.1016/j.rser.2021.111986

[2] C. L. Chambon *et al.*, “Fractionation by Sequential Antisolvent Precipitation of Grass, Softwood, and Hardwood Lignins Isolated Using Low-Cost Ionic Liquids and Water,” *ACS Sustain Chem Eng*, vol. 8, no. 9, pp. 3751–3761, Mar. 2020, doi: 10.1021/acssuschemeng.9b06939

[3] M. Mattonai, G. S. Messina, F. Nardella, and E. Ribechini, “New Parameters to Model Microwave-Assisted Deep Eutectic Solvent Extraction of Lignin Using Analytical Pyrolysis-GC/MS,” *ACS Sustain Chem Eng*, vol. 10, no. 48, pp. 15660–15669, Dec. 2022, doi: 10.1021/acssuschemeng.2c03461

Upcycling of Plastic Scraps from Biomedical Membrane Production and Their Reuse in Water Treatment Technologies

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The conversion of industrial plastic waste into functional sorbent materials is a promising strategy for sustainable water treatment. [1] In the framework of a collaboration with Medica SpA, we present the conversion of hollow fibers scraps of polysulfone (PSU, Medisulfone ®) and PSU–graphene oxide (PSU–GO, Graphisulfone®) hollow fiber membranes into granular materials and their use as sorbent. [2,3] Manual grinding of the production scraps was performed and the obtained granules were tested as sorbent toward emerging and priority water contaminants, such as pharmaceuticals, perfluoroalkyl substances (PFAS), and heavy metals.[4,5] Compared to granular activated carbon (GAC), PSU–GO granules exhibited up to 10 times higher adsorption of lead (230 µg/g vs 21 µg/g) and about double the efficiency for diclofenac (2400 µg/g vs 950 µg/g) and PFOA (6 µg/g vs 3 µg/g). The scale up production of the granules was performed and the performance of PSU–GO granules was demonstrated under real tap flow conditions for PFOA and lead, with validation ongoing at a real-scale potabilization plant (Hera, Pontelagoscuro, FE). [6,7] Molecular dynamics simulations provided insight into adsorption mechanisms, highlighting the key role of graphene oxide in enhancing performance, while surface-enhanced Raman spectroscopy confirmed no graphene oxide release in treated water. Overall, these materials are highly versatile, suitable for various environmental contexts, and easily scalable. Moreover, thanks to graphene oxide, they can be chemically modified to further enhance adsorption capacity and selectivity toward specific contaminants.[8]

Figure 1: *Conversion of industrial scraps into granular materials used as sorbent*

References

[1] D. Cserbik et al., npj Clean Water 2023, 6, 16
[2] Khaliha et al., Journal of Membrane Science, 2022, 658, 120707
[3] M. Zambianchi et al., Advanced Sustainable Systems 2017, 1,1700019
[4] Khaliha et al., Environ. Sci.: Water Res. Technol., 2024,10, 1097-1107
[5] Patent: Melucci M., et al. EP3208241
[6] https://www.cnr.it/it/nota-stampa/n-12571/ferrara-al-potabilizzatore-di-pontelagoscuro-presentato-l-innovativo-water-living-lab
[7] https://liferemembrance.eu
[8] Pintus et al., RSC Appl. Interfaces, 2025, Advance Article

Urea hydrolysis in batch reactors: preliminary optimisation of reaction setup and process conditions

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Hydrogen is a clean and sustainable vector for energy generation [1]. A variety of hydrogen carriers have been proposed; among them urea, a major component of human/animal urine, is a safe and sustainable chemical with a high hydrogen content [2]. Valorisation of urea-rich animal farm-waste, a non-critical feedstock detrimental for soil and water, to green hydrogen, will contribute to decarbonise energy sector while simultaneously mitigating environmental pollution.

Urea hydrolysis was carried out in liquid phase using different magnetic stirred batch reactor for reactor optimisation. The reactor for urea hydrolysis included: i) a basic reaction setup consisting of a three-necked flask heated with an oil bath and equipped with a thermometer, a gas inlet tube for flush the system with nitrogen and a reflux condenser connected to three traps in series for ammonia and isocyanic acid (the first filled with water and the other two with HCl 1M); ii) a stainless steel autoclave reactor pressurized with nitrogen and equipped with temperature and pressure indicators, as well as a valve for gas sampling and a heating jacket; iii) five equivalent 4 mL vials, refrigerated with water, using an annular LED light source with a monochromatic irradiation (λ= 365 nm). Temperature, reaction time and catalyst loading were the reaction parameters investigated. The concentrations of unreacted urea and heavy byproducts were determined by HPLC equipped with a DAD detector using a reversed-phase column, ammonia and isocyanic acid were quantified by UV-Vis analysis using the salicylate method, and of gaseous products using a gas chromatograph equipped with a TCD detector.

Different reaction setups were used for the preliminary tests of urea hydrolysis carried out with and without TiO2 as catalyst. Every system has its advantages and challenges; therefore, the limitations and advantages of each system will be presented. The basic reaction setup is the simplest in operation and control but is not gas-tight and the reproducibility of the catalyst suspension preparation is low, therefore this system was not used for further investigations. The reactions carried out in the autoclave reactor and in the photoreactor have improved reproducibility, but lower conversions compared with the former setup were obtained at the same reaction conditions, because gaseous products were not continuously removed from the reaction environment.

Finally, the parallel photoreactors ware used to investigate the catalytic steam reforming of urea using metal catalysts supported on TiO_2, with the reaction conditions previously optimized.

References

[1] J.O.M. Bockris, « The hydrogen economy : Its history », *International Journal of Hydrogen Energy, 38* (2013) 2579-2588

[2] S. Satyapol, J. Petrovic, C. Read, G. Thomas, G. Ordaz, « The U.S. Department of Energy's National Hydrogen Storage Project : Progress towards meeting hydrogen-powered vehicle requirements », *Catalysis Today, 120* (2007) 246-256

Biochars as conductive filler in bipolar plate

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Proton exchange membrane fuel cells (PEMFCs) are expected to play a pivotal role in the near future due to their efficiency in utilizing hydrogen as fuel. In these devices, bipolar plates (BPs) represent one of the major components in terms of both weight and cost. Among the different types of BPs, composite bipolar plates made of a thermosetting polymers and synthetic graphite, ensure lightness, mechanical strength and chemical stability. To reduce the environmental impact of these materials, it is necessary to limit or replace synthetic graphite with a more sustainable carbon source. A promising candidate is biochar, derived from biomass waste. In this project, we studied biochars obtained from five different biomass sources: apricot shell, plum shell, cherry shell, defatted grape seeds, and olive pit powder, as conductive fillers in composite materials. Biochars were produced by pyrolysis at 350 °C for 3 hours under a nitrogen flow. Proximate composition and elemental analysis of the biochars revealed the formation of carbon-rich materials characterized by a low H/C ratio, indicating their aromatic structure. FT-IR analysis confirmed the presence of aromatic structures, heavily substituted with aliphatic side chains and functionalized with hydroxyl and ether groups. Raman spectroscopy showed the formation of a significant amount of well-ordered graphitic structures, especially in biochars derived from plum shell and olive pit powder. To evaluate the performance of biochars as fillers for BPs, composite samples were prepared by replacing synthetic graphite with six different loadings (ranging from 0 to 30 wt%). In-plane conductivity (IPC) values decreased progressively with increasing biochar content in all formulations. However, all samples exhibited IPC values $\geq$ 100 S/cm, with plum shell biochar retaining the highest conductivity at 30 wt% (115 S/cm). Helium permeability (HEP) was performed on composite samples, showing only a slight increase in permeability with higher biochar loading.

References

[1] D'Eusanio, Veronica, et al. "Technological Prospects of Biochar Derived from Viticulture Waste: Characterization and Application Perspectives." *Energies* 17.14 (2024): 3421
[2] Kane, Seth, et al. "Physical and chemical mechanisms that influence the electrical conductivity of lignin-derived biochar." *Carbon Trends* 5 (2021): 100088
[3] Mierzwa-Hersztek, Monika, et al. "FT-IR analysis and the content of phenolic compounds in exogenous organic matter produced from plant biomass." *Journal of Elementology* 24.3 (2019)
[4] Sousa, Daniel Vieira de, et al. "Dynamic of the structural alteration of biochar in ancient Anthrosol over a long timescale by Raman spectroscopy." *PloS one* 15.3 (2020): e0229447
[5] Roncaglia, Fabrizio, et al. "Graphite-epoxy composites for bipolar plates: The gas permeability issue." *International Journal of Hydrogen Energy* 48.54 (2023): 20935-20944

Deep Eutectic Solvents (DESs) as sustainable alternative electrolytes for Vanadium Redox Flow Batteries (VRFBs)

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VRFBs are large-scale energy storage systems that currently use sulfuric acid as aqueous electrolyte for vanadium redox couples, originating deep challenges related to waste management and recovery of the metal ions. Such setup also frequently leads to cross contamination, poor thermal stability of the redox ions, a potential window limited by water electrolysis and an overall low concentration (≈1,5M) of the redox species.1 With the present work our aim is to substitute H_2SO_4 with DESs, to both decrease the environmental impact of the systems and increase the concentration of the vanadium species, to better the performances of VRFBs in a non-acidic, biodegradable, non-toxic, non-inflammable medium. We tried different DESs formulations, all with ChCl as HBA, and carboxylic acids, polyols or amides as HBD with different ratios and variable water content; we also formulated some ternary mixtures (ChCl:Ethylene glycol:Urea). We then proceeded solubilising VCl_3 starting from 2M up to 3M: the choice of VCl3 is related to its reported solubility in ChCl, thanks to the shared Cl- atoms. The best performing compounds in terms of viscosity, which was the main limiting factor, had either ethylene glycol, glycerol or propanediol as HBD, as well as the ternary mixtuers. The only two formulations that were able to dissolve VCl_3 3M however were ChCl:Ethylene glycol = 1:2 and ChCl:Propanediol = 1:6.

Preliminary evaluations with TGA validated the chance of working at temperatures up to 100°C without any significant degradation in the DES, confirming the good thermal stability of the compounds and the possibility of working at 60°C-70°C, to decrease the high viscosity of the electrolyte.

Cyclic voltammetries conducted with a three electrode setup on ChCl:propanediol=1:6 with VCl_3 3M between -2V and +0,5V at 60°C showed visible peaks related to the vanadium redox ions; the lower peak is probably affected from the catalytic reaction with oxygen, suggesting that working in an atmosphere of argon would be the best solution. The cyclic voltammetries overall showed the importance of decreasing the viscosity of the compound to allow the ions movement and proved the abscence of any interference between the electrolyte and the working electrode in graphite.

Acknowledgements

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

References

[1] Q. Xu .; L.Y. Qin. *Electrochimica Acta.* 2019, *293, 426-431.*

An environmentally sustainable approach for metal recovery from battery cathode production scraps

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As global demand for lithium-ion batteries rises—driven largely by the expansion of electric vehicles and renewable energy storage—the need for sustainable and ethical sourcing of critical battery metals becomes increasingly urgent. Recycling spent batteries to recover valuable elements such as lithium, cobalt, nickel, and manganese helps reduce dependence on raw material extraction. This not only lowers the environmental impact of mining but also relieves pressure on finite natural resources. Additionally, recycling strengthens the supply chain by lowering risks associated with geopolitical and socio-economic challenges in metal sourcing regions. Current recycling technologies for lithium-ion battery are still considered unsustainable due to the usage of strong acids, toxic solvents, or high temperature treatments. To further enhance the sustainability of battery recycling, innovative methods such as soft-leaching using environmentally friendly solvents are gaining attention. In this context, we propose a novel recycling approach that utilizes green solvents, like triethyl phosphate (TEP) and deep eutectic solvents (DES) to recover materials from real lithium cobalt oxide (LCO) cathode scraps. The process was also evaluated through Life Cycle Assessment (LCA) methodology to demonstrate that this method provides a scalable and more environmentally sustainable pathway for metal recovery, reducing dependence on primary raw material extraction and mitigating environmental impact.

Acknowledgement

We acknowledge for financial support the projects: "RELY: Transformation of REcovered/recycled spent Lithium-ion BatterY cathodes into porous materials for high power-energy storage" (MAECI-Italy South Africa Grande Rilevanza bilateral project); "DiGreen: a digital and chemical approach for green recycling of Li-based batteries" funded by the European Union - Next Generation EU, Missione 4 Componente 1 Project CUP J53D23008790006, and MOST—Sustainable Mobility Center project, funded by the European Union Next-Generation EU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) e MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 e D.D. 1033 17/06/2022, CN00000023.

References

[1] D. Marchese et al., Batteries, 2024, Vol. 10, Page 27. 10 (2024) 27
[2] C. Padwal et al., Adv. Energy Sustain. Res. 3 (2022) 2100133
[3] R. Morina et al., ChemSusChem 2022, 15, e202102080

Selective separation of lithium and transition metals from spent Li-ion battery leachate using p-*tert*-octylphenoxyacetic acid via extraction–precipitation

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Lithium-ion batteries (LIBs) are widely recognized for their high energy density, long cycle life, and low self-discharge rates, making them essential components in electric vehicles (EVs), portable electronics, and renewable energy storage systems. The growing demand for LIBs has heightened the importance of sustainable end-of-life management strategies, particularly the recovery and reuse of valuable metals such as lithium, nickel, and manganese. Commercial LIBs typically contain complex mixtures of transition metals, lithium salts, graphite, and organic electrolytes, presenting both a challenge and an opportunity for efficient recycling. This study proposes a sustainable method for the selective recovery of transition metals from spent LIBs using p-tert-octylphenoxyacetic acid (POAA) as a tailored precipitating agent. POAA was synthesized and applied to leachate derived from LiNiMnO (LNMO)-based cathodes. Through pH-controlled chemical precipitation, POAA enabled the selective extraction of Li, Ni, and Mn. The resulting metal–POAA complexes were acid-treated to strip the metals, which were subsequently used to synthesize Ni/Mn-based metal–organic frameworks (MOFs) via a solvothermal route. The MOFs were characterized using SEM, UV–Vis, Raman, XRD, and FTIR, confirming successful metal coordination and framework formation. The Ni–Mn MOF electrode exhibited promising electrochemical performance, delivering a specific capacity of 20.7 mAh g^{-1} at 1 A g^{-1} in 3 M KOH, with 99.2% coulombic efficiency and 40% capacity retention after 5,000 charge–discharge cycles at 5 A g^{-1}. This approach offers an efficient and circular strategy for LIB waste valorization, with future potential for lithium recovery and reintegration into new battery production.

Acknowledgements

This research was enabled by the Bilateral project between NRF, South African and Italy (ISARP) (Grant number 2204072535).

Tayloring porosity of activated biochar for energy storage applications

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The rising global need for energy storage, stimulated by the fast growth of renewable energy to replace fossil fuels, has triggered interest in developing affordable, eco-friendly materials for batteries and supercapacitors. Organic and agrifood waste, abundant and renewable, offer a promising route for producing cost-free porous carbon through pyrolysis/pyrogasification. This process not only efficiently disposes of hard-to-remove waste and utilizes biomass for green energy production in biomass powerplants, but also produces biochar, a carbon-negative byproduct. Biochar, an economical active carbon source, is ideal for further energy storage applications.

In this study, we explored the use of some organic waste from the Italian economy as a new source for creating highly porous activated carbon, aimed primarily for use in energy storage as electrodes in supercapacitors and sodium-ion batteries. We produced biochar by pyrolyzing or hydrothermally carbonizing various agricultural and farm wastes, including rice bran, melon and pumpkin skins, corn cobs, and poultry litter [1]. Subsequently, we tailored the biochar's porosity through various activation methods to optimize it for specific applications [2]. For instance, we achieved significant microporosity using chemical activation (e.g., KOH, $ZnCl_2$) at high temperatures under an argon atmosphere. The super-activated biochars produced this way proved to be outstanding active materials for symmetric supercapacitors, eliminating the need for additional conducting agents. The inclusion of heteroatoms like S, P, and N enhanced the electrode wettability and overall capacitance (through pseudocapacitance), while uniformly sized nanometer-scale pores broadened the electrochemical range typically seen with aqueous electrolytes. For battery use, however, excessive open micro- and mesoporosity was avoided to prevent large solid-electrolyte interphase (SEI) formation and high initial irreversible capacity [3]. Instead, biochar electrodes were created through high-temperature thermal annealing above 1000°C, fostering the development of a porous structure with closely packed pores and disordered pseudo-graphitic areas. These materials have shown promise as negative electrodes in sodium-ion batteries.

References

[1] D. Pontiroli, et al., Microporous Mesoporous Mater. 285 (2019), 161
[2] N. Ahmad, D. Pontiroli et al., J. Energy Storage, 99 (2024), 113267
[3] D. Alvira, D. Antoran, J. J. Manyà, J. En. Chem. 75 (2022), 457

VisioNing: Valorization of agro-industrial wastewater. From research bench to business

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The escalating pollution caused by agro-industrial wastewater is an alarming environmental threat. Apart from the obvious water wastage, valuable nutrients within are also lost [1]. The wastewater treatment sector and that of fertilizers' production account for over 3% and 1.2% of world's energy [2]. Moreover, fertilizer costs are continually growing as they are related to the energy cost and population growth. This represents a significant economic damage to companies in the sector. The agro-industrial wastewater treatment market is witnessing a surge in interest towards efficient and sustainable technologies. In fact, technological innovation and the embrace of eco-friendly solutions are driving industry transformation.

In this context, the mission of VisioNing is simple but ambitious: transforming wastewater from a problem to a resource with 100% circularity and sustainability. VisioNing was conceived after a meticulous examination of the challenges in wastewater treatment. Combining bioelectrochemical and photocatalytic technologies powered by solar energy, our process not only purifies water but also recovers and reuses the nutrients it contains. While numerous wastewater treatment solutions exist, our combined technology offers dual benefits: energy efficiency and recyclability. This empowers us to position ourselves as frontrunners in sustainability and innovation, ensuring a 30% reduction in operational costs compared to traditional systems.

Having conducted in-depth research and developed prototypes at the University of Milan, we have now refined an operational and highly efficient model. A pilot test was conducted with several companies in Lombardy, financed by the "Farming Future" investment fund of CDP Venture Capital SGR and ToSeed & Partners, confirming the preliminary results in terms of nutrients recovery and water purification.

Figure 1: *VisioNing pilot plant: from manual to automatic & remote-controlled version*

References

[1] J. R. Jones, J. A. Downing, Agriculture. Encyclopedia of Inland Waters 2009, Volume, 225 – 223
[2] https://www.caprari.com/wp-content/uploads/2023/07/Trattamento_acque-reflue.pdf

Controlled electrodeposition of Co/Ni-MOF from NMC-333 leach solution from lithium-ion battery materials for supercapacitor electrode application

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Multi-step cathodic electrodeposition was used to fabricate Co/Ni-MOF electrodes on carbon cloth (CC) from a mixed solution of NMC-333 leach and 2-methylimidale organic linker. The large overpotential in earlier steps are due to rapid nucleation resulting in a stronger adhesion of electrode material to the CC, while the low overpotential in later stages cause progressive layer formation and crystallisation increasing porosity and ion diffusion. The optimisation of pH controls H2 evolution and adherence to the substrate, this affects porosity and morphology. Different Co/Ni-MOF-pH=α electrodes were synthesized by varying the pH value, α. The electrode: Co/Ni-MOF-pH=3, with aggregated flower-like morphology resulted in great electrochemical performance with a specific capacity of 102 mAh g-1 at 1 A g-1 in 6 M KOH in a 3-electrode set-up and excellent stability with a capacity retention of 81 % after 5,000 GCD cycles at 5 A g^{-1}.

Sustainable carbon nanoparticles as additives in inverted hybrid perovskite solar cells

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Global warming is becoming an urgent and concrete emergency, with the average global temperature in 2024 exceeding, for the first time, 1.5°C above pre-industrial levels [1]. In this context, the transition to clean energy sources alone is not sufficient; it is also essential to carefully assess the impact of the entire production chain associated with the energy transition. Some materials commonly used in the fabrication of energy storage devices are scarce and their extraction has a significant environmental impact. Production processes must also be considered to minimize energy consumption and economic costs, to keep prices low and facilitate the widespread adoption of clean energy technologies.

Here, the use of carbon nanoparticles synthesized from readily available precursors under mild reaction conditions as additives in methylammonium lead iodide ($MAPbI_3$)-based solar cells. These carbon nanomaterials were synthesized from citric acid with L-tryptophan added as a nitrogen doping source. The synthesis was carried out at 200°C under atmospheric pressure without solvents, and the carbon nanoparticles were used as-synthesized, without any purification steps, in the solar cells. An improvement in the solar cell performance was observed, depending on the amount of L-tryptophan used, indicating that nitrogen doping significantly modulates the properties of the carbon nanoparticles.

Acknowledgements

The authors would like to thank the following projects for the financial support: Prin 2022 "DiGreen: A digital and chemical approach for green recycling of Li-based batteries" (no. 2022W37L2L)—MUR (Ministero Italiano dell'Università e della Ricerca) (L.S., F.D.G., A.M., and C.D.); PNRR MUR project ECS_00000033_ECOSISTER (L.S., F.D.G., M.N., L.G., A.M., C.D., E.L., M.S., and G.R.); Mission Innovation Program, Ministero dello Sviluppo Economico (MiSE), under the Grant "Italian Energy Materials Acceleration Platform—IEMAP" (L.S., F.D.G., M.N., C.D., M.S., and G.R.). D.T. acknowledges financial support of this work by the Regione Toscana (FSC 2014-2020, GiovaniSi acronym project QD4OPH). CSGI (Florence) is kindly acknowledged for partial financial support. L.S., F.D.G., M.N., C.D., M.S., and G.R. wish to thank Vincenzo Ragona (CNR-ISMN) for his valuable technical support.

References

[1] The Copernicus Global Climate Highlights Report 2024

Sustainable recovery of cobalt from spent cathodes into functional 1D/2D coordination polymers

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The growing demand for critical raw materials in energy storage technologies, particularly for cathodic materials, highlights the importance of sustainable metal recycling and upcycling strategies. In this context, a cobalt recovery process based on deep eutectic solvents (DESs) enables the extraction of cobalt from real LIB LCO cathode waste in the form of cobalt hydroxide, $Co(OH)_2$.1 To valorize the recovered material, $Co(OH)_2$ is first converted into cobalt nitrate, $Co(NO_3)_2$, via controlled reaction with nitric acid, then reacted with organic ligands to yield Co-based coordination polymers with potential cathodic activity. In this work, we report the synthesis and structural characterization of two cobalt-based coordination polymers employing 4-aminocinnamic acid (4-ACAH) as organic linker. Under pH-controlled aqueous conditions, $Co(NO_3)_2$ reacts with two equivalents of 4-ACA-, previously deprotonated with NaOH, to form both Co^{2+} centered one-dimensional (1D) linear chain polymer or a two-dimensional (2D) sheet-like layered framework, depending on hydration state. The materials were characterized by single-crystal and powder X-ray diffraction, and thermogravimetric analysis, confirming their hydration states and phase coherence. These findings establish a direct connection between recycled cobalt and the preparation of structurally defined coordination polymers. These findings establish a direct connection between recycled cobalt and the preparation of structurally defined coordination polymers.

Acknowledgement

We acknowledge for financial support the projects: "RELY: Transformation of REcovered/recycled spent Lithium-ion BatterY cathodes into porous materials for high power-energy storage" (MAECI-Italy South Africa Grande Rilevanza bilateral project); "DiGreen: a digital and chemical approach for green recycling of Li-based batteries" funded by the European Union - Next Generation EU, Missione 4 Componente 1 Project CUP J53D23008790006, and MOST—Sustainable Mobility Center project, funded by the European Union Next-Generation EU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) e MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 e D.D. 1033 17/06/2022, CN00000023.

References

[1] Omar, K. A. & Sadeghi, R. Database of deep eutectic solvents and their physical properties: A review. J Mol Liq 384, 121899 (2023)

[2] d'Agostino, S., Macchietti, L., Turner, R. J. & Grepioni, F. From 0D-complex to 3D-MOF: changing the antimicrobial activity of zinc(II) via reaction with aminocinnamic acids. Front Chem 12, 1430457 (2024)

[3] Zhang, J. et al. Research Progress of Cobalt-Based Metal Organic Frameworks and Their Derivatives in Energy Storage and Conversion. ACS Omega (2024)

Development of $LaFeO_3$ perovskite and molten salt activated sewage sludge biochar modified screen-printed electrode for the determination of methylparaben in seawater samples

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The widespread use of personal care products (PCPs) has led to the release of emerging organic contaminants such as parabens into aquatic environments. Methylparaben (MP), one of the most common preservatives, can enter seawater through wastewater discharge and recreational activities, posing potential risks to marine ecosystems [1]. In this study, a novel electrochemical sensor was developed based on screen-printed electrodes (SPE) modified with a composite of lanthanum ferrite ($LaFeO_3$) perovskite and biochar obtained from sewage sludge pyrolysis. The sewage sludge, as a biomass waste, was pyrolyzed at 800 °C under nitrogen atmosphere both in the absence and in the presence of molten salt (Na_2CO_3/K_2CO_3, 1:1 w/w). The biochar synthesized in the presence of molten salt exhibited significantly improved textural and electrocatalytic properties compared to the biochar obtained without molten salt activation. The enhanced performance is attributed to the molten salt's role in promoting a more porous carbon structure, better conductivity, and increased active sites on the biochar surface.The combination of $LaFeO_3$ perovskite and molten salt-activated biochar provided synergistic effects, greatly enhancing the electrode's catalytic activity toward the oxidation of MP. Electrochemical measurements were carried out in Britton-Robinson buffer at pH 7 using cyclic voltammetry (CV) and differential pulse voltammetry (DPV), demonstrating excellent sensitivity, stability, and reproducibility for MP detection (Figure 1). The developed sensor was successfully applied for the determination of methylparaben in real seawater samples, indicating its potential for practical environmental monitoring applications. This approach not only contributes to the valorization of sewage sludge waste into high-performance electrochemical materials but also offers a sustainable and cost-effective strategy aligned with circular economy principles.

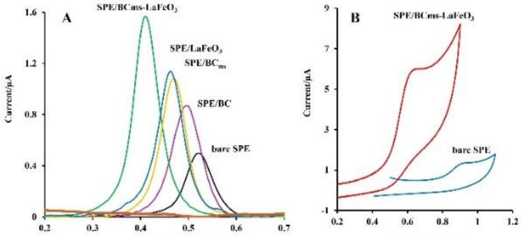

Figure 1: *(A) DPV of MP (40 µM) at various electrode surfaces; (B) CV at bare and modified SPE; scan rate: 100 mV/s; both in BR buffer (pH 7.0).*

Acknowledgments

This work was supported in part by the Italian Ministry of Foreign Affairs and International Cooperation", grant number PGR02118 Italy-China Project GREENHYDCM (Co-production of green hydrogen and carbon materials with high electrochemical performance through molten-salt

References

[1] H. Arfaeinia, et al, « Monitoring and eco-toxicity effect of paraben-based pollutants in sediments/seawater, north of the Persian Gulf, », *Environ Geochem Health, 44* (2022) 4499-4521

Solvometallurgical approach for the recovery of valuable metals from EoL batteries

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On the website of the European Commission is reported: “Raw materials are crucial to Europe’s economy. They form a strong industrial base, producing a broad range of goods and applications used in everyday life and modern technologies. Reliable and unhindered access to certain raw materials is a growing concern within the EU and across the globe. To address this challenge, the European Commission has created a list of critical raw materials (CRMs) for the EU, which is subject to a regular review and update. CRMs combine raw materials of high importance to the EU economy and of high risk associated with their supply [1].” In the list of the critical raw materials are included Cobalt, Nickel and Lithium. These metals are essential components of the Lithium-ion batteries (LIBs). This family of batteries are spread world wide, for this reason in the last few years the attention of scientific community is focused on the recycling of the spent LIBs in order to extract the CRMs and use them for the development of second life batteries. The methods used until now for the extraction of metals from the spent batteries involve hydrometallurgy and pyrometallurgy which are high energy-consuming approaches[2]. In the last few years the approach to the extraction of these metals is shifting towards more sustainable methods. A good option that is gaining ground is to recover metals from cathodes via Deep Eutectic Solvents (DES). The use of DES in metals recovery processes has several advantages, for example the solvent can be formed by green, non-toxic and very cheap components, the operating conditions are milder than those used in pyrometallurgy and hydrometallurgy and in some cases the same deep eutectic solvent might be used for several subsequent extractions[3][4]. As a task of the RENOVATE WP4 “CAM (Cathodic Active Materials) recovery: solvometallurgy and direct recycling” in this study we present a novel three-component deep eutectic solvent (DES) composed by Choline chloride : Lactic acid : Urea for the recovery of Li, Ni and Co from End of Life (EOL) batteries via Microwave Assisted Extractions (MAE). The ternal DES composition and the parameters of the microwave extractions procedure are optimized through the Design of Experiments (DoE) performing a mixture-process design. The metals extracted by the DES are precipitated, characterized and used to assemble second life CAM which preliminary electrochemical performances are compared to those of the commercial cathodic active materials.

References

[1] https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en
[2] R. Morina, D. Callegari, D. Merli, G. Alberti, P. Mustarelli, E. Quartarone, Cathode active material recycling from spent lithium batteries: a green (circular) approach based on deep eutectic solvents, *ChemSusChem*, 15 (2022)
[3] Z. Whang, S. Li, T. Li, T. Hu, X. Ge, Deep eutectic solvents (DESs) for green recycling of wasted lithium-ion batteries (LIBs): progress on pushing the overall efficiency, *Mining, Metallurgy & Exploration*, 39 (2022) 2149
[4] C. Padwal, H.Duc Pham, S. Jadhav, T. Trang Do, J. Nerkar, L. Thi My Hoang, A. Kumar Nanjundan, S.G. Mundree, D.P. Dubai, Deep eutectic solvents: green approach for cathode recycling of Li-ion batteries, *Adv. Energy Sustainability Res.*, 3 (2022) 2100133

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