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Introduction to Materials and Devices for the Energy Transition in Latin America

Ana Flávia Nogueira, ^{*a} Gustavo Doubek ^b and Hudson Zanin ^b

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Energy transition is a pressing matter and, despite being a global challenge, the knowledge and solutions might be different as the local infrastructure, weather conditions, government policies, population wealth and equality, among other particularities may find very distinct scenarios and thus the solutions should take this big picture into account. In Latin America we face several challenges in terms of access to high-end technologies and therefore the local development and the use of readily available materials receive great importance, not only to create better access but also to improve the value of manufactured goods, creating better jobs and triggering a neo-industrialization process.

One important factor that is in the heart of the energy transition in Latin America is the use of the abundant solar irradiation, as most countries reside not only close to the equator line but with large areas with high solar incidence during entire seasons. Countries like Bolivia, Peru, Brazil and Ecuador have an overall irradiation on their lowest irradiated areas that is still 40% superior to the German average. On top of that the unique combination of geographic position and cloud

formation can lead to spikes of concentrated radiation that reach up to 1.7 suns in some locations. These unique combinations urge the development of novel materials and devices capable of coping with the harsh environment for the creation of a new generation of photovoltaics.

Energy storage technologies are rapidly evolving to meet the growing demands for safety, sustainability, and scalability. Among the most promising innovations are sodium and lithium batteries with non-flammable liquid or solid electrolytes, making the systems inherently safer. In addition to enhanced safety, these batteries offer higher energy density, longer lifespan, and a lower environmental impact. Latin America, with its vast lithium reserves and growing clean energy infrastructure, is uniquely positioned to play a leading role in this transition. By combining access to critical materials with emerging innovation ecosystems, the region can drive the development and adoption of next-generation storage technologies. This new wave of batteries represents a strategic alternative for large-scale stationary applications and electric mobility, accelerating the global energy transition while fostering sustainable industrial growth in Latin America.

Some of the most recent advances in the field of materials and technologies for energy transition, spanning from batteries, CO₂ electrochemistry, photoelectrolysis, fuel cells, bioenergy and strategic minerals among others, are now gathered in this themed collection.

Gutiérrez and Ruiz-Léon provided an overview of lithium's role in Chile, focusing on the country's lithium strategy and its global significance as an energy resource (<https://doi.org/10.1039/D4MA00625A>). It examines the evolution of Chile's lithium industry and the current national lithium strategy. The paper also reviews materials science research in Chile since the 1960s, particularly related to lithium, batteries, and brines. It concludes by asserting that lithium is crucial in the transition to renewable energy and has strategic potential for Chile's technological development.

Crespilho and co-workers explored the shift towards eco-friendly, sustainable, and safe batteries inspired by nature to address the growing demand for clean energy (<https://doi.org/10.1039/D4MA00363B>). The article highlights challenges in current energy storage devices related to performance, cost, and environmental impact. Biomolecule-based electrode materials, green biobatteries, and biodegradable materials offer promising solutions. Biomolecule electrodes enhance capacitor performance, while nature-inspired designs improve electrochemical performance. The review emphasizes the need for balancing performance with eco-conscious solutions in the development of energy storage technologies.

In another review, Longo and co-workers discussed the potential of complex oxides as next-generation photoelectrode materials

^a Instituto de Química, Universidade Estadual de Campinas, UNICAMP, P.O. Box 6165, 13083-859 Campinas, São Paulo, Brazil.

E-mail: anaf@unicamp.br

^b Advanced Energy Storage Division, Center for Innovation on New Energies, University of Campinas, São Paulo 13083-852, Brazil



for solar energy conversion (<https://doi.org/10.1039/D3MA01013A>), highlighting their improved sunlight harvesting and stability over traditional binary oxide semiconductors. Despite their promise, experimental performance still falls short of theoretical values. The review explores recent progress in synthesizing multinary complex oxides using both conventional and less common “dry” and “wet” methods. The goal is to advance the development of n- and p-type semiconductors for sustainable energy applications, including hydrogen generation, CO₂ reduction, and biomass valorization.

The group of Mascaro developed an amine-functionalized ZnO catalyst for efficient electrochemical CO₂ reduction to CO (<https://doi.org/10.1039/D4MA00750F>). The modified ZnO, combined with 25% carbon black support, achieved a current density of -130 mA cm^{-2} and a faradaic efficiency over 80% at -1.2 V *vs.* RHE. Impedance analysis showed reduced charge transfer resistance. *In situ* FTIR spectroscopy revealed CO₂ consumption and formation of intermediates during reduction. The catalyst demonstrated stability over 100 hours with faradaic efficiency above 70%. The amine-functionalization strategy shows promise for improving the performance of other catalysts in CO₂ reduction.

Fernández-Gamboa, Tielens and Zulueta explored alkali hexazirconates (A₂Zr₆O₁₃, where A = Li, Na, K) as potential electrode materials for Li-ion and alkali-ion batteries (<https://doi.org/10.1039/D4MA00254G>). Using atomistic simulations, the materials were found to be insulating, with mechanical analysis showing that Li₂Zr₆O₁₃ and Na₂Zr₆O₁₃ are more compressible along the *x* and *y* axes. Electrochemical testing revealed stable charge/discharge phases with voltage plateaus at 1.3 V (Li) and 2.9 V (Na), and theoretical capacities of 69.68 mA h g⁻¹ and 66.89 mA h g⁻¹, respectively. The findings suggest that alkali hexazirconates are promising candidates for energy storage due to their mechanical stability and performance characteristics.

Santana-Villamar *et. al.* proposed a solventless method for creating polymer matrix-based bipolar plates (BPs) using low-viscosity epoxy resin and high-expansion ratio graphite (<https://doi.org/10.1039/D4MA00327F>). High-quality

expanded graphite (EG) was prepared using microwave heating, oxygen removal, and sieving. The resulting composites showed excellent electrical conductivity (177.99 S cm⁻¹ at 60 wt% EG) and met or exceeded the U.S. Department of Energy’s flexural strength requirement (25 MPa). This solventless approach demonstrates a promising method for producing high-performance bipolar plate composites for polymer electrolyte fuel cells.

Mascaro and Santos explored the use of p-CuO nanostructures functionalized with n-CuO and CuS particles as a photo-cathode for the water splitting reaction (<https://doi.org/10.1039/D4MA00343H>). The CuO/Cu₂O/CuS film achieved a photocurrent of -2.74 mA cm^{-2} at 0 V_{RHE}. The type II p-n heterojunction between CuO and Cu₂O enhanced charge separation, while CuS facilitated the hydrogen evolution reaction demonstrating the potential of this system for solar-driven hydrogen production.

In the study of Almeida *et. al.*, the authors synthesized CuO photocatalysts through a chemical precipitation method, and explored the effects of different alkalis (NaOH, KOH, NH₄OH) and the incorporation of monoethanolamine (MEA) on catalyst performance (<https://doi.org/10.1039/D4MA00337C>). MEA significantly altered the surface chemistry of CuO, introducing nitrogen-containing functional groups that improved photocatalytic CO₂ reduction, particularly enhancing methane production. The findings offer valuable insights for designing photocatalysts to enhance CO₂ conversion and support sustainable climate solutions.

Dalpian and co-workers investigated phase transitions in CsPbBr₃ perovskite, a material with great potential for solar cells but facing challenges in stability and complexity (<https://doi.org/10.1039/D4MA00216D>). Using *ab initio* NPT molecular dynamics simulations, the phase transitions were observed between 300–325 K and 400–450 K, aligning with previous experimental findings. The research highlights the polymorphic nature of CsPbBr₃, showing that the material exhibits different structures depending on exposure time and temperature. It suggests that different time window averages must be considered depending on the type of

experiment, with long-time averages suitable for X-ray diffraction, and short-time averages for techniques like PDF or Raman.

Hydrogen is a promising alternative to fossil fuels, and niobium pentoxide (Nb₂O₅) is an effective photocatalyst for water splitting. However, its narrow bandgap limits efficiency. Cathodic polarization doping shifts the bandgap to the visible light range and adjusts band positions, improving performance. In the work of Menezes *et. al.*, Nb₂O₅ was produced by anodizing metallic niobium, followed by thermal and cathodic treatment (<https://doi.org/10.1039/D4MA00316K>). The cathodically treated films showed a 2.1-fold increase in photocurrent and better performance than thermally treated films. These films also demonstrated excellent stability for over 30 days, making Nb₂O₅ a more efficient and durable material for water electrolysis.

Torresi and co-workers studied sodium vanadium fluorophosphate (NVPF) as a positive electrode material for sodium-ion batteries (<https://doi.org/10.1039/D4MA00106K>). The study explored how a simple mechanochemical treatment can overcome the issues. After treatment, the contribution from the sodiation/desodiation of Na₁⁺ increased, and discharge capacities were 30% greater at 0.8 C. The modified electrode showed improved cycling stability with a coulombic efficiency of 96.2% and 82.6% capacity retention after 150 cycles. The diffusion coefficients and charge transfer resistance were significantly higher compared to untreated NVPF. These results highlight the kinetic improvements achieved through mechanochemical treatment, enhancing both the synthesis and electrochemical performance.

Souza and co-workers coupled tungsten oxide (WO₃) with graphene oxide (GO) by using microwave-assisted solvothermal synthesis (<https://doi.org/10.1039/D3MA00972F>). The effect of synthesis parameters, including irradiation time and reaction temperature, was investigated. WO₃ nanoplatelets were obtained under all conditions, with the addition of GO not altering the WO₃ morphology. WO₃/GO materials showed improved electronic conductivity which impacted the photoactivity



for photodegrading methylene blue, rhodamine B, and methyl orange.

In another study, Ribeiro and co-workers investigated monoclinic BiVO_4 as a cathode in a photoelectrochemical system for CO_2 reduction (CO_2R) (<https://doi.org/10.1039/D4MA00232F>). The best performance was observed under photoelectrocatalysis powered by a light-emitting diode (LED), producing $22 \mu\text{mol cm}^{-2}$ of methanol and $5.5 \mu\text{mol cm}^{-2}$ of acetic acid, outperforming other methods. The improved performance is due to the application of an external potential that enhances charge separation and electron transfer to reduce CO_2 at a lower overpotential. More important, LED illumination was more effective than UV light, as UV light alters the catalyst surface, reducing the number of catalytic sites available.

Arsha and Biju investigated thermally deoxygenated graphite oxide (TDGO) supercapacitor electrodes by incorporating a redox additive, $0.03 \text{ M } \text{K}_3\text{Fe}(\text{CN})_6$ in 6 M KOH (<https://doi.org/10.1039/D3MA01188G>). The system achieved an areal specific capacitance of 817 F cm^{-2} at 1 A g^{-1} , a 2.5-fold increase compared to using 6 M KOH alone. The redox couple $[\text{Fe}(\text{CN})_6]^{3-}/[\text{Fe}(\text{CN})_6]^{4-}$ added shifts the charge storage mechanism to diffusion-controlled pseudocapacitance. A symmetric TDGO300 supercapacitor exhibited a capacitance of 414.6 F cm^{-2} , delivering 17.4 W h kg^{-1} at 235 W kg^{-1} , with 97.4% capacitance retention after 2000 charge-discharge cycles. This study highlights the potential of redox additives to significantly improve TDGO supercapacitors.

Finally, Spinacé and co-workers explored the photocatalytic conversion of methane into ethane (C_2H_6) and hydrogen (H_2) using TiO_2/WO_3 heterojunction photocatalysts modified with Pt nanoparticles (<https://doi.org/10.1039/D3MA00844D>). The $\text{TiO}_2/\text{WO}_3/\text{Pt}$ photocatalyst demonstrated superior performance, achieving C_2H_6 and H_2 production rates of $1.18 \text{ mmol g}^{-1} \text{ h}^{-1}$ and $57 \text{ mmol g}^{-1} \text{ h}^{-1}$, respectively, which were 37% and 34% higher than those from TiO_2/Pt . The results indicate that the addition of WO_3 at a small concentration, along with Pt as a co-catalyst, significantly enhances methane conversion. The approach highlights the potential of these ternary photocatalysts for efficient methane conversion under mild conditions.

