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Book of Abstracts

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PLENARY LECTURE

POLYMER BASED ELECTROLYTES FOR SAFER LITHIUM METAL BATTERIES

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To decrease carbon dioxide emissions, unprecedented efforts are being undertaken toward the development of efficient and inexpensive electric vehicles and stationary energy-storage systems. Lithium-ion batteries represent an efficient solution, that have transformed personal electronics and enabled the market introduction of electric vehicles. However, the ever-growing energy storage industry imposes great demands that current lithium-ion batteries could hardly satisfy. In this perspective, the use of metallic lithium as anode, both in Li-ion cells and in the so-called "post Li-ion technologies", would represent the "holy grail" of battery research thanks to its extremely high theoretical specific capacity (3860 mA h g^{-1}), the lowest redox potential (-3.040 V *vs*. the standard hydrogen electrode) and a low gravimetric density (0.534 g cm^{-3}).

However, metallic Li also presents many challenges derived primarily from dendrite formation upon cycling causing both safety issues and poor cycling performance. In addition, liquid electrolytes contain combustible organic solvents that can cause leakage and fire risks during overcharge or abuse conditions, especially in large-scale operation. Therefore, replacement of liquid electrolytes with a solid electrolyte has been recognized as a fundamental approach to effectively address the above problems.

Among the solid-state systems under study, polymer-based electrolytes represent a good compromise in term of room temperature ionic conductivity, thermal and electrochemical stability, and above all, interfacial contact. In lithium metal batteries, the preparation of methacrylate-based polymer matrix, in a one pot, solvent free polymerization, is an inexpensive and quick method to obtain versatile membranes. Meanwhile, eventual activation with small amounts of ionic liquids can allow to obtain composite electrolytes with outstanding room-temperature conductivities, while preserving the non-flammability of the system thus enhancing the safety. The simplicity of the formulation and the preparation method open the road to highly versatile electrolytes, adaptable in function of the

final application. Additionally, the insertion of particular groups in the matrix can introduce self-healing abilities (for example through dynamic hydrogen bonding), further improving the safety features of the cells. Last but not least, bio-derived macromolecules can be functionalized with methacrylate groups to be then directly used as oligomers in the same kind of procedures, obtaining interesting quasi solid state electrolyte systems directly from waste, and fully integrating the final device in a circular economy approach.

Keywords: *Lithium Battery; Lithium Metal; Electrolyte; Quasi-Solid-State, Polymer Electrolyte*

STRUCTURAL AND INTERFACIAL REGULATION MECHANISMS OF POROUS CARBON-BASED SILICON/CARBON COMPOSITE ANODE MATERIALS PREPARED BY CHEMICAL VAPOR DEPOSITION

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The rapid development of electric vehicles, energy storage systems, and portable electronic devices has imposed increasingly stringent requirements on the energy density, power capability, and cycle life of lithium-ion batteries. Silicon (Si)-based anode materials, owing to their high theoretical specific capacity, are widely considered promising candidates for next-generation high-capacity anodes. However, their practical application is limited by significant volume expansion during cycling, unstable solid electrolyte interphase (SEI), and low intrinsic electronic conductivity. Constructing silicon/carbon (Si/C) composites is regarded as an effective strategy to alleviate these issues by buffering volume variation and improving electrical conductivity. Among various fabrication approaches, chemical vapor deposition (CVD) enables the *in situ* growth of Si on the surface of carbon hosts or within their pore channels, offering advantages such as controllable deposition, uniform Si/C distribution, and enhanced interfacial contact. However, conventional CVD-derived Si/C anodes typically employ nonporous or macroporous carbon materials (such as graphite, carbon black, carbon nanotubes, and carbon fibers). Such materials provide limited spatial confinement and insufficient stress-buffering capability, making it difficult to simultaneously achieve high Si loading, high capacity, and long-term cycling stability. As a result, further development and application of conventional CVD-derived Si/C anodes remain restricted. To address these issues, we focus on porous carbon-based CVD-derived Si/C anodes, aiming to simultaneously improve specific capacity, cycling stability, and rate capability.

First, an activated carbon (AC)-confined nanosilicon composite anode (CVD-AC@Si) was constructed through pore-confinement structural design combined with a CVD process, and was employed as a representative porous carbon-based CVD-derived Si/C system. Characterization by cross-section polisher scanning electron microscopy (CP-SEM), high-resolution transmission electron microscopy, and related techniques demonstrate that Si is confined within the carbon pores as

nanometer amorphous domains and forms a homogeneous composite structure with the continuous carbon framework, thereby effectively suppressing Si agglomeration. Electrochemical measurements show that the optimized material delivers a volumetric capacity of 4403 mAh cm^{-3}, an initial Coulombic efficiency of 88%, and a capacity retention of 85.5% after 200 cycles, indicating high volumetric capacity and excellent interfacial and cycling stability. Further analyses based on electrochemical measurements and scanning electron microscopy (SEM) reveal that pore-confined Si can suppress the formation of crystalline $Li_{15}Si_4$ through mechanical confinement and stress-potential coupling, thereby alleviating phase-transition-induced stress concentration and structural degradation. These results indicate that the confinement effect of porous carbon frameworks is beneficial for balancing volumetric capacity and cycling stability.

Based on the above model system, two key issues are identified, namely early-stage capacity decay and insufficient rate capability. Electrochemical measurements and pore-structure characterization reveal that, with increasing Si content, the deposited Si progressively extends from micropores into mesoporous and macroporous regions, where it evolves into larger Si domains. This structural evolution aggravates electrode polarization, deteriorates interfacial stability, and increases irreversible capacity loss. To address the issue of early-stage capacity decay, a silane-acetylene co-deposition strategy was developed to regulate Si growth across different pore domains, thereby maintaining nanoscale dispersion and enabling a more uniform distribution of Si. Further analyses based on X-ray photoelectron spectroscopy (XPS), electrochemical impedance spectroscopy, and galvanostatic intermittent titration technique demonstrate that the co-deposited structure reduces interfacial resistance, enhances lithium-ion transport kinetics, and facilitates the formation of a stable lithium fluoride-rich SEI. As a result, the optimized material retains 94.4% of its capacity after 350 cycles, indicating that early-stage capacity decay is effectively mitigated.

To address the insufficient rate capability, the lithiation behavior and transport mechanism at the Si/C interface were systematically investigated, and germanium (Ge) was further introduced for interfacial regulation to improve rate capability. We developed a germanium-decorated silicon/carbon composite (ACGS@C) via chemical vapor deposition of Si into a porous carbon scaffold, concurrently introducing just 2 wt% Ge nanograins at the Si/C interface. X-ray diffraction (XRD), XPS, and CP-SEM results show that Ge nanocrystals are confined and anchored within the carbon pores and undergo in situ alloying with Si during lithiation, thereby forming a continuous Si/Ge/C three-phase interfacial structure. Electrochemical kinetic analysis, together with *ex situ* XRD results, demonstrates that Ge and its lithiated products enhance charge transport and reduce interfacial resistance. Raman spectroscopy and electrode-expansion measurements indicate that Ge interfacial regulation effectively suppresses electrode volume expansion

and preserves the integrity of the conductive network. These Ge nanograins not only build continuous electron/ion pathways but also chemically anchor Si, thus buffering expansion and mitigating interfacial degradation. Benefiting from the dual-function design, the ACGS@C-2 electrode exhibits a high initial reversible capacity of 1986.2 mAh g^{-1} with an initial coulombic efficiency of 87.4%. Moreover, it delivers a specific capacity of 626 mAh g^{-1} at 3.4 A g^{-1} and retains 80% of its capacity after 270 cycles. This trace-Ge interfacial engineering strategy offers a scalable route to unlock the full potential of Si anodes without compromising energy density, rate capability, or cycling stability.

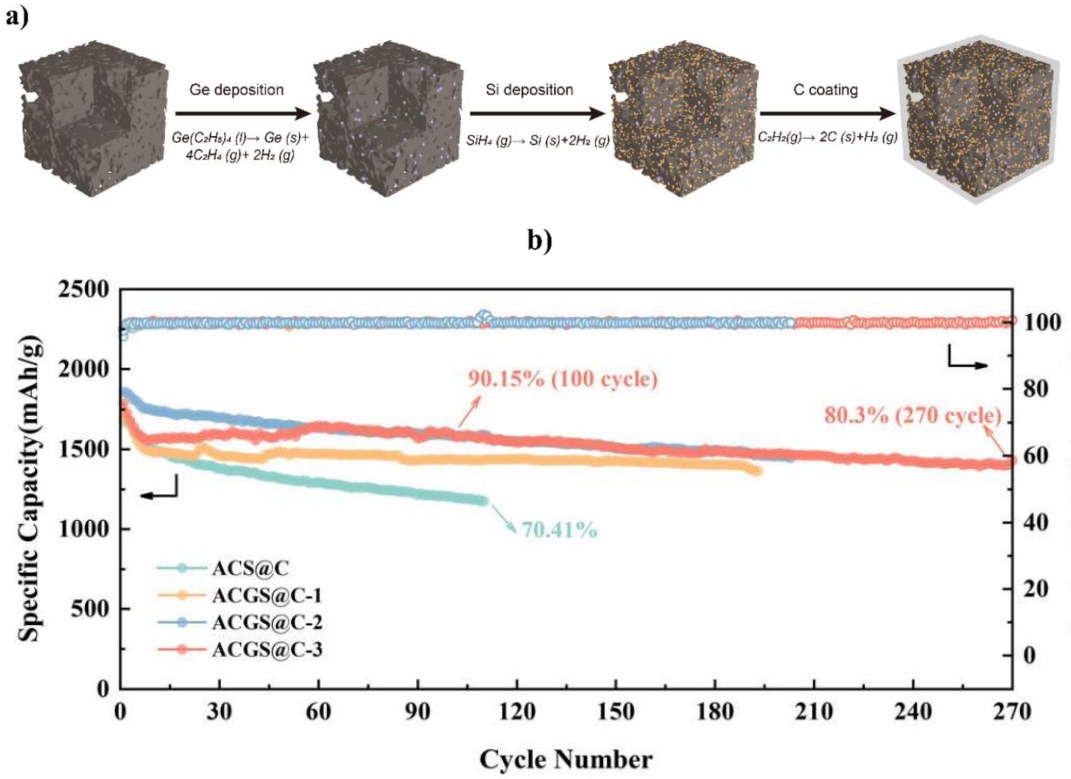


Fig. 1 (a) Schematic illustration of the synthesis process of ACGS@C; (b) Comparison of cycling performance

Keywords: *Lithium-ion batteries, Silicon/carbon composite anodes, Chemical vapor deposition, Interfacial modification, Deposition process regulation*

MOFs: FROM EFFICIENT AIR CONDITIONING TO INSPIRATION FOR SUSTAINABLE BATTERIES

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Metal-organic frameworks (MOFs) have emerged as serious contenders as advanced materials for enabling water sorption-based climate control applications. These include atmospheric water capture, heat pumps, desiccation, humidity control, and thermal batteries. Here, I will discuss the fundamental chemical principles that allow MOFs to display water stability as would be required in such applications. Applying such principles to material design has eventually led to the development of revolutionary technology for efficient air conditioning.

Relatedly, the emergence of electrically conductive MOFs has been one of the most paradoxical developments in the field in the last few years. Indeed, how can one transport charges through a material that is mostly "empty" space? In this sense, MOFs made from layers of organic ligands connected by (typically) square-planar metal ions have shown particularly good electrical conductivity. I will show how fundamental investigations of electrically conductive MOFs eventually led to the development of new, organic cathode materials for sustainable Li- and Na-ion batteries.

Keywords: *metal-organic frameworks, sustainable materials, batteries, water sorption, energy efficiency*

CIRCULAR ECONOMY APPROACH FOR ENERGY TECHNOLOGIES

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The need for renewable energy systems and energy storage devices is increasing significantly in the future as we are facing out from fossil energy. However, while we reduce our dependency of fossil fuels, we should not become dependent on critical materials that are needed for renewable energy systems. To make the latter truly sustainable, we will need to ensure that at end of life it is possible to recover the materials that were invested. However, this is not enough, but we also need to ensure the high quality of these recovered materials so that they can used back into the same applications as secondary raw materials. Only this will ensure the circularity of energy systems. This is the only way to provide circular solutions for the material design for energy applications and enable sustainable renewable energy applications.

Currently, the scientific new material development is unfortunately suggesting more complex material combinations for energy systems. This is partly due to the need to provide something new for the scientific community in journal publications. However, these more complex materials are also more difficult to separate from each other with high purity. The use of these materials both increase the energy use and cost of end-of-life energy system recycling. Therefore, the focus to provide new advanced features should be moved from the complexity of the materials to more intelligent design of energy devices and systems.

Design for recycling is a concept that was introduced for any manufactured products, and it has been also possible to be apply for energy systems (Miettunen and Santasalo-Aarnio). In this strategy the liberation and recovery of critical and valuable components is considered prior to the production of the devices. This would ensure the circularity of these critical and valuable materials for the use of new devices and truly provide sustainable energy systems.

Keywords: *Circular Economy; Energy systems; Design for recycling; Energy materials*

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INNOVATION TO DEPLOYMENT: CIRCULAR ENERGY SYSTEMS AND THE COMMERCIALISATION OF HYDROGEN-DERIVED LOW-CARBON FUELS

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HOLISTIC SYSTEM FOR RECOVERING DEUTERIUM FROM WASTE STREAMS: OPERATIONAL EXPERIENCE AND FUTURE HORIZONS

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The global demand for deuterium is rapidly increasing due to its expanding role in semiconductor manufacturing, advanced materials, and emerging biomedical technologies. Conventional production routes based on natural abundance extraction are energy-intensive and insufficient to meet growing demand. This work presents a **holistic lifecycle approach** for recovering deuterium from downgraded and contaminated heavy water streams, enabling circular isotope management and reducing environmental impact.

Downgraded D_2O feedstocks typically range from 20 to 99 atom % deuterium and may contain up to 6% impurities. A robust and scalable purification process has been developed, combining **distillation, catalytic ozonolysis, and ion-exchange polishing**. This sequence effectively removes organic and inorganic contaminants, producing chemically pure D_2O suitable for isotopic upgrading.

Subsequent enrichment is achieved using a **combined electrolysis and catalytic exchange (CECE)** process, allowing efficient upgrading from intermediate concentrations to ≥99.92 atom % deuterium. By starting from downgraded D_2O rather than natural abundance (~147 ppm), the process significantly reduces **energy consumption and greenhouse gas emissions**, overcoming a key barrier in conventional deuterium production.

Beyond recovery, this integrated platform supports the production of **high-value deuterated products**, including medical-grade D_2O, semiconductor-grade D_2 gas (up to 5N purity), and advanced biomolecules. Recent developments include patented methods for **deuterated mRNA synthesis with enhanced thermal stability**, as well as efficient preparation of compounds such as **caffeine-d_9** at gram scale.

Operational experience demonstrates that this holistic approach provides a flexible, scalable, and sustainable solution for deuterium recovery from diverse industrial waste streams. The presented framework strengthens supply chain resilience and highlights future opportunities for deuterium applications in energy, health, and advanced manufacturing sectors. "It is estimated that between 15 and 20% of deuterium sold for non-nuclear applications may be recoverable and used in new manufacturing." Isowater is working on new processes to optimize through our Deuterium Recovery Program".

SOURCES, DETECTION, AND MITIGATION STRATEGIES OF MICRO AND NANOPLASTICS, TIRE-WEAR PARTICLES, AND FOREVER CHEMICALS FROM THE AQUATIC ENVIRONMENT

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The pervasive contamination of aquatic ecosystems by persistent organic pollutants (POPs), including per- and polyfluoroalkyl substances (PFAS), micro- and nanoplastics (MNPs), returned pharmaceuticals, and tire wear organic particles (TWOP), represents one of the most pressing environmental challenges of the twenty-first century. Many of these synthetic contaminants exhibit exceptional chemical stability, persistence, and resistance to degradation. While these properties have enabled widespread industrial and commercial applications, they also pose serious risks to ecosystem integrity, biodiversity, and human health. Accordingly, there is an urgent need to identify pollutant sources, improve analytical characterization, and develop effective remediation strategies for contaminated water systems. Building on preliminary findings on MNPs and ongoing results from the DEEP-CLEAN project, this presentation highlights the potential of Natural Deep Eutectic Solvents (NADES) as a sustainable, highly efficient platform for removing recalcitrant POPs from aquatic environments. NADES are an emerging class of green solvents composed of naturally derived, biodegradable constituents and exhibit favorable physicochemical properties for environmental applications. Their remediation performance is governed by synergistic mechanisms including liquid–liquid extraction, adsorption, and extensive hydrogen-bonding interactions, enabling remarkable removal efficiencies (>99%) for PFAS compounds such as PFOS and PFOA, as well as structurally related contaminants. The presentation critically examines the current state of knowledge on NADES-based remediation, including contaminant–solvent interactions, extraction pathways, comparative advantages over conventional treatment technologies, and key technical limitations such as viscosity, solvent recovery, scalability, and economic feasibility. Experimental evidence is evaluated alongside regeneration and reuse strategies that support circular economy principles, and emerging regulatory frameworks accelerating innovation in advanced water treatment are also discussed. Finally, future research directions are proposed that integrate computational molecular design, artificial intelligence (AI), and process

optimization to accelerate the translation of NADES technologies from laboratory validation to industrial-scale implementation. In combination with complementary remediation approaches such as nanophotocatalysis and microbial consortia-assisted degradation, NADES may provide a transformative, technically robust, economically viable, and environmentally responsible solution to mitigate POPs and safeguard long-term aquatic sustainability.

Keywords: *NADES; PFAS; TWOS; persistent organic pollutants; microplastics; nanoplastics; green chemistry; sustainability.*

Project Collaboration: *Scientific Center of Zoology & Hydroecology, National Academy of Sciences of the Republic of Armenia, Yerevan, Armenia.*

ISOTOPIC INSIGHTS INTO ATMOSPHERIC NITROGEN FIXATION, MYCORRHIZAL TRANSFER, AND NITROGEN ALLOCATION IN FOOD CROPS

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Legume food plants/crops play an important role in sustainable agriculture through their symbiotic association with nitrogen-fixing bacteria, which enables the utilization of atmospheric nitrogen and contributes to soil fertility. Legume-based cropping systems and biofertilizers exploiting biological nitrogen fixation (BNF) represent important tools for sustainable agriculture.

By enhancing nitrogen inputs, improving soil health, and stimulating beneficial microbial communities, crop productivity can be increased while reducing the environmental impacts associated with intensive fertilizer application. However, maximizing the benefits of BNF under the cool climatic conditions of Northern and Eastern Europe requires the identification of well-adapted plant genotypes and effective microbial inoculants. Biological nitrogen fixation can be quantified using the stable isotope ratio method to assess nitrogen sources and utilization efficiency. In addition, a range of agronomic and physiological parameters were measured to evaluate plant responses to inoculation and their relationship with nitrogen acquisition. We present fields experiments involving the soybean varieties Laulema and Merlin and selected commercial nitrogen fixing bacterial strains. The natural abundance nitrogen isotope ratio in inoculated and non-inoculated plant parts showed significant differences related to the atmospheric or soil nitrogen sources.

Additionally, we present experiments investigating mycorrhizal colonization intensity, which plays a vital role in the plant nutrient cycling and has a potential improve tolerance to drought and pathogens. Stable isotopes were used to test intercropping effects on nutrient allocation in spring barley, oat and field pea.

These experiments showed the potential of use of stable isotopes for investigation fungal or/and bacterial interactions during the growth period of food crops. The optimization of legume-microbe or fungi interactions through the selection of compatible crop varieties and rhizobial strains can substantially enhance biological nitrogen fixation, nitrogen use efficiency, and yield-related traits. Such targeted inoculation or intercropping strategies represent a promising approach for improving the sustainability and productivity of food crop production systems under cool European climatic conditions.

SPEAKING A COMMON LANGUAGE: THE IMPORTANCE OF SCALE DEFINITIONS, TRACEABILITY AND CONSISTENT TERMINOLOGY IN ISOTOPIC ANALYSES

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A fundamental activity in measurement science is the comparison of measurement results between laboratories or against thresholds. Those comparisons require four things: (i) the numerical value of the result; (ii) the unit in which it is expressed; (iii) an indication of uncertainty; and (iv) a clear and unambiguous definition of the quantity being reported. If measurement units are different then a unit conversion must be applied. If there is no indication of measurement uncertainty, then the significance of a difference is unknowable. Similarly, if different terms, symbols or definitions are used for the same quantity, then comparison and interpretation become difficult and prone to error.

Isotope delta is a relative difference in isotope ratio between a sample and a reference (Coplen, 2011). Complexity for comparison of isotope-delta values arises from several sources. These include changes to assigned values for reference materials (e.g. Brand et al 2009), deliberate or inadvertent introduction of additional references (e.g. Coplen et al, 2006, Dunn & Camin, 2024) and new recommendations for calibration or normalisation (e.g. Coplen 1995). Simply stating results are reported as permille (‰) deviations from a stated reference may not be enough to ensure comparability as there are subtle but important variations in how isotope-delta values are made traceable to those references (Dunn & Skrzypek, 2023, Salouros et al, 2023). Comparison is complicated further by inconsistent nomenclature and notation. The quantity that the International Union of Pure & Applied Chemistry (IUPAC) designates as isotope delta has been represented in the literature by several symbols (δ, ε, μ or γ), while many quantities commonly used in isotope-ratio measurements are described by multiple synonymous names and symbols that vary between scientific communities (Coplen, 2011).

Considering isotope delta "scales" rather than just the reference for the quantity can provide a robust framework that helps understand the issues. Isotope delta scales are defined by assigning exact and unchanging isotope-delta values to at least one specific material (Camin et al, 2025). In most cases, a single material defines the scale zero-point (i.e. it is the reference itself), while in others, non-zero values or multiple materials define a

single scale. The coexistence of multiple scales for a given isotope system, overlapping scale definitions that share common materials, and even discovery of instability in the isotopic composition of a scale-defining material can lead to ambiguity. Clear and consistent terminology is therefore essential, not only for identifying which scale has been used but also for ensuring that quantities reported by different laboratories are interpreted in the same way (Skrzypek et al, 2022, Dunn et al, 2025).

The situation is particularly well illustrated for carbon isotopes where there are two delta scales in current use that share a defining point and have very similar names, VPDB (Vienna Peedee belemnite) and VPDB-LSVEC (LSVEC is the name given to a specific lithium carbonate reference material). Reference materials may be traceable to one of the scales, or, increasingly, to both through different calibration strategies. For the end user, it may not be clear to which scale a reference material value is traceable to. As a result, values that appear directly comparable may in fact reflect subtly different measurement frameworks (Dunn & Camin, 2024, Camin et al, 2025).

Beyond scale definitions, the isotope community continues to employ multiple naming conventions for equivalent quantities, such as isotope amount fraction, isotope abundance, isotopic abundance, atom fraction and mole fraction, together with a wide variety of associated symbols. Such inconsistencies can act as a barrier to communication and data exchange between measurement communities, laboratories and end users, particularly as isotopic data are increasingly exchanged, reused and combined.

This presentation will discuss the need for clarity and in reporting isotope-delta values for the purpose of comparison and will emphasise on the precautions to be taken when using data from external sources. It will also highlight the importance of consistent terminology, nomenclature and symbols in isotope-ratio measurements, as these are fundamental prerequisites for the reliable exchange, comparison and interpretation of isotopic data.

Keywords: *isotope ratio, isotope delta scales, traceability, bias, uncertainty, terminology.*

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Heidi Goenaga-Infante, Simon Cowen and Steve Ellison all of the National Measurement Laboratory, LGC Ltd.

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ADVANCING FOOD AUTHENTICITY AND TRACEABILITY THROUGH STABLE ISOTOPE TECHNIQUES: FROM BULK MEASUREMENTS TO MOLECULAR-LEVEL ISOTOPE INFORMATION

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Stable isotope analysis provides a powerful approach for food authentication and traceability because isotopic signatures naturally reflect environmental conditions, biological processes, and production history. Measurements of stable isotope ratios have been widely applied to investigate geographical and botanical origin and to detect food adulteration. However, conventional bulk isotope measurements integrate isotopic information from multiple molecular components and may therefore provide limited discrimination when samples from different origins exhibit overlapping signatures.

This presentation describes current methodological developments at the IAEA aimed at increasing the analytical selectivity of hydrogen isotope analysis and exploiting molecular-level isotopic information for food authentication. Particular attention is given to hydrogen isotopes, which are strongly influenced by source water, precipitation, temperature, humidity, evapotranspiration, and plant physiological processes, making δ^2H a potentially valuable complementary tracer to $\delta^{13}C$. At the same time, hydrogen isotope analysis is analytically challenging because carbohydrates contain both exchangeable hydrogen, which rapidly equilibrates with environmental water, and carbon-bound non-exchangeable (CBNE) hydrogen, which retains information from biosynthetic processes.

Three complementary analytical strategies are presented. The first preserves the molecular structure while selectively accessing CBNE hydrogen through derivatisation with N-methyl-bis(trifluoroacetamide) (MBTFA), enabling compound-specific measurements by GC-CrAg/HTC-IRMS. The validated approach showed excellent chromatographic separation, repeatability of approximately ±2–3‰, and no detectable isotope fractionation during derivatisation. Importantly, combining δ^2H with $\delta^{13}C$ provided additional

discrimination for samples that could not be differentiated using carbon isotope information alone.

The second strategy simplifies the analytical workflow by chemically transforming carbohydrates into hexamethylenetetramine (HMT), while quantitatively retaining carbon-bound hydrogen isotope information. This approach avoids GC derivatisation and enables δ^2H determination using routine EA-IRMS instrumentation. Validation demonstrated quantitative conversion, high repeatability, and compatibility with routine isotope-ratio measurements, supporting its application to food authenticity studies.

The third strategy further increases molecular resolution by targeting a specific functional group rather than the entire carbohydrate molecule. Methoxy groups are selectively converted into methyl iodide, allowing methoxy hydrogen to be analysed by headspace GC-IRMS. Validation confirmed complete functional-group conversion, good repeatability, and reproducible isotope measurements, while application to mango samples demonstrated that methoxy-group δ^2H retains geographical information and can provide additional discrimination among origins. Overall, these developments illustrate a progressive increase in analytical resolution, from bulk isotope measurements to compound-specific and functional-group-specific analysis. The results demonstrate that different molecular domains preserve distinct aspects of environmental and biological information and that greater analytical selectivity can substantially enhance the discriminatory capability of isotope-based food authentication. Future developments may extend this concept towards position-specific isotope analysis, with the ultimate objective of obtaining more selective and information-rich isotopic fingerprints for food authenticity and traceability.

Keywords: *food authenticity; food traceability; stable isotopes; δ^2H; $\delta^{13}C$; compound-specific isotope analysis; functional-group-specific isotope analysis; IRMS; hydrogen isotopes; geographical origin*.

HYDROGEN ISOTOPES HANDLING AND SAFETY REQUIREMENTS FOR FUSION DEVICES

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Deuterium is the main fuel currently used in the plasma experimental devices with the ultimate aim for the fusoin development. Deuterium and tritium fusion reaction is so far most promising to realise fusion energy in future fusion devices. While deuterium can be extracted from the water, one of the most abundant resources on the earth, the radioactive nature of tritium requires specific supply of the tritium fuel and dedicated prevention of any accidental release to the environment. Tritium inventory requirement on both tritium self-sufficiency and initial start-up inventory have long been a significant topic towards future fusion energy realisation due to challenges of the hydrogen isotopes handling. In order to pursue and accelerate the development of key technologies associated with fusion, more experimental fusion devices have been built to operate in either D-D or D-T modes. As a result, the safe hanlding of deuterium and tritium would inevitably be an important task. The handling process includes fueling, burning, retention and recycling need to be optimized in order to minimise the tritium inventory throughout. An essential process for achieving tritium self-sufficiency in fusion systems is not only sufficient tritium production but also effective extraction and recycling, i.e. from the generation in the breeding material to its delivery back to the fuel cycle. This contribution also presents requirements to minimize the retention of hydrogens in the fuel cycle system, to shorten the process time and to ensure the safe usage of hydrogen isotopes.

HYDROGEN RESEARCH AND INNOVATION: STRATEGIC PRIORITIES AND R&D DIRECTIONS WITHIN ROHYDROHUB

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The transition towards a climate-neutral and resilient energy system requires coordinated advances across the entire hydrogen value chain, from renewable hydrogen production and storage to conversion, integration and end-use applications. The Romanian Hydrogen and New Energy Technologies Hub – RO-HydroHub represents a strategic national initiative aimed at strengthening Romania's research, innovation and technology transfer capacity in the field of hydrogen and advanced energy systems.

The main strategic priorities and R&D directions currently addressed within RO-HydroHub are outlined, with a focus on the development, validation and integration of hydrogen technologies at component, system and infrastructure levels. Key research activities include the development of advanced proton exchange membrane electrolysis technologies and fuel-cell systems, the development of integrated balance-of-plant, control and safety strategies. Beyond electrochemical conversion, RO-HydroHub addresses hydrogen production through alternative pathways, advanced storage and liquefaction technologies, hydrogen compression and handling, as well as integrated Power-to-X concepts and hybrid energy systems. Research efforts also include portable and stationary hydrogen-based power systems, sector coupling, digitalization, artificial intelligence and advanced modelling tools for performance prediction, optimization and system-level integration.

A central objective of the hub is to move beyond individual technology development towards integrated demonstrators and research infrastructures capable of supporting validation at relevant technology readiness levels. Through the integration of research organizations, universities and industrial partners, RO-HydroHub aims to create a collaborative framework that accelerates innovation, strengthens national competencies and facilitates knowledge and technology transfer. The long-term ambition is to contribute to a competitive Romanian hydrogen ecosystem while positioning the developed research infrastructure and expertise within european hydrogen and clean-energy value chains.

Keywords: *Renewable hydrogen; Hydrogen production; Hydrogen storage and liquefaction; Fuel cells; Power-to-X; Integrated energy systems; Technology demonstration.*

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PERSPECTIVE ON THE NEED FOR ROBUST DATA TO SUPPORT THE DEVELOPMENT, IMPLEMENTATION AND EVALUATION OF POLICIES IN THE *LULUCF*-SECTOR

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Policies in the area of land use and forestry (LULUCF) that has been implemented during the past decade and those under development puts light on the need for robust data for reporting and verification at different scales. Two examples are the LULUCF regulation (EU 2023/839) which strongly emphasize that the methods used to follow up member states commitments on the national level must be enhanced and the CRCF methodologies that push the requirements for MRV on a project level. At the same time, policies are under development on the country level and reporting of LULUCF-related emissions and removals may also be included in included in company reporting under GHG protocol. The situation among member states is very different regarding the availability to data on carbon stocks and carbon stock changes at different scales and for different land use categories. The systems for collecting data may also differ. This will be a challenge for actors at different levels of society and highlight the importance to assess the needs of data and methods in each policy and in each application.

INTEGRATED ENERGY SYSTEMS AND CIRCULAR ENERGY INFRASTRUCTURE

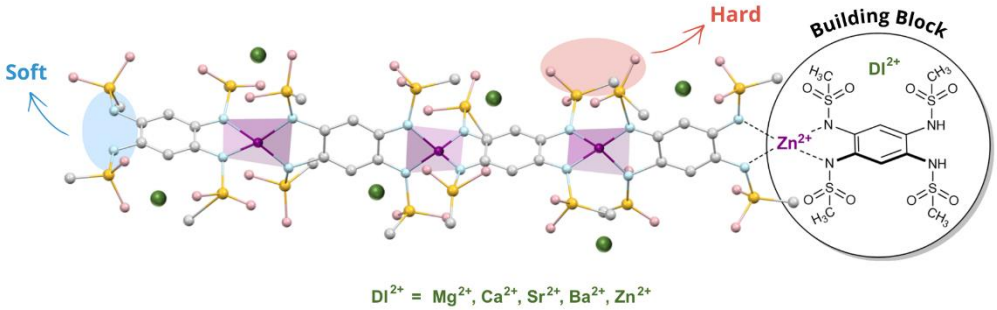
ENGINEERING MULTIVALENT-ION STORAGE IN AMORPHOUS COORDINATION POLYMERS

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Divalent metal-ion batteries constitute promising alternatives to lithium-ion systems due to their potential advantages in volumetric energy density, cost, sustainability, and safety. However, the reversible storage of multivalent cations remains challenging because their strong interactions with rigid inorganic hosts hinder ion mobility and reversibility. Although substantial efforts have focused on electrolyte development, the positive electrode remains a critical bottleneck. Recently, we developed a family of cation-containing amorphous sulfonamide coordination polymers as a versatile platform for multivalent-ion storage. These materials reversibly accommodate Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, and Zn^{2+} cations, operating at high working potentials of 3.2 V vs. Ca^{2+}/Ca and 2.8 V vs. Mg^{2+}/Mg, while delivering fast kinetics, long cycling stability, and exceptionally low hysteresis. Notably, this platform enables the first demonstration of reversible Sr^{2+} and Ba^{2+} storage, extending reversible solid-state storage beyond the commonly investigated Mg^{2+} and Ca^{2+} systems. The electrochemical behavior originates from the deliberate combination of three structural features: delocalized anionic charge, disordered cation coordination, and the structural adaptability of an amorphous framework. Together, these characteristics weaken metal-ion binding while providing dynamically accessible coordination environments that facilitate rapid ion transport. This design enables the reversible storage of pure solid-state divalent cations, without solvent or anion co-intercalation, overcoming a longstanding limitation in multivalent-ion electrode chemistry. These results establish amorphous coordination polymers as an adaptable materials platform for engineering multivalent-ion storage. The combination of earth-abundant, non-toxic elements, structural disorder, and tunable coordination environments provides a set of general design principles for controlling cation binding, mobility, and storage. By integrating the stability of coordination networks with the flexibility of amorphous organic-inorganic frameworks, this approach opens new opportunities

for high-performance Mg and Ca batteries, highlighting the importance of simultaneously engineering electrode structures and high-voltage electrolytes toward practical multivalent batteries.



Keywords: *Multivalent Batteries, Organic Battery Materials, Calcium Storage, Coordination Polymers.*

Reference:

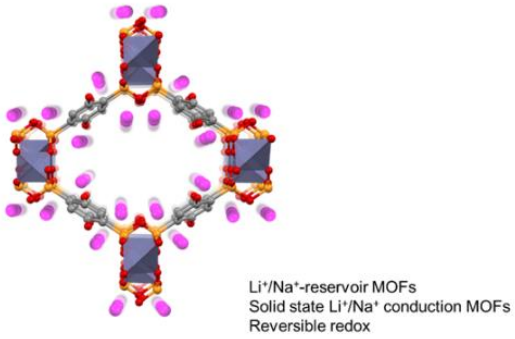
Markowski, R., et al. Energy & Environmental Science, 2025. (doi:10.1039/d5ee02567b)

BRIDGING ION CONDUCTION AND CHARGE STORAGE IN LITHIUM-RICH ZINC PHOSPHONATE FRAMEWORKS

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Metal-organic frameworks (MOFs) have recently emerged as an important and challenging class of electrochemical energy storage materials. While previous examples of alkali-containing MOFs are mainly based on carboxylate linkers, new category of materials must be studied to exceed carboxylate limitations. Herein, we present a new phosphonate-based anionic bimetallic organic framework, with the general formula of A_4-Zn-DOBDP (wherein A is Li^+ or Na^+, and $DOBDP^{6-}$ is the 2,5-dioxido-1,4-benzenediphosphate ligand) prepared and characterized for energy storage applications.1,2 With four alkali cations per formula unit, the A_4-Zn-DOBDP MOF is found to be the first example of non-solvated cation conducting MOF with measured conductivities of 5.4×10^{-8} Scm^{-1} and 3.4×10^{-8} Scm^{-1} for Li_4- and Na_4-phases, indicating phase and composition effects of Li^+ and Na^+ shuttling through the channels. Three orders of magnitude increase in ionic conductivity is further attained upon solvation with propylene carbonate, placing this system among the best MOF ionic conductors at room temperature. As positive electrode material, Li_4-Zn-DOBDP delivers a specific capacity of 140 $mAhg^{-1}$ at a high average discharge potential of 3.2 V (vs. Li^+/Li) with 90 % of capacity retention over 100 cycles. The significance of this research extends from the development of a new family of electroactive phosphonate-based MOFs with inherent ionic conductivity and reversible cation storage, to providing elementary insights into the development of highly sought yet still evasive MOFs with mixed-ion and electron conduction for energy storage applications.



Keywords: *Battery, Organic Battery Materials, MOFs, Ionic conductivity*

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ELECTROLYTE ENGINEERING AND INTERFACIAL STABILIZATION IN ANODE-FREE SODIUM-METAL BATTERIES FOR SUSTAINABLE ENERGY STORAGE

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Anode-free sodium metal batteries (AFSMBs) have drawn significant attention for developing large-scale energy storage systems owing to their high energy density, low cost and resource-efficient cell design, compared to conventional lithium-based systems. By eliminating the excess metallic anode of sodium metal batteries (SMBs), they offer a simplified and secure cell architecture that aligns with the principles of circular and sustainable energy systems. However, the sole dependence on cathode as the sodium (Na) source make AFSMBs highly sensitive to irreversible Na loss arising from the unstable Na plating/stripping processes and parasitic interfacial reactions. These phenomena result in rapid depletion of active Na inventory, leading to reduced Coulombic efficiency (CE) and poor cycling stability [Hu et all., 2024; Liu, et all., 2024; Li et all., 2025]. We therefore investigate rational electrolyte design strategies using novel salt-solvent combinations and functional additives, aimed at stabilizing electrode interfaces and improving cell durability.

Different Na salts ($NaPF_6$, $NaBF_4$, and $NaCF_3SO_3$) and their combinations were evaluated in single and binary ether-based solvents (G2 and G4). Selected electrolyte formulations incorporated NaDFOB salt as a sacrificial additive to promote robust solid-electrolyte and cathode-electrolyte interphases (SEI & CEI) [Wang and Hofmann, 2025]. Preliminary electrochemical studies reveal that both current collector surface chemistry and electrolyte solvation structures strongly influence Na nucleation behaviour and initial CE. Furthermore, presence of associative salts such as $NaCF_3SO_3$ and $NaBF_4$ promote contact-ion-pair (CIP)-dominated solvation environments, leading to the formation of inorganic-rich

interphases that suppress polarization fluctuations and improve cyclic stability. The formulated electrolytes were further studied with $Na_3V_2(PO_4)_3$ (NVP) and high-voltage $Na_3V_2(PO_4)_2F_3$ (NVPF) cathodes. Ongoing work involves controlled electrochemical studies to establish optimized testing protocols along with advanced interfacial characterizations to establish a suitable electrolyte formulation for durable AFSMBs [Rupp and Vlad, 2019]. The development of AFSMBs can contribute to sustainable and resource-efficient energy storage technologies required for future integrated energy systems.

Keywords: Anode-free sodium metal battery, electrolyte engineering, sodium plating, stable interphase, high energy density batteries, sustainable energy storage

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DRY-PROCESSED *NVP* CATHODE: A SCALABLE PATH TO NEXT-GENERATION SODIUM-METAL BATTERIES FOR SUSTAINABLE ENERGY STORAGE

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The fabrication of high-mass loading electrodes is becoming increasingly important in large-scale battery applications, such as electric vehicles and grid-scale energy storage systems. Conventional synthesis methods generally involve solvent-based procedures, leading to high fabrication costs, environmental harm, and toxicity. Moreover, high mass loading electrodes fabricated via a slurry-based process often suffer from weaker mechanical properties, heterogeneity issues, and lower electrochemical performance [Lu et al., 2022]. Recent advancements in electrode fabrication techniques, have provided many alternatives to these conventional approaches. In particular, solvent-free electrodes fabricated via dry-processing have shown promise in overcoming these challenges, with strong potential to produce high-loading electrodes[Gou et al., 2026; Schumm et al., 2025].

As interest in sodium battery technology has increased in recent years, this researach work focuses on the fabrication of a free-standing solvent-free $Na_3V_2(PO_4)_3$ (NVP) cathode via dry processing. This approach entails mixing the NVP active material and conductive additives with the polytetrafluoroethylene (PTFE) binder in a completely dry state under a shear force.

The resulting cathodes are solvent-free, thick and flexible self-standing films achieving a mass loading of 80 mg cm^{-2}. Sodium Metal Batteries (SMB), using this solvent-free NVP electrode exhibited good cycling stability over 90 cycles with a Coulombic efficiency of 97%. More importantly, when these electrodes are paired with a bare Cu current collector in a pouch-cell Anode-Free Sodium Metal Battery

(AFSMB) configuration, the cell retained 68% of its initial capacity after more than 50 cycles under high mass-loading conditions. This study demonstrates the potential for practical deployment of dry processing in next-generation sodium battery technology, promising a more sustainable future.

Keywords: *High mass-loading, Solvent-free, Dry-process, Anode-Free Sodium Metal Battery (AFSMB), Free-standing cathode.*

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FROM STANDARDS TO SENSORS: BRIDGING REGULATORY GAPS FOR HYDROGEN–NATURAL GAS BLENDS IN RESIDENTIAL COMBUSTION

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The transition toward decarbonising the residential combustion sector requires, at least at this moment, the gradual injection of hydrogen into natural gas networks. To date, this practice has been validated up to about 20% by volume across several European projects [Cadent Gas Ltd. et al., 2024; Hy4Heat Programme, n.d.; THyGA Consortium, 2022]. At the same time, current regulations and standards, developed for conventional gases, do not clearly address hydrogen's physicochemical characteristics. Therefore, we show that three specific gaps remain in the existing standardisation framework for hydrogen-natural gas (H_2NG) blends in residential combustion, and we propose an experimental and monitoring framework to address them. A three-stage analysis (normative, experimental, and technical) was carried out within the Ro-HydroHub project.

An analysis of the technical standards for domestic burners revealed three major limitations regarding hydrogen integration. No NO_x emission limits are set by the standard SR EN 30-1-1+A1:2024 [ASRO, 2024], which addresses the safety and performance of gas-fired cooking applications, while its test methods for flame lift-off and flashback phenomena are not calibrated for the significantly higher propagation speed and lower ignition energy of hydrogen. On the other hand, EN 437:2021 [CEN, 2021], which defines reference gases and appliance categories, although it includes certain hydrogen mixtures (e.g., limit gas G222, 23% H_2), does not consider the dynamic behaviour associated with variable CH_4/H_2 composition transitions (as in our proposed research scenarios). The reference method for NO_x emissions is defined by the standard SR EN 14792:2017 [ASRO, 2017] as chemiluminescence but does not distinguish between the contributions of specific NO_x formation mechanisms (thermal, prompt, and fuel-derived); this is a relevant limitation for correctly interpreting hydrogen's impact on flame temperature and radical kinetics.

Table 1. Summarises the key physicochemical differences between CH_4 and H_2, along with the direct implications for adapting the standardisation framework.

Table 1. CH_4 vs. H_2 differences relevant to standardisation

Property	CH_4	H_2	Implication for standardisation
Flame propagation speed	low	very high	flashback risk
Minimum ignition energy	high	very low	increased sensitivity
CO_2 emissions	significant	none	paradigm shift
NO_x trend	moderate	temperature-dependent	requires a new model

To address the identified regulatory gaps, an experimental methodology was designed based on a response surface matrix (central composite design), using the hydrogen volume fraction (x_H_2) and the excess air coefficient (λ) as primary factors across three combustion scenarios: 100% CH_4, 100% H_2, and a CH_4/H_2 mixture (up to 20–23% H_2, aligning with the limit gases specified in EN 437:2021). A comparative analysis of available measurement systems (portable analysers vs. stationary AMS-type systems - Automated Measuring Systems) and sampling methods (direct extractive, dilution, in-situ) was conducted to select a stationary system architecture including direct extractive sampling for gaseous compounds and in-situ optical measurement for particulates.

During the research, cross-interference between residual hydrogen and electrochemical CO sensors emerged as an important technical challenge. This interference produces a false-positive response ranging from 30% to 100% of the CO sensitivity (Crowcon Detection Instruments Limited, n.d.). Therefore, optical reference methods (non-dispersive infrared, chemiluminescence) were selected for the primary analyser, complemented by a dedicated chromatographic measurement chain for residual hydrogen, a pollutant for which no European reference standard currently exists. The proposed monitoring system is structured around seven complementary functional components, selectively activated based on the specific combustion scenarios being tested.

By clearly connecting the identified regulatory gaps to an experimental design and a monitoring system able to address them, this work provides a critical precondition for developing a mathematical model to estimate emissions from the combustion of CH_4, H_2, and CH_4/H_2 mixtures.

The results are relevant to the ongoing revision of European EN and ISO standards, offering both a summary of the current framework's limitations and a specific proposal for a replicable experimental methodology for similar research on integrating hydrogen into residential combustion systems.

Keywords: *hydrogen-natural gas mixtures, residential appliances, emissions monitoring, standardisation gaps, SR EN 30-1-1*

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ANALYSIS OF WASTE HEAT RECOVERY OPTIONS FROM AN H_2/CH_4-FUELED *CHP* SYSTEM INTEGRATED WITH AN *ORC* AND A HEAT PUMP

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This study investigates waste heat recovery options for an H_2/CH_4-fueled combined heat and power (CHP) unit integrated with an Organic Rankine Cycle (ORC) and a heat pump. The main objective is to assess how the successive integration of these recovery technologies affects the utilization of the energy available from the CHP unit. Four configurations are considered: standalone CHP, CHP-ORC, CHP-heat pump, and CHP-ORC-heat pump. For each configuration, the analysis determines the electrical power output, useful thermal energy, additional electricity generated by the ORC, heat pump electricity consumption, recovered thermal energy, and heat rejected through the dry cooler. All configurations are evaluated under comparable CHP operating conditions and the same thermal demand boundary conditions. The comparison quantifies the individual contribution of the ORC and the heat pump and evaluates their combined effect on waste heat utilization. The analysis identifies the configuration that provides the most effective use of the available waste heat by increasing useful energy production while reducing the amount of heat rejected to the environment.

Keywords: Combined heat and power (CHP); Organic Rankine Cycle (ORC); Heat pump; Waste heat recovery; H_2/CH_4 fuel mixture

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TECHNO-ECONOMIC AND PERFORMANCE ASSESSMENT OF A MODULAR SOLAR-HYDROGEN *CCHP* MICROGRID

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The transition toward decentralized generation demands resilient, small-scale backup solutions for diverse end-users, including emerging energy communities. This paper presents a techno-economic and thermodynamic assessment of a modular solar-hydrogen combined cooling, heating, and power (CCHP) microgrid. Driven by distributed photovoltaics, surplus electricity powers a proton exchange membrane (PEM) electrolyzer. The synthesized green hydrogen provides seasonal storage for PEM fuel cell emergency backup and dynamic Power-to-Gas (PtG) blending into the local natural gas network. To maximize system efficiency, low-grade waste heat from the electrochemical units is recovered via a centralized thermal loop, driving a small-scale absorption chiller to meet domestic hot water, heating, and cooling loads.

Employing dynamic annual simulations, a multi-objective optimization framework balances the Levelized Cost of Energy (LCOE) with overall thermodynamic efficiency, benchmarking the proposed architecture against conventional standalone setups. The analysis evaluates how sector coupling, thermal recovery, and load aggregation mitigate thermal losses and reduce grid-gas reliance through local hydrogen injection. Ultimately, the study validates the integrated CCHP microgrid as a scalable, zero-emission decarbonization pathway, ensuring long-duration autonomy and optimized operational costs for decentralized applications.

Keywords: *Decentralized microgrid; Modular CCHP; Green hydrogen; Power-to-Gas blending; Sector coupling; Thermodynamic simulation.*

BUILDING ENERGY EFFICIENCY AS VIRTUAL ENERGY CAPACITY: COOLING, RESILIENCE AND THE EURO-*MEDITERRANEAN ENERGY CORRIDOR*

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Europe's energy transition requires not only rapid deployment of renewable generation and cross-border infrastructure, but also a reduction in the energy required to provide essential services. This study examines building energy efficiency and cooling-demand reduction as strategic components of energy security within the emerging Euro-Mediterranean energy relationship. It proposes the concept of "virtual energy capacity", defined as electricity capacity and energy made effectively available through avoided consumption resulting from improved building performance and cooling-system efficiency.

The research focuses primarily on MENA, where exceptional renewable-energy potential coincides with rapidly increasing electricity demand for cooling. It investigates how improvements in building envelopes, solar shading, glazing, HVAC efficiency, intelligent controls, ventilation, thermal-energy storage, and district cooling can reduce both annual electricity consumption and peak cooling demand. The study then considers the Romanian electricity system as a European reference case, where increasing summer cooling demand can coincide with heatwaves, drought, and constraints affecting electricity generation. Although Romania and MENA have fundamentally different climatic conditions, both illustrate the same engineering principle: reducing cooling demand can improve electricity-system resilience during periods of extreme weather and system stress.

The research focuses primarily on MENA, where exceptional renewable-energy potential coincides with rapidly increasing electricity demand for cooling. It investigates how improvements in building envelopes, solar shading, glazing, HVAC efficiency, intelligent controls, ventilation, thermal-energy storage, and district cooling can reduce both annual electricity consumption and peak cooling demand. The study then considers the Romanian electricity system as a European reference case, where increasing summer cooling demand can coincide with heatwaves, drought, and constraints affecting electricity generation. Although Romania and MENA have fundamentally different climatic conditions, both illustrate the same

engineering principle: reducing cooling demand can improve electricity-system resilience during periods of extreme weather and system stress.

The research ultimately proposes a Euro-Mediterranean Cooling and Building Efficiency Framework linking technical efficiency with renewable-energy development, energy-system resilience, and international cooperation. By reducing unnecessary electricity consumption, efficient buildings can release capacity for domestic development, renewable integration, green hydrogen production, and potentially electricity exports. The study therefore argues that energy efficiency should be treated not as a secondary environmental measure, but as a form of strategic energy infrastructure that complements renewable generation and transmission.

This interdisciplinary approach connects HVAC engineering, building performance, European energy security, and international cooperation, demonstrating how a building-level engineering intervention can contribute to the resilience and strategic value of a wider Euro-Mediterranean energy system.

WIND-TO-HYDROGEN INTEGRATED SYSTEM USING A COUNTER-ROTATING LENZ 2 VERTICAL AXIS WIND TURBINE: DESIGN ALGORITHMS, EXERGY ANALYSIS AND *PEM* ELECTROLYZER COUPLING

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This paper presents the design, modelling, and experimental validation of an integrated wind-to-hydrogen system based on a counter-rotating Lenz 2 vertical axis wind turbine (VAWT) coupled directly to a proton exchange membrane (PEM) electrolyzer, without intermediate energy storage. The system is the subject of Romanian patent application OSIM A/00259/2025 (VortexDublu) and constitutes the core of an ongoing doctoral research programme at POLITEHNICA Bucharest.

The turbine architecture consists of two coaxial Lenz 2 rotor sets rotating in opposite directions, connected to a dual-rotation permanent-magnet synchronous generator (PMSG). This configuration produces a double relative rotational speed compared with a single-rotor solution, increasing mechanical power extraction without modifying the global kinematic regime. The blades operate primarily in the drag regime, enabling omni-directional operation, self-starting at wind speeds as low as 3 m/s, and low acoustic emission (< 40 dB at 12 m). Aerodynamic performance was characterised through 2D CFD simulations in ANSYS Fluent 2024 R1 and validated in a wind tunnel at the University POLITEHNICA Bucharest. Experimental results yielded $C_{p,max} \approx 0.33$ at TSR = 0.6–0.7, confirmed by CFD with deviations below 6% for C_p and below 8% for shaft torque.

The multi-physics model of the integrated system couples three subsystems through a state-space formulation. The aerodynamic model uses Blade Element Momentum (BEM) theory with Gaussian correction for the power coefficient: $C_p(\lambda) = C_{p,max} \cdot \exp[-((\lambda - \lambda_{opt})/\sigma)^2]$. The electrical model is formulated in the d–q rotor reference frame of the PMSG. The electrochemical model governs hydrogen production via Faraday's law: $\dot{n}H_2 = \eta_F \cdot I / (2F)$, with Faraday efficiency $\eta_F \approx 0.95$ at nominal operating current. The direct wind-to-hydrogen path (without batteries) constitutes the principal innovative feature of the proposed system.

Power electronics and control are implemented around a hybrid MPPT controller running on an STM32F4 microcontroller (ARM Cortex-M4, 168 MHz). A comparative analysis of Maximum Power Point Tracking strategies — Perturb & Observe (P&O), Optimal Torque Control (OTC), and TSR-based control — identifies the quadratic torque law $T_{ref} = K_{opt} \cdot \omega^2$ as the preferred strategy for the counter-rotating configuration, avoiding the

permanent oscillations of classical P&O and eliminating the need for an anemometer. A buck-boost DC–DC converter (L = 470 µH, C = 1000 µF, f_{sw} = 20 kHz, η ≈ 95%) stabilises the DC bus at 12 V and provides multi-layer protection of the PEM electrolyzer membrane (OVP, OCP, UVP, OTP, reverse-polarity).

A complete exergy analysis quantifies irreversibility across all subsystems. At V_∞ = 10 m/s and TSR = 0.6, the exergy input from wind is 110.25 W, of which 31.68 W reach the turbine shaft (aerodynamic efficiency 28.7%), 26.93 W are delivered electrically, and only 2.22 W are stored as chemical exergy in hydrogen (global exergetic efficiency ψ ≈ 2%). The dominant irreversibility source is aerodynamic (71.3% of inlet exergy lost in the rotor), followed by the PEM electrolyzer (22.5%). The counter-rotating architecture improves aerodynamic efficiency by 15–25% relative to the single-rotor Lenz 2 variant, through wake energy recovery by the lower rotor.

The PEM electrolyzer was selected after dynamic compatibility analysis against alkaline (AWE) and solid oxide (SOEC) technologies. Only PEM meets the sub-second response time required by the variable wind power profile. The designed stack comprises 6 cells in series (Nafion 115/117 membrane, active area 25 cm²/cell, Pt/C cathode 0.5 mg/cm², IrO_2/TiO_2 anode 2 mg/cm²), operating at V_{cell} = 1.85–2.1 V and 40–60°C. At V_∞ = 12 m/s, the system produces approximately 9.2 L/h of hydrogen (standard conditions), with an overall system efficiency $\eta_{sys} \approx 14.3\%$ (wind power to H_2 chemical energy). This figure is consistent with published results for small VAWT–PEM systems (Oprina et al., 2016; Le et al., 2023).

The integrated system is validated at laboratory scale (< 100 W) and provides a documented pathway to medium-power decentralised green hydrogen production (1–5 kW). Future work targets geometric optimisation of Lenz 2 blades to raise C_p toward 0.38–0.40, integration of a supercapacitor buffer to smooth electrolyzer input, and scaling of the PEM stack to match increased turbine power.

Keywords: *vertical axis wind turbine; counter-rotating Lenz 2; green hydrogen; PEM electrolyzer; MPPT control; exergy analysis*

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RATIONAL DESIGN OF ECO-FRIENDLY BINARY BINDERS FOR STABLE AND HIGH-PERFORMANCE SiO_X/C LITHIUM-ION ANODES

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In the context of the energy transition towards more efficient and environmentally friendly systems, the strategic role of batteries and their improvement is crucial. Optimizing the production processes for materials, their engineering, and their implementation in batteries is essential for enhancing performance, reducing costs, and ensuring sustainability. Batteries, being complex systems composed of various materials such as inorganic and polymeric substances, metals, and liquid solutions, require a thorough study of each component and their integration. Additionally, beyond developing individual materials and components, it is vital to optimize the electrode and battery production processes to fully exploit their synergistic contributions while mitigating potential drawbacks. While the study and development of new active materials have enhanced key battery parameters like energy and power density, a significant challenge lies in enhancing the electrochemical performance of batteries through "non-active" materials (binder, current collector, separators) that are cost-effective, environmentally friendly, and easily recyclable.

This study explores improvements in the production process of Lithium-ion Battery (LIB) electrode materials for next-generation LIBs by identifying water-compatible binders that ensure robust mechanical and electrochemical properties. The principal aim is to provide a sustainable and cost-effective alternative to the conventional PVdF/NMP (polyvinylidene fluoride/N-methyl pyrrolidone) system and a more versatile substitute for the Na-CMC/SBR (sodium carboxymethyl cellulose/styrene-butadiene rubber) binder combination.

A comprehensive screening of water-soluble binders, primarily polysaccharides, was conducted. Rheological, electrochemical, and morphological analyses were combined to evaluate slurry processability, electrode integrity, and cell performance. To further enhance mechanical resilience and long-term cycling stability, the most promising

polysaccharide (Alginate) was combined with lithiated polyacrylic acid (LiPAA) in binary mixtures (total binder content 3 wt.%). Statistical analysis was employed to quantify the influence of binder composition on electrochemical responses. The 2LiPAA:1ALG formulation demonstrated superior cycling stability, lower total interfacial resistance, improved initial Coulombic Efficiency (>95%), and enhanced capacity retention during long-term cycling compared to single-binder systems. The study revealed complementary functional roles of the two polymers: LiPAA promoted the formation of a less resistive SEI, while ALG provided improved mechanical cohesion and reduced charge-transfer resistance [Tamboia et al., 2026].

Unlike crosslinked or chemically modified binder systems, the proposed strategy relies on simple physical blending, maintaining slurry processability and industrial scalability. These findings demonstrate that rationally engineered combinations of natural and synthetic aqueous binders offer an effective and sustainable pathway to enhance the electrochemical and mechanical performance of next-generation SiOx/C anodes.

Keywords: *Lithium-ion battery, Aqueous binder, SiOx/C, Binary binder mixture*

Reference:

Tamboia L., Montinaro G., Ravesio E., Amici J, Francia C., Bodoardo, Bella F., Versaci D., *"Optimization of binary binder blends for aqueous-based slurries of SiOx/C for next-generation lithium-ion batteries"*, Journal of Cleaner Production 554, 2026, 148153

EVALUATING SYNTHESIS PARAMETERS OF $Ti_3C_2T_x$ MXENES TO BALANCE POLYSULPHIDES ADSORPTION AND Li_2S DEPOSITION IN LITHIUM-SULPHUR BATTERIES

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Nowadays lithium-ion batteries (LIBs) are the most spread and reliable energy storage technology, but they also show some drawbacks that hinder the possibility to satisfy the rising demand for energy storage devices. Consequently, the study and development of alternative post-lithium-ion technologies is of crucial importance to make them commercially viable in the future. Among these systems, Lithium-Sulphur batteries (Li-S) are one of the most interesting due to the high theoretical specific capacity (1672 mAh g^{-1}) and natural abundance of sulphur. However, the practical application of Li-S is still strongly limited by some issues. The most impactful one is the so-called shuttle effect, caused by the diffusion of soluble lithium polysulphides formed upon cell discharge. To prevent this problem, different materials capable of binding these soluble species and catalysing their conversion reactions have been proposed as cathodic sulphur hosts.

The present work aimed at studying a recent class of bidimensional metallic carbides and nitrides, discovered in 2011 and known as MXenes, and their direct and simple application as sulphur hosts in Li-S. Particularly, four samples of $Ti_3C_2T_x$ were prepared by varying the parameters of the classic synthesis, taking into account the results of a previous experimental design study. The different samples of $Ti_3C_2T_x$ obtained were characterised by XRD, FESEM and XPS and then electrochemically tested to evaluate their affinity and activity towards lithium polysulphides. After this, the studied materials were directly implied as hosts for sulphur through melt diffusion, obtaining a MXene/sulphur composite that was characterised and tested by galvanostatic cycling.

The obtained results showed that the combination of low acid concentration and higher reaction time allows to synthesise MXenes characterised by good morphological, physico-chemical and electrochemical properties overall. In addition, using MXenes as sulphur host limits polysulphides shuttling and stabilises cell specific capacity. The best MXene sample was then furtherly tested up to 500 cycles and compared with standard carbon black-based sulphur cathodes. Although the obtained values are still far from the maximum theoretical specific capacity, $Ti_3C_2T_x$ as host material provides stable Coulombic Efficiency (>99%) and very low capacity loss per cycle (<0,27 mAh g^{-1}) if compared to standard carbon-based sulphur electrodes.

Keywords: *Lithium-sulphur batteries; MXenes; Cathode; Polysulphides*

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CONFINED WATER, FAST IONS, FLEXIBLE POWER: UNRAVELING K^+ STORAGE MECHANISMS IN $Ti_3C_2T_X$ *MXenes*

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MXenes, a family of 2D transition-metal carbides, have emerged as promising energy-storage materials owing to their high electrical conductivity, mechanical robustness, rich surface chemistry, and tunable ionic transport particularly in water confinement environment. Among them, $Ti_3C_2T_X$ MXene exhibits pseudocapacitive ion storage and has been widely studied in acidic electrolytes; however remains underexplored in safe, and sustainable neutral aqueous electrolytes, which is necessary for wearable devices.[1,2,3] In this presentation, I will reveal the fundamental K^+-ion storage mechanism in water-confined $Ti_3C_2T_X$ MXene flexible freestanding films using neutral aqueous K_2SO_4 electrolyte. By integrating advanced electrochemical characterizations with multiscale theoretical simulations, we uncover the critical role of confined interlayer water in governing pseudocapacitive K^+-ion intercalation and lattice dynamics. *Ex-situ* XRD coupled with DFT elucidates structural evolution during K^+-ion intercalation, while *in-situ* DRT, GITT, power-law analysis, and *ab initio* molecular dynamics simulations provide insights into ion-transport kinetics and capacitive charge-storage mechanisms. Furthermore, a leakage-free flexible pseudo-solid-state single layer pouch cell based on freestanding $Ti_3C_2T_X$ films and a PVA/ K_2SO_4 gel polymer electrolyte demonstrates excellent electrochemical, mechanical and thermal stability with with low self-discharge characteristics. We further explore the MXene as a conductive substrate for Prussian Blue electrodeposition to develop flexible 2D-printed interdigitated high-power hybrid ion capacitors.

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ARTIFICIAL INTELLIGENCE-BASED PREDICTION OF CIRCUIT BREAKER BEHAVIOR UNDER SHORT-CIRCUIT CONDITIONS

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The integration of Artificial Intelligence (AI), Machine Learning (ML), and Internet of Things (IoT) technologies into electrical engineering has created new possibilities for the analysis, simulation, and monitoring of electrical equipment. In particular, AI-based methods can provide effective solutions for modelling the dynamic behaviour of switching devices and for identifying operating conditions that may affect their performance and reliability. The combination of intelligent algorithms with real-time measurement and data acquisition systems enables continuous assessment of equipment behaviour and supports the development of predictive and diagnostic applications.

This paper presents the development of an Artificial Intelligence-based algorithm for simulating the dynamic behaviour of a circuit breaker under specific operating conditions. The proposed algorithm is intended to reproduce the characteristic electrical response of the circuit breaker during its operation and to provide a reliable representation of the measured signals. In order to evaluate the performance of the proposed approach, the simulated results are compared with oscillographic data recorded during laboratory tests performed on an actual circuit breaker. The comparison between experimental measurements and AI-generated results is used to assess the accuracy of the developed model and its ability to reproduce the dynamic characteristics of the switching process. The obtained results demonstrate the potential of AI-based algorithms as useful tools for circuit breaker analysis, predictive assessment, condition monitoring, and fault diagnosis. Such an approach can contribute to the development of intelligent solutions for the real-time simulation and evaluation of electrical switching equipment.

Keywords: *artificial intelligence, machine learning, circuit breaker, dynamic simulation, electrical switching, predictive analysis.*

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EXPERIMENTAL ASSESSMENT OF INSTRUMENT TRANSFORMER PERFORMANCE UNDER INTERNAL ARC FAULT CONDITIONS

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This paper investigates the behaviour of an instrument transformer under internal arc fault conditions, with the main objective of assessing its ability to withstand such faults while maintaining the safety of personnel and adjacent equipment. The study focuses on the physical and electrical effects produced by an internal arc occurring between the high-voltage and low-voltage windings and evaluates the capability of the transformer construction to withstand the resulting stresses without causing hazardous effects to the surrounding environment. Experimental investigations were carried out on a single instrument transformer, with the selected test specimen considered relevant for the assessment of this particular transformer design and for the potential extrapolation of the obtained results to transformers of the same constructive type. The paper describes the test conditions, experimental methodology, measurement configuration, and parameters considered during the internal arc fault test. The electrical and physical phenomena recorded during the experiment are analyzed in order to characterize the transformer response under fault conditions. The obtained results provide relevant information regarding the behaviour and fault withstand capability of the investigated transformer construction and contribute to a better understanding of the effects associated with internal arc faults in this type of instrument transformer.

Keywords: instrument transformers, internal arcing, internal fault, electrodynamic stresses, short-circuit current, electrical safety.

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THE TECHNICAL DESIGN AND MODELLING OF A LARGE-SCALE GREEN HYDROGEN-BASED BACK-UP POWER SUPPLY SYSTEM FOR DATA CENTERS

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The fast development of data centers worldwide leads to increasing power demand to supply these facilities. Data centers are very sensitive to any power supply interruptions, since they can lead to increasing costs, reduced availability and even security-related issues. Integrating hydrogen-based solutions can improve energy supply security and, at the same time, reduce the environmental impact of energy generation (International Energy Agency, 2025), hydrogen-based back-up and cogeneration systems being increasingly investigated as a clean alternative to conventional diesel generators for data centers (Celestine et al., 2021; Ham et al., 2023; Chen et al., 2025).

The paper presents the technical design and modelling of a large-scale hydrogen-based back-up power supply system for a data center of about 200 kWe. As illustrated in Figure 1, the proposed solution is organized in six functional containers: the IT (data processing) container, the power supply container, the hydrogen production (electrolysis) container, the hydrogen compression and storage container, the fuel cell container and the HVAC (cooling) container. The authors have performed the conceptual design and preliminary modelling for each major component of the system, as follows:

- Conceptual design of the data center, including its architecture and all major components;
- Estimation of data center energy demand, with hourly, daily, monthly and yearly power consumption simulated/estimated;
- Preliminary design of the data center power supply system, including its architecture and all major components;
- Preliminary design of the electrolysis (hydrogen production) system, including its architecture and all major components;
- Preliminary design of the fuel cell system, including its architecture and all major components;
- Preliminary design of the hydrogen compression and storage system, including its architecture and all major components;
- Estimation of the energy demand for cooling of the entire facility, with hourly, daily, monthly and yearly energy demand simulated/estimated.

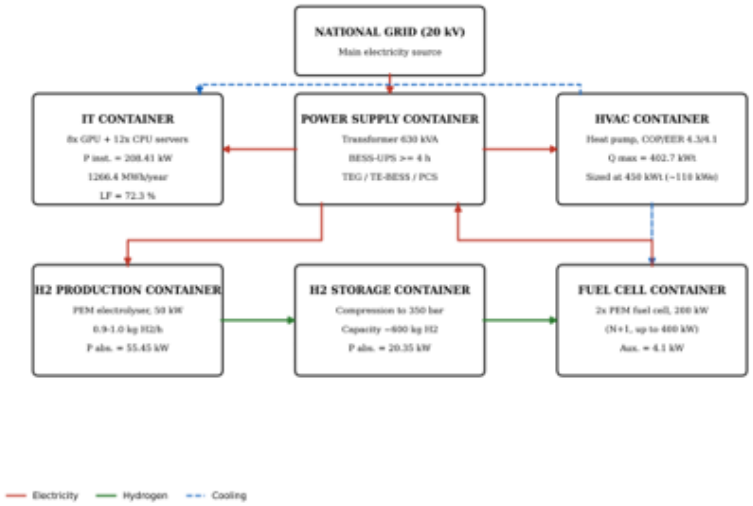


Figure 1. *General architecture of the proposed large-scale hydrogen-based back-up power supply system for data centers*

The analysis performed by the authors is the first step within a larger project that aims at integrating hybrid hydrogen-based solutions together with renewable energy systems for the back-up energy supply of data centers. This work is a continuation of previous research and aims at scaling up the solutions already developed for a 10 kWe system. After the preliminary design and modelling, the next steps of the research will include the simulation and optimization of the entire power back-up system for the data center, as well as its techno-economic assessment.

Keywords: *green hydrogen; data center; back-up power supply; PEM electrolysis; fuel cell; energy modelling*

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REDOX CONTROL IN A CONDUCTING *MOF* THROUGH COUPLED ELECTRONIC–VIBRONIC EFFECTS

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Electrically conducting metal–organic frameworks (MOFs) are attractive positive-electrode materials for alkali-ion batteries, as they combine redox-active anionic frameworks with intrinsic electronic conductivity, reducing the need for conductive carbon additives. Alkali cations (A^+) intercalated within such frameworks act as both charge-compensating species and structural/electronic modulators, yet how cation choice governs redox potential and conductivity remains poorly understood. Here we report a family of isostructural conducting MOFs, A_2-Mn-DOBDC (A^+ = Li^+, Na^+, K^+; $DOBDC^{4-}$ = 2,5-dioxido-1,4-benzenedicarboxylate), obtained by postsynthetic cation exchange from the parent H_2-Mn-DOBDC framework. [Rambabu et al., 2021] Structural, spectroscopic (FTIR, PXRD), and elemental characterization confirm reversible alkali–proton exchange with minimal alkali deficiency and cation-dependent lattice breathing, with unit-cell volume scaling with cation radius ($Li^+ < Na^+ < K^+$).

Contrary to predictions from a simple electrostatic (cation-polarizing power) model, which anticipates a Li > Na > K ordering, both the room-temperature electronic conductivity and the redox potential of A_2-Mn-DOBDC follow the nonintuitive sequence K < Li < Na. Variable-temperature conductivity measurements reveal thermally activated, electron-dominated transport (negligible ionic contribution, confirmed by comparing DC and AC measurements), consistent with mixed-valence charge transfer between the redox-active DOBDC linker and the Mn center. To rationalize the anomalous redox-potential ordering, we performed a finite-temperature free-energy partitioning combining FTIR band-shift analysis with DFT-computed vibrational densities of states. The electronic free-energy term (ΔF_{EL}) decreases along Li > Na > K,

following the expected electronegativity/polarizing-power trend, while the vibrational free-energy term (ΔF_{VIB}) increases along Li < Na < K, reflecting cation-induced reorganization of framework vibrational modes. The competition between these two contributions produces a maximum stabilization for the Na-containing phase, quantitatively reproducing the experimentally observed K < Li < Na potential ordering.

Electrochemically, Na_2-Mn-DOBDC delivers a high median discharge voltage of ~3.0 V vs Na^+/Na (0.29 V vs SHE), an initial capacity of 89 mAh/g (0.98 e^- per formula unit, close to the theoretical one-electron limit), and 58% capacity retention after 500 cycles at 0.1 C, outperforming the Li_2- and K_2-analogues and all previously reported Na-ion organic/MOF positive electrodes. These results establish a general electronic–vibronic framework for understanding and predicting redox energetics in conducting MOFs, demonstrating that cation-programmable vibrational reorganization, and not electrostatics alone, can be exploited as a design lever for high-voltage alkali-ion battery electrodes. [Morari et al., 2024; Rambabu et al., 2026]

Keywords: *metal–organic framework, redox potential, electronic conductivity, vibronic coupling, sodium-ion battery, cation exchange*

Acknowledgments

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TOWARDS HIGH-EFFICIENCY NA ANODE-FREE CELLS: SUBSTRATE SCREENING AND ELECTROLYTE COMPATIBILITY

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Sodium anode-free batteries offer the potential for increased energy density and lower production costs compared with conventional sodium-ion battery configurations [Hu et al., 2026]. However, their performance depends strongly on the current collector substrate, which must enable uniform sodium nucleation and support stable sodium plating and stripping over repeated cycles [Zhao et al., 2026]. The interaction between the substrate surface and the electrolyte also plays an important role in determining the overall electrochemical behavior of the cell.

A standardized electrochemical protocol [Rupp and Vlad, 2019] was developed to evaluate copper- and aluminum-based substrates in Na|substrate coin cells. The protocol included an initial formation cycle with a capacity of 3 mAh, followed by 100 galvanostatic cycles at 2 mAh/cm² and a current density of 1 mA/cm². Sodium was stripped until reaching 1.0 V vs. Na/Na^+ without applying a capacity limit, allowing differences in sodium utilization and cell stability to be observed.

The substrates were evaluated in two diglyme-based electrolytes: 1 M $NaPF_6$ and a mixed electrolyte containing 0.9 M $NaPF_6$ and 0.1 M $NaBF_4$. Among the tested configurations, the carbon-coated aluminum substrate (Al/C) showed the most consistent performance in both electrolytes. It maintained stable Coulombic efficiency and exhibited clean depletion profiles throughout cycling, indicating favorable sodium deposition and removal behavior.

The results also showed that substrate performance cannot be evaluated independently of electrolyte composition. A clear substrate–electrolyte compatibility effect was observed for CuHCl, which experienced significant degradation when tested in the mixed $NaPF_6/NaBF_4$ electrolyte, likely due to interactions involving the BF_4^- species and the modified copper surface. In contrast, untreated copper showed an

unexpected improvement in the mixed electrolyte and produced one of the cleanest electrochemical profiles in the entire set of experiments. This result suggests that even relatively simple, untreated substrates can provide favorable conditions for sodium deposition when paired with an appropriate electrolyte.

The results demonstrate that both current collector selection and electrolyte composition play a key role in the performance of sodium anode-free cells and must be considered together during cell design. Carbon-coated aluminum emerged as the most robust substrate among the configurations investigated, providing stable behavior in both electrolytes. At the same time, the performance of untreated copper in the mixed electrolyte highlights the potential for simpler substrate configurations and suggests that further optimization of substrate–electrolyte combinations could improve cell performance.

Overall, the standardized electrochemical protocol provides a reproducible approach for comparing different substrates and electrolytes under consistent testing conditions. The results establish a basis for selecting suitable current collectors and electrolyte systems for the development of sodium anode-free cells with improved Coulombic efficiency and cycling stability.

Keywords: *anode-free, sodium, plating, stripping, coulombic efficiency*

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NEW CATHODE MATERIALS IN THE Fe-PO_4-F CHEMICAL SPACE FOR HIGH-PERFORMANCE SODIUM-ION STORAGE

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The development of sustainable sodium-ion batteries (SIBs) requires cathode materials combining high energy density, low cost, and abundant elements. Iron-based polyanionic compounds are attractive candidates, but their electrochemical performance is often limited by their thermodynamically stable crystal structures. Here, the Fe-PO_4-F chemical space was explored to identify metastable fluorophosphate phases with enhanced sodium-storage properties. A series of $Na_{(0.6+x)}Fe_{1.2}PO_4F_x$ ($0 \leq x \leq 1$) compositions was synthesized using high-energy ball milling followed by controlled thermal treatment, enabling access to amorphous, metastable, and stable phases. [Liu et al., 2022] Among the investigated compositions, metastable $Na_{1.2}Fe_{1.2}PO_4F_{0.6}$ exhibited the best electrochemical performance. Structural evolution was investigated by powder X-ray diffraction, Mössbauer spectroscopy, Fourier-transform infrared spectroscopy, and in situ X-ray diffraction, revealing that the enhanced activity originates from metastable mixed-phase structures rather than the thermodynamically stable phase. The metastable material delivered a reversible capacity exceeding 140 mAh.g^{-1} at low current density with an average discharge voltage of approximately 2.9V versus Na^+/Na, corresponding to an estimated energy density of about 400 Wh.kg^{-1} at the material level. Galvanostatic intermittent titration technique measurements demonstrated reversible Na^+ diffusion with coefficients between 10^{-18} and 10^{-16} cm^2.s^{-1}, while in situ diffraction confirmed highly reversible structural evolution during cycling. The metastable phase also exhibited excellent cycling stability and outperformed its amorphous, stable, and carbon-coated stable counterparts, highlighting the importance of metastable phase engineering for high-performance SIB cathodes. [Liu et al., 2022]

Keywords: *Sodium-Ion battery; cathode material; ferrofluorophosphate*

Acknowledgments *(if applicable)*

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BREAKING THE ION-SIZE BARRIER: HIGH-PERFORMANCE ORGANIC CATHODES FOR ALKALI-ION STORAGE

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In the context of ever-increasing global energy demand, the development of efficient and sustainable energy storage technologies has become a major scientific and technological priority. Among the various available technologies, rechargeable batteries have emerged as key solutions owing to their versatility, scalability, and high energy density. However, the widespread deployment of conventional battery technologies remains constrained by their reliance on critical and geographically limited resources, such as lithium and cobalt. These challenges have stimulated growing interest in alternative battery chemistries based on more abundant and sustainable alkali ions. Yet, the substantially larger ionic radii of these species compared to Li^+ generally result in sluggish ion diffusion within conventional host materials, ultimately limiting their electrochemical performance.

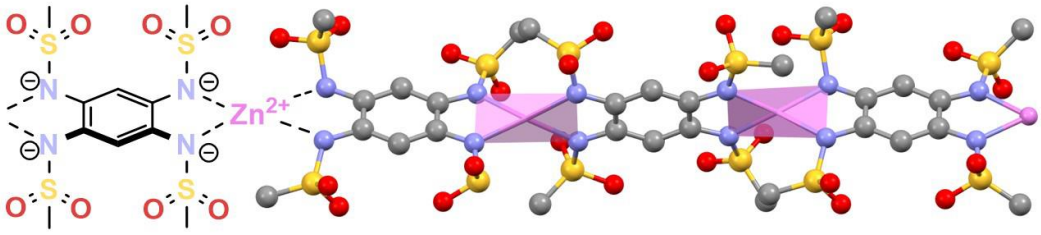


Figure 1. *Structure of the M2-Zn-PTtSA coordination polymer, based on analogous compound*

Herein, we report a novel coordination polymer capable of accommodating a broad range of alkalimetal ions, from Li^+ to Cs^+, while maintaining remarkably consistent electrochemical performance. By combining the chemical versatility of organic materials with the structural robustness of inorganic frameworks, the resulting M_2(M=Li-Cs)-Zn-PTtSA (PTtSA = benzene 1,2,4,5-tetra(methanesulfonamide)) coordination polymer (Figure 1) overcomes the conventional ion-size limitation. Remarkably, all investigated cations

exhibit nearly identical redox potentials, high activematerial utilization (~95 mAh g^{-1}), and low voltage hysteresis, demonstrating a cation-sizeindependent electrochemical response. These results highlight the potential of coordination polymers as versatile platforms for sustainable alkali-ion energy storage beyond conventional lithium-ion chemistry.

This behavior originates from the framework's amorphous flexibility and the delocalized electronic structure of the conjugated sulfonamide ligand, which together enable weak, reversible metal–ligand interactions and fast cation transport (D = 10-9 cm^2 s^{-1}). Consequently, M_2-Zn-PTtSA delivers high-rate capability and long-term cycling stability across the entire alkali-metal series, providing a platform that decouples ion size from electrochemical performance and supports "cation-of-choice" battery chemistries.

Keywords: *Alkali-ion storage, Coordination polymers, Cation-size, Amorphous frameworks, Ion transport, Organic electrodes*.

Acknowledgments

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ENHANCED 3D ELECTROCHEMICAL–ELECTROMAGNETIC MODELLING OF HIGH-FREQUENCY IMPEDANCE IN CYLINDRICAL LI-ION BATTERIES

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Electrochemical impedance spectroscopy (EIS) is a powerful non-invasive technique for investigating the internal processes of lithium-ion batteries. However, conventional pseudo-two-dimensional models cannot accurately reproduce the high-frequency inductive response of cylindrical cells because they neglect the complex three-dimensional current pathways associated with the spiral-wound jellyroll architecture.

In this work, a fully coupled three-dimensional electrochemical–electromagnetic modelling framework is presented for the analysis of the impedance response of a commercial 21700 lithium-ion cell. The model combines porous-electrode theory, electrochemical kinetics and mass transport with Maxwell–Ampère's law on the same computational mesh. The realistic geometry explicitly describes the individual layers of the jellyroll and the position of the current-collector tabs, enabling the spatially resolved simulation of current paths and magnetic-field distributions.

The model was evaluated against potentiostatic EIS measurements performed on commercial cells at 50% state of charge over a frequency range from 0.1 Hz to 5 kHz. Coupling the electrochemical and electromagnetic phenomena significantly improves agreement with the experimental impedance and phase-angle data at high frequencies, with inductive contributions becoming evident from approximately 100 Hz. Simulations of different negative-tab configurations further demonstrate that relatively small changes in cell architecture markedly influence current distribution, magnetic-field localization and the resulting impedance response. In particular, the inner-tab configuration produces stronger localized magnetic fields and a more pronounced inductive behaviour than the outer-tab configuration.

These findings demonstrate that high-frequency impedance features are strongly governed by the internal geometry of cylindrical cells. The proposed framework therefore provides a valuable tool for interpreting EIS spectra, optimizing battery design and supporting non-invasive quality-control strategies

aimed at identifying tab-welding defects, layer misalignment and other structural anomalies.

Keywords: *Electrochemical impedance spectroscopy; Lithium-ion batteries; Multiphysics modelling; Electromagnetic coupling; Cylindrical cells.*

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PREPARATION AND PERFORMANCE RESEARCH OF MODIFIED POLYACRYLIC ACID BINDERS FOR SILICON-CARBON ANODES IN LITHIUM-ION BATTERIES

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Lithium-ion batteries (LIBs) have emerged as the mainstream technology in electrochemical energy storage due to their superior energy density and long cycle life. As the anode material is a decisive factor in determining the energy density of LIBs, traditional graphite anodes, limited by their low theoretical specific capacity, struggle to meet the evolving demands of high-energy-density systems. Silicon (Si) is widely regarded as one of the most promising next-generation anode materials due to its exceptionally high theoretical capacity and resource abundance. However, the drastic volume expansion of silicon during lithiation/delithiation leads to electrode structural instability and rapid capacity decay, severely hindering its practical application. Although constructing silicon-carbon (Si/C) composite anodes can partially mitigate the volume effect, the stress accumulation caused by the periodic drastic volume changes of silicon means that the structural stability of the electrode remains highly dependent on the performance of the binder.

Polyacrylic acid (PAA) binders, rich in carboxyl groups that form hydrogen and covalent ester bonds with silicon surfaces, are widely employed in Si/C anodes. However, they commonly suffer from insufficient interfacial adhesion with Si/C active materials and limited elasticity, making it difficult to effectively accommodate the severe volume changes of Si/C anodes. Consequently, we focus on enhancing the interfacial adhesion and mechanical performance of PAA binders for Si/C anodes. Systematic research was conducted by directional interfacial anchoring and construction of gradient energy dissipation networks. Our work investigates the structure-performance relationships between the structural characteristics of modified PAA binders, their interfacial interaction mechanisms, mechanical regulation behavior, and the resulting electrochemical performance of Si/C anodes.

To address the issue of insufficient interfacial adhesion between the PAA binder and Si/C active materials, a directional anchoring strategy was proposed. Lithium polyacrylate (PAALi, PL) was synthesized via the pre-lithiation of PAA, and tannic acid (TA), rich in phenolic hydroxyl groups and aromatic structures, was

introduced to construct a PAALi-TA (PLT) cross-linked binder. The aromatic rings of TA enable π-π stacking with carbonaceous layers, while its phenolic hydroxyls establish hydrogen and covalent ester bonds with the silicon surface. Simultaneously, the carboxyl groups and lithium carboxylate in PAALi form ester bonds, hydrogen bonds, and ion-dipole interactions with the silicon surface. This multi-site directional anchoring mechanism significantly enhances the electrode's adhesion strength. The optimized PLT binder increased the peeling force of the Si/C@PLT electrode by 8.3% and facilitated the formation of a stable SEI layer rich in Li_2CO_3 and LiF. Electrochemical results showed that the Si/C@PLT electrode achieved an initial reversible capacity of 947.7 mAh g^{-1}, an initial Coulombic efficiency of 83.31%, and a capacity retention of 90.02% after 100 cycles (Figure 1), all superior to the non-crosslinked PAALi binder.

To mitigate the excessive rigidity of PAA which hinders effective buffering of volume change-induced stress, a gradient energy dissipation strategy was proposed. A PAA-PVA-Borax (PPB) dynamic cross-linked network, comprising hydrogen bonds and reversible borate ester bonds, was constructed by incorporating flexible polyvinyl alcohol (PVA) and borax. Reversible bonds with different bond energy levels break and reform hierarchically under stress, enabling gradient energy dissipation and contributing to the maintenance of electrode structural integrity. The optimized PPB binder exhibited an elastic modulus of 1.6 GPa, which is ~43% lower than that of pure PAA. Furthermore, it actively participated in regulating the formation of a stable, inorganic-rich SEI. Electrochemical tests revealed that the Si/C@PPB electrode achieved an initial reversible specific capacity of 1029.5 mAh g^{-1}, significantly higher than the 925.9 mAh g^{-1} of the PAA electrode, and maintained an excellent capacity retention of 98.4% after 100 cycles.

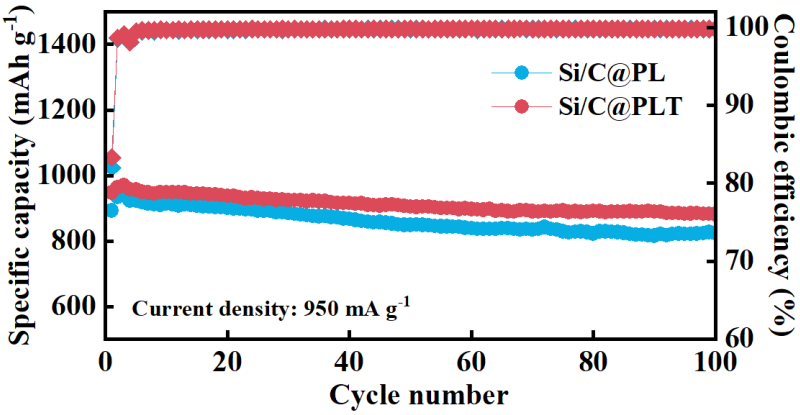


Figure 1. *Cycle performance of Si/C@PLT and Si/C@PL electrodes at 0.5 C*

Keywords: *Silicon-carbon anode, Binder, Poly(acrylic acid), Crosslinking, Interaction mechanism*

CATECHOL-DERIVED SODIUM SALT FOR STABLE HIGH-CAPACITY ORGANIC SODIUM-ION BATTERIES

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The increasing interest in sustainable and high-performance sodium-ion batteries has gain significant attention toward organic cathode materials, which are favoured for their low weight, tuneable molecular structures, and ecofriendly composition[1]. Since conventional organic cathode materials suffer with limited specific capacity and poor cycling stability as a result of their intrinsic solubility and poor conductivity, research community has paid considerable attention toward the design and development of high performing organic cathode materials (OCMs) [Poizot et al., 2020]. Among the promising approaches, π-conjugated frameworks infused with catechol-derived ortho-quinone moieties has emerged as an important research direction for the development of OCMs[2]. In this work, we aim to develop a stable, high-performance organic cathode material derived from a monohydrated catechol derivative bearing sodium sulfonate group for sodium-ion batteries. We explored how variables such as solvent system, temperature and atmosphere control influence the deprotonation of hydroxy groups in catechol derivative by sodium ions. The synthesized molecule in electrochemical evaluation as cathode material exhibited a promising first cycle specific capacity of 130 mAh/g which is approximately equal to 80% of its theoretical capacity when assembled in coin cells. The favourable electrochemical evaluation results obtained in this study highlights the potential of the synthesized material as an organic cathode for sodium-ion batteries. Further optimizations are needed to achieve stable cycling data, full theoretical capacity and hence unlock the material's full potential [Yong et al., 2027].

Keywords: sodium-ion batteries, cathode materials, catechol-derivative, separator modification**.**

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ELECTROCHEMICAL PERFORMANCE ASSESSMENT OF SULFUR-BASED ELECTRODES IN LI–SULFUR POUCH CELLS

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Lithium–sulfur (Li–S) batteries are among the most promising next-generation electrochemical energy-storage systems because of the high theoretical capacity of sulfur and the possibility of achieving high energy density. Nevertheless, their practical implementation remains limited by the low electrical conductivity of sulfur, the dissolution and migration of lithium polysulfides, instability of the lithium metal anode and electrolyte degradation during cycling (Han et al., 2024; Kim et al., 2023; Li et al., 2019; Zhang et al., 2024). These challenges become even more critical in pouch-cell configurations, where electrode architecture, electrolyte utilization, separator design and lithium inventory strongly influence the electrochemical performance and long-term cyclability (Zhang et al., 2021).

In the present work, sulfur-based electrodes were developed and systematically evaluated through the optimization of the cathode architecture and cell configuration, followed by their integration into lithium–sulfur pouch cells. The active material, denoted as 51S, was synthesized using a resorcinol–formaldehyde-derived carbon aerogel as a porous conductive host for sulfur. The synthesis consisted of resorcinol–formaldehyde gel formation, supercritical drying with CO_2, carbonization at 1000°C under nitrogen atmosphere and sulfur infiltration by ball milling followed by successive thermal treatments. Porous carbon aerogels represent attractive sulfur hosts because their interconnected pore structure can enhance sulfur accommodation and contribute to improved electrochemical behavior in Li–S cathodes (Balakumar and Kalaiselvi, 2015). SEM–EDX characterization confirmed the successful sulfur incorporation, the sulfur content increasing from 4.45 wt.% in the carbonized material to 36.45 wt.% after sulfur treatment.

Electrochemical investigations were initially performed in CR2032 coin cells using cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS) and galvanostatic charge–discharge measurements. Several cell parameters were comparatively investigated, including separator modification, cathode deposition gap and lithium metal anode configuration. Functionalized separators have been widely recognized as an effective strategy for regulating polysulfide transport and improving interfacial stability in lithium–sulfur batteries (Li et al., 2021; Mori, 2023). In agreement with these concepts, the TiO_2-modified Celgard 2325 separator exhibited the best electrochemical behavior among the investigated separators, providing improved activity and enhanced cycling stability, whereas the MnO_2-modified separator showed limited electrochemical reversibility under the tested conditions.

The influence of cathode deposition gap was also significant. Electrodes fabricated using a 0.3 mm deposition gap exhibited lower impedance, better-defined redox peaks, higher specific capacity and superior cycling stability compared with electrodes prepared using a 0.05 mm gap. The smaller gap resulted in increased polarization and reduced electrochemical kinetics, demonstrating the importance of electrode architecture and ionic transport pathways for efficient sulfur utilization.

The lithium metal configuration was subsequently optimized. Coin cells assembled with lithium metal discs delivered an initial discharge capacity of approximately 800 mAh g^{-1} and stabilized between 600 and 650 mAh g^{-1} during cycling, whereas cells employing lithium foil exhibited considerably lower capacities of approximately 250–300 mAh g^{-1} together with larger fluctuations and higher charge-transfer resistance. These observations highlight the crucial influence of the lithium anode configuration on the electrochemical response of Li–S cells.

Based on the optimized conditions identified in coin cells, lithium–sulfur pouch cells were assembled using the 51S sulfur cathode, TiO_2-modified Celgard 2325 separator and different lithium metal inventories. The pouch cell containing two lithium metal foils achieved a discharge capacity of approximately 1000 mAh g^{-1}, while the configuration containing a single lithium foil delivered approximately 800 mAh g^{-1}. These results demonstrate that increasing the available lithium inventory contributes to improved electrochemical performance in the investigated pouch-cell configuration.

Complementary in situ mass spectrometry measurements were performed to investigate gas evolution during charge–discharge cycling at 0.1 C. The detected volatile species were mainly associated with the degradation of the DME/DOL electrolyte and included CH_4, hydrogen, C_2–C_3 hydrocarbon fragments and oxygenated compounds, together with species attributed to $LiNO_3$ and LiTFSI decomposition, including nitrogen-containing products and HF. Similar gas-evolution phenomena associated with lithium nitrate-containing electrolytes have previously been reported in Li–S systems (Jozwiuk et al., 2016). Comparison between pouch cells with and without the sulfur-based cathode indicated

differences in the intensity of selected mass signals, suggesting that sulfur electrochemistry influences electrolyte degradation pathways.

Overall, the present study demonstrates that the electrochemical performance of lithium–sulfur pouch cells strongly depends on the combined optimization of the sulfur-based cathode, separator, cathode deposition gap and lithium metal anode configuration. The optimized system based on the 51S active material, TiO_2-functionalized separator, 0.3 mm cathode deposition gap and increased lithium inventory enabled the successful transition from coin-cell optimization to pouch-cell evaluation while providing valuable insight into the gas-generation processes occurring during battery operation.

Keywords: *lithium–sulfur batteries; sulfur cathode; carbon aerogel; pouch cell; TiO_2-modified separator; electrochemical characterization*

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REINTEGRATION OF LITHIUM IRON PHOSPHATE CATHODE SCRAP INTO BATTERY PRODUCTION VIA A LOW-COST CIRCULAR MANUFACTURING APPROACH

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Lithium iron phosphate (LFP) batteries are increasingly adopted in energy storage and electric vehicle applications owing to their affordability, long cycle life, and superior safety. However, the growing deployment of LFP batteries is accompanied by a corresponding increase in spent battery waste, creating environmental and resource-recovery challenges. Consequently, considerable efforts have been devoted to developing efficient recycling technologies for LFP cathodes, including pyrometallurgical and hydrometallurgical treatments, as well as direct regeneration methods aimed at restoring the electrochemical performance of degraded materials (Visone, 2025).

The recycling of spent lithium-ion batteries (LIBs) is still at an early stage of development, requiring further research efforts, technological innovation, and investment to establish more efficient, economically viable, and environmentally sustainable recycling processes. Such approaches should not only maximize the recovery of valuable materials but also ensure the proper treatment and disposal of hazardous by-products to minimize their impact on human health and the environment (Dobó, 2023).

In this way, deep eutectic solvents (DESs) are regarded as a novel class of environmentally acceptable solvents due to their low cost, ease of synthesis, stable chemical and physical properties, tunable structural characteristics, and high solubility to metal oxides. DESs can provide notable benefits in terms of low toxicity, efficiency, and cost-effectiveness when compared to conventional solvents and ionic liquids. As a result, DESs have become more well-known in the field of recycling spent lithium batteries in recent years (Freitas, 2024, Tran, 2019)

In this work, we propose a safe and environmentally benign strategy for the selective recovery of lithium and the efficient separation of iron and phosphorus from spent $LiFePO_4$ (LFP) cathode materials using water-based deep eutectic solvents (DESs). The process combines DES leaching with an oxidative pretreatment step,

enabling effective element separation. Specifically, oxidative treatment at 700 °C for 3 h transforms the spent $LiFePO_4$ cathode into soluble phases, namely $Li_3Fe_2(PO_4)_3$ and Fe_2O_3, which can be efficiently dissolved in the DES medium. Under optimized conditions—oxidative pretreatment at 700 °C for 3 h, leaching at 90 °C for 30 min, and a solid-to-liquid ratio of 60 g L^{-1}—high recovery efficiencies were achieved. In addition, electrochemical tests were conducted to evaluate the structural stability and electrochemical performance of the recovered materials. Overall, the results demonstrate that the proposed recycling route offers a sustainable and scalable approach for spent cathode reutilization, combining operational simplicity with low processing cost and reduced environmental impact.

Keywords: *Lithium-ion batteries, Deep eutectic solvents, Priority recovery, Recycling processes*

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INVESTIGATION OF RESIDUAL STRESSES AND HEAT-AFFECTED ZONES INDUCED BY WELDING PROCESSES IN LITHIUM-ION POUCH CELLS

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The joining of thin metallic components represents an important manufacturing step in lithium-ion pouch cell assemblies, where the local thermal and mechanical effects generated during welding may influence the condition and integrity of the resulting joint. Although solid-state welding processes are characterized by joining below the bulk melting temperature, previous investigations have demonstrated that substantial localized heating and severe plastic deformation can still occur within and around the weld region. In ultrasonic spot welding of aluminium alloys, the formation of distinct heat-affected zones (HAZ) and thermomechanical affected zones (TMAZ) has been associated with rapid thermal cycles, localized softening, and significant microstructural modification [Chen et al., 2012]. Studies on dissimilar Al–Cu ultrasonic welding further indicate that welding time and applied pressure strongly influence interfacial deformation, material flow, local thinning, hardness evolution, and the resulting mechanical and electrical characteristics of the joint [Mojaverpour et al., 2025]. More recently, electro-thermo-mechanical investigations performed directly on ultrasonic-welded Al and Cu tab-to-busbar interconnects for Li-ion pouch cells have highlighted the coupled influence of joint configuration, mechanical loading, electrical resistance, and thermal behaviour on interconnect performance [de Leon et al., 2024].

In addition to these localized thermal and microstructural effects, residual stresses represent another important consequence of welding-induced thermomechanical loading. Investigations performed on friction-based solid-state welding have shown that the residual stress distribution is closely associated with the thermal field generated during joining, with changes in cooling conditions producing substantial variations in both longitudinal and transverse residual stresses [Papahn et al., 2016]. While electro-thermo-mechanical performance has

recently been investigated in battery-specific Al–Cu tab-to-busbar joints [de Leon et al., 2024], the relationship between welding-induced thermal history, local material modification, HAZ development, and residual stress formation remain insufficiently characterized in thin welded configurations representative of lithium-ion pouch cell assemblies.

A recent investigation of battery-specific Al–Cu tab-to-busbar ultrasonic joints reported comparatively low welding temperatures, remaining below approximately 120°C, while still observing pronounced interfacial deformation and localized bonding phenomena [de Leon et al., 2024]. This difference illustrates the strong sensitivity of the thermal response to material thickness, joint architecture, and welding parameters. Residual-stress measurements in friction stir welding further demonstrated the importance of thermal history, with active cooling reducing longitudinal residual stresses by approximately 17% within the nugget zone and transverse residual stresses by as much as 70% within the HAZ [Papahn et al., 2016].

The present work provides a theoretical analysis of welding-induced residual stresses and heat-affected zones in joint configurations relevant to lithium-ion pouch cells. The study focuses on the underlying thermo-mechanical relationships governing the welding process, with particular emphasis on how process parameters influence localized heat generation, temperature gradients, thermal expansion and plastic deformation, and ultimately the spatial evolution of the heat-affected region and residual stress fields. Rather than considering the thermal and mechanical consequences of welding independently, the investigation addresses them within a common thermomechanical framework, with the objective of establishing correlations between the local thermal history of the joint, the development of heat-affected regions, and the formation of residual stress fields. This approach is intended to distinguish between effects associated primarily with thermal exposure and those related to localized mechanical deformation during the welding process.

By combining the assessment of heat-affected regions with residual stress characterization, this study aims to provide a more comprehensive description of the thermomechanical consequences of welding thin metallic components used in lithium-ion pouch cell assemblies. Establishing the relationship between welding conditions, localized thermal history, material modification, and residual stress development may contribute to a better understanding of the mechanisms governing joint integrity. Such knowledge can provide a basis for the systematic evaluation of welding parameters and support the optimization of joining conditions for lithium-ion pouch-cell manufacturing without relying exclusively on conventional indicators such as mechanical strength or electrical resistance.

Keywords: *Ultrasonic welding; Residual stresses; Heat-affected zone; Lithium-ion pouch cells; Aluminium–copper joints.*

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AMORPHOUS COORDINATION POLYMERS AS CATHODE MATERIAL FOR NEXT-GENERATION CALCIUM-ION BATTERIES

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The development of sustainable and cost-effective energy storage technologies requires the exploration of alternative battery chemistries beyond conventional lithium-ion systems. Multivalent-ion batteries (Zn^{2+}, Mg^{2+}, Ca^{2+}, and Al^{3+}) have attracted significant attention due to their ability to transfer multiple electrons per ion, offering the potential for higher theoretical energy densities. Among these chemistries, calcium batteries have emerged as promising candidates for next-generation energy storage owing to their high theoretical energy density, low cost, and the abundance and widespread availability of calcium (Bakuru et al., 2026). However, the development of suitable cathode materials remains a major challenge, particularly in terms of structural stability and reversible Ca-ion storage [Zhou et al., 2026]. Coordination polymers constructed from redox-active organic linkers and transition-metal centers are an important class of electroactive materials for battery applications (Wang et al., 2022). An amorphous coordination framework can provide a flexible structure that can accommodate reversible Ca-ion insertion/extraction while offering accessible redox-active sites (Markowski et al., 2026).

In this work, we synthesized an amorphous Ca–Zn–PTtSA coordination polymer and investigated its potential as a cathode material for calcium-ion batteries. A dry-processing method for cathode fabrication was optimized to produce mechanically robust electrodes with improved electrochemical performance and scalability toward pouch-cell applications. Electrochemical characterization in a full-cell configuration demonstrated a coulombic efficiency of over 98.5% after 200 cycles. The performance of the optimized cathodes was further validated through the design and assembly of laboratory-scale calcium-ion pouch-cell prototypes,

highlighting the potential of the developed material and processing approach for next-generation calcium-based energy storage.

Keywords: *calcium-ion storage, organic positive electrode, coordination polymers, self-standing electrodes*

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RECONDITIONING AND ASSESSMENT OF CYLINDRICAL LI-ION CELLS FOR SECOND-LIFE APPLICATIONS

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Economic and environmental benefits have been demonstrated by using the remaining capacity of retired lithium-ion (Li-ion) batteries from electric vehicles (EVs) for second-life applications. In order to fully utilize the advantages, cells must have similar capacities before their second life (Rasheed et al., 2023).

Interest in extending the operational lifetime of lithium-ion battery (LIB) cells beyond their primary use phase has increased in response to the growing demand for sustainable energy storage solutions. Following repeated charge-discharge cycling, cylindrical Li-ion cells commonly used in consumer electronics and electric vehicles - undergo capacity degradation. They typically reach end-of-first life criteria when their state of health declines to approximately 80% of their initial nominal capacity (Patel et al., 2024). In line with the principles of the circular economy, reconditioning techniques provide a means of restoring their functionality and redirecting these cells toward less demanding second-life applications, rather than disposing of them (Li et al., 2023).

This study investigates reconditioning methods for cylindrical Li-ion cells that have reached or are approaching the end of their first life. The techniques employed include controlled charge-discharge cycling, voltage hold procedures, and temperature - assisted recovery protocols tailored to the specific active materials of the cells under investigation. Recovered capacity and overall restoration performance are used to evaluate the effectiveness of each technique. The results indicate that the recovered capacity varies significantly depending on both the cell chemistry and the reconditioning method. These findings confirm that reconditioning can significantly extend cell lifetime, reduce replacement costs, and

promote the feasibility of second-life applications, such as short-range electric mobility and stationary energy storage.

Keywords: *Lithium-ion batteries, Second life batteries, Battery reconditioning, Cylindrical Li-ion cells*

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LITHIUM MANGANESE IRON PHOSPHATE (*LMFP*) AS A NEXT-GENERATION BATTERY CATHODE FOR ENERGY STORAGE

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The increasing global demand for electric vehicles (EVs), portable electronics, and clean energy storage systems has accelerated the development of high-energy-density lithium-ion batteries (LIBs). The electrochemical performance of LIBs, including their energy density, cost, and safety, is strongly influenced by the properties of the cathode materials used. Among the currently available cathode materials, $LiMn_xFe_{1-x}PO_4$ (LMFP) has emerged as a promising candidate for next-generation lithium-ion batteries due to its high safety, excellent structural stability, long cycling life, and cost-effectiveness (Peng et al., 2025; Li et al., 2025). LMFP retains the stable olivine crystal structure of $LiFePO_4$ (LFP), while the partial substitution of Fe by Mn introduces the higher-voltage Mn^{3+}/Mn^{2+} redox couple (Sun et al., 2024). This compositional modification enables a higher operating voltage and increased energy density compared with LFP, while maintaining its favorable safety, structural stability, and cost advantages. Beyond the intrinsic properties of the cathode material, the electrode manufacturing process plays an important role in battery performance. Conventional electrode fabrication generally relies on organic solvent-based processing, whereas water-based processing has gained increasing attention as a more sustainable and cost-effective alternative, owing to its reduced environmental impact and potential to simplify electrode manufacturing (Gonçalves et al., 2022).

In this work, preliminary results are presented for the preparation of $LiMn_{0.6}Fe_{0.4}PO_4$ cathode materials using two different processing routes: aqueous and conventional organic solvent-based. The electrochemical performance of the resulting electrodes was evaluated in a half-cell configuration using different

electrolyte formulations to investigate their impact on capacity retention, rate capability, and cycling stability.

Keywords: *Cathode material, $LiMn_{0.6}Fe_{0.4}PO_4$, lithium-ion battery, aqueous processing*

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INTEGRATED STACK PRESSURE MANAGEMENT SYSTEM TO ENHANCE THE CYCLE LIFE OF ANODE-FREE SODIUM-METAL BATTERIES

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The electrochemical performance and morphological stability of anode-free sodium-metal batteries (AFSMB) are highly sensitive to the applied pressure on the stack [Sun et al., 2025]. In this work, a precision mechanical clamping fixture for testing pouch-type cells was designed, prototyped and validated. The system uses a 5-point compression spring clamping mechanism for rigorous control, fine adjustment and constant monitoring of the applied force. Flexible silicone pads were incorporated between the rigid metal clamping plates and the pouch cell to minimize surface imperfections and to achieve a uniform pressure distribution over the entire active surface of the electrode.

Relying only on rigid metal plates causes localized mechanical stresses (hot spots), which exacerbate uneven sodium deposition and promote dendrite growth. The integration of silicone pads into the 5-point clamping architecture improved pressure distribution, accommodating manufacturing tolerances and the volumetric expansion of pouch-type cells during cycling. From an electrochemical standpoint, this optimized mechanical configuration led to a reduction in the premature failure rate of the tested cells. Anode-free pouch cells operating under these controlled pressure conditions showed superior cycling stability, maintaining higher coulombic efficiency and highly reversible sodium electrodeposition and electrodissolution processes, compared to conventional rigid configurations. In conclusion, the 5-point mechanical press, complemented by the use of silicone membranes, represents a robust and reproducible solution for controlling stacking pressure.

Keywords: *anode-free, sodium, stack pressure, silicone pads, pouch cell, 5-point pressing device;*

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ENERGY DISTRIBUTION STRATEGIES IN AN H_2/CH_4-FUELED *CHP* SYSTEM INTEGRATED WITH AN *ORC* AND A HEAT PUMP

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This study presents a theoretical analysis of energy distribution strategies in an integrated system consisting of an H_2/CH_4-fueled combined heat and power (CHP) unit, an Organic Rankine Cycle (ORC), and a heat pump. The main objective is to evaluate how the thermal energy recovered from the CHP unit can be allocated among the ORC, the heat pump, the thermal consumer, and the dry cooler. Several operating strategies are considered, each defined by a different priority for the use of the available thermal energy. For each strategy, the analysis determines the thermal energy transferred to each subsystem, the additional electricity generated by the ORC, the heat pump electricity consumption and thermal output, the energy supplied to the thermal consumer, and the surplus heat rejected through the dry cooler. The comparison highlights the trade-off between additional electricity generation, coverage of the thermal demand, and reduction of heat rejection to the environment. The analysis identifies the energy distribution strategy that provides the most effective utilization of the available energy within the integrated system.

Keywords: *CHP, H_2/CH_4 fuel blend, Organic Rankine Cycle, heat pump, energy distribution strategy, waste heat recovery*

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ENGINEERING A WEARABLE HYDROGEN MICROREACTOR: CATALYST SELECTION AND PROTOTYPE DESIGN FOR PORTABLE FLEXIBLE FUEL CELLS

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In this study, $CoCl_2.6H_2O$ and $Ni(CH_3COO)_2.4H_2O$ were used as precursor salts for the in-situ formation of Co-B and Ni-B catalysts, respectively, for $NaBH_4$ hydrolysis. The maximum hydrogen generation rate obtained with $CoCl_2.6H_2O$ was 514 $mL.min^{-1}.g^{-1}$, which was higher than that obtained with $Ni(CH_3COO)_2{\cdot}4H_2O$ (450 $mL.min^{-1}.g^{-1}$). The total hydrogen production reached 186 L after 86 min when using the Co-based catalyst, compared with 183 L for the Ni-based catalyst. In addition, the reactor temperature and pressure were lower in the presence of $CoCl_2.6H_2O$ than with $Ni(CH_3COO)_2.4H_2O$. Structural and morphological characterizations of the recovered catalysts by X-ray diffraction (XRD) and scanning electron microscopy (SEM) showed that both Co-B and Ni-B were amorphous alloys. Co-B exhibited agglomerated sand-like clusters, whereas Ni-B consisted of large agglomerated particles. The recovered catalysts were subsequently reused in a solid-liquid reactor system. A significant difference in performance was observed, with the Co-B catalyst producing approximately 112 L of hydrogen after 1 h of reaction, whereas the Ni-B catalyst generated only about 20 L under the same conditions. Finally, a portable microreactor design was proposed for future development as a hydrogen source for supplying a flexible proton exchange membrane fuel cell (PEMFC).

Keywords: *$NaBH_4$ hydrolysis; Hydrogen production; Co-B catalyst; Ni-B catalyst; Microreactor.*

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CHARACTERIZATION OF *PEMFC* CATALYSTS USING BRUNAUER–EMMETT–TELLER (*BET*) MEASUREMENTS

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Proton exchange membrane fuel cells (PEMFCs) are promising electrochemical energy-conversion devices for clean and efficient power generation. However, their widespread commercialization remains limited by the high cost of platinum catalysts, catalyst degradation, and insufficient utilization of active catalytic sites. Platinum supported on carbon (Pt/C) is one of the most commonly used electrocatalysts, particularly for the oxygen reduction reaction at the cathode. The performance of Pt/C catalysts is strongly influenced by the physical properties of the carbon support, including specific surface area, pore volume, pore-size distribution, and surface structure (Debe, 2012; Antolini & González, 2006). Brunauer–Emmett–Teller (BET) analysis is therefore an important technique for characterizing catalyst supports and evaluating their suitability for PEMFC applications.

The BET method, originally developed by Brunauer, Emmett, and Teller, determines the specific surface area of porous materials from gas adsorption measurements (Brunauer et. al., 1938). In PEMFC catalyst characterization, nitrogen adsorption–desorption measurements at cryogenic temperatures are commonly used to obtain adsorption isotherms, from which specific surface area and pore characteristics can be calculated. Additional methods, including Barrett–Joyner–Halenda (BJH) analysis and t-plot analysis, can provide information about pore-size distribution and micropore volume. These parameters are particularly relevant to Pt/C catalysts because the porosity and surface area of the carbon support affect platinum nanoparticle dispersion and accessibility of catalytic sites (Antolini and González, 2009; Ignaszak et al., 2009)

Previous studies have demonstrated that the structure of carbon supports can significantly influence PEMFC catalyst performance. Antolini and González (2009), reported that different carbon materials produce substantial variations in platinum dispersion and catalyst properties. High-surface-area carbon supports can provide more sites for platinum deposition and promote the formation of smaller Pt nanoparticles. However, a high BET surface area does not necessarily correspond directly to high electrochemical activity because some micropores may be inaccessible to reactant gases, water, or ionomer. Ignaszak et al. (2009), demonstrated that the interaction between carbon-support

meso/microstructure and Nafion distribution plays an important role in determining the accessibility and utilization of Pt sites.

It is therefore important to distinguish between the physical surface area obtained by BET measurements and the electrochemically active surface area (ECSA). Ferreira-Aparicio et al. (2007) emphasized the importance of appropriate methods for determining the active surface area of platinum catalysts.

BET analysis can also be applied to investigate catalyst degradation. Changes in surface area and pore structure may occur as a result of thermal treatment, carbon corrosion, platinum particle agglomeration, or pore blockage. Lee et al. (2014) reported substantial changes in the physical and electrochemical properties of Pt/C catalysts following thermal treatment, demonstrating the relationship between carbon-support structure and catalyst performance.

Overall, BET measurements provide valuable quantitative information about the specific surface area and porous structure of PEMFC catalyst supports. When interpreted together with electrochemical and microscopic characterization techniques, BET data can help explain platinum dispersion, catalyst accessibility, mass transport, and degradation. Such characterization is essential for developing Pt/C catalysts with improved platinum utilization, electrochemical performance, and durability in PEMFC systems.

Keywords: *PEMFC; Pt/C catalyst; BET; nitrogen adsorption; specific surface area; pore-size distribution; platinum dispersion; catalyst characterization*.

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ASSESSMENT OF MEASUREMENT UNCERTAINTY IN *BET* SPECIFIC SURFACE AREA DETERMINATION

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The Brunauer–Emmett–Teller (BET) method is one of the most extensively used techniques for determining the specific surface area of powders, porous solids, catalysts, adsorbents, nanomaterials, and other finely divided materials. Since its introduction by Brunauer, Emmett, and Teller in 1938, the method has become a fundamental tool for the characterization of solid surfaces through the measurement of physically adsorbed gases (Brunauer et. al. 1938). The reliability of the reported BET specific surface area, however, depends not only on the performance of the adsorption analyzer but also on measurement conditions, data acquisition, and mathematical treatment of the adsorption isotherm. Consequently, an evaluation of measurement uncertainty is essential for establishing the quality and comparability of BET results.

This study focuses on the systematic assessment of uncertainty associated with the determination of specific surface area by nitrogen adsorption at cryogenic temperature. The measurement procedure is considered as a sequence of interrelated operations involving sample weighing, degassing, adsorption–desorption measurements, and conversion of the resulting adsorption data into specific surface area. The methodology is aligned with the principles of the Guide to the Expression of Uncertainty in Measurement (GUM) and the recommendations established for gas adsorption measurements (JCMG, 2008; Rouquerol et. al, 1994; Thommes et. al, 2015)

Particular attention is given to the identification and quantification of the principal sources of uncertainty. These include sample mass, instrument repeatability, and accuracy. The current ISO 9277 standard similarly specifies procedures for determining the overall specific surface area of disperse and porous solids using gas adsorption and the BET approach (ISO 9277:2022).

Repeat measurements are used to evaluate the contribution of random effects, while sensitivity analysis is applied to identify the input quantities that make the largest contribution to the combined standard uncertainty. Previous investigations have demonstrated that uncertainties in volumetric nitrogen adsorption measurements can propagate significantly into calculated surface areas and other textural properties, emphasizing the importance of both experimental control and appropriate data analysis (Walton et. al, 2007).

The resulting uncertainty budget provides an integrated estimate of the reliability of the measured BET specific surface area. The assessment demonstrates that the overall uncertainty can arise from both instrumental and methodological contributions, with their relative importance

depending on the surface characteristics of the material. For low-surface-area materials, measurement sensitivity and sample mass may become particularly important, whereas for highly porous materials, the reproducibility of sample pretreatment may represent more significant sources of variation.

The proposed approach provides a practical framework for incorporating measurement uncertainty into routine BET surface-area analysis. Establishing an uncertainty budget can improve the reliability of reported values, facilitate comparison between laboratories, and strengthen quality assurance and method validation. The study therefore emphasizes the importance of standardized sample preparation, controlled experimental conditions, replicate measurements, and transparent reporting of uncertainty. Such an approach is essential for achieving more reliable and metrologically defensible specific surface-area measurements across a wide range of porous and finely divided materials.

Keywords: *BET; specific surface area; measurement uncertainty; nitrogen adsorption; catalyst characterization*

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PERSPECTIVES AND CHALLENGES IN METHANOL PRODUCTION VIA CATALYTIC HYDROGENATION OF CO_2

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The conversion of carbon dioxide into methanol through catalytic hydrogenation represents an important research direction for CO_2 valorisation and the development of sustainable processes for producing value-added chemicals. Methanol is of particular interest both as a feedstock for the chemical industry and as a potential energy carrier and fuel, while the use of hydrogen produced from renewable sources may contribute to the development of low-emission carbon cycles. This work presents a theoretical analysis of the main perspectives and challenges associated with methanol production via the catalytic hydrogenation of CO_2, based on results reported in the scientific literature. The main classes of catalysts employed in this process are reviewed, with emphasis on Cu-based systems, as well as In_2O_3-based catalysts, bimetallic systems, and advanced catalytic materials. The main proposed mechanisms for CO_2 conversion to methanol and the competition with the reverse water-gas shift (RWGS) reaction, which influences process selectivity, are also discussed. Particular attention is given to the effects of temperature, pressure, H_2/CO_2 ratio, support nature, active-phase dispersion, and surface properties on catalytic performance. The main limitations of the process are also highlighted, including thermodynamic equilibrium constraints, secondary product formation, catalyst deactivation and sintering, as well as the influence of water formed during the reaction. Based on the literature analysis, several development directions are identified, focusing on the design of more active, selective, and stable catalysts, control of active-phase–support interactions, the use of hydrogen from renewable sources, and the integration of the process into sustainable CO_2 utilization systems. The study highlights the potential of catalytic CO_2 hydrogenation for methanol production and the need for further research to overcome current limitations and improve the technological feasibility of the process.

Keywords: *perspectives, methanol production, catalytic hydrogenation, Cu-based catalysts.*

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INFLUENCE OF THE SUPPORT ON THE ACTIVITY AND SELECTIVITY OF CU-BASED CATALYSTS FOR CO_2 HYDROGENATION TO METHANOL

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Catalytic hydrogenation of carbon dioxide to methanol represents a promising pathway for CO_2 valorisation and the production of value-added chemicals, contributing to the development of carbon conversion and utilization technologies. The performance of this process is strongly influenced by the nature of the catalyst, the dispersion of the active phase, and the interaction between the metal and the support. This work presents a theoretical analysis of the influence of the support on the activity and selectivity of Cu-based catalysts used for CO_2 hydrogenation to methanol. The study is based on the analysis and comparison of results reported in the scientific literature for Cu catalysts supported on oxides with different physicochemical properties, focusing on the role of specific surface area, pore structure, active-phase dispersion, and Cu–support interactions in determining catalytic performance. The main structural, morphological, and surface characteristics of the supports are analyzed, together with their influence on the chemical state and dispersion of copper species. In addition, the effects of reaction conditions, such as temperature, pressure, and H_2/CO_2 ratio, on CO_2 conversion, methanol selectivity, and the formation of secondary products, particularly CO associated with the reverse water-gas shift (RWGS) reaction, are evaluated. The analysis aims to identify correlations between support nature, active-phase properties, reaction mechanism, and catalytic performance, highlighting the advantages and limitations of the main types of supports used for Cu-based catalysts. The study provides an overview of strategies for the design of Cu–support systems and of the factors that may promote the selective conversion of CO_2 to methanol.

Keywords: *catalytic supports, methanol selectivity, hydrogenation, Cu-based catalysts.*

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EFFECT OF CO_2 RECIRCULATION ON THE PERFORMANCE OF *NASICON*-BASED SEAWATER BATTERIES

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The growing demand for sustainable energy-storage technologies has increased interest in the use of abundant and renewable natural resources. Rechargeable seawater batteries (SWBs) represent a promising alternative to conventional Li-ion batteries, primarily because seawater provides an abundant and readily available source of Na^+ ions. In addition to resource availability, the open-cathode architecture of SWBs can facilitate heat dissipation, potentially enhancing operational safety and extending system lifetime. Furthermore, seawater-based Na–CO_2 technologies offer an attractive platform for developing integrated systems that combine electrochemical energy storage with CO_2 capture and utilization. In this study, the electrochemical performance of a seawater battery incorporating a NASICON solid-electrolyte membrane was investigated under CO_2 recirculation conditions. The experiments revealed a complex interplay between sodium-storage processes and parasitic reactions occurring in the aqueous catholyte, particularly the hydrogen evolution reaction (HER). Gas chromatographic analysis confirmed H_2 generation, with equivalent flow rates ranging from 2.42×10^{-3} to 3.90×10^{-3} $mL \cdot min^{-1}$. Moreover, the Faradaic efficiency toward H_2 increased from 9.1% after 5 h to 39.5% after 34 h of operation, indicating a progressive shift in electrochemical selectivity toward HER. The relatively stable cell voltage observed under specific operating conditions, together with the time-dependent evolution of the Faradaic efficiency, suggests that system performance is strongly influenced by local pH variations, the accumulation and speciation of carbonate/bicarbonate species, and the catalytic properties of the Pt/C electrode. Overall, the experimental results demonstrate the feasibility of operating a NASICON-based seawater battery under recirculated CO_2 conditions while also identifying key challenges that require further investigation. In particular, future optimization should focus on improving catalytic selectivity, suppressing parasitic hydrogen evolution, reducing electrode

polarization, and controlling the local chemical environment to enhance the overall electrochemical performance and efficiency of the system.

Keywords: *NASICON; Seawater batteries; Energy storage; CO_2 capture and conversion.*

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NASICON-BASED SEAWATER BATTERIES: CHALLENGES, OPPORTUNITIES, AND FUTURE PERSPECTIVES

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NASICON-based seawater batteries (SWBs) are emerging as promising electrochemical energy-storage systems due to the abundance of sodium resources, the use of aqueous seawater catholytes, and the favorable Na^+-ion conductivity and stability of NASICON (Na Super Ionic CONductor) solid electrolytes. Acting as a selective separator between the non-aqueous anode and aqueous catholyte compartments, NASICON is a key component for enabling reversible sodium-ion transport while maintaining physical separation between the two electrochemical environments. Despite these advantages, several challenges still limit the efficiency and long-term performance of NASICON-based SWBs. High interfacial resistance, electrode polarization, membrane degradation, and complex reactions occurring in seawater can affect cycling stability and overall energy efficiency. In the aqueous compartment, local pH variations and carbonate/bicarbonate equilibria may influence electrochemical behavior, while parasitic reactions, particularly the hydrogen evolution reaction (HER), can compete with the desired processes and reduce Faradaic efficiency. Therefore, improved control of the NASICON-electrolyte and electrode-electrolyte interfaces, together with the development of selective and stable electrocatalysts, remains essential. An important opportunity offered by the open-cathode configuration is the possibility of integrating energy storage with CO_2 capture and conversion. Dissolved CO_2 interacts with the aqueous electrolyte through carbonate/bicarbonate equilibria, creating the basis for developing multifunctional Na–CO_2/seawater electrochemical systems. Such systems could potentially combine electrical energy storage with CO_2 management, although improved understanding of the competition between CO_2-related electrochemical processes and hydrogen evolution is required. Future research should focus on optimizing the composition, microstructure, thickness, and surface properties of NASICON membranes, reducing interfacial resistance,

improving electrode architecture, and developing catalysts capable of suppressing parasitic reactions. Control of local pH, mass transport, carbonate chemistry, and gas–liquid–solid interfaces will also be critical. In parallel, in situ characterization and electrochemical modelling could provide valuable insights into ion transport, reaction mechanisms, and degradation pathways. Overall, NASICON-based seawater batteries provide a versatile platform for sustainable energy storage and potentially integrated CO_2 management. Further advances in solid-electrolyte engineering, catalytic selectivity, interface stability, scalability, and long-term durability will be essential for moving this technology from laboratory-scale concepts toward practical and efficient electrochemical systems.

Keywords: *NASICON; Seawater batteries; Energy storage; CO_2 capture and conversion.*

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FLUID DYNAMICS AND DESIGN ARCHITECTURE IN LARGE-Surface *PEMWEs*

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Proton exchange membrane water electrolysis (PEMWE) represents a benchmark technology for integration of hydrogen production with intermittent renewable energy sources. While small-scale lab cells (typically 5 to 25 cm²) demonstrate excellent performance, scaling up to large-surface cells introduces major engineering challenges regarding multiphase fluid dynamics and design architecture of the components. This paper investigates the coupled effects of fluid dynamics and design architecture in a 200 cm² active area single cell developed for Large-Surface PEMWEs, where macro-scale fluid maldistribution and mass transport limitations begin to heavily impact overall efficiency.

One of the primary challenges in large-surface PEMWEs is the optimized management of the evolved oxygen and hydrogen gases. For an active area of 200 cm², appearance of the two-phase flow phenomenon (liquid water and gas bubbles), especially in the anode part becomes a primary bottleneck mainly due to the presence of highly complex, non-isothermal multiphase flow regimes. As fluids move from the inlet to the outlet across a large surface area, accumulation of oxygen gas increases local void fractions along the channel's length, depending on the architecture of the bipolar plate. This occurrence has the tendency to restrict water access to the catalyst layer of the membrane exchange assembly (MEA), leading to localized mass transport limitations and accelerated membrane degradation due to formation of hot spots (high resistance imperfect contacts), localized mass transport overpotentials and uneven current density distribution. To mitigate these effects, this study evaluates three distinct flow field architectures: conventional parallel, triple-serpentine, and an optimized pin-matrix hybrid design. A two-phase, non-isothermal computational fluid dynamics (CFD) model was utilized to simulate the velocity profiles, gas volume fractions, and pressure drops across the 200 cm² domain.

Obtained results with CFD simulations demonstrate that standard parallel channels suffer from severe flow maldistribution across large surfaces, leading to stagnant zones with high void fractions near the outer rib areas due to a low-pressure gradient. This stagnation leads to severe gas accumulation and localized hot spots. The triple-serpentine configuration effectively eliminates stagnant zones and flushes out oxygen bubbles, but introduces high pressure drop. This increases parasitic pumping losses and places unwanted mechanical stress on the membrane electrode assembly (MEA) and also introduces high mechanical stress locally on the sealing components. The proposed optimized pin-matrix hybrid design optimizes flow uniformity while maintaining a manageable pressure drop. The pin-matrix design offers several critical engineering advantages over conventional channel-based configurations (like parallel or triple-serpentine designs) in large-surface PEMWEs. By replacing continuous channel walls with an array of discrete, staggered pillars, this design fundamentally alters the dynamic of the biphasic fluids movement across the active area acting as continuous in-line micro-mixers. As oxygen bubbles traverse the matrix, they are subjected to continuous three-dimensional splitting and localized shear forces. This prevents bubble agglomeration, maintaining a low local void fraction, and ensuring uninterrupted liquid water replenishment to the catalyst layer of the MEA.

The developed multiphase CFD model, indicates an optimization of the fluid dynamics and how the structural architecture ensures uniform distribution, reducing hot spots, allowing the maximization of the efficiency of large active area PEMWE stacks.

This study results clearly approves that an optimized pin-matrix hybrid design architecture successfully balances the trade-off between fluid distribution uniformity, pressure drop and suppression of extreme thermal gradients. Configuration of geometric parameters of this matrix (such as pin shape, pitch, and spacing) provides a flexible and highly scalable design envelope. Implementing this architecture in commercial-scale cells is can be proved as a significant step forward in maximizing energy efficiency, ensuring uniform catalyst utilization, and extending the operational lifetime of next-generation green hydrogen utility-scale stacks.

Keywords: *Proton exchange membrane water electrolysis, 200 cm² active area, Two-phase flow, Flow field architecture, Mass transport*.

***Acknowledgments** (if applicable)*

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A RECTANGULAR CATHODE-VAPOR-FED *PEM* WATER ELECTROLYSIS CELL FOR 1-NEWTON-CLASS PROPULSION SYSTEMS

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This work presents the design of an electrolyser cell for water electrolysis, aimed at generating gaseous hydrogen and oxygen at elevated pressures for subsequent use in a 1-N-class Water Electrolysis Propulsion System. An active area of 50 cm² was selected for the present configuration, which employs a Cathode Vapor-Fed (CVF) electrolyser architecture. This configuration is particularly attractive for compact platforms, such as CubeSats and microsatellites, where system volume and mass are critical design constraints [Selamet et al., 2013; Heizmann et al., 2023].

The key aspects of the operating principle are as follows: (i) water is supplied to the anode side of the Electrochemical Hydrogen/Water Compressor (EHC) and is transported in the vapor phase toward the cathode side of the PEM-CVF electrolyser; (ii) driven by the concentration gradient across the different layers of the electrolyser, the water vapor subsequently diffuses through the Nafion 115 membrane toward the anode; (iii) upon reaching the anode, water undergoes electrochemical oxidation, producing oxygen, protons, and electrons; and (iv) the integrated system generates pressurized hydrogen at the cathode side of the PEM-EHC and pressurized oxygen at the anode side of the CVF electrolyser.

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INTEGRATION OF A HYDROGEN FUEL CELL INTO A HYBRID PHOTOVOLTAIC-WIND POWER GENERATION SYSTEM

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The increasing integration of renewable energy sources into electrical power systems creates new challenges related to the variability and intermittency of energy production. Photovoltaic and wind generation are strongly dependent on environmental conditions, making the use of complementary energy sources important for improving the reliability and flexibility of hybrid power systems. This paper investigates the integration of a hydrogen fuel cell into a hybrid photovoltaic-wind power generation system. The fuel cell is considered as a controllable energy source capable of supporting the system during periods of insufficient solar and wind generation. The proposed architecture combines renewable generation, hydrogen-based electricity production, energy storage, and power conversion equipment within a coordinated energy system. Particular attention is given to the management of energy flows between the available sources, the storage system, local consumers, and the electrical grid. The integration of hydrogen technology improves the continuity of power supply, reduces dependence on conventional grid energy, and increases the capability of the system to operate under variable generation conditions. The presented approach highlights the potential of photovoltaic-wind-hydrogen hybrid systems as a flexible and sustainable solution for distributed electricity generation and future smart energy systems.

Keywords: *hydrogen fuel cell, photovoltaic energy, wind energy, hybrid renewable energy, energy management, microgrid.*

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IRON LOADING-DRIVEN STRUCTURE–ACTIVITY RELATIONSHIPS IN Al_2O_3-SUPPORTED CATALYSTS FOR AMMONIA DECOMPOSITION

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Ammonia is increasingly considered a practical hydrogen carrier because it combines high hydrogen content with established infrastructure for production, liquefaction, storage, and transportation. Its catalytic decomposition produces hydrogen without direct carbon-containing products, offering a route toward carbon-free hydrogen generation for distributed and fuel-cell applications (Lamb et al., 2019; Mukherjee et al., 2018). The performance of ammonia decomposition catalysts is governed by a balance between N–H bond cleavage and recombinative nitrogen desorption. For iron-based catalysts, nitrogen recombination/desorption can be kinetically limiting, while the strong interaction between iron and nitrogen may also generate iron nitride phases that participate in the catalytic cycle (Tseng et al., 2018). In this work, the effect of iron loading on the physicochemical properties, reducibility, adsorption-desorption behaviour, kinetics, and ammonia decomposition performance of alumina-supported iron catalysts was systematically evaluated.

A series of catalysts containing 10, 20, and 30 wt% iron, denoted 10FAl, 20FAl, and 30FAl, respectively, was prepared on high-purity alumina by sequential incipient-wetness impregnation. The targeted loading was introduced through successive impregnation steps, followed by drying at 105°C and calcination at 850°C. Iron content was verified by X-ray fluorescence, while the fresh and spent catalysts were characterized using N_2 physisorption, X-ray diffraction (XRD), hydrogen temperature-programmed reduction (H_2-TPR), and H_2/N_2 temperature-programmed desorption (TPD). Catalytic activity was evaluated in a fixed-bed stainless-steel tubular reactor using 0.3 g catalyst at atmospheric pressure over 200–700°C. Prior to reaction, the catalysts were treated under a reducing environment at 550°C for 1 h. Effluent ammonia was quantified using gas chromatography with a thermal conductivity detector, and experiments were repeated three times with results within ±5%. Major findings of this work are added in Table 1.

Table 1. Major findings of this work

Catalyst	Fe loading (wt%)	BET surface area (m^2/g)	Pore volume (cm^3/g)	Pore diameter (nm)	Main H_2-TPR peak (°C)	NH_3 conversion at 600 °C (%)	Apparent Ea (kJ/mol)
10FAl	10	55.7	0.29	20.8	433	52	91.4
20FAl	20	42.9	0.24	22.1	418	58	89.7
30FAl	30	25.9	0.18	27.1	405	85	48.2

Increasing iron loading produced pronounced changes in catalyst texture and structure. The Brunauer-Emmett-Teller surface area decreased from 73.7 m^2/g for bare alumina to 55.7, 42.9, and 25.9 m^2/g for 10FAl, 20FAl, and 30FAl, respectively, accompanied by a reduction in pore volume from 0.33 to 0.18 cm^3/g and an increase in average pore diameter from 17.7 to 27.1 nm. The decline in surface area and pore volume was attributed primarily to progressive pore blockage and structural changes associated with iron incorporation. Despite this loss of surface area, catalytic activity increased with iron loading, demonstrating that total surface area alone did not control the reaction performance. XRD analysis of fresh catalysts showed alumina-related reflections together with Fe_2O_3 and iron aluminate phases; the intensity of iron oxide reflections increased as the iron loading increased. Higher iron contents also produced clearer evidence of iron aluminate arising from interaction between iron species and the alumina support.

The H_2-TPR profiles revealed that higher iron loading facilitated reduction of iron oxide species. The first reduction maximum shifted from 433°C for 10FAl to 418°C for 20FAl and 405°C for 30FAl. 20FAl and 30FAl exhibited broader intermediate-temperature features consistent with multistep reduction of iron oxides, together with high-temperature features assigned to strongly interacting iron-aluminate species. Thus, increasing the iron content increased the population of reducible species while lowering characteristic reduction temperatures. The TPD results further differentiated the catalysts. Hydrogen uptake increased from 0.097 mmol/g for 10FAl to 0.114 mmol/g for 20FAl and 0.295 mmol/g for 30FAl, whereas nitrogen uptake decreased from 0.511 to 0.451 and 0.367 mmol/g, respectively. The lower measured nitrogen desorption at higher iron loading was interpreted as evidence of stronger Fe-N interaction and an increased probability of iron nitride formation rather than simply a loss of adsorption sites. XRD of spent catalysts supported this interpretation by showing metallic iron and iron nitride phases in addition to alpha-alumina. The beneficial role of iron nitride species in ammonia decomposition has also been reported for other Fe-based catalytic systems (Zhang et al., 2018; Lu et al., 2022).

These physicochemical trends were directly reflected in catalytic performance. At 600°C, ammonia conversion increased from 52% over 10FAl to 58% over 20FAl and 85% over 30FAl. The 30FAl catalyst therefore achieved the highest activity despite having the lowest specific surface area. Kinetic analysis using Arrhenius plots yielded apparent activation energies of 91.4, 89.7, and 48.2 kJ/mol for 10FAl, 20FAl, and 30FAl, respectively. The substantially lower apparent activation energy of F30Al was consistent with its superior conversion profile. Comparison with previously reported transition-metal and Ru-based systems showed that the alumina-supported iron catalysts provided competitive performance under the investigated conditions, with 30FAl reaching 85% conversion at 600 °C using 30 wt% iron. Overall, the results establish a structure-property-activity relationship in which increased iron loading simultaneously promotes reducibility, increases hydrogen adsorption/desorption capacity, favors Fe-N interactions and nitride formation, and lowers the apparent kinetic barrier. These effects outweigh the accompanying loss of surface area and account for the superior performance of 30FAl. The findings demonstrate that controlled iron loading and management of the dynamic Fe/Fe–N phase chemistry are important design parameters for developing cost-effective, non-noble-metal catalysts for clean hydrogen production from ammonia.

Keywords: *Clean hydrogen; Iron catalyst; Alumina; Iron nitride; Reducibility*

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IMPACT ASSESSMENT OF 40Pt/C ON OXYGEN REDUCTION REACTION AT LOW LOADING OF Pt FOR POLYMER ELECTROLYTE MEMBRANE FUEL CELLS (*PEMFCs*)

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Urbanisation, industrialization, expansion of transportation, and changing lifestyle increased the energy demand. Of today´s total energy need, >80 % energy exclusively derived from fossil fuel-based technology, releasing carbon at unprecedently rate, resulting serious issues to the human being and environment. Therefore, balancing energy need and environment become essentially important. Some new technologies haven been evolved in course of development of science and engineering and matured. The polymer electrolyte-based fuel cell is a particular technology that produces useful form of electrical energy electrochemically from hydrogen or other fuels, such as ammonia, methanol, at highest conversion rate of 60 to 80%, when exhausted heat used in combined heat and power system [Barbir, 2008]. Also, PEMFC works silently and at room temperature, with no carbon traces, and hence, it attracts researcher for their fast adoption. It constitutes electrolyte, anode and cathode, as primary components, similar to revealed in other electrochemical devices, the additional requirement of gas diffusion layer (GDL), bipolar and end plates increase system complexity.

As expressed above, PEMFC has number of benefits. The commercialization of technology is not easy and faced by several challenges, such as high cost, inadequate operational life, reduced fuel and mechanical flexibility, higher weight, lower power density compared to other type of fuel cells, etc [Hellmana et al., 2007]. Depending on interest, researcher emphasizes on a specific objective and resolve it through various tactics, including but not limited to tuning material compositions, controlling particle size and distribution, adopting core-shell structure, alternation of design from conventional to bipolar plate free, etc. Nevertheless, the present study confined to addressing forefront issue of low Pt loading and its distribution on fundamental characteristic of cathode catalyst, where 4 electron transfer oxygen reduction reaction (ORR) is sluggish and high activation energy constrained.

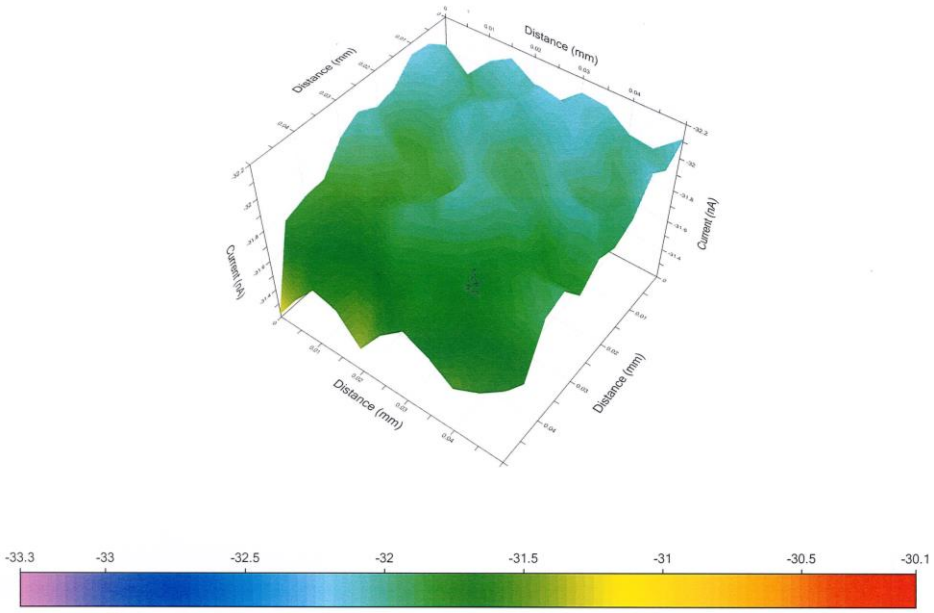


Figure 1. SECM image recorded on top of 40Pt/C catalyst deposited on gold electrode

In all the experiments, a fixed 40Pt/C of 0.14 mg cm^{-2} catalyst loading was considered. The ink was prepared by mixing 5 mg of catalyst powder (purchased from Aldrich with purity ≥ 98 %), 20 µl Nafion, 242 ml of iso-propyl alcohol, and 10 µl of deionized waters in a plastic vial. The ink was then ultrasonicated for 2h and drop casted onto glassy carbon and gold, for rotating disc and rotating ring disc electrodes (RDE and RRDE) and scanning electrochemical microscopy (SECM) working electrodes, respectively, with approximate volume of 5 µl. The ink was dried at ambient condition and a fine drop of 0.5M H_2SO_4 placed onto. The identical procedure was ensured in all three cases, studied in a 0.5 M H_2SO_4, using Pt and Ag/AgCl (3M KCl) as counter and reference electrodes, respectively.

The spatial catalytic distribution (faint blue colour) determined in initial SECM reveals partial heterogeneity with small degree of roughness (Fig.1). The activation of 40Pt/C and thereby measured electrochemical surface (ECS) was 40 m^2 g_{Pt}^{-1}. The specific and mass activities, evaluated for ORR in linear sweep voltammetry (LSV), were 0.015 mA cm^{-2} and 6.05 mA mg_{Pt}^{-1} (Table 1), respectively. While 40Pt/C exhibited adequate mass and specific activities, chronoamperometry (CA) exhibited noticeable degradation (Fig. 2a), with net loss of 11.5% active sites (Fig. 2b). Additionally, the RRDE highlighted hydrogen peroxide (<1%) contributes to degradation by generating reactive radicals, that damages carbon support, leading to Pt agglomeration and reduced catalytic performance [Singh et al., 2018].

Table 1. Summary of parameters evaluated from dimension of electrode, catalyst mass, active area, and electrochemical study

Pt loading (mg)	0.035
Pt loading (mg cm^{-2})	0.14
Tafel slope for 1000 rpm curve (mV dec^{-1})	108
Charge transfer coefficient	0.53
Mass activity (mA mg_{pt}^{-1})	6.05
ECSA (cm^2 mg^{-1})	39.7
Sp. Activity (mA cm^{-2})	0.015
Electron-transfer number	~ 4

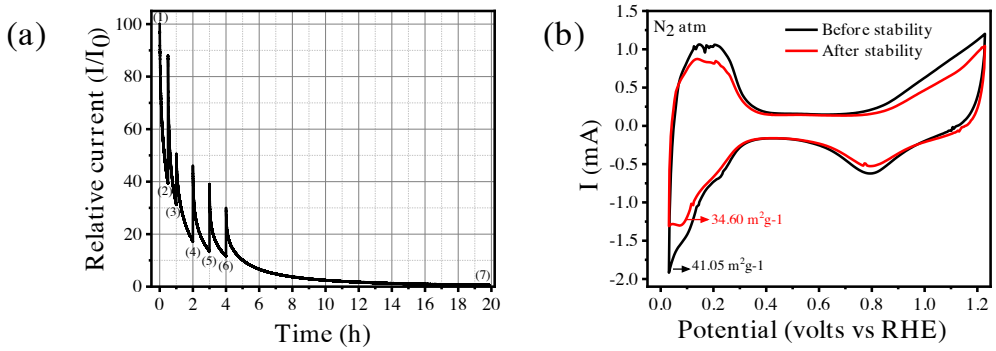


Figure 2. Chronoamperometric stability of 40Pt/C catalyst with intermittent LSV (a) and CV curve recorded at before and after stability study (b).

Key words: PEMFC; 40Pt/C catalyst; oxygen reduction reaction; Linear sweep voltammogram; scanning electrochemical microscopy

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METHANOL SUPPLY VERSUS CROSSOVER: THE CENTRAL TRADE-OFF IN DIRECT METHANOL FUEL CELLS

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Methanol is a liquid at room temperature, is inexpensive (on the order of 500-600 $/metric ton) and has a high volumetric energy density (~ 15.7 MJ/L, compared to 4.5 MJ/L for hydrogen at 700 bar). These properties of methanol make direct methanol fuel cells (DMFCs) particularly attractive for low-temperature and portable power applications (Osman et al., 2025). However, DMFC operation involves a fundamental trade-off between providing sufficient methanol to the anode and limiting methanol crossover through the polymer electrolyte membrane.

Although the theoretical reversible potential of a methanol-oxygen fuel cell is 1.213 V at 25°C, practical DMFCs typically exhibit significantly lower open-circuit voltages (OCVs; often in the 0.4-0.6 V range), partly due to methanol crossover through the polymer electrolyte membrane into the cathodic compartment and the resulting mixed cathode potential caused by methanol oxidation at the cathode (Fig. 1).

Methanol concentration is therefore a key parameter governing DMFC performance. Low methanol concentrations reduce crossover and enable very high fuel utilization, but mass transport limitations prevent the achievement of useful power densities. High methanol concentrations reduce anode-side fuel limitations and improve the achievable current density, but the resulting increase in methanol flux across the membrane can cause significant voltage, power and fuel-efficiency losses. Consequently, methanol concentrations around 1-2 M have often been reported as a practical compromise for DMFCs.

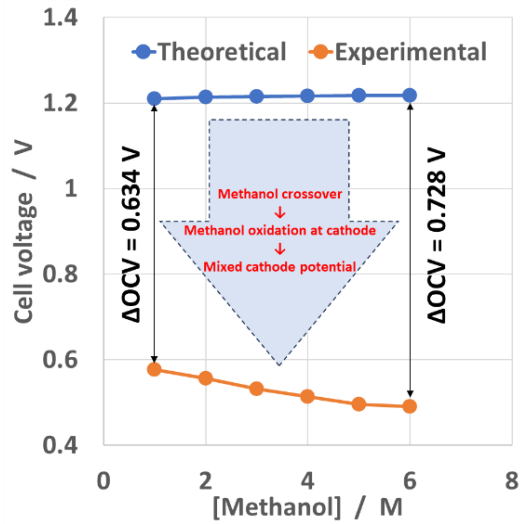


Figure 1. Theoretical reversible potential and typical experimental OCVs of a DMFC as a function of methanol concentration. The experimental values are typical OCVs reported in the literature (e.g., in (Liu et al., 2005; Masdar et al., 2017). The substantial deviation of the experimental OCV from the theoretical reversible potential is primarily attributed to methanol crossover through the membrane and the resulting mixed potential at the cathode. Increasing methanol concentration enhances methanol crossover and consequently contributes to a lower experimental OCV.

This poster presents an analysis of i.) the mechanisms underlying this trade-off, ii.) the experimental parameters governing the balance between improved fuel supply and increased crossover, and iii.) commonly proposed mitigation strategies. The analysis basically highlights that, with current polymer electrolyte membranes, substantial compromises between fuel utilization and attainable power density remain unavoidable.

Keywords: direct methanol fuel cell, methanol crossover, polymer electrolyte membrane, fuel utilization, power density

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STRUCTURE–ACTIVITY–STABILITY RELATIONSHIPS OF IRIDIUM OXIDES IN *PEM* WATER ELECTROLYSIS

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Proton exchange membrane water electrolysis (PEMWE) requires anodic electrocatalysts that combine high activity for the oxygen evolution reaction (OER) with resistance to dissolution in acidic media and at high anodic potentials. Iridium oxides best meet these requirements, but their electrochemical behavior is significantly influenced by structure, crystallinity, and degree of hydration [Speer, et al., 2026, Mom et al., 2022]. This paper presents a critical analysis of the relationships between structure, activity, and stability for hydrated amorphous, semicrystalline, and crystalline forms of IrO_x. Studies using cyclic and linear voltammetry for activity assessment, operando spectroscopic techniques for structure investigation, and inductively coupled plasma mass spectrometry for determining dissolution and understanding the behavior of iridium are reviewed [Mom et al., 2022, Kasian, et al., 2019]. At the heart of the analysis is an apparent paradox: the same structural features that favor catalytic activity can also contribute to material degradation. The amorphous and hydrated forms present a more open structure and more accessible sites, being associated with high OER activity, but also with a higher susceptibility to dissolution [Mom et al., 2022; Kasian, et al., 2019]. Crystalline IrO_x exhibits a better connected Ir–O network and superior stability, but lower catalytic activity, while semi-crystalline oxides exhibit intermediate behavior [Mom et al., 2022; Czioska, et al., 2021]. The analysis highlights the need to simultaneously evaluate activity and stability and shows that optimizing crystallinity and hydration can contribute to more efficient use of iridium in PEM electrolysers.

Keywords: *PEMWE, iridium oxides, Oxygen Evolution Reaction; crystallinity; Electrocatalytic Activity; Structural Stability*

Acknowledgments

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UNLOCKING GREEN HYDROGEN: ADVANCED CATALYSTS FOR EFFICIENT AMMONIA DECOMPOSITION

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The transition toward sustainable and decarbonized energy systems requires efficient strategies for the storage, transportation, and on-demand utilization of hydrogen. Ammonia (NH_3) has attracted increasing attention as a carbon-free hydrogen carrier because of its high hydrogen content, established infrastructure for large-scale storage and transportation, and favorable energy-storage characteristics (Lan et al., 2012; Valera-Medina et al., 2018). Nevertheless, the effective recovery of hydrogen from ammonia remains challenging because its catalytic decomposition is strongly endothermic and generally requires elevated temperatures to achieve high conversion rates. Consequently, the development of highly active and durable catalysts capable of promoting ammonia cracking at lower temperatures is essential for the implementation of ammonia-based hydrogen supply systems (Mukherjee et al., 2018; Lucentini et al., 2021).

This study focuses on the rational design of advanced heterogeneous catalysts for efficient ammonia decomposition, with particular emphasis on enhancing catalytic activity while reducing dependence on expensive noble metals. The decomposition process proceeds through sequential surface reactions involving ammonia adsorption, N–H bond dissociation, hydrogen recombination and desorption, followed by nitrogen recombination and N_2 release. The overall reaction kinetics are therefore strongly influenced by the electronic structure, surface morphology, active-site density, and adsorption characteristics of the catalyst (Lucentini et al., 2021; Su et al., 2023). Accordingly, catalyst morphology, particle dispersion, metal–support interactions, and promoter effects are systematically considered as key parameters for controlling catalytic performance.

The theoretical analysis systematically evaluates three key catalyst classes:

- Noble Metal Systems (: Highly active at low temperatures due to near-optimal N-binding energies. Kinetic efficiency is optimized on basic oxide supports (MgO, CeO_2), where promoter addition (K, Ba) alters the Fermi level of Ru nanoparticles,

drastically accelerating the recombinative N_2 desorption step (Takahashi et. al., 2016).

- Earth-Abundant Transition Metals (Ni, Co, Fe): Cost-effective alternatives whose performance is kinetically hindered by excessive surface nitrogen coverage. Incorporating supports with high oxygen storage capacity or conductive carbon networks enhances metal dispersion and alters d-band centers to facilitate N_2 clearance.

- Bimetallic and Nitride Architectures (Fe-Co, Mo_2N): Synergistic formulations where ensemble effects and orbital hybridization modify adsorption thermodynamics, circumventing linear scaling relations to achieve low-temperature activation energies comparable to Ru (Khan et al.,

Ruthenium-based materials are widely recognized among the most active catalysts for ammonia decomposition because their metal–nitrogen interaction provides a favorable balance for the activation and subsequent removal of nitrogen-containing intermediates. However, the high cost and limited availability of Ru constitute significant obstacles to their widespread industrial application (Chen et al., 2021; Su et al., 2023). This has stimulated considerable interest in reducing Ru loading and developing alternative catalysts based on more abundant transition metals, particularly Ni. Nickel-based systems offer an attractive combination of comparatively low cost, availability, and catalytic activity, although their performance at lower temperatures generally remains inferior to that of optimized Ru-based formulations (Mukherjee et al., 2018; Su et al., 2023). The incorporation of promoters and tailored supports therefore represents an important strategy for modifying the electronic properties and surface chemistry of the active phase. Previous studies have demonstrated that carbonaceous materials and metal oxides can significantly influence the dispersion and electronic environment of supported Ru catalysts, while alkali and alkaline-earth promoters can enhance catalytic activity by modifying the surface properties of the active phase (Chen et al., 2021; Su et al., 2023). These concepts provide the basis for developing catalyst architectures capable of operating efficiently under less severe reaction conditions.

Keywords: *Ammonia decomposition; Green hydrogen; Advanced catalysts; Hydrogen production*.

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CATALYTIC DECOMPOSITION OF AMMONIA AS A ZERO-CARBON ENERGY CARRIER

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Ammonia (NH_3) has emerged as a promising carbon-free energy carrier for hydrogen storage, transportation, and distributed energy generation because of its high hydrogen content, relatively favorable liquefaction characteristics, and well-established global infrastructure for production, storage, and transportation. In contrast to compressed or liquefied hydrogen, ammonia can be stored and transported using technologies that are already widely deployed by the chemical and fertilizer industries, making it an attractive intermediate vector for the development of large-scale hydrogen supply chains (Lan et al., 2012; Valera-Medina et al., 2018). Ammonia contains approximately 17.7 wt% hydrogen and can therefore function as a chemically bound hydrogen carrier that enables hydrogen to be transported over long distances and subsequently released near the point of use through catalytic decomposition (Bell & Torrente-Murciano, 2016; Lucentini et al., 2021). Releasing hydrogen on demand requires overcoming significant kinetic barriers governing the endothermic decomposition reaction: $2NH_3 = 3H_2 + N_2$, $\Delta H^0 = +46.2$ kJ/mol. This theoretical study provides a rigorous fundamental assessment of the catalytic reaction dynamics, microkinetic models, and structural factors across various transition metal centers (Farooqui et al., 2026).

Elementary reaction mechanisms proceed via successive dehydrogenation steps ($NH_{3,ads}$ -> $NH_{2,ads}$ -> NH_{ads} -> N_{ads}) culminating in recombinative nitrogen desorption ($2N_{ads}$ -> $N_{2,g}$) and hydrogen release. Kinetic modeling demonstrates that for ruthenium-based systems (e.g., Ru/CeO_2, Ru/Al_2O_3), recombinative N_2 desorption serves as the rate-determining step (RDS), with catalytic turnover heavily dictated by the density of highly active step-edge B_5-type sites. Conversely, on late transition metals such as nickel (Ni) and iron (Fe), strong nitrogen adsorption energies induce surface poisoning, shifting the RDS toward initial N-H bond cleavage or surface coverage clearance under low-temperature regimes (Takahashi et. al., 2016). The role of electron-donating promoters (K^+, Cs^+, Ba^{+2}) and strong metal-support interactions (SMSI) in facilitating electron transfer to the metal

d-band is analyzed. This electronic tuning weakens the M-N binding strength and lowers activation barriers for N_2 recombination.

The theoretical analysis demonstrates that catalytic ammonia decomposition is a promising pathway for hydrogen generation and integration into low-carbon energy systems. Ammonia provides an attractive hydrogen carrier because of its high hydrogen content and established storage and transportation infrastructure (Lan et al., 2012; Valera-Medina et al., 2018). However, its endothermic decomposition and kinetic limitations require highly active catalysts capable of operating at reduced temperatures (Mukherjee et al., 2018; Lucentini et al., 2021). Although Ru-based catalysts exhibit high activity, their cost encourages the development of Ni-based and promoted alternatives (Su et al., 2023). Optimized catalyst design and reactor conditions could enable efficient, scalable ammonia-to-hydrogen conversion.

Keywords: *Ammonia decomposition; Hydrogen production; Renewable energy.*

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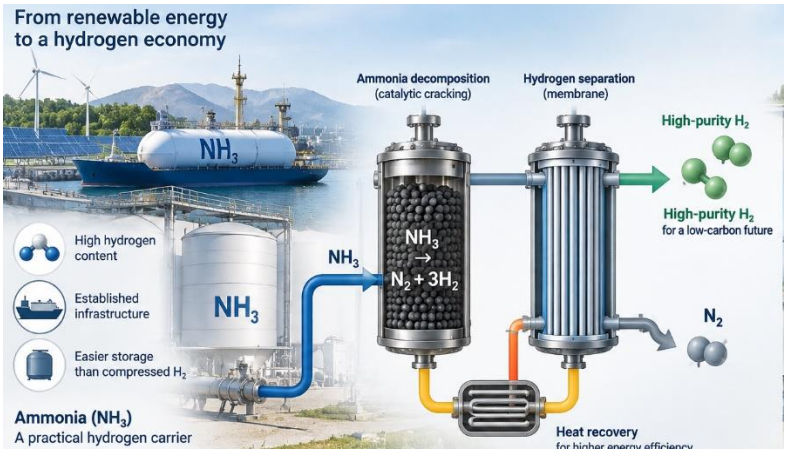
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DEVELOPMENT OF SUSTAINABLE *CRM*-FREE CATALYTIC SYSTEMS FOR AMMONIA DECOMPOSITION

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Hydrogen is considered a key energy carrier for the transition toward low-carbon energy systems; however, its large-scale deployment is still limited by challenges related to storage, transportation, safety, and cost. Ammonia (NH_3) represents a promising hydrogen carrier due to its high hydrogen content, established transport infrastructure, and more convenient storage conditions compared with compressed hydrogen. Efficient hydrogen recovery from ammonia therefore represents an important technological step toward the development of sustainable hydrogen supply chains. This work focuses on the development of an integrated technological approach for high-purity hydrogen production through catalytic ammonia decomposition, combining advanced catalyst development, reactor design, membrane-based hydrogen separation, and thermal management. Two complementary ammonia cracking concepts are considered. The first consists of a laboratory-scale two-stage system comprising an optimized catalytic reactor followed by a selective membrane unit for hydrogen purification. The second approach involves an integrated membrane reactor, with a targeted capacity of approximately 0.2 $Nm^3\ h^{-1}$, in which ammonia decomposition and hydrogen separation occur simultaneously.



A major research objective is to reduce the operating temperature and associated energy demand of conventional ammonia cracking processes through the development of critical raw material-free (CRM-free) catalytic systems. The proposed catalysts are investigated in terms of physicochemical and structural properties, thermal stability, catalytic activity, ammonia conversion, and long-term performance. Particular attention is also given to hydrogen separation efficiency and heat recovery as key parameters for improving the overall energy efficiency of the process. The proposed approach creates the basis for a compact, energy-efficient, and scalable ammonia-to-hydrogen technology. Further development and prototype validation will focus on demonstrating high-purity hydrogen production at reduced operating temperatures and evaluating the potential integration of the technology into renewable hydrogen supply chains, including applications in heavy-duty transportation.

Keywords: *ammonia cracking; hydrogen production; CRM-free catalysts; membrane reactor; hydrogen carrier*.

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BIOLOGICAL HYDROGEN PRODUCTION IN EUROPEAN UNION: TECHNOLOGICAL PATHWAYS, FEEDSTOCK ECONOMICS, AND DEPLOYMENT BARRIERS

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Achieving the European Union's net-zero targets requires expanding clean hydrogen pathways beyond water electrolysis and steam methane reforming with carbon capture (Kalt and Cezne 2026; Voss and Poeppelbuss 2026). Biological hydrogen (bio-H2) offers a zero-carbon route that couples directly with circular energy infrastructures through the valorization of agro-industrial residues (Kumari and Saxena 2026). This work reviews progress across dark fermentation (DF), photo-fermentation, and biophotolysis, including hybrid dark fermentation – microbial electrolysis cell (DF–MEC) configurations as an example of sector coupling between pure biological and bio-electrochemical hydrogen routes (Table 1).

Table 1. Comparative overview of biological hydrogen production pathways.

Pathway	Reported H_2 performance	Primary limitations
Dark fermentation	1.5–2.5 mol H_2/mol hexose (vs. 4 mol theoretical)	VFAs accumulation; methanogenic contamination in continuous mode
DF–MEC hybrid	+0.5–1.0 mol H_2/mol residual COD *vs.* DF alone	Electrode cost; long-term biocathode stability
Photo-fermentation	Polishes DF effluent VFAs; strain-dependent	Light penetration; photobioreactor footprint
Biophotolysis	Low areal yield	O_2 sensitivity of hydrogenases

VFAs = volatile fatty acids;
COD = chemical oxygen demand.

Organic waste, forestry, and agricultural residues are assessed as primary feedstocks (carbon sources): their negative net cost, set by avoided disposal fees, is what currently makes bio-H2 economically viable at small and medium scale (Mukherjee and Mohan 2022; Gesese et al. 2026). Translating bench-scale results to continuous industrial operation, however, remains constrained by (bio)reactor engineering, long-term process stability, and low volumetric hydrogen production rates (system-level barriers rather than purely biochemical ones). Based on current

TRL positioning and typical scale-up patterns, dark fermentation and DF-MEC hybrids are projected to reach demonstration-to-near-commercial readiness by 2035, while photo-fermentation and biophotolysis mature more slowly (Figure 1).

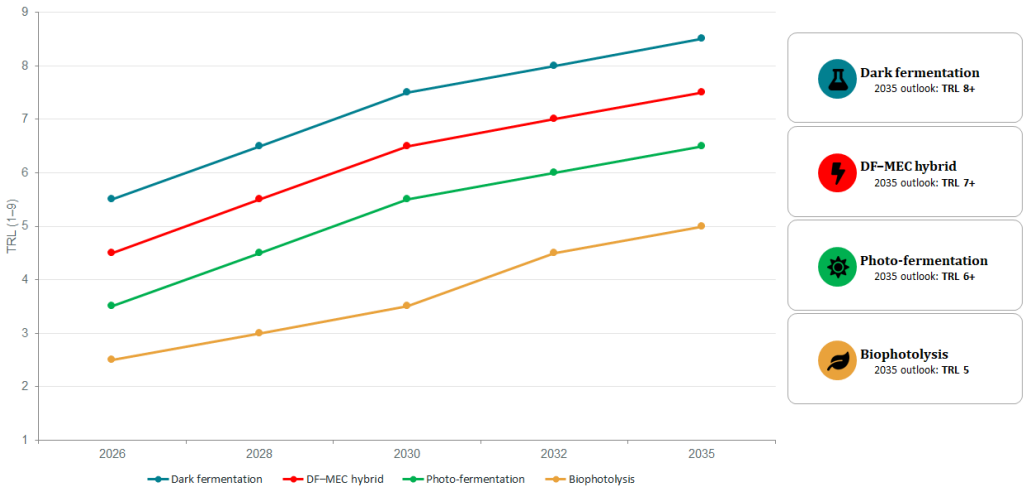


Figure 1. Projected TRL trajectory (2026–2035) for the four biological hydrogen production pathways. Illustrative projection based on current literature trends, not a formal forecast.

Evaluated against EU policy frameworks, bio-H_2 occupies a distinct regulatory niche: while recognized as an Annex IX (Part A) advanced biofuel under the Renewable Energy Directive (RED III) and benefiting from transport quotas and double-counting provisions, it remains excluded from binding Renewable Fuels of Non-Biological Origin (RFNBO) target mechanisms and primary Clean Hydrogen JU funding priorities. Aligning bio-H_2 within mainstream EU industrial hydrogen strategy will be just as vital to its deployment as resolving its remaining technical bottlenecks.

Keywords: *biological hydrogen; dark fermentation; circular energy infrastructure; agro-industrial residue valorization; EU hydrogen policy*

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ELECTROLYTE MATERIALS FOR SOLID OXIDE FUEL CELLS: FROM CONVENTIONAL SYSTEMS TO EMERGING CONCEPTS

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Solid oxide fuel cells (SOFCs) were initially developed as high-temperature electrochemical energy conversion systems. The electrolyte was also playing a central role in determining both the operating regime and the electrochemical performance of the cell. At the beginning of the 2000s, SOFCs were primarily described as high-temperature electrochemical energy-conversion systems, while material selection was already recognized as a major factor affecting performance, durability and cost [Yamamoto, 2000, Stelee et al, 2001]. Yttria-stabilized Zirconia (YSZ) became a reference electrolyte because of its ionic conductivity, chemical stability and compatibility with established SOFC architectures. However, its conductivity decreases considerably with decreasing temperature, thus motivating the search for alternative electrolyte materials and architectures. By 2006, the development of intermediate-temperature SOFCs became a clear research direction, primarily intended to reduce materials constraints, extend component lifetime and decrease the costs of the system. In this context, zirconia-based electrolytes, including Scandia-stabilized Zirconia (ScSZ), were considered alongside doped-Ceria and Lanthanum-gallate systems [Fergus 2006]. ScSZ offered higher ionic conductivity than YSZ over relevant SOFC temperature ranges, whereas doped ceria, particularly gadolinium- and samarium-doped materials, showed improved conductivity at lower temperatures. Strontium- and magnesium-doped lanthanum gallate (LSGM) also emerged as an important alternative. By 2010, the research was increasingly focused on adapting SOFC materials to intermediate operating temperatures of approximately 500–800°C, emphasizing the need to preserve adequate ionic transport while maintaining chemical and mechanical compatibility between cell components [Jacobson, 2010]. The development of proton-conducting ceramic electrolytes introduced a new pathway for lowering SOFC operating temperatures. In 2012, proton-conducting oxides were explicitly proposed as a

route toward SOFC operation below 600°C. In particular, chemically stable doped barium-zirconate electrolytes demonstrated increasing potential for protonic transport in ceramic fuel cells, establishing this path as an alternative to the conventional oxide-ion conduction mechanism [Fabbri et al., 2012]. By 2020, the electrolyte landscape expanded beyond conventional oxide-ion conductors and was broadly described in terms of three classes: oxide-ion-conducting, proton-conducting and dual-ion-conducting electrolytes. At this stage, lowering the operating temperature while maintaining low ohmic resistance, sufficient ionic conductivity and long-term chemical and mechanical stability became a central materials challenge [Shi et al., 2020].Recent progress further strengthened research toward lower-temperature SOFC operation. A 2025 assessment of ceria-based electrolytes identified Gd-doped ceria (GDC) and Sm-doped ceria (SDC) as relevant candidates for lower-temperature operation [Kaur et al., 2025]. In parallel, new proton-conducting perovskites have pushed the accessible temperature range further downward. Also, Sc-doped barium stannate and barium titanate electrolytes exceeded a proton conductivity of 0.01 S cm^{-1} at 300°C, while $BaSn_{0.3}Sc_{0.7}O_3-\delta$ also demonstrated chemical stability under demanding conditions [Tsujikawa et al., 2025]. More recently, Aurivillius-type oxide-ion-conducting thin films reported in 2026 reached an ionic conductivity of 0.025 S cm^{-1} at 350°C and enabled a fuel cell power density of 0.726 W cm^{-2} at 400°C [Huo et al., 2026].

This work aims to highlight the gradual evolution of SOFC electrolyte materials toward lower operating temperatures. While YSZ continues to serve as a well-established technological benchmark, materials such as ScSZ, doped ceria, and LSGM have contributed significantly to the development of intermediate-temperature SOFCs. More recently, proton-conducting ceramics and advanced oxide-ion conductors have opened new pathways toward operation at substantially lower temperatures. However, the 300–400°C range still represents an emerging research domain, in which high ionic conductivity must be achieved together with long-term durability, interfacial compatibility, scalable fabrication, and stable cell-level performance.

Keywords: SOFC, electrolyte, materials, lower, temperatures.

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FLEXIBLE MEMBRANE ELECTRODE ASSEMBLIES FOR NEXT-GENERATION PORTABLE FUEL CELLS: STRUCTURAL DESIGN AND ELECTROCHEMICAL KINETICS

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Flexible fuel cells have recently emerged as power sources for wearable smart devices, elastomeric robotic systems, and on-body biomedical devices. The core bottleneck in achieving a high-power density under mechanical deformation lies in the structural integrity and mass transport efficiency of the Membrane Electrode Assembly (MEA) [Duan et al., 2023]. This prospective review examines the most recent innovations in the development of flexible MEAs on two tiers: (1) next-gen architecture designs and (2) novel materials. Specifically, we designed our literature review by mapping the overlaps between mechanical strain, charge transfer, and triple-phase boundary stability. We identified and discussed strategies for designing flexible components such as ultra-thin gas diffusion layers, high-conductivity polymer electrolyte membranes, and flexible topologies of the catalyst layer. We also compared the efficiency of structural configurations such as corrugated structures, elastic polymer matrices, and conductive nanomaterial networks (e.g., carbon nanotubes, graphene) for preventing mechanical degradation, micro-cracking, and delamination [Li et al., 2024, Youn et al. 2025]. Additionally, the kinetic effects of mechanical stress on proton transport rates and the activity of the oxygen reduction reaction were examined [Redondo et al., 2026]. Overall, this study offers solid guidelines for creating high-performance flexible MEAs based on electrochemical kinetics and mechanical resilience.

Keywords: *Flexible, fuel, cells, structural, electrochemical, kinetics.*

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INFLUENCE OF IRON LOADING ON THE ELECTROCATALYTIC ACTIVITY OF Pt–Fe/rGO FOR OXYGEN REDUCTION REACTION IN *PEM* FUEL CELLS

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Fuel cells (FCs) play a pivotal role in tackling global energy challenges and achieving net-zero emissions by providing sustainable, scalable energy conversion. As integral alternatives to conventional energy sources that cause environmental damage, Proton Exchange Membrane Fuel Cells (PEMFCs) stand out due to their high efficiency, low operating temperatures, and technological maturity [Zhan, et al., 2025]. However, the sluggish kinetics of the cathodic Oxygen Reduction Reaction (ORR) require large amounts of expensive Pt-based catalysts, significantly increasing overall costs. To overcome this limitation, alloying Pt with transition metals on supports such as reduced graphene oxide (rGO) represents a key strategy for catalyst design [Chen, et al., 2026]. This study investigates the impact of iron concentration on Pt–Fe/rGO electrocatalysts synthesized for ORR enhancement. Two samples with a constant platinum content (~10% Pt) and varying Fe proportions—Sample A (~16% Fe) and Sample B (~22% Fe)—were evaluated using Cyclic Voltammetry (CV) and Linear Sweep Voltammetry (LSV). CV provided key insights into redox behavior, electron transfer kinetics, and surface adsorption processes, while LSV delivered precise analysis under static and controlled hydrodynamic conditions. CV measurements revealed the typical electrochemical behavior of platinum in both samples, evidenced by characteristic hydrogen adsorption/desorption profiles and oxide formation/reduction regions. Quantitative evaluation demonstrated a more favorable electrochemical response for Sample A, which exhibited an enhanced hydrogen desorption charge, an improved electrochemically active surface area (ECSA) compared to Sample B, and a more intense cathodic response during ORR in both static and rotating electrode measurements. Increasing the Fe content from ~16% to ~22% proved counterproductive, suppressing platinum availability and reducing ECSA. In this particular case, an iron content of ~16% represents the optimal threshold for the

evaluated system, demonstrating that exceeding this ratio compromises active site accessibility and overall ORR efficiency under the tested conditions.

Keywords: *Oxygen Reduction Reaction, PEMFCs, ECSA, reduced graphene oxide, Pt–Fe alloy.*

Acknowledgments

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SUSTAINABLE ADVANCED MATERIALS FOR SOLID-STATE SODIUM-ION BATTERIES: AN EFFICIENT, SAFE AND ECO-FRIENDLY ENERGY STORAGE SYSTEM

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The accelerating deployment of renewable energy technologies and electric mobility is intensifying the need for safe, sustainable, and cost-effective energy-storage solutions. Although lithium-ion batteries currently dominate the market, concerns related to resource availability, cost, supply-chain constraints, and environmental impact are driving the search for alternative electrochemical storage technologies. Sodium-ion batteries are receiving increasing attention in this context, owing to the natural abundance, broad geographical distribution, and comparatively low cost of sodium resources.

Among the different sodium-based technologies, solid-state sodium-ion batteries represent a particularly promising approach. By replacing conventional liquid electrolytes with solid ion-conducting materials, these systems have the potential to improve battery safety while enabling the development of more robust and sustainable cell architectures. Nevertheless, their practical implementation still depends on overcoming several challenges related to ionic conductivity, interfacial compatibility, electrochemical stability, and the integration of environmentally responsible materials.

The **4SIBAT project – Development of Sustainable Materials for Sodium Solid-State Batteries** addresses these challenges through the development and integration of advanced materials specifically designed for solid-state sodium-ion systems. Particular emphasis is placed on sustainable material concepts, including green monomers and single-ion-conducting membranes, with the aim of combining efficient sodium-ion transport, electrochemical stability, and reduced environmental impact.

The project targets the design and validation of functional materials and cell components that can be integrated into an optimized Sustainable Solid-State Sodium-Ion Battery architecture. The resulting prototype will be developed to meet the performance and operational requirements of robotic applications, while demonstrating the feasibility of a safer and more sustainable sodium-based energy-storage technology.

Through this approach, 4SIBAT aims to strengthen European capabilities in next-generation battery materials and contribute to the European Union's objectives for sustainable energy storage, reduced dependence on critical raw materials, and technological leadership in the renewable-energy transition.

Keywords: *Sustainability, Advanced materials, Solid-State Sodium Batteries, Energy*

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CORRELATING THE EFFECTS OF TEMPERATURE, CLAMPING PRESSURE AND CURRENT DENSITY ON THE PERFORMANCE OF A 50CM^2 SINGLE-CELL PEM ELECTROLYZER

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The growing demand for clean hydrogen production has increased interest in proton exchange membrane (PEM) water electrolysis as a scalable route to green hydrogen. PEM electrolyzers are attractive because they combine high current density operation, compact cell design, and rapid dynamic response, enabling integration with variable renewable power, while producing high-purity hydrogen without extensive downstream purification. Since cell performance is strongly governed by the operating conditions under which the stack is run, systematic characterization of temperature, clamping pressure, and current density is essential for optimizing efficiency and cell lifetime. In this study, a custom-built testbench for 50 cm² single-cell PEM electrolyzers was used to investigate the combined influence of temperature (approximately 20-80°C), clamping torque (1.5-3.5N·m), and current density on cell performance, allowing MEA exchange and reproducible acquisition of polarization curves across the full operating matrix. At a fixed clamping torque of 1.5 N·m and fixed current density, raising the temperature from 25°C to approximately 65°C reduced the required cell voltage from 2.00 to 1.74 V, a reduction of about 13%, consistent with improved reaction kinetics and membrane ionic conductivity. Clamping torque showed a monotonic rather than optimum-limited effect: at 2.0 V and approximately 70-75°C, increasing torque from 1.5 to 3.5 N·m raised the sustained current density by 29%, with no sign of performance loss at the highest compression tested. Combining the highest tested temperature and clamping torque more than doubled the current density achievable at 2.0 V relative to ambient, lightly-clamped conditions, substantially widening the cell's operating window. The polarization curve remained close to linear up to the highest current density reached, with no clear onset of mass-transport-limited behavior within the tested range. Overall, the results confirm the testbench's capability to systematically correlate temperature, clamping torque, and current density with single-cell PEM electrolyzer performance, showing that

higher temperature and higher compression consistently improve performance rather than trading off against one another. Future work will extend the matrix beyond 3.5 N·m and 80°C to include variations in the system pressure and the DI water flow to determine whether an optimum torque or mass-transport limitation eventually emerges, alongside durability testing and MEA characterization.

Keywords: *Green Hydrogen, Electrolysis, PEM, Evaluating Performance;*

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HYDROGEN ISOTOPES, NUCLEAR AND ADVANCED ENERGY APPLICATIONS

LEAD-COOLED FAST REACTOR TECHNOLOGY IN ROMANIA. CURRENT STATUS AND PERSPECTIVES

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Lead-cooled fast reactors (LFRs) represent a promising generation IV technology, combining a fast neutron spectrum with the favourable thermal properties of liquid lead and the potential for improved fuel utilisation and sustainable fuel-cycle strategies. ROMANIA contributes to European LFR development through a coordinated programme of research, experimental infrastructure development and preparation for reactor demonstration, centred on RATEN and the mioveni nuclear platform.

THIS paper reviews the current status of the Romanian LFR programme and examines its scientific, technological and deployment perspectives. Particular attention is devoted to the experimental infrastructure supporting the Advanced Lead-cooled Fast Reactor European Demonstrator (ALFRED). Athena and ChemLab, together with the HELENA-2, ELF, Hands-ON and Meltin'Pot facilities being developed through the 4ALFRED project, are discussed in relation to the experimental evidence required for technology qualification. Key research priorities include lead thermal hydraulics, oxygen monitoring and coolant chemistry control, structural-material compatibility and corrosion mitigation, component performance, inspection and handling technologies, and phenomena relevant to reactor safety. The role of these facilities in generating validation data for computational tools and supporting safety assessment is also addressed.

The paper further examines Romania's contribution to the EAGLES consortium and the relationship between national research capabilities, ALFRED demonstration and the development of the EAGLES-300 reactor. Future perspectives are assessed through the interdependence of experimental qualification, design maturity, licensing preparation, industrial participation, human-resource development and sustained financing. THE central argument is that progress towards LFR deployment requires an integrated programme linking research priorities and infrastructure operation to clearly defined demonstration and industrial objectives. Within this framework, romania has the opportunity to consolidate its role as a European centre for LFR research, qualification and demonstration.

Keywords: *Lead-cooled fast reactors; generation iv; raten; alfred; 4alfred; eagles-300; experimental infrastructure.*

EXTREME LIGHT INFRASTRUCTURE NUCLEAR PHYSICS – STATUS UPDATE

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Located in Bucharest-Măgurele, Romania, the Extreme Light Infrastructure – Nuclear Physics (ELI-NP) stands as an important European research pillar dedicated to pioneering light-matter interactions. Since 2020, ELI-NP has facilitated groundbreaking research through its user access program, providing pulse delivery at various power tiers, including 100 TW, 1 PW, and its flagship 10 PW system. Currently recognized as one of the most powerful laser systems in the world, the High Power Laser System (HPLS) at ELI-NP consistently delivers 10 PW pulses to experimental stations, opening new frontiers in fundamental physics and practical applications. ELI-NP also oversees the building of the Centre For High Power Optics, a new manufacturing and R&D facility dedicated to high power optics.

We will provide a comprehensive technical overview of the ELI-NP infrastructure, detailing recent developmental milestones and the specific engineering advancements implemented to optimize the temporal contrast of the 10 PW system. these improvements ensure the facility remains at the cutting edge of ultra-high intensity laser science, supporting a diverse range of experiments from particle acceleration to medical diagnostics.

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OPTIMIZING THE POWER SYSTEM DECARBONIZATION COST THROUGH RENEWABLES AND NUCLEAR

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Introduction

The decarbonization of the power sector is a key component of the transition towards a low-carbon energy system. Romania, in line with European climate and energy objectives, is committed to substantially reducing greenhouse gas emissions while maintaining the security, reliability and affordability of electricity supply. Achieving these objectives requires a progressive reduction of fossil-fuel-based generation and the deployment of low-carbon electricity sources, while accounting for the technical and economic constraints of the power system.

Renewable energy sources, particularly variable renewable energy sources (vRES) such as wind (W) and photovoltaic (PV), represent an important pathway for reducing power-sector emissions. However, their variable and weather-dependent generation creates additional requirements for system flexibility, balancing and integration. Nuclear energy can complement vRES by providing low-carbon, dispatchable generation. In this context, Small Modular Reactors (SMRs) offer a potential option for replacing retiring fossil-fuel capacities and supporting the decarbonization of the electricity system.

The optimal combination of nuclear and renewable generation therefore requires consideration not only of generation costs, but also of the additional system costs associated with integrating different technologies. This study investigates the potential for reducing the power-system decarbonization cost through the coordinated deployment of small modular reactors (SMRs), W and PV generation, using the IAEA FRAMES modelling framework.

Methodology

The analysis was performed using the FRAMES (Framework for Analysis of Energy Systems) (IAEA, 2026) modelling framework developed by the International Atomic Energy Agency (IAEA). FRAMES is a system-level energy modelling tool that determines the least-cost configuration of an energy system while satisfying

technical, operational and policy constraints. In the present study, the model was applied to the Romanian electricity system to evaluate alternative low-carbon generation mixes and their associated system costs.

$$C_S_{optim} = Min \left\{ \sum_t \frac{1}{(1+r)^t} \left(C_{cap,t} + C_{fix,t} + C_{var,t} + C_{fuel,t} + C_{start,t} + C_{em,t} + C_{shed,t} \right) \right\}$$

The optimization minimizes the total system cost (composed by capital costs, fixed and variable operation and maintenance costs, carbon/emission costs, and energy-storage costs). The optimization is subject to a set of technical constraints, including hourly electricity balance, existing and expansion capacity limits, minimum stable generation, unit start-up/shut-down and minimum operating times, ramp-up/ramp-down limits, reserve requirements, vRES generation and curtailment limits, storage capacity and charging/discharging constraints. Demand-side management and energy-not-served constraints are also considered. This formulation allows the effects of vRES generation and dispatchable nuclear capacity on both the generation mix and the overall cost of power-system decarbonization to be quantified.

In this study, FRAMES was applied to the Romanian electricity system, characterized by an annual electricity demand of approximately **65 TWh**, to investigate alternative pathways for replacing fossil-fuel-based generation with low-carbon technologies. The analysis targets the replacement of approximately 5 GWe of fossil-fuel capacity (coal and natural gas) with vRES (wind and PV) and SMRs. The main assumptions and generation configurations are: (1) nuclear: two CANDU-6 units (~1.4 GWe), complemented by 2.4 GWe of SMR capacity in three alternative configurations: 24 modules of 100 MWe, 12 modules of 200 MWe, or 8 modules of 300 MWe; (2) vRES and hydropower: 5.0 GWe of PV, 6.0 GWe of W, 0.5 GWe of run-of-river hydropower, and 1.5 GWe of dispatchable hydropower operating in continuous mode; and (3) energy storage: 0.1 GWh of pumped-storage capacity and 1.6 GWh of battery storage with a two-hour discharge duration.

Results

The FRAMES simulations show relatively small differences in the overall system cost among the three SMR configurations. The minimum total system cost ranges from $3.439 billion for SMR100 to $3.448 billion for SMR300, while the corresponding cost of SMR-generated electricity decreases from $54.25/MWh to $52.11/MWh as the module size increases. The SMR capacity factor also increases from 67.98% for SMR100 to 71.58% for SMR300. However, larger modules require substantially more operational flexibility, with the number of annual ramps per module increasing from 42 for SMR100 to 120 for SMR300.

The generation mix remains largely stable across the three cases. The CANDU units operate at a capacity factor of approximately 85.5–86%, while SMR capacity factors range between 68% and 72%. PV and onshore wind achieve capacity factors of approximately 14.3% and 26.7–27.7%, respectively. The integration of vRES results in significant curtailment, predominantly from wind generation, with total annual curtailment ranging from 4.56 to 5.14 TWh. Energy storage contributes approximately 1.0 TWh/year of discharged energy, mainly through batteries and reservoir hydropower.

The resulting total electricity generation is 59.44 TWh/year in all three configurations (the rest from import). The average electricity price at the national grid level is approximately $104/MWh, with only marginal differences between cases. Overall, the results indicate that the three SMR configurations provide comparable system-level economic performance, while the larger-module configurations benefit from lower SMR generation costs and higher capacity factors but impose greater operational ramping requirements (EUR, 2012).

Conclusions

The FRAMES analysis indicates that the coordinated deployment of nuclear and vRES generation can provide an effective pathway for reducing fossil-fuel-based electricity generation in Romania. The three investigated SMR options (100, 200 and 300 MWe modules) result in very similar total system costs, ranging from $3.439 to $3.448 billion. Larger SMR modules provide lower specific nuclear generation costs and higher capacity factors, but require substantially more operational ramping, therefore cannot satisfy the actual constraints on the material thermal cycling.

The results also highlight the integration challenge associated with high vRES penetration. Wind generation accounts for most of the observed curtailment, while storage and dispatchable hydropower provide additional system flexibility. Overall, the results support a diversified low-carbon portfolio combining nuclear, wind, PV, hydropower and storage, with dispatchable nuclear generation complementing variable renewables while maintaining comparable system costs across the investigated SMR configurations.

Keywords: *renewables, small modular reactors, system cost, optimal configuration*

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ICSI EXPERIENCE IN HYDROGEN ISOTOPE PERMEATION THROUGH METALLIC MEMBRANES

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The National R&D Institute for Cryogenic and Isotopic Technologies (ICSI) has nearly 50 years of research experience in the field of hydrogen isotopes. Its research activities began with the development of heavy water production technology based on isotopic exchange in the bithermal water–hydrogen sulfide system and continued with the development of hydrogen isotope separation technologies based on catalyzed water–hydrogen gas isotopic exchange and cryogenic distillation.

These main research directions have been complemented by activities in related fields, including hydrogen isotope storage, permeation through metallic membranes, and the development and application of analytical techniques such as gas chromatography, mass spectrometry, infrared spectroscopy, and liquid scintillation counting. Among these areas, the study of hydrogen isotope permeation through metallic membranes represents a relatively recent research direction at ICSI.

This paper presents the theoretical and experimental research carried out at ICSI on hydrogen isotope permeation through metallic membranes, with a focus on the main challenges encountered, the technical solutions adopted, and the results obtained to date. Relevant related results and aspects contributing to the development of this research direction are also discussed.

Keywords: *Hydrogen isotopes, Permeation, Metallic membranes, Isotope separation*

OVERVIEW ON TRITIUM FOR FUSION ENERGY

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The commercial generation of electricity and thermal energy via fusion technology remains one of the promising alternatives for energy production.

Fusion technology can play a major role when carbon-based fuels for electricity and heat will arrive at one end and a switch shall be done to be replaced by alternative solution – fusion energy.

Many countries have their own fusion research and development programs, while large research efforts are being undertaken in international collaborations, such as ITER. Recently, fairly new (semi-) commercial organizations have been successful in initiating independent development programs funded by government grants and private investments.

Tritium (and deuterium) should be well managed considering the requirements that arise from different projects and an entire tritium related culture will be developed up to when commercial fusion reactors will be in place.

The availability of tritium may be a concern and we may consider it as strategic material even now, if request to supply will increase from different fusion research or commercial projects.

As Romania can be an important resource in tritium supply by CANDU Cernavoda NPP, it can be one of the country who can adopt fusion technology for new reactors build on different sites across the country.

This paper presents a point of view related to future tritium roadmap and decision-making exercises conducted within the community. Romania shall adhere to fusion at least from commercial point of view, as fusion can be a possible solution to increase Romanian energy production using internal resources

Keywords: *Tritium, fusion reactors, infrastructure, energy.*

THE EFFECT OF LOW-DOSE IRRADIATION ON THE LOCALIZED CORROSION BEHAVIOR OF TRITIUM PERMEATION BARRIER IN HIGH-TEMPERATURE PRESSURIZED WATER

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Alumina stands out as a leading candidate for tritium permeation barriers (TPBs) due to its high hydrogen isotope permeability reduction factor (PRF) [Lyu, et al., 2020]. Nevertheless, energetic-particle irradiation in fusion reactors can affect the corrosion behavior of TPBs under high-temperature and high-pressure water conditions [Liu, et al., 2023]. The initial stage of corrosion, which progresses rapidly, coincides with the irradiation low-dose stage, during which irradiation-induced defects may affect corrosion behavior. Consequently, the impact of low-dose irradiation on corrosion was systematically investigated. This study examined both unirradiated and Fe-ion irradiated pre-oxidized FeCrAl alloy after 1000 h of water corrosion at 300°C and 15.5 MPa. It was observed for the first time that even a very low dose of irradiation can enhance local corrosion along grain boundaries. Furthermore, increased irradiation damage led to a more continuous distribution of localized corrosion grooves. The increased local defect concentration creates more short-circuit diffusion channels, accelerating the inward diffusion of oxygen ions and the outward diffusion of metal cations, thereby promoting local corrosion along grain boundaries. Fe-ion irradiation alone up to 0.1 dpa caused little change in deuterium permeability. For the irradiated pre-oxidized FeCrAl alloys subsequently exposed to pressurized water, the low-temperature permeability was higher than that before corrosion. After the high-temperature permeation measurements, the permeability measured again at a comparable low temperature decreased. The initial increase is attributed to corrosion-induced damage to the protective Al-rich oxide layer, whereas the subsequent decrease may result from partial regrowth of the Al-rich oxide layer during high-temperature permeation measurements.

Keywords: *irradiation; tritium permeation barrier; oxide layer; localized corrosion*

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APPLICATION OF PALLADIUM-BASED MEMBRANE MATERIALS IN HYDROGEN ISOTOPE PURIFICATION FOR FUSION FUEL CYCLE

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Research pertaining to palladium (Pd)-based membranes for hydrogen isotope purification in fusion fuel cycles predominantly focuses on three domains: (1) development and performance optimization of Pd-based membrane materials; (2) innovative design of Pd-based membrane permeators; and (3) engineering integration of Pd-based membranes within fusion fuel cycles. Pd-based membrane materials are broadly classified into two categories: self-supported Pd-based alloy membranes and supported composite Pd-based membranes. To preserve mechanical stability and structural integrity, self-supported Pd-based alloy membranes necessitate a minimum thickness of 25μm. To circumvent the inherent trade-off between membrane thickness and mechanical strength, further augment hydrogen permeation flux, and mitigate costs, a thin Pd-based layer can be deposited onto a porous substrate to fabricate supported composite Pd-based membranes. Consequently, investigations into supported composite Pd-based membranes are of critical significance for reducing material expenditures, enhancing permeation flux, and advancing the engineering application of Pd-based membranes. In the present study, a permeator comprising 45 porous stainless steel-supported Pd membranes (an effective length of 35 cm, a diameter of 6 mm, and the membrane thickness of 5-7μm) was constructed. Its hydrogen isotope purification performance and key influencing parameters were systematically evaluated via hydrogen and simulated tokamak exhaust gas permeation experiments conducted within the temperature range of 320-470°C. The results indicated the absence of a helium peak in the mass spectrum of the product gas treated by the permeator, demonstrating its efficacy in separating hydrogen isotopes from helium. Following the separation of the simulated tokamak exhaust gas via the permeator, the hydrogen purity of the product gas attained 98.0%–99.9%. Furthermore, excessively high operating temperatures exacerbate the concentration polarization effect, thereby compromising the purification performance. Subsequent evaluations demonstrated that when treating gas mixtures of 79.4% H_2/20.6% He and 86.2% H_2/13.8% N_2, the hydrogen purity of the product gas reached 98.1% and 97.3%, respectively.

Keywords: *Fusion fuel cycle, Stainless steel-supported palladium membrane, Hydrogen isotope purification, Key factors*

DESIGN AND CONSTRUCTION OF A HYDROGEN-ISOTOPE HANDLING TEST FACILITY IN SUPPORT OF FUSION DEVELOPMENT

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The deuterium-tritium fuel cycle system serves as the critical fuel-processing subsystem for fusion reactors. To verify key performance parameters and accumulate operational experience, this study designs, constructs and operates a hydrogen-deuterium gas-mixture simulation experimental platform integrating hydrogen-isotope storage-extraction, purification, separation and off-line measurement functions. The platform consists of a 10-mol-level storage-extraction unit, a 32 NL/min-level palladium-membrane purification unit, a 2-NL-level thermal-cycling adsorption separation unit, and an off-line measurement-and-analysis unit. Unit-level operation tests demonstrate that the single-pass hydrogen-isotope storage efficiency reaches 92.7%, the extraction efficiency achieves 96.0 %; the single-pass purification efficiency of the palladium membrane is no less than 99.51%, and the analytical accuracy of the measurement unit is no less than 98.35%.

Nevertheless, the palladium-on-alumina (Pd/Al_2O_3) packing material encounters process-adaptability issues during separation-column packing. Furthermore, the initial processing capacity of 2 NL is too small; sampling operations induce significant disturbance to the pressure distribution inside the separation column, which distorts the measured separation-efficiency results. To mitigate sampling-induced disturbance, the processing capacity of the separation column is scaled up from 2 NL to 50 NL to improve the detection sensitivity of pressure variation during thermal-cycling processes. Simulation calculations of separation efficiency are performed under the scaled-up condition. Preliminary simulation results reveal that, at the 50 NL processing capacity, the hydrogen molar fraction at the separation-column exhaust can be relatively increased by 48.9% compared with the initial state after 8 thermal cycles. Future work will focus on the development and performance validation of the optimized separation unit. Meanwhile, design, construction and experimental assessment of fast-cycle and full-cycle fuel-cycle loops for this platform will be implemented, providing database support and operational experience for tritium-fuel-cycle facilities of fusion reactors.

Keywords: *Fusion; Hydrogen Isotope; Fuel Cycle; Experimental Platform*

PERFORMANCE TEST OF ZRCO-BASED STORAGE BED FOR HYDROGEN ISOTOPES

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To support the preliminary research on hydrogen isotope storage and extraction processes in the Storage and Delivery System (SDS) for magnetic confinement fusion, a hydrogen isotope storage and supply system was developed in our laboratory. The system features a double thin-walled concentric tube ZrCo-based storage bed with a single-bed capacity of approximately 10 mol, capable of rapidly extracting elemental or mixed hydrogen isotope gases. To date, 77 hydrogen/deuterium (H/D) absorption–desorption cycles have been completed. The results demonstrate a maximum single-bed hydrogen isotope storage exceeding 10 mol and a single-bed gas extraction efficiency greater than 95%. After 10 cycles, the capacity retention remains above 90%, demonstrating the cyclic stability of the ZrCo bed at an engineering scale. Furthermore, nitrogen (N_2) was found to significantly affect hydrogen absorption performance. This work provides critical experimental data for the engineering application of ZrCo-based storage beds in fusion reactors, highlighting the importance of impurity control.

Keywords: *ZrCo; hydrogen isotope storage; cyclic stability; fusion fuel cycle*

Acknowledgments

This work was supported by the Comprehensive Research Facility for Fusion Technology (CRAFT) Program of China [Contract No. 2018-000052-73-01-001228], the Fusion Tritium Utilization & Recycling Experiment Platform (FUTURE) Program of China [Contract No. 2504-000000-04-05-426271], and Anhui Provincial Major Science and Technology Project (2023z020004).

EVOLUTION 2 – HIGH RESOLUTION GAS SOURCE MASS SPECTROMETER

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Development and Applications Scientist, Nu Instruments

Nu Instruments Evolution 2 is a high-resolution gas-source isotope-ratio mass spectrometer designed for the precise determination of stable isotope ratios in gaseous samples. The instrument combines high-resolution magnetic-sector mass spectrometry with high efficiency ion optics and multi-collector detection, providing excellent precision, sensitivity and stability for demanding isotope-ratio applications.

Its high-resolution capability allows the separation of closely spaced or interfering ion species, improving the reliability of isotope measurements in complex samples. The gas-source configuration makes Evolution 2 particularly suitable for analysing isotopes of carbon, nitrogen, hydrogen, oxygen and sulphur, either through direct gas introduction or coupled sample-preparation systems.

Robust and user-friendly, Evolution 2 features a large-dispersion magnetic sector analyser and a flexible range of inlet systems tailored to nuclear applications. In addition to direct quantification of hydrogen (H), deuterium (D), and tritium (T), it enables precise analysis of their distribution within molecular species in complex gas mixtures.

Selectable mass resolutions up to 5000, enabling effective separation of H, D, and T species (excluding ^{3}He) for accurate analysis.

Specialised materials and design ensure safe and efficient handling of hazardous gases.

Customisable inlet systems tailored to meet diverse nuclear application requirements.

Intuitive software suite designed to streamline work flows and enhance the user experience.

Main applications:

Environmental & Earth Sciences

- Stable isotope tracing in environmental systems
- Hydrology and water-source studies
- Carbon-cycle and ecosystem research
- Paleoclimate and paleoenvironmental investigations
- Geochemical studies

Agriculture & Plant Science

- Nutrient cycling and ^{15}N tracing
- Plant metabolism and nutrient uptake
- Water-use and plant physiology studies
- Ecological studies and trophic-level determination

Oil, Gas & Energy

- Determination of the origin of methane
- Differentiation between biogenic and thermogenic methane
- Isotopic fingerprinting of hydrocarbons
- Source and provenance studies

ROMANIAN HEAVY WATER: REALITY, LEGEND, INOVATIVE CONTRIBUTIONS AND PERSPECTIVES

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According to first the first Romanian Nuclear National Program in order to develop the production of energy of nuclear origin, CANDU technology based on natural uranium as fuel and heavy water as moderator has been chosen. A small pilot plant called "G Plant" was established in 1970, aiming to develop the technology for heavy water production. First drop of heavy water of nuclear quality was produced on August 9-th, 1976 and present paper is dedicated to this event as well as to the centenary of the birth of academician Marius Sabin Peculea, who is recognized as ''father of heavy water'', in Romania.

The paper presents a review of main achievements and improvements of "G Plant "starting selection and development of the technology to its extrapolation at industrial level to Drobeta Turnu Severin, ROMAG factory. The elaboration of specific technologies (natrium sulphide and hydrogen sulphide production), designing and achievement of specific and complex equipment's; heavy water upgrading technology; implementing of innovative solutions; are presented and briefly discussed. Technical aspects regarding heavy water production at industrial level in ROMAG factory and safety management and long-term storage related to the future nuclear reactors from Cernavoda NPP are also presented.

Also, some legends relating production of heavy water in Romania and its utilization in various field are presented and discussed.

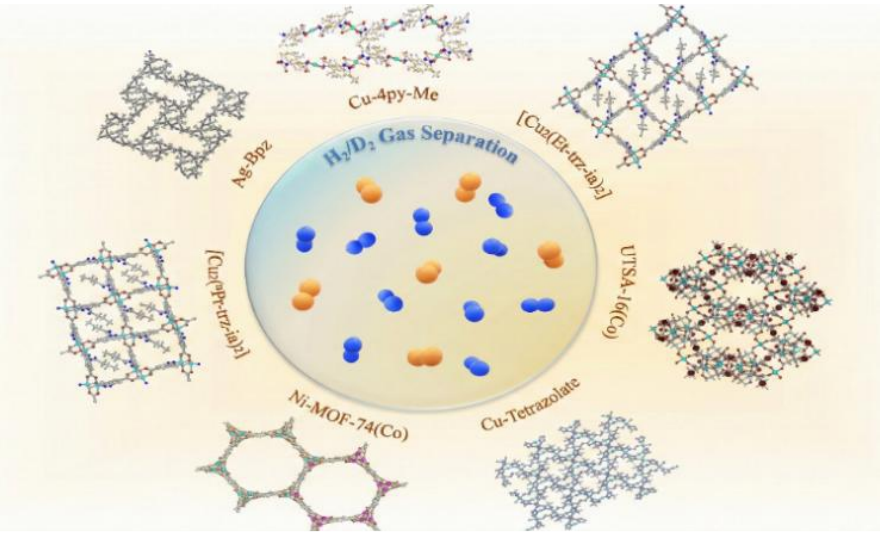
Taking in consideration the present increased interest, the perspective of restarting production and new applications of heavy water are also, discussed.

STRUCTURAL DETERMINANTS OF DIHYDROGEN ADSORPTION AND ISOTOPOLOGUES SEPARATION IN METAL-ORGANIC FRAMEWORKS

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The purification of deuterium (D_2) is essential for nuclear technology and medicinal chemistry, yet conventional cryogenic distillation remains energy-intensive with low selectivity (S ≈ 1.4) [Rae, 1978]. This study systematically investigates how structural features in metal-organic frameworks (MOFs) specifically ultra-micropores, open metal sites (OMS), and framework flexibility influence D_2/H_2 separation efficiency [Chetry et al., 2026]. We employed Thermal Desorption Spectroscopy (TDS) to evaluate various MOF geometries under cryogenic conditions. Our findings demonstrate that ultra-microporous frameworks facilitate D_2 preference through kinetic quantum sieving (KQS), leveraging the smaller effective radius of heavier Isotopologues in confined spaces [2]. Notably, Ni-MOF-74(Co) exhibited exceptional performance, achieving a selectivity of S = 52 at 77 K [Chetry et al., 2026]. This high efficiency is attributed to chemical affinity quantum sieving (CAQS) at the open metal sites, where differences in zero-point energies enhance the adsorption enthalpy for D_2 [Chetry et al., 2026]. Furthermore, we examined flexible MOFs, [Cu_2(nPr-trz-ia)$_2$] and [Cu_2(Et-trz-ia)$_2$], which displayed temperature-responsive structural transitions [Chetry et al., 2026]. These materials achieved D_2/H_2 selectivity ranging from 1.4 to 2.3 at 77 K, indicating that cryogenic flexibility can be tuned for isotope discrimination [Chetry et al., 2026]. In conclusion, this research establishes that the rational design of pore apertures and the integration of specific adsorption sites are vital for advancing Isotopologues separation [Rae, 1978; Chetry et al., 2026]. By moving beyond traditional distillation, these MOF-based strategies offer a path toward more sustainable and efficient deuterium enrichment at practical operating temperatures.



Keywords: *Metal-Organic Frameworks, Hydrogen Isotopologues, Quantum Sieving, Thermal Desorption Spectroscopy, Gas Separation*

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Rae H. K., Selecting Heavy Water Processes, Separation of Hydrogen Isotopes; ACS Publications, 1978; Vol. 85, pp 123−134.

Chetry S., Sarkar P., Bakhtian M., Hirscher M., Krautscheid H., Influence of Structural Determinants on Dihydrogen Adsorption and Isotopologue Separation in Nanoporous Metal-Organic Frameworks. ACS Appl. Mater. Interfaces, 2026, ASAP. https://doi.org/10.1021/acsami.5c24726

CHARACTERIZATION OF PACKINGS FOR SEPARATION OF HYDROGEN ISOTOPE MIXTURES BY CRYOGENIC DISTILLATION

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Cryogenic distillation, although it can be a costly process and presents major challenges if not implemented correctly, certainly represents a unique solution when it is necessary to separate a wide range of isotopes, and, in this regard, there is an increased interest in finding a viable technical design that would serve to build a functional cryogenic distillation plant for tritium separation. The paper presents the results of the experiments in the campaign (2023-2025), with the experimental stand of the ICSI Cryogenic Laboratory for the cryogenic distillation of the H_2-HD-D_2 mixture. The test system using a Phillips A-20 hydrogen liquefier is unique, allowing the determination of HETP and pressure drop for different ordered or random distillation packings. In order to perform the analysis of the functionality of cryogenic distillation columns, a conditioning system for a chromatographic column, type Agilent CP-Molsieve 5A, with a length of 50 meters and a diameter of 0.53 mm, was developed, much better insulated and with which it was possible to maintain the column temperature within a difference of -115°C ÷ 114°C, using a Shimadzu GC-2030 N chromatograph, with BID detector (helium plasma). The experimental results from the total and dynamic reflux regime, at different loads (concentrations/pressures/flow rates of the mixture), will be presented, together with the results obtained for different catalysts for the equilibration reaction and for the ortho-para conversion.

Keywords: *hydrogen, cryogenic, distillation*.

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MODELING OF HYDROGEN ISOTOPE MIXTURE ABSORPTION IN SPONGE PALLADIUM AT LOW TEMPERATURES

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Hydrogen isotopic mixture absorption is more complex than the description of single-isotope systems, since the equilibrium behavior is governed not only by isotope-specific solubility but also by the distribution of hydrogen among the H_2, HD, and D_2 molecular species. This work presents an equilibrium model for the absorption of hydrogen isotope mixtures in sponge palladium under dilute loading conditions.

The model is built upon experimental absorption data previously obtained for pure protium and deuterium in the α-phase of the Pd–H(D) system at low pressures and temperatures. The corresponding temperature-dependent Sieverts constants for H and D are used as the thermodynamic basis of the formulation. In contrast to a direct application of Sieverts' law using total gas pressure, this model explicitly considers the H_2–HD–D_2 gas composition, isotopic exchange equilibrium, and the individual contribution of protium and deuterium partial pressures to the total hydrogen loading in palladium.

Model predictions are evaluated against experimental measurements obtained with isotopic mixtures at 200, 225, 250 and 273 K. The calculated pressure–loading relationships reproduce the observed equilibrium trends and demonstrate that accounting for isotope partitioning in both the gas and solid phases is necessary for describing mixed-isotope absorption.

MEASUREMENT OF HYDROGEN ISOTOPES FLOWING THROUGH A FUSION DEVICE

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A hydrogen (deuterium) simulation experiment was conducted on the EAST tokamak during the 2026 summer campaign, serving as a prelude to the future tritium experiment. The primary objectives were to track hydrogen isotope transport from fuel injection into the plasma chamber, through plasma discharge, to exhaust pumping, and to analyze Hydrogen retention in the vacuum vessel as a proxy for tritium behavior.

Two fueling methods were employed: supersonic molecular beam injection (SMBI) with an H:D ratio of 0.1737 and conventional gas puffing of pure deuterium. A total of 7 successful discharges were achieved among 19 attempts, with plasma currents of approximately 0.3–0.4 MA, electron densities of 4–6×10^{19} m^{-3}, and discharge durations exceeding 50 s for four shots (two approaching 100 s). The total injected hydrogen amounted to 493.5 mL (at STP), equivalent to 0.0408 g. Exhaust gases were collected using ZrCo getter beds for post-shot analysis of isotopic composition and retention.

This campaign successfully validated the experimental workflow for isotopic tracking and uncovered critical hardware and procedural deficiencies that must be addressed prior to the future tritium operation. The results provide essential guidance for system upgrades, diagnostic optimization, and safety assurance measures required for the future tritium experiment on EAST.

Keywords: *EAST tokamak, hydrogen isotope transport, deuterium retention, tritium readiness, plasma fueling, exhaust analysis, ZrCo getter bed.*

PRELIMINARY ASSESSMENT OF REDUCED-FLOW AND REDUCED-PRESSURE OPERATION FOR THE *WLCB* TRITIUM EXTRACTION AND REMOVAL SYSTEM

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Efficient tritium extraction from ceramic breeder blankets is essential for achieving fuel self-sufficiency in future fusion power plants. The Water-Cooled Lead Ceramic Breeder (WLCB) concept employs a helium purge-gas loop connected to a Tritium Extraction and Removal system comprising Reactive Molecular Sieve Beds (RMSBs) for the capture of tritiated water and Getter Beds for the removal of elemental hydrogen isotopes. Compared with the Helium-Cooled Pebble Bed reference configuration, the WLCB concept offers the possibility of operating the purge-gas circuit at reduced flow rates and lower pressures.

This work presents a preliminary model-based assessment of the influence of purge-gas throughput and operating pressure on hydrogen-isotope concentration, RMSB hydrodynamics and system power demand. Hydrogen-isotope partial pressures were calculated as a function of purge-gas flow rate using ideal-gas relationships. The superficial velocity and pressure drop across the RMSB were evaluated using the reference geometry of 72 parallel adsorption tubes and the Ergun equation, with bed porosity estimated using the Jeschar correlation. The effects of operating pressure, adsorbent particle diameter and bed-to-particle diameter ratio were also investigated. Compression and purge-gas cooling power requirements were estimated parametrically.

Reducing the purge-gas flow rate from approximately 11,200 to 2,000 m³/h at 30°C increases the calculated HT partial pressure from approximately 1 to 5 Pa, due to reduced dilution in helium. For the reference RMSB geometry, the corresponding superficial velocity decreases from approximately 20 m/s to below 4 m/s. The pressure-drop analysis shows that hydraulic losses increase significantly with superficial velocity and operating pressure and are further amplified by small adsorbent particles and low bed-to-particle diameter ratios. At a constant volumetric flow rate of 11,203 m³/h and a compressor pressure increase of 3 bar,

operation at an inlet pressure of 80 bar is predicted to require approximately 20% more compression power than operation at 3 bar.

The results indicate that combined reduction of purge-gas throughput and operating pressure can improve RMSB operating conditions, reduce pressure losses and decrease circulation power. The resulting preliminary operating window must be further refined by considering adsorption kinetics, tritium-release transients, allowable tritium inventory and permeation into the cooling-water circuit..

Keywords: *tritium extraction; WLCB; helium purge gas; reactive molecular sieve bed; packed-bed pressure drop; fusion breeding blanket*

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References

N/A

EFFECT OF BIOMASS-DERIVED SYNGAS COMPOSITION ON THE PERFORMANCE OF A SPARK-IGNITION ENGINE-GENERATOR SYSTEM

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Biomass gasification can provide a renewable gaseous fuel for power generation applications, although the relatively low heating value and variable composition of syngas may significantly affect engine performance (Marculescu et al., 2016; Mărculescu et al., 2022). This study evaluates the influence of biomass-derived syngas composition on the mass and energy balance of a naturally aspirated spark-ignition engine coupled to a 100 kWe generator. The engine operating on natural gas was considered as the reference case, while three representative syngas compositions reported in the literature were investigated, with calculated lower heating values between 3.46 and 5.67 MJ/Nm^3 (James et al., 2016; Oveisi et al., 2018; Simone et al., 2012). For each fuel, the stoichiometric oxygen requirement, air-to-fuel ratio, fuel consumption, thermal input and electrical output were calculated while maintaining the same engine geometry, speed, intake capacity, and excess-air ratio. The lower air requirement of the investigated syngas allowed a larger fraction of the intake volume to be occupied by syngas fuel, compensating for their lower volumetric energy density. The calculated electrical output decreased relative to natural gas, with power reductions ranging from approximately 3.5 to 13.8%, depending on syngas composition. The results show that the suitability of biomass-derived syngas for spark-ignition engines is strongly dependent on its composition and on the balance between fuel heating value, combustion-air requirement, and intake-volume limitations.

Keywords: *biomass gasification, syngas, spark-ignition engine, natural gas, power generation*

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HYDROGEN ADDITION EFFECT ON THE PERFORMANCE OF MICRO-*CHP* PLANT WITH RECIPROCATING SPARK IGNITION ENGINE

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The integration of hydrogen into natural gas fueled combined heat and power (CHP) systems represents a potential pathway for reducing fossil-fuel consumption while maintaining the use of existing gas-engine infrastructure (Marculescu & Alexe, 2014; Marculescu et al., 2016; Porumb et al., 2023). This study evaluates the effect of hydrogen addition on the mass and energy balance of a spark-ignition engine coupled to an electrical generator and heat-recovery system. Natural gas was considered as the reference fuel, while mixtures containing up to 25 vol.% H_2 were investigated (Fichtner et al., 2023; Ingo et al., 2024). For all fuel compositions, the engine geometry, speed, total volumetric intake flow, and excess-air ratio were maintained constant, while the resulting fuel and air flows and engine output were determined by calculation. Increasing the hydrogen fraction reduced the volumetric lower heating value of the fuel from 34.5 to 28.57 MJ/Nm^3 and therefore increased the required fuel flow from approximately 26.7 to 32.4 Nm^3/h. The lower combustion-air requirement of the hydrogen mixtures partially compensated for their lower volumetric energy density, resulting in a slight increase in electrical output. The recovered thermal power and overall CHP efficiency also varied only slightly across the investigated range. The results indicate that hydrogen addition can be accommodated in a natural-gas engine with limited changes in overall energy performance.

Keywords: *hydrogen, natural gas, spark-ignition engine, combined heat and power*

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COMPLEMENTARY UGA AND CRYOGENIC GC FOR HYDROGEN-ISOTOPE MEASUREMENT ON A HANDLING TEST FACILITY

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Gas pressure, flow rate, and composition vary considerably in fusion fuel-cycle systems. A quadrupole mass-spectrometric universal gas analyzer (UGA), although capable of rapid multicomponent measurements, cannot distinguish the overlapping contributions of He and D_2 at m/z 4. Consequently, the UGA alone cannot provide both rapid response and unambiguous species identification across all monitoring conditions. In this study, a complementary analytical system combining UGA with cryogenic gas chromatography (GC) was implemented and evaluated on a fusion fuel-cycle simulation platform. Before measurement, the shared sampling lines and storage vessel were evacuated to an absolute pressure below 300 Pa and subsequently purged with the sample gas for at least three cycles to minimize interference from residual gases and cross-contamination. For UGA sampling, the system was equipped with interchangeable inlet capillaries for measurements at absolute inlet pressures above 10 Torr (1.33 kPa). Most experiments were conducted using the nominal 360–760 Torr capillary. In the tested configuration, an Alicat mass flow controller maintained a sampling flow of approximately 2 sccm over an absolute inlet-pressure range of 50–177 kPa. For cryogenic GC, the sampling valve and transfer lines were evacuated and purged before sample introduction. Separations were performed at approximately 77 K using Ne as the carrier gas, a 20 µL injection volume, and an $MnCl_2$-modified Al_2O_3 capillary column. System performance was evaluated using H_2/D_2 standard mixtures, repeatability tests, cross-method comparisons, and measurements at the storage/extraction, purification, and isotope separation subsystems.

The UGA calibration curves for H_2 and D_2 yielded coefficients of determination (R^2) of 0.9992 and 0.9988, respectively. The mean relative errors were 1.65% for H_2 and 0.82% for D_2, while the corresponding signal RSDs obtained in repeatability tests were 1.36% and 0.82%. Stable UGA measurements were obtained within 5

min. The cryogenic-GC calibration curves yielded R^2 values of 0.9997 for H_2 and 0.9999 for D_2, with mean relative errors of 0.53% and 0.70%, respectively. The retention-time RSDs for H_2 and D_2 were 0.062% and 0.115%, while the corresponding peak-area RSDs were 0.637% and 0.861%. Each cryogenic-GC analysis was completed within 10 min. Cross-method comparisons of the H_2 and D_2 measurements yielded correlation coefficients above 0.99.

UGA provided rapid measurements over a broad inlet-pressure range through capillary selection and mass-flow control, but could not resolve the overlapping contributions of He and D_2 at m/z 4. Cryogenic GC resolved He, H_2, and D_2 in multicomponent mixtures and separated the H_2/HD/D_2 isotopes; quantitative calibration of HD remains to be completed. The combined workflow supports rapid UGA screening, chromatographic resolution of nominal-mass interferences, periodic cross-validation, and composition assessment during the development and commissioning of fusion fuel-cycle systems.

Keywords: *hydrogen isotopes; universal gas analyzer; cryogenic gas chromatography; fusion fuel cycle; process monitoring*

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PROGRESS IN THE DEVELOPMENT OF COMPACT ECR-DD NEUTRON GENERATORS

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Accelerator neutron sources have significant advantages such as controllability, wide neutron energy spectra, and no long-lived radioactive waste. They are gradually becoming the core neutron sources for miniaturized and mobile neutron application scenarios. The Neutron Technology Application Research Center of the Energy Research Institute of Hefei National Science Center (Anhui Energy Laboratory), based on the large-area ion source technology accumulated in the NBI system of the EAST device to develop a series of accelerator-based neutron generators and relate application technologies. Serving the nuclear fusion field and new cancer treatment equipment, thermal neutron imaging system, prompt gamma neutron activation analysis and other fields. A compact deuterium-deuterium (D-D) neutron generator device based on the 2.45-GHz electron cyclotron resonance (ECR) ion source and titanium (Ti) drive-in target has been designed. The device achieves a neutron yield rang of 1×10^{6}~1×10^{9}n/s, its maximum single operation time reaches 260 hours. It has been tested for more than 1000 hours, this neutron generators operate repeatedly and stably at present. Based on the compact ECR-DD Neutron Generator, the developed thermal neutron imaging device achieves a spatial resolution of 0.5 mm with a neutron yield of 1×10^{9} n/s, and it has an excellent detection capability for the residual core of aero engine blades. The developed prompt gamma neutron activation analysis device can achieve online detection of metal elements such as Cu, Fe, Al, and Ti under a neutron yield of 10^{7}-10^{8} n/s. The detection accuracy of Cu and K elements contents can reach within 0.3%. The performance of these two devices are still being further improved. In addition, a study for material irradiation and boron medicine for cancer performance has also been carried out on Neutron Generators.

Keywords: *ECR ion source; Neutron Generators; D-D reaction; Neutron application*

Acknowledgments

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DETECTION EFFICIENCY DETERMINATION OF TOTAL COMBUSTION EQUIPMENT USING SPECIFIC STANDARDS

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Various alloys, especially stainless steels, and pure metals are used as the main materials in the construction of fusion or fission devices and tritium facilities dedicated to obtaining of sources like neutron generators, radio-luminescent sources, power sources, etc. Consequently, these materials have been closely studied with respect to permeation under simulated working conditions, and some good studies have been done on sorption of tritium.

Also, polymeric materials, ceramics, glass, concrete are ubiquitous in the construction of fusion and future fusion nuclear facilities.

The main methods used for determination of tritium in solid samples are Calorimetry, only for high activity tritium sources [Lee E-S, 2008], Total Combustion coupled with Liquid Scintillation Counting [Ratya A, 2019], Thermal Desorption (TD) [Temmerman De G, 2017], Accelerator Mass Spectrometry (AMS) [Enachescu M, 2018].

At present, the calibration of the TD and AMS equipment are performed with tritiated standards validated using TC method as secondary standard and Triple-to-Double Coincidence Ratio (TDCR) as primary standard [Antohe A, 2019].

This paper presents the results obtained regarding the calibration of the TC equipment within IFIN HH using secondary standards made through the controlled contamination of a wide range of materials (concrete, brick, plaster, glass, cellulosic materials, polymeric materials, steels) found within a unit operating with tritium.

The polymeric and cellulosic materials, ceramics, glass, concrete standard sources were achieved by controlled contamination of these materials using organic solutions of labelled compounds (Organically Bound Tritium or OBT) or labile tritium (tritiated water or HTO).

Tritiated steel standards were obtained by low-temperature sintering of AISI 306 stainless steel powder with tritiated zirconium alloy micro-powder with a size

smaller than 5 µm [Popovici I, 2026]. Tritiated zirconium alloy micro-powder was obtained by: (i) Preparation of HTO and determination of its specific activity using the primary standard LSC-TDCR, (ii) Quantitative conversion of tritiated water (HTO) to tritiated hydrogen (HT) with an identical H/T ratio [Postolache C, 2020], (iii) Quantitative absorption of HT in ZrCo. Obtaining micro-powders of zirconium alloys with metal hydride with controlled H/T ratio and mass activity [Postolache C. 2020].

The total yields of the combustion stage and the HTO retention were determined using obtained standard sources.

The results obtained indicate quasi-unitary values of the oxidation and collection efficiency of HTO vapors, ranging from 95-98%. The determined yields will be used to correct the experimental values obtained in the characterization of various solid samples using TC facility and specific protocols. 25th International Conference "New Cryogenic and Isotope Technologies for Energy and Environment" - *EnergEn* 2026 Râmnicu Vâlcea, Romania, October 07 – 09, 2026

Keywords*: Tritium, Total combustion, Tritium standards, Tritium wastes, Fusion, Fission*

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POLARIZATION-CURVE-BASED DEGRADATION DIAGNOSTICS OF *PEM* ELECTROLYZERS FOR *CECE* HYDROGEN ISOTOPE PROCESSES

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Combined Electrolysis and Catalytic Exchange (CECE) processes are based on proton exchange membrane (PEM) electrolyzers as main approaches for hydrogen isotope separation from water, where long-term operational stability has a direct impact on separation efficiency and plant economics. However, objective and reproducible methodologies for assessing electrolyzer health using standard operating data are currently scarce. In this work, a Python-based diagnostic platform is developed to convert polarization-curve measurements taken at ICSI Râmnicu Vâlcea into quantitative indicators of PEM electrolyzer degradation.

The software integrates automated preprocessing, stack-to-cell normalization, temperature-dependent thermodynamic modeling, and voltage-loss decomposition into reversible, kinetic, ohmic, and unresolved contributions. Electrochemical parameters are determined by least-squares fitting of a lumped three-parameter polarization model, a reversible voltage, a Tafel kinetic term, and an ohmic term, yielding the Tafel slope, exchange current density, and area-specific resistance.

A dedicated two-state comparison framework evaluates how the performance evolved between reference and aged operating conditions, providing degradation rates at selected current densities, statistical detection limits and hysteresis-based secondary diagnostics.

Using practical operational data along with electrochemical modeling, the proposed framework enables non-intrusive health assessment of PEM electrolyzers operating in CECE isotope-exchange systems without the need for impedance spectroscopy or specialized instrumentation. The methodology establishes a reproducible analysis workflow suitable for laboratory studies, durability investigations, and industrial monitoring of electrolyzer performance in applications regarding hydrogen isotope separation.

Keywords: *PEM, CECE, Python, Electrochemistry, Workflow, Statistical Calculations*

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DEVELOPMENT AND IMPLEMENTATION OF AN INTEGRATED *SCADA* CONTROL SYSTEM FOR AN IN-HOUSE ELECTROLYZER WITHIN A *CECE* FACILITY

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This paper presents the design, architecture, and operation of a dedicated Supervisory Control and Data Acquisition (SCADA) system developed for an in-house engineered electrolyzer. The electrolyzer is a key component of a Combined Electrolysis and Catalytic Exchange (CECE) facility, designed to process tritiated water and to facilitate hydrogen isotope separation. Given the stringent safety and process stability requirements inherent to isotopic separation and hydrogen processing systems, robust control and continuous monitoring are essential.

The developed control architecture features a dual-layer interface designed to ensure operational redundancy and flexible process management. Locally, the electrolyzer is equipped with an intuitive graphical user interface (HMI/local control panel) that allows operators to perform direct configuration, real-time adjustments, and immediate maintenance tasks. Complementarily, the system is fully integrated into a centralized control room via a secure communication network. This remote SCADA station enables comprehensive supervisory control, advanced process monitoring, and high-frequency data logging of critical parameters such as cell voltage, current density, operating temperatures, pressures, and gas flows.

Key features of the implemented SCADA system include automated safety interlocks, dynamic alarm management for fault detection, and structured historical database logging for post-run analysis and process optimization. The paper details the hardware integration (PLC/RTU controllers and field instrumentation), the communication protocols utilized for reliable remote data acquisition, and the software environment developed for both local and remote interfaces. The operational results demonstrate that this integrated control strategy significantly enhances the reliability, safety, and efficiency of the electrolyzer within the overall CECE process.

Keywords: *SCADA, PEM electrolyzer, CECE, isotopic separation, process monitoring, data archiving, PLC*

DEVELOPMENT OF A MOBILE WATER DETRITIATION FACILITY

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Significant quantities of tritiated water are generated during the operation of nuclear power plants (NPP) in the EU. Generally, due to the low tritium content in water collected from various systems, processing it to recover tritium is not of interest to plant operators. However, given increasingly stringent safety requirements, discharge into the environment is facing opposition and may no longer be an acceptable option in the coming years. Consequently, the TITANS project aims to provide a solution for processing tritiated water from various nuclear power plants, focusing on the development of a mobile water detritiation unit. This activity aligns with the overall objective of the TITANS project: proposing new activities, even those at a low Technology Readiness Level (TRL), that can serve as a foundation for future developments with potential for application across the EU.

The development of a mobile water detritiation facility has been carried out aiming to recover tritium from the water and dispose into the environment almost tritium free gaseous or liquid effluents. The conceptual configuration based on skids approach and the selection of the technics/technologies will allow transportation to various NPP locations for service purposes. The technology for the mobile water detritiation system is based on the more advanced technics such as CECE (Combined Electrolyse Catalytic Exchange) process, a small cryogenic distillation system and final enrichment based on GDC (Gas Displacement Chromatography). The above configuration allows operation with reduced inventory of hydrogen and tritium and consequently mitigate the safety concerns.

The paper aims to present the main results of the work on TITANS Project: the configuration of the water detritiation facility, the preliminary sizing of the components, 3D- layout of various skids and an appropriate distribution of the containers on site in order to minimize the process connections and to ensure enough space around the containers for installation or maintenance activities.

Keywords: *tritium recovery, combine electrolyse with catalytic exchange, cryogenic distillation, gas chromatography*.

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CFD THERMAL EVALUATION OF A *ZAO* BASED *GB* TO BE USED IN *TER* SYSTEM

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Non-evaporable getters are considered as an alternative solution for the tritium recovery from the solid breeders purge gas to the cryogenic adsorption on zeolites. ZAO material (a quaternary alloy: Zr V Ti Al, patented by SAES, Italy) [1-3] is a high potential candidate for its low equilibrium pressure, high embrittlement limit and trapping capacity. In order to prevent reaching the embrittlement limit, the getter has to undergo regeneration, by heating it to high temperatures under vacuum or near-vacuum conditions.

In this work, a representative three-dimensional CFD model was developed in ANSYS Fluent to assess conductive heat-transfer enhancement strategies for a sintered-disc-form ZAO bed, heated by hot helium circulation through a separate path that the adsorption.

Modeling and CFD simulations were carried out to evaluate heat transfer during bed regeneration, including temperature gradients, the influence of hot helium flow velocity, and the effective heat-transfer coefficients under different design configurations. Considering the disk-shaped form of the ZAO material intended for hydrogen trapping, two getter-bed configurations were assessed from a thermal perspective: a baseline configuration and an enhanced configuration incorporating additional heat-transfer elements.

The CFD analysis of getter-bed heating under different design configurations shows that heat-transfer effectiveness is governed not only by the helium flow velocity, but also by the flow-path geometry, the thermal conductivity of the supporting materials, and radiative heat transfer at elevated temperatures. The numerical simulations indicate that the enhanced configuration, which uses copper supporting elements, provides the fastest thermal homogenization and the most stable steady-state thermal performance.

Keywords: *Getter Bed, ZAO, CFD, Heat Transfer*

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The ZAO alloy is covered by the granted *European patents EP2745305* and *EP3071720* as well as by corresponding Intellectual Property Rights in the rest of the World.

METHOD FOR MEASURING THE CHARACTERISTIC PARAMETERS OF THE POROUS STRUCTURE OF A SUPER-FILTER

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A method for measuring the structural parameters of a porous super-filter material specific to this task is described. The results of these measurements are necessary for adequate modelling of separation processes for a lean ^{3}He-^{4}He isotope mixture. The key element of the technology for separating the ^{3}He isotope from a lean ^{3}He-^{4}He mixture is the super-filter, a system of channels through which the superfluid isotope ^{4}He can predominantly pass. In known applications of this technology, the super-filter channels ranged in size from 10^{-4} m to 10^{-8} m. It is also known that the separation of these isotopes is more efficient with smaller super-filter channels. Currently, it is impossible to manufacture a filter with channels of the required shape and such small dimensions. Therefore, various porous materials characterized by an irregular structure and, accordingly, different flow channel sizes and shapes are used to manufacture super-filters. This circumstance, coupled with the hydrodynamic properties of the superfluid ^{4}He isotope, poses challenges in adequately modelling the operating processes in the super-filter and, consequently, in selecting and measuring the porous structure parameters of its material to ensure the desired efficiency.

Keywords: *^{3}He-^{4}He, super-filter, cryogenic*

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SELECTING SUPER-FILTER PARAMETERS FOR SEPARATING ^{3}He-^{4}He MIXTURE

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The paper contains the prerequisites necessary for the development of an algorithm for calculating the parameters of a super-filter that can be used in the technological process of extracting the ^{3}He isotope from natural helium. A method for evaluating the parameters of the working process in a super-filter and its efficiency based on the results of measuring the parameters of the structure of samples of a porous super-filter material is presented.

The results of experiments carried out in the last century demonstrate the possibility of using the phenomenon of osmosis for the separation of liquid mixtures of helium isotopes at temperatures below 2,1 K. As is known, the basis of this method is the unique property of the ^{4}He isotope at this temperature, quite freely, in contrast to the ^{3}He isotope, to flow through very narrow channels. Therefore, the main element of this technology is a super-filter, which is a system of channels through which the ^{4}He isotope can mainly penetrate. In known cases of the implementation of this technology, the super-filter channels had dimensions from 10^{-4} m to 10^{-8} m. It is also known that the separation of these isotopes is the more efficient, the smaller the characteristic size of the super-filter channels. At present, it is not possible to manufacture a filter with channels of the correct shape and of such small dimensions. Therefore, for the manufacture of a super-filter, various porous materials are used, which are characterized by an irregular structure and, accordingly, different sizes and shapes of flow channels. This circumstance and the peculiarities of the hydrodynamics of the ^{4}He isotope cause problems of adequate modelling of working processes in the super-filter and, accordingly, the problem of choosing the parameters of the porous structure of its material that ensure its specified efficiency.

Keywords: *^{3}He-^{4}He, super-filter, cryogenic*

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OPTIMIZATION OF THE TRITIUM SEPARATION PROCESS WITHIN THE *CECE* ADVANCED MODULAR SYSTEM: A COMPREHENSIVE PARAMETRIC AND MODELLING STUDY

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Efficient management of tritium isotopes and tritiated water generated by nuclear reactors remains a critical challenge for the sustainability of nuclear energy systems [H. Boniface, et.al., 2011;T.V. Vasyanina, et.al., 2008; R. Michling, et.al., 2009].

To address this, the National Research and Development Institute for Cryogenic and Isotopic Technologies (ICSI) Rm. Valcea leverages its extensive tradition in hydrogen isotope engineering to develop an *Advanced Modular System.* This technological installation is based on the integration of the CECE (*Combined Electrolysis and Catalytic Exchange*) process coupled with an isotopic permeation cascade [M. Zamfirache, et.al., 2024; A.M. Bornea, et al., 2011].

Currently, the installation's development focuses on the CECE isotopic separation stage, which is engineered to operate in three highly distinct fluid-dynamic configurations:

- **Mode 1:** A single CECE module consisting of two series-connected LPCE (*Liquid Phase Catalytic Exchange*) columns and a dedicated electrolysis cell.
- **Mode 2:** A dual-module CECE configuration, where the secondary module is systematically fed with water extracted from the bottom of the primary LPCE column.
- **Mode 3:** A dual-module CECE configuration, where the secondary module is directly supplied with water from the electrolyzer unit of the first CECE module.

Characterizing this system is mathematically complex due to its inherently non-steady-state regime, where isotopic concentrations across the liquid, vapor, and gas phases undergo continuous, time-dependent variations.

Because the induction periods required to achieve steady-state and reach target concentrations are exceptionally prolonged, empirical trial-and-error approaches are economically and operationally prohibitive.To mitigate these challenges, a previously validated mathematical model was upgraded to rigorously

map the numerical boundaries and physical layouts of the three specific operating topologies.

This paper comprehensively details the underlying calculation schemes and numerical algorithms developed for the system's operational simulation. Furthermore, a rigorous parametric analysis is presented to define the precise operational envelopes that maximize the tritium concentration factors. Ultimately, this optimization framework balances maximum process efficiency with strict compliance regarding gas decontamination thresholds at the system's exhaust, significantly reducing experimental overhead and paving the way for scale-up validation.

Keywords: *Tritium Separation; CECE Process; Liquid Phase Catalytic Exchange (LPCE); Process Optimization; Advanced Modular System*

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DESIGN AND EXPERIMENTAL EVALUATION OF AN ADVANCED MODULAR *CECE* SYSTEM FOR HYDROGEN ISOTOPE SEPARATION

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This paper advances the ongoing research of the ICSI Nuclear Department and the Pilot Plant for Tritium and Deuterium Separation (PESTD)—a national interest facility—in the field of hydrogen isotope separation technologies.

The primary objective of this study is to validate the operational data required to implement an innovative, demonstrative solution named the Advanced Modular System (AMS). Based on a Combined Electrolysis and Catalytic Exchange (CECE) process coupled with isotopic permeation, the AMS introduces a novel technology for isotopic enrichment in both liquid and gas phases.

The process yields either tritium-concentrated tritiated water or tritium-concentrated hydrogen. The modular architecture of the system supports three distinct operating configurations: an electrolysis cell integrated with two Liquid Phase Catalytic Exchange (LPCE) columns, and two serial CECE modules, where the second module can be supplied via two different modes. The AMS was constructed based on a preliminary conceptual design, leveraging expertise from prior projects. Process lines between the main equipment are connected progressively for each operating mode, following successful sequential testing.

Validation experiments were conducted using low-concentration tritiated water (~1000 Bq/L). Measurements at critical process nodes were performed on both gas and liquid phases. Gas samples were converted to liquid phase using copper oxide (CuO) reactors, and all water samples were analyzed via liquid scintillation counting (LSC). The experimental phase successfully verified the functionality and performance of the automation and control systems. The insights gained led to specific optimizations in both the conceptual design and the physical execution of the system, which are detailed in this study.

Finally, this paper evaluates the experimental results, outlines the current state of development, and presents the future research roadmap for the AMS facility.

Keywords: hydrogen isotope separation; electrolysis; catalyst.

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ASPECTS OF MODELLING PROCESSES IN AN ADIABATIC ORTHO-PARA HYDROGEN CONVERTER

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The production of liquid parahydrogen generally involves the catalytic conversion of hydrogen spin isomers. It is known that the conversion of the ortho modification of hydrogen into the para modification is an exothermic reaction. The heat released in the ortho-para converter negatively affects the efficiency of the overall liquid parahydrogen production process. For the optimal selection of the converter type, its dimensions, and its location in the hydrogen flow from the perspective of process efficiency, an adequate model of the processes occurring in the converter is required. Such a model is particularly important for the correct evaluation of the parameters of other components of the system, such as heat exchangers, compressors, and expanders, which ensure its efficient operation.

A so-called "isothermal" converter is known, in which the heat of the ortho-para reaction is removed through the walls of the converter. Modelling the processes in such a converter is complicated by the need to adequately model the heat transfer from the hydrogen inside the converter to the surrounding environment. Obviously, in this case, heat transfer between the hydrogen and the environment is always non-ideal. The assessment of the degree of hydrogen heating will therefore always depend on the questionable adequacy of the model used to describe heat removal from the converter.

In contrast, when modelling the processes in an adiabatic ortho-para converter, there is no need to model heat losses to the environment. This is an important prerequisite for ensuring the adequacy of the adiabatic converter model.

This paper presents a model of the processes occurring in an adiabatic ortho-para converter that can be used for numerical analysis of processes in systems equipped with ortho-para hydrogen converters.

Keywords: *ortho-para hydrogen, adiabatic converter, cryogenic*

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NEW APPROACHES TO FLEXIBLE ELECTRODES FOR WEARABLE *PEM* FUEL CELLS

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The main characteristics of a fuel cell - well known for its uninterrupted operation (as long as it is provided with fuel and oxidant), for its high energy density and instant refuelling capacity, all of which making it particularly advantageous for long-term and outdoor missions - are leading to considering it as a possible alternative to the batteries, which are generally used now to empower flexible, wearable electronics.

As concerning the PEMFC's electrodes, one important limitation is represented by designing and realizing them from materials owing good electrical conductivity and low-elasticity modulus. Simoultaneously, electrodes have to meet a series of mechanical requirements, such as structural flexibility, repeated bending resistance and maintaining good interfacial contact with the membrane. Hence, the need to find new approaches to reconcile these generally contradictory requirements.

Platinum-based catalysts represent the current standard for the electrochemical reactions in PEMFCs. Traditionally, Pt nanoparticles are dispersed on carbon supports (Pt/C). However, degradation of the carbonaceous support and agglomeration of Pt particles can lead to decreased performance over the long term.

Various support materials have been investigated for dispersing platinum nanoparticles at PEM fuel cell electrodes, with the aim of improving electrocatalytic activity and stability. The following table presents a comparison between traditional carbon-based supports, graphene-based materials, and MXene materials (Zhang X.et al., 2021; Marinoiu, A. et al., 2020; Liu K.et al., 2024).

Table 1. Comparative table between carbon, graphene and MXene as supports for Pt catalysts in PEM fuel cells

Characteristic	Carbon (Pt/C)	Graphene (Pt/Graphene)	MXene (Pt/MXene)
Structure	amorphous or graphitic carbon (e.g., Vulcan XC-72)	two-dimensional carbon-based material	two-dimensional metal carbide/nitride material (e.g., $Ti_3C_2T_x$)

Characteristic	Carbon (Pt/C)	Graphene (Pt/Graphene)	MXene (Pt/MXene)
Electrical conductivity	high	very high	very high
Specific surface area	large	very large	large
Surface functional groups	limited	moderate	abundant (–OH, –O, –F)
Metal–support interaction	relatively weak	moderate	strong
Pt nanoparticle dispersion	good	very good	very good
Electrochemical stability	limited (carbon corrosion)	better than amorphous carbon	promising, but still under investigation
Mechanical stability	good	very good	good
Electrocatalytic activity (ORR)	high	high	high or improved
Pt catalyst utilization	moderate	more efficient	very efficient
Material cost	low	moderate	moderate–high
Technology readiness level (TRL)	8–9	5–7	4–6

While Pt/C catalysts represent the current standard, two-dimensional materials such as graphene and MXene offer promising prospects due to their high conductivity, large specific surface area, and favorable metal–support interactions.



Although modern technologies including electrospinning, inkjet printing and spray coating have enabled the deposition of catalyst layers as thin as 10–50 µm with substantially reduced material loading, though achieving reproducible structural uniformity

across large areas and translating these processes to industrially scalable production remain open challenges, particularly for electrospun architectures.

Keywords: *flexible electrodes, electro-catalytic activity, stability, Platinum-based electrocatalyst, graphene, MXene.*

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INNOVATIVE MATERIALS FOR *PEM* FLEXIBLE FUEL CELLS MEMBRANES

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Flexible proton exchange membrane fuel cells (F-PEMFCs) have emerged as a promising energy solution for next generation of wearable, portable, and flexible electronic systems due to their high energy density, low operating temperature, quiet operation, and environmentally friendly characteristics. The challenge is that flexible fuel cells need to preserve their entire functionality under mechanical deformation such as torsion, bending, or compression.

The proton exchange membrane's (PEM) role is to transport protons generated at the anode to the cathode, while maintaining physical separation between the fuel and the oxidant. The most widely used membranes in PEMFCs are those based on perfluorosulfonic acid polymers, such as Nafion, due to their high proton conductivity and chemical stability.

However, certain issues arise in portable and flexible applications, such as:

- membrane dehydration at high temperatures,
- increased gas permeability,
- worsened mechanical stability under deformation conditions.

Compared with conventional, rigide PEMFCs, the flexible ones are generally made thinner, in order to contribute to increasing the overall flexibility of the cell, but this can also compromise mechanical stability and increase gas permeability, with a negative impact on efficiency and durability. So, new approaches became necessary to develop innovative materials with an inherent ability to simultaneously deliver both high proton conductivities, mechanical flexibility, minimal fuel crossover and scalability of manufacturing processes.

Despite rapid advancements in materials engineering, several critical challenges remain:

- achieving high proton conductivity (>0.1 S cm^{-1}) under low humidity conditions is still difficult;

- the trade-off between mechanical flexibility and dimensional stability limits long-term durability;
- scalable and cost-effective manufacturing of advanced PEMs still remains a major barrier.

Finally, the integration of these materials into functional devices without performance losses under cyclic deformation is still not fully achieved (*Simari C, et al.- 2019; Nicotera I, Coppola L, Simari C. – 2024; Li Y, et al – 2020*).

Table 1. Comparative analysis of some advanced proton exchange membranes for flexible and wearable PEMFCs

PEM type	Typical proton conductivity	Mechanical behaviour	Main advantages	Main limitations	Suitability for wearable PEMFCs
Nafion / PFSA	0.08–0.12 S cm^{-1} at high RH	Moderate flexibility; Young's modulus ~150–300 MPa	High conductivity, chemical stability, commercial maturity	Strong RH dependence, high cost, PFAS concerns, crossover in thin films	High benchmark performance, but limited under dry/deformed conditions
Reinforced Nafion	0.08–0.12 S cm^{-1}	Improved dimensional stability	Better mechanical strength and lower swelling	Still expensive and humidity-dependent	Suitable as near-term solution
SPEEK - Sulfonated Poly(ether- ether ketone)	0.03–0.08 S cm^{-1}; up to >0.1 S cm^{-1} at high DS	High stiffness; may become brittle at high sulfonation	Low cost, tunable chemistry, low fuel crossover	Swelling, oxidative instability, RH dependence	Promising, but needs reinforcement/ crosslinking
SPAES- Sulfonated Poly(arylene ether sulfone)	0.02–0.07 S cm^{-1}	Good tensile strength and stability	Better oxidative resistance than SPEEK	Conductivity drops at low RH	Good compromise for flexible PEMFCs
GO-based nanocomposites	0.10–0.13 S cm^{-1}	Improved crack resistance	Better water retention, lower crossover, improved fatigue resistance	GO aggregation at high loading	Very promising
MXene-based nanocomposites	0.10–0.15 S cm^{-1}	Good flexibility via layered structure	High hydrophilicity, fast proton transport, reduced crossover	Oxidation instability, processing challenges	Highly promising but needs stabilization
SiO_2/TiO_2 nanocomposites	0.09–0.12 S cm^{-1}	Improved dimensional stability	Better water retention and oxidative resistance	Excess filler may reduce flexibility	Good as reinforcing/filler strategy
Nanocellulose-based PEMs	10^{-3}–10^{-2} S cm^{-1}; up to 0.08–0.10 S cm^{-1} after functionalization	Excellent flexibility and fatigue resistance	Sustainable, lightweight, mechanically robust	Swelling and oxidative stability issues	Very promising for sustainable wearable PEMFCs
Self-healing PEMs	0.02–0.08 S cm^{-1}; up to ~0.1 S cm^{-1} in hybrids	Recovery >80–95% after damage	Mechanical repair, fatigue tolerance	Complex synthesis, scalability issues	Highly promising for long-life wearable PEMFCs

Keywords: *flexible proton exchange membrane, proton conductivity, hydrophilicity, fuel crossover.*

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POWER MANAGEMENT FOR A PORTABLE SYSTEM BASED ON HYDROGEN TECHNOLOGY

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A portable power supply-type energy generator, based on hydrogen technology, which uses a polymer electrolyte membrane fuel cell (PEMFC) assembly powered by locally generated hydrogen, represents a solution for generating electricity that is practically non-toxic, if we compare it to the classic diesel generator, and with a greater degree of portability compared to a system based on rechargeable batteries of comparable power - higher specific energy per unit of mass, respectively volume. [Dunn, 2002]

This portable hydrogen-based power system designed to serve as a power source for personal electronic equipment can be configured in a series-parallel hybrid architecture, where the rechargeable battery covers peak loads and the fuel cell provides base load and battery recharge, which is an energy storage source. The proposed configuration for the portable hydrogen system for powering field electrical equipment is shown in Figure 1 and includes subsystems S1 to S5.

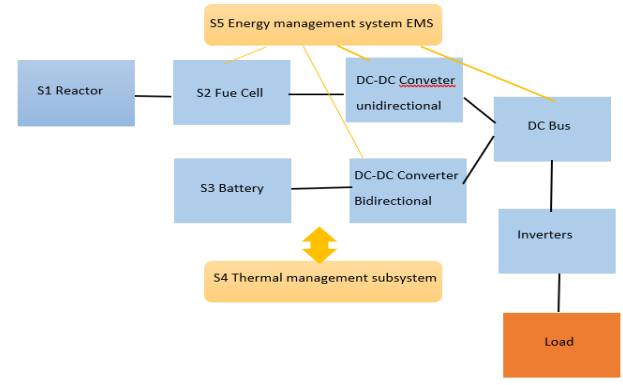


Figure 1. Proposed block diagram for a hydrogen hybrid system for powering electrical field equipment

S1 - Hydrogen Generation Subsystem (Sodium Borohydride Chemical Reactor - NaBH4) It is identified as the area assigned for the catalytic hydrolysis of sodium borohydride, resulting in the generation of a hydrogen gas flow that feeds the cell. This subsystem also includes other modules / subsystems such as: - Flow Control Subsystem It is identified as the subsystem responsible for controlling the solution / solid injection, which has the ability to adjust the H2 flow depending on the current demand of the fuel cell; - Moisture Separator / Filters It is identified as the unit / module for cleaning and filtering the H2 flow, which is mounted / mounted between the exit from the chemical reactor and the Anode feed area of the fuel cell.

S2 - Fuel Cell (FC) Subsystem It is identified as the electrochemical module that converts the chemical energy of H2 into direct current. This subsystem also includes other modules / subsystems such as: - DC/DC Converter (Boost/Buck) It is identified as the electronic module that stabilizes the variable voltage of the cell to the fixed voltage of the DC bus;

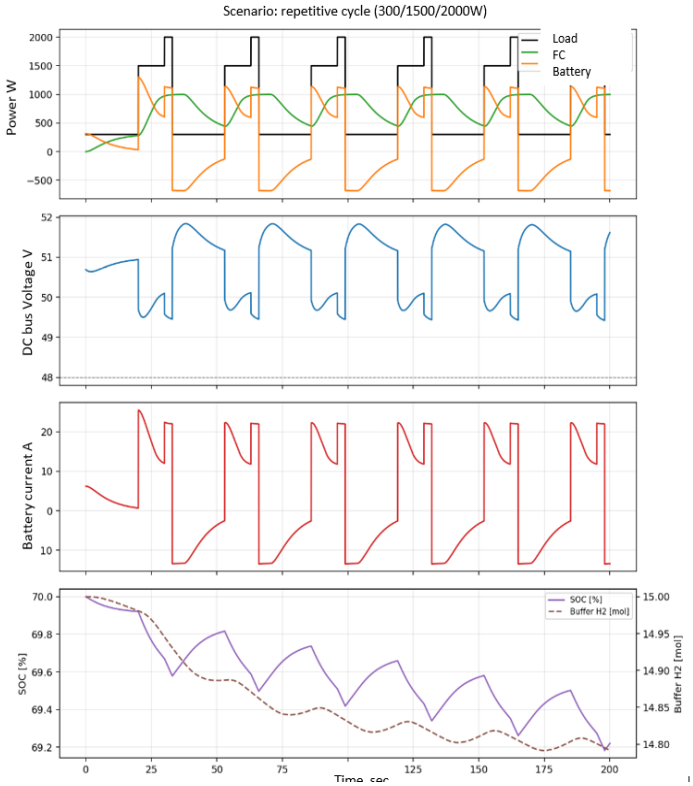
S3 - Energy storage and delivery subsystem It is identified as the subsystem responsible for controlling the storage and delivery to consumers of the electrical energy generated by the portable hybrid system. This subsystem also includes other modules / subsystems such as: - Battery / Rechargeable battery bank. It is identified as the subsystem that fulfills a dual role, primarily ensuring the energy needs for all subsystems dependent on the electrical supply (transducers, actuators, control electronics, etc.) at the time of system start-up, but at the same time ensuring the role of "buffer" to mitigate part of the transient regimes of the fuel cell that could be generated by fluctuations in the hydrogen supply flow; - Inverter (DC/AC converter) It is identified as the power electronic module subsystem that transforms the direct current (DC) taken from the rechargeable battery, into alternating current (AC) at parameters similar to the network (220 V, 50 Hz), to supply electrical consumers;

S4 - Thermal Management Subsystem TMS It is identified as the subsystem responsible for cooling / heating the other systems dependent on maintaining a constant temperature regime and mainly serves the Generation subsystem ((NaBH4 Chemical Reactor), for regulating the reaction temperature, as well as starting and operating at nominal parameters of the fuel cell;

S5 - Control and Monitoring Subsystem (EMS - Energy Management System) It is identified as the subsystem that fulfills the role of managing the functionality and operation of the system as a whole by coordinating the electrical energy generated with the load requirements, respectively the hydrogen flow rate provided by the NaBH4 reactor with the state of charge (SoC) of the battery, the operation of the fuel cell, etc.

Simulation of the hybrid power system ($NaBH_4$ → PEM → battery → 2kW/220V inverter) Simulation methodology 1. Implementation in MATLAB/Simulink (Simscape Electrical + Simscape Fluids for the H_2 part). Simulink is the industry

standard for this type of multi-domain study (electrical + electrochemical + fluidic). 2. Step-by-step validation: first each subsystem isolated (cell current step response, battery voltage response), then full integration. 3. Sensitivity analysis: vary key parameters (Battery internal, cell τ, H_2 generator delay) to identify the worst case for each of the above criteria. An example of the behavior of the portable source resulting from the simulations is presented below.



Keywords: *power management, portable energy, hydrogen technology, simulation of the hybrid power system*

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THE VECTOR OF CHANGE: SUSTAINABLE SOLUTIONS FOR THE CONVERSION AND STORAGE OF CLEAN ENERGY

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The transition toward low-carbon energy systems necessitates a rigorous academic framework across all university levels, spanning from undergraduate studies to advanced doctoral research. This paper serves a pronounced informative and educational purpose, aiming to familiarize students and PhD researchers with the strategic importance, versatility, and practical applications of hydrogen as an energy vector. The first part of the study develops the mathematical analysis of hydrogen energy conversion, providing early-career researchers with the formal theoretical foundation and thermodynamic balance equations required to model complex processes. Subsequently, the current energy storage possibilities are systematically mapped, offering a comparative analysis of the techno-economic advantages and limitations of gaseous, liquefied, and metal hydride storage methods. To demonstrate the applicability of these concepts and to foster new directions in applied research, the paper investigates the operation of high-resolution experimental platforms. It details the study of energy conversion via the GENIUS PROFESSIONAL Installation, a system that enables the dynamic visualization of energy phenomena, followed by the study of energy conversion using Proton Exchange Membrane (PEM) fuel cells, which represent a core technology in global decarbonization efforts. To ensure an integrated perspective on industrial systems, the research addresses the monitoring of parameters and data acquisition from an installation for the production, transport, and distribution of gaseous fluids and compressed air, a critical domain for understanding sensor networks, automation, and safe fluid management. In conclusion, this work demonstrates that the utilization of modern experimental platforms, coupled with real-time data acquisition, constitutes a fundamental educational and research pillar. Due to its comprehensive structure, this study serves as a valuable informative resource for students and a rigorous methodological guide for PhD candidates, stimulating

interest in scientific excellence, knowledge dissemination, and the development of advanced projects within the field of clean hydrogen technologies.

Keywords: *hydrogen energy vector, student training, doctoral research, GENIUS PROFESSIONAL installation, PEM fuel cells, data acquisition.*

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ENVIRONMENTAL SYSTEMS, CLIMATE ACTION AND WATER–ENERGY–FOOD NEXUS

AUGMENTED INTELLIGENCE-BASED SENSING PLATFORMS FOR ENHANCED SITUATIONAL AWARENESS

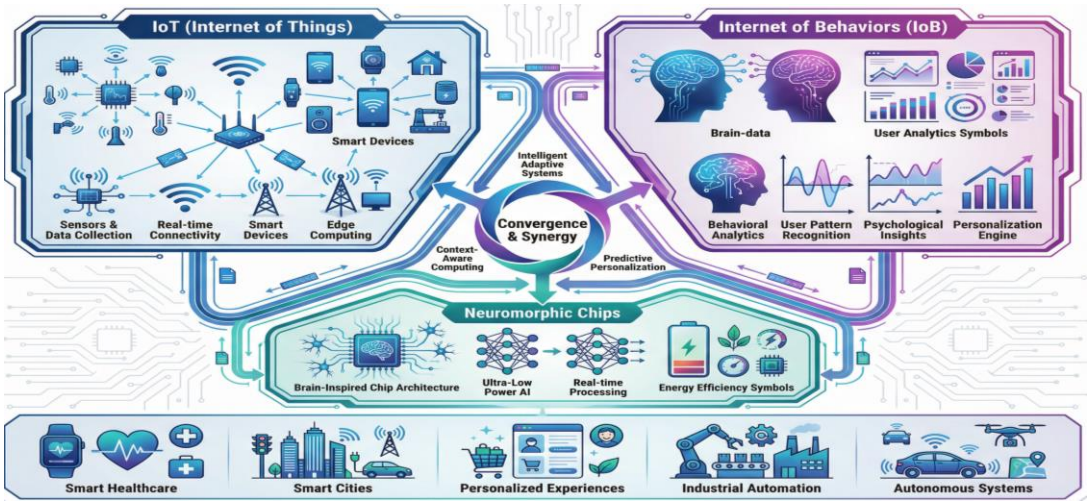
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The rapid convergence of nanotechnology, artificial intelligence (AI), and advanced materials science is fundamentally transforming sensing technologies, enabling platforms with unprecedented precision, adaptability, and cognitive functionality. Once limited to narrowly defined tasks, conventional sensors are now evolving into multifunctional, autonomous systems capable of operating across a wide spectrum of domains, including biomedical diagnostics, environmental surveillance, smart manufacturing, aerospace, and defense. Quantum sensors, exploiting principles such as entanglement and quantum coherence, deliver ultra-high sensitivity in measuring time, gravity, magnetic fields, and inertial forces, surpassing the performance limits of classical devices. In parallel, bio-inspired and bio-integrated sensors leverage biological architectures, living systems, or synthetic twins to enable continuous, real-time, noninvasive physiological monitoring, accelerating advances in personalized medicine, wearable therapeutics, and human–machine symbiosis. The integration of AI with edge computing further enables sensors to incorporate embedded intelligence, including context-aware interpretation, predictive analytics, anomaly detection, adaptive self-calibration, and decentralized decision-making in agile environments. Parallel progress in flexible, stretchable, biodegradable, and self-healing materials expands sensor deployment to unconventional surfaces and in extreme operating conditions, while energy-harvesting technologies and ultra-low-power electronics enable self-sustaining operation. Collectively, these innovations redefine sensing from passive data acquisition to an active, distributed, and intelligent capability, catalyzing the emergence of cognitive sensing ecosystems that can autonomously learn, adapt, and evolve. Future next-generation sensors will play a pivotal role in building resilient societies, sustainable industries, precision healthcare systems, and secure critical infrastructure, while simultaneously introducing urgent challenges related to ethics, privacy, cybersecurity, and governance. Although their ultimate potential may be fully realized in the era of artificial general intelligence (AGI), these emerging technologies, including neuromorphic

sensing architectures, have already signaled a new paradigm of intelligence-driven interaction among humans, machines, and the surrounding environment.

Keywords: *AI, AGI, Neuromorphic, Sensors, Edge computing, Dielectric, Energy, Biomedical*



ADVANCING MOLECULAR-LEVEL ISOTOPE RATIO ANALYSIS WITH AN INTEGRATED ORBITRAP-*IRMS* WORKFLOW

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Stable isotope measurements are widely used to investigate sources, transport, and transformation processes across environmental, geochemical, and biogeochemical systems. Orbitrap-based isotope ratio mass spectrometry complements conventional IRMS approaches by measuring isotope and isotopologue ratios directly from intact molecular ions using high-resolution accurate-mass detection, thereby retaining molecular context.

In this presentation, we introduce an integrated Orbitrap-IRMS workflow combining Thermo Scientific™ Orbitrap™ Isora™ MS, Vanquish™ Duo UHPLC System, and Isotope Discoverer™ Software. The workflow streamlines sample/reference introduction, isotope ratio acquisition, calibration, visualization, and reporting, converting raw Orbitrap mass spectra into calibrated δ values through a transparent processing sequence.

The analytical breadth of the approach will be illustrated using nitrate and glutamic acid as complementary examples. Analysis of intact nitrate ions enables $\delta^{15}N$, $\delta^{17}O$, and $\delta^{18}O$ measurements within a single method, supporting investigation of nitrogen sources and transformation pathways. High-resolution accurate-mass detection also enables access to low-abundance and multiply substituted isotopologues that are difficult to resolve with conventional approaches.

Glutamic acid demonstrates an additional dimension of Orbitrap-IRMS by connecting isotope ratios with molecular structure through controlled fragmentation. Combining intact molecular ion measurements with HCD fragment-ion analysis enables multi-isotope measurements and position-specific isotope information from defined molecular substructures.

Together, these examples demonstrate how Orbitrap-IRMS can extend isotope ratio analysis beyond whole-molecule measurements toward richer molecular and structural isotope information. Access to low-abundance and multiply substituted isotopologues may further expand the isotopic information available from environmental and biogeochemical samples and open opportunities to explore new molecular isotope proxies.

ESTIMATING ENTERIC FERMENTATION PARAMETERS IN ROMANIAN CATTLE FOR THE NATIONAL GREENHOUSE GAS (GHG) INVENTORY

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To aim of the current article was to provide an updated characterization of the Romanian dairy cattle sector, including farm typology, herd structure, and production performance, in support of the national greenhouse gas (GHG) inventory. Data were collected from the National Institute of Statistics, Eurostat, the Ministry of Agriculture and Rural Development, FAO, the National Agency for Animal Husbandry, the National Sanitary Veterinary and Food Safety Authority, as well as from the herd books of cattle breeders' associations. analyses primarily covered the 2014–2024 period; however, for selected time-series datasets, historical records were retrospectively extended to capture long-term trends (e.g., 1970–2024). An analysis based on data from 9,361 farms showed that the romanian dairy sector was numerically dominated by small, extensive farms (72.77%), followed by semi-intensive (23.10%) and intensive farms (4.12%). At the national level, there were 1.052 million dairy cows, producing a total of 3.97 billion kg of milk, with an average milk yield of 3,773 kg per lactation. Accurate characterization of farm structure and production performance is essential for developing robust, country-specific enteric fermentation parameters, thereby enhancing the reliability of romania's national GHG inventory and supporting evidence-based climate policies.

Keywords*: enteric fermentation; greenhouse gas emissions; dairy cattle; emission factors.*

HYDROGEN COMBUSTION TECHNOLOGIES FOR MICRO GAS TURBINE COMBUSTORS: CURRENT STATUS, CHALLENGES AND FUTURE DIRECTIONS

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The rising interest in the development of low carbon emission energy systems has been accompanied by the increased investigations of hydrogen combustion technologies in gas turbines and micro gas turbines, especially in CHP applications. Hydrogen is regarded as one of the most prospective carbon-neutral fuels that have the potential to considerably reduce greenhouse gas emissions. Nevertheless, the presence of hydrogen in the fuel mixture poses some special problems associated with its high laminar flame speed, broad flammability limits, low ignition energy, and diffusivity. This article provides a thorough overview of the latest achievements in the field of hydrogen combustion technologies for the micro gas turbine combustors with pure hydrogen and hydrogen-methane (H_2-CH_4) blends. The overview involves the latest modern combustion systems, such as Dry Low Emission (DLE), Wet Low Emission (WLE), Micromix combustors, porous media combustion and hybrid combustion systems, which are characterized by their principles of functioning, advantages and limitations. Special emphasis is made on the impact of hydrogen blending on fuel characteristics, combustion process, emissions and other factors. In addition to this, the paper also highlights the major technological constraints that prevent the widespread adoption of hydrogen combustion, which include fuel flexibility, material compatibility, combustor design, and reliability. In the end, areas of future research are outlined, highlighting the significance of combustor design, computational fluid dynamics (CFD) based optimization, testing, and manufacturing processes. This paper gives an organized account of hydrogen combustion technology and its future research needs.

Keywords*: hydrogen combustion; micro gas turbines; hydrogen–methane blends; combustion chambers; Dry Low Emission; Micromix combustors; low-NOx combustion.*

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PRELIMINARY DESIGN OF A MODULAR HYDROGEN–METHANE COMBUSTION CHAMBER FOR PIV/LIF INVESTIGATIONS

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The increased utilization of hydrogen as a low-carbon energy source necessitates the development of combustion systems that could work reliably with hydrogen fuel mixtures. Nevertheless, the features of the hydrogen such as fast laminar flame propagation, broad flammability limits, and higher temperature of the combustion process present difficulties in the design due to such factors as flame stabilization, flashback, heat load, and NOx generation. The paper describes the design procedure and engineering development of a laboratory combustion chamber aimed at the investigation of the premixed methane-hydrogen combustion process. The developed facility is intended for working with the premixed fuels containing 20%, 40%, and 60% hydrogen in volume fraction under the lean combustion conditions. The procedure of the systematic sizing has been developed which allows estimating the fuel and air flows, equivalence ratio, compressed air consumption, the geometry of the fueling system, and the safety considerations. The proposed combustion chamber features a modular design with interchangeable burner heads and optical access for PIV and LIF diagnostics. Thus, the developed design serves as a platform for studies of flame stabilization, flow topology, combustion instabilities, and pollutants generation.

Keywords: *hydrogen combustion; methane–hydrogen blends; combustion chamber; burner design; PIV; LIF; experimental combustion; hydrogen technologies.*

Acknowledgements:

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DEVELOPMENT AND CONFIGURATION OF AN EXPERIMENTAL STAND FOR SMOKE-BASED FLOW VISUALIZATION THROUGH POROUS MEDIA

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This paper documents design, configuration and operational preparation of a modular experimental stand built for smoke-based visualization of airflow through porous media [Virginia Tech, 2020], developed in support of hydrogen and methane–hydrogen burner prototypes. The stand integrates a centrifugal fan as primary air source, a mixing zone fed with a glycerine-based aerosol tracer, interchangeable upstream guiding elements, a porous-media test section, a modified downstream evacuation path with dedicated ventilation, and a high-speed optical acquisition system. Three perforated porous plates were tested: a single Ø30 mm opening (706.86 mm² flow area, taken as reference), 23 × Ø2 mm holes (72.26 mm², 10.22% of the reference area) and 23 × Ø3 mm holes (162.58 mm², 23.00%). Three guiding geometries were used, with the active window reduced by approximately 20% and 60% relative to the baseline element. The nine resulting combinations were run under identical mounting, illumination, air-supply and evacuation conditions, so that observed differences could be attributed to geometry rather than to setup variability. Sequences were recorded with a Phantom VEO 710L camera (1 MP CMOS, 1280 × 800 px, 12-bit) operated at 200 frames per second, corresponding to a 5 ms interval between successive frames, and stored in Cine RAW format through Phantom Camera Control software to preserve acquisition parameters for later reprocessing. Recordings were assessed against three criteria: uniformity of tracer distribution across the section, sharpness of the smoke front, and apparent propagation time estimated from frame counts. The sequences distinguish configurations in which the smoke front advances almost planar from configurations exhibiting preferential channels and delayed penetration regions. Results are qualitative to semi-quantitative, since smoke is a tracer rather than the fluid itself and all tests were performed in cold flow, without

fuel. The stand provides a reproducible platform for subsequent quantitative image processing and for screening burner geometries before reactive testing.

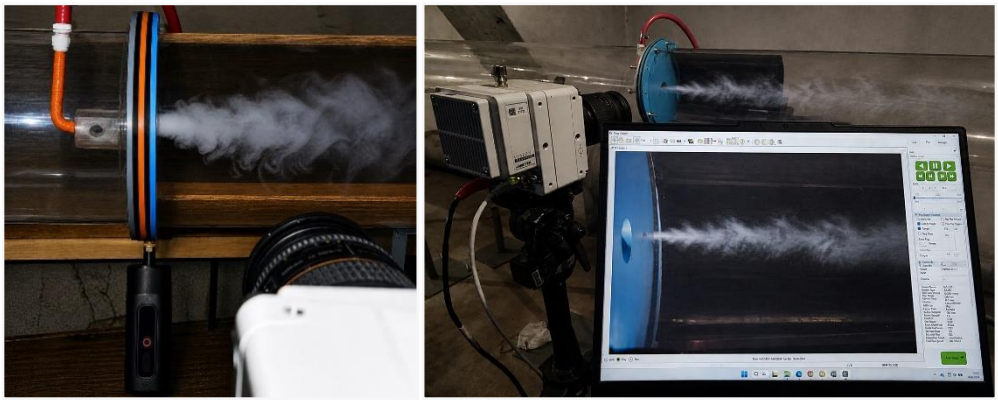


Figure 1. Experimental setup for fluid flow visualization using a portable smoke generator and a high-speed camera.

The image-processing and velocimetry workflow applied to high-speed recordings of smoke-seeded airflow downstream of perforated porous media, acquired on a cold-flow stand developed for hydrogen and methane–hydrogen burner prototypes. Fourteen sequences were processed: nine geometric combinations of three porous plates and three guiding elements at the maximum tracer-generator setting, plus one combination examined across all six generator command levels. Pre-processing followed a fixed sequence — region-of-interest delimitation, grayscale conversion, contrast-limited adaptive histogram equalization and 3 × 3 median filtering — required because tracer and porous plate exhibit overlapping grey levels. Displacement fields were computed in PIVlab by FFT cross-correlation with window deformation [Schmidt B. E., & Sutton J. A., 2019], using four passes with interrogation windows of 200, 100, 50 and 25 px and corresponding steps of 100, 50, 25 and 13 px, with Gaussian 2 × 3-point sub-pixel estimation and repetition of the final pass until the quality slope fell below 0.025. Vectors were validated by a 1σ standard-deviation filter, a local median filter with threshold 3 and a manually defined acceptance domain in the (u, v) plane; rejected positions were reconstructed by interpolation. Spatial calibration used a 30 mm reference measured at 209.35 px, giving 1 px = 1.433×10^{-4} m, which combined with the 5 ms inter-frame interval yields 0.0287 m/s per pixel per frame. Time-averaged fields were extracted globally, along seven longitudinal probing lines and over three transverse sectors, up to 60 mm downstream. Global mean apparent velocities ranged from about 0.02 to 0.09 m/s, the highest values corresponding to porous plate 3 combined with guiding elements 2 and 3. Area-weighted sectoral means agreed with the global mean within 3%, the smallest deviation being 0.77%. Since the tracer is not calibrated seeding and generator settings are command steps

rather than measured flow rates, all values are reported as apparent, two-dimensional and semi-quantitative.

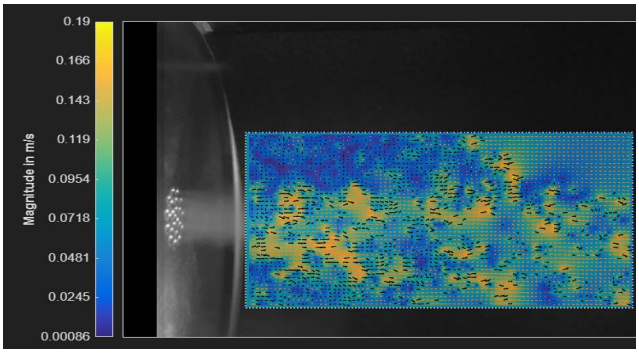


Figure 2. Velocity magnitude field and vector distribution of the jet flow obtained via PIVlab post-processing

Keywords: *flow visualization; porous media; smoke tracer; high-speed imaging; experimental stand; hydrogen burners*.

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A NEW IMPROVEMENT DESIGN AND ANALYSIS OF STIRLING ENGINE AND *DC* GENERATOR COUPLED BASED ON BY CONTROL THEORY

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The indicated power and thermal efficiency are the most important features of the Stirling engine. In the most general way, the efficiency depends on a set of parameters, such as the ratio between the volumes and temperatures of the working gas in the hot and cold compartment, the adiabatic function and energy losses due to friction processes between engine components. To verify the developed model, the technical design data of the Stirling Genoa03 engine are used as input data for our αSETS code. The data resulting from the code were used to estimate the thermal efficiency of the considered Stirling engine. The main contributions are obtained from control theory analysis of output data αSETS code.

EFFECTS OF TRITIUM DISCHARGE FREQUENCY FROM CHINA'S COASTAL NUCLEAR POWER PLANTS ON MARINE TRANSPORT, BIOLOGICAL ACCUMULATION, AND INGESTION DOSE

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Routine liquid tritium discharges from nuclear power plants are often summarized by annual discharge totals, although the same annual amount can be released through markedly different temporal patterns. Such differences can alter short-term seawater concentrations and the duration of environmental exposure, and may propagate into biological tritium and seafood-ingestion dose. This work examined whether discharge frequency changes the source-to-dose response of routine tritium releases from China's coastal nuclear power plants when the annual discharge activity of each source is held constant.

Reported annual tritium discharges for 2020 were redistributed into Weekly (53 releases), Monthly (12 releases), and Quarterly (4 releases) scenarios. Three-dimensional marine transport of HTO was simulated using ROMS and linked sequentially with sediment–water exchange, a dynamic marine food-web model distinguishing tissue-free-water tritium (TFWT) and organically bound tritium (OBT), and adult seafood-ingestion dose assessment. Laboratory experiments were used to constrain sediment partitioning and fish TFWT/OBT behaviour. The three scenarios used the same hydrodynamic setting, source locations, annual discharge totals, and other model conditions.

Changing discharge frequency did not alter the overall coastal–shelf pattern of HTO transport, but it substantially changed the temporal exposure regime. At the representative Guangdong coastal station ST01 on 1 July, surface HTO concentrations were 3.52×10^4, 1.41×10^5, and 3.71×10^5 Bq m^{-3} under Weekly, Monthly, and Quarterly discharge, respectively. In contrast, the number of days above 50 Bq m^{-3} was 364, 297, and 157 d. Quarterly discharge therefore produced stronger short-term peaks, whereas Weekly discharge maintained elevated concentrations for longer periods. This ordering did not propagate directly to biological accumulation. At the high-exposure fishing ground FG01, Monthly

discharge produced the highest annual mean OBT in all six modelled biological groups. Annual mean OBT in non-piscivorous fish was 0.1990, 0.2394, and 0.1968 Bq kg^{-1} for Weekly, Monthly, and Quarterly discharge, respectively. The corresponding seafood-ingestion doses were 4.10 × 10^{-7}, 4.69 × 10^{-7}, and 3.91 × 10^{-7} mSv a^{-1}, with OBT contributing 66.21%, 68.58%, and 67.32% of the total dose. Thus, the scenario with the highest short-term seawater concentration did not produce the highest annual biological accumulation or ingestion dose. The slower formation and elimination of OBT, together with food-web transfer, decoupled the annual biological response from the short-term HTO maximum.

The estimated adult ingestion doses remained extremely low in all scenarios. Nevertheless, identical annual tritium discharge totals generated different combinations of peak intensity, exposure persistence, biological retention, and dose. Annual discharge totals alone therefore do not fully characterize temporal marine exposure. Discharge frequency should be retained as an explicit temporal source-term descriptor in marine tritium transport and ingestion-dose assessment.

Keywords: *Tritium; Discharge frequency; Marine transport; Organically bound tritium; Ingestion dose.*

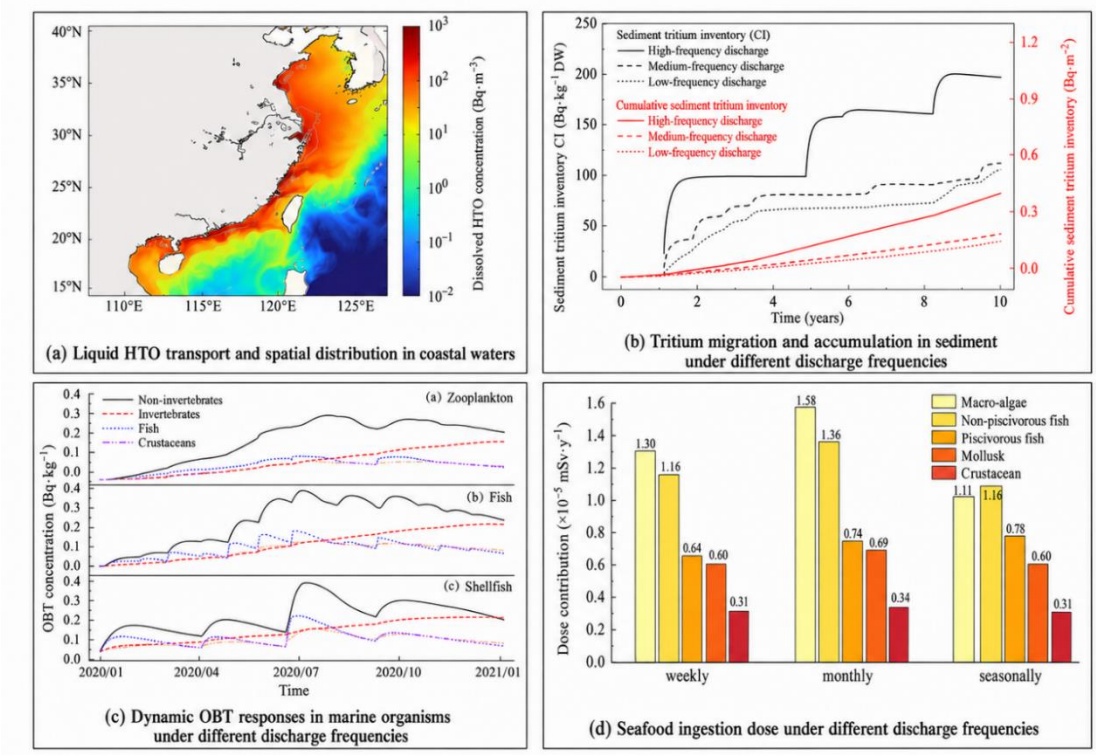


Figure 1. Effects of tritium discharge frequency on marine transport, sediment accumulation, biological OBT dynamics, and seafood ingestion dose

ISOTOPIC SIGNATURES IN MONTANE SMALL MAMMALS SUPPORT THE NICHE THEORY

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We assessed the isotopic niche of small mammals along the elevational gradient at both population and community levels in various inter- and intraspecific competitive contexts, to test the niche theory based on stable isotope analysis.

To reach this objective, we surveyed small mammal communities along an elevational gradient in low and high-density years and collected hair samples to assess their isotopic niche and its spatial, temporal and interspecific variation. We tested four hypotheses: 1. In accordance with the niche theory, we hypothesised that isotopic niches at high elevations are narrower, with reduced intraspecific variation, as ecological opportunity decreases with increasing elevation. 2. We also hypothesised that apart from differences in habitat selection and activity patterns, the codominance of forest specialists *Apodemus flavicollis* and *Clethrionomys glareolus* in the relatively continuous forested landscape is facilitated by dietary segregation. Therefore, we predicted that their isotopic niches would be segregated, with little or no overlap, and that this segregation would become more pronounced at higher elevations due to more limited resources, according to the niche theory. 3. We predicted that our results will confirm the less overlapping diet of *Apodemus agrarius* reported in the literature, by its distinct position in the isotopic space. 4. At the community level, we predicted that overall isotopic niche space (community-level convex hull area) would contract with increasing elevation, reflecting a reduction in resource diversity and availability, and that the overlap among species' isotopic niches would also decrease as dietary specialisation increases.

We assessed the isotopic niche of small mammals along an elevational gradient, testing the high-elevation diet specialisation and niche divergence as a mechanism to promote coexistence. To the best of our knowledge, this is the first study testing the niche theory in small mammals in European mountains. It aims to shed light on the trophic

strategies of small mammals under environmental constraints imposed by elevation, and their implications for species coexistence and community structuring.

In accordance with our first hypothesis based on the niche theory, we found that small mammal isotopic niches were significantly smaller at the timberline compared to the habitats at lower elevations. Habitats at high elevations are characterised by harsher environmental conditions (e.g., lower temperatures, more acidic and skeletal soils); therefore, one might expect that animals living here are forced to exploit a narrower range of food sources. Our results confirm that the scarcity of resources (low ecological opportunity) leads to niche size reduction and are consistent with results of studies on rodents from elsewhere, which confirm the niche theory in this taxa.

Our results confirmed partly our second hypothesis, the segregation of isotopic niches of *A. flavicollis* and *C. glareolus* was more pronounced at high elevations, but in the oak forest the niche of the bank vole was almost completely integrated in the niche of the mouse. The niche theory postulates that the scarcity of resources leads not only to niche size reduction but also limited overlap to allow species coexistence. The relationship between resource availability and niche partitioning is in line with the limiting similarity concept—when resources are abundant competition decreases and the need for the niche differentiation relaxes.

Apodemus agrarius had the smallest niche among the species found in the oak forest, but it was completely segregated from the other species, characterised by the highest values of both $\delta^{13}C$ and $\delta^{15}N$. However, in the spruce forest, the position of the single *A. agrarius* was embedded in the isotopic niches of *C. glareolus* and *A. flavicollis.* Thus, our third hypothesis was partly confirmed.

Comparing the community parameters in the oak forest and the timberline, we found that all of them, except the total area of the convex hull, were significantly higher in oak forests. The higher $\delta^{13}C$ range in the oak forest is given by the input of C_4 plant matter from open habitats to the forest, through the feeding habits of *A. agrarius.* The higher $\delta^{15}N$ range in the oak forest is probably also linked to the foraging behaviour of *A. agrarius*. Thus, these rodents act as a functional link between the forest and the neighbouring habitats, conveying nutrients of anthropogenic origin to forest food webs.

When interpreting our results we need to consider that the isotopic niche is not the same as the trophic niche. However, using stable isotope analysis to infer diet composition through mixing models allows the incorporation of stable isotope data into the classical approach of trophic niche. This implies sampling and isotopic analysis of potential food resources, which enables the establishment of the isotopic baseline for each community (environmental signature), allowing for more robust comparisons across the elevational gradient. Further studies need to evaluate the elevational trend of the ecological opportunity, which would allow to test whether the sudden drop in niche size at timberline corresponds to a drop in the resource availability and the large niche size of *A. flavicollis* in the beech forest is associated with peak in ecological opportunity in this forest, or some other mechanisms are also involved. Further studies should also establish whether the

large isotopic niche in the beech forest appears also in *C. glareolus*, or is an idiosyncrasy of *A. flavicollis*.

Keywords: *Bayesian ellipses, convex hull metrics, niche packing, niche segregation and overlap*

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DEVELOPING A COUNTRY-SPECIFIC TIER 2 CARBON ACCOUNTING FRAMEWORK FOR TEMPERATE FRUIT ORCHARDS: FROM FIELD MEASUREMENTS TO NATIONAL CARBON STOCK ESTIMATION

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Perennial fruit production systems represent long lived agricultural ecosystems capable of storing substantial amounts of carbon in woody and belowground biomass. However, their contribution remains inadequately represented in national greenhouse gas inventories, primarily due to the limited availability of country specific biomass data, age stratified measurements, and validated allometric relationships. This study presents a harmonized field to inventory methodology developed to support country specific Tier 2 biomass and carbon stock estimation in Romanian perennial fruit production systems, in accordance with the methodological principles of the Intergovernmental Panel on Climate Change (IPCC, 2006; 2019). A stratified sampling framework was established to capture the structural variability of Romanian perennial fruit crops according to species, orchard age or developmental stage, planting density and production system. Seventeen major fruit tree, nut, berry and small-fruit crops were included: apple (*Malus domestica*), pear (*Pyrus communis*), quince (*Cydonia oblonga*), plum (*Prunus domestica*), sweet cherry (*Prunus avium*), sour cherry (*Prunus cerasus*), apricot (*Prunus armeniaca*), peach (*Prunus persica*), walnut (*Juglans regia*), hazelnut (*Corylus avellana*), blueberry (*Vaccinium corymbosum*), currant (*Ribes* sp.), sea buckthorn (*Hippophae rhamnoides*), aronia (*Aronia melanocarpa*), raspberry (*Rubus idaeus*), blackberry (*Rubus fruticosus*) and strawberry (*Fragaria × ananassa*). Tree-fruit orchards were additionally classified into traditional, intensive and high-density production systems, where applicable.

At individual plant level, the protocol combines detailed biometric measurements with component-specific biomass assessment. Recorded structural variables include tree height, trunk dimensions, crown diameters and crown volume, together with the number, diameter and length of primary scaffold, secondary and tertiary branches and annual shoots. Aboveground biomass (AGB) is partitioned into trunk, structural branches, annual shoots, leaf biomass and fruit components. Fresh mass is determined for each biomass compartment and representative subsamples are oven dried to derive dry matter content

and component specific dry biomass. For woody components, measured or geometrically estimated fresh volume can additionally be related to oven dry mass to derive basic density parameters. Belowground biomass (BGB) is characterized separately using diameter based root classes, including primary roots (>5 mm), secondary roots (1-5 mm) and fine roots (<1 mm), followed by the same fresh-mass and dry-matter determination procedure. This component level approach enables the direct estimation of AGB and BGB at the individual plant level and their subsequent quantification on a per unit area basis using crop and production system specific planting densities. Biomass estimates are subsequently converted into carbon stocks using measured or appropriate carbon fractions and aggregated by species, age class and production system.

The proposed framework was developed as a standardized methodological approach for generating country specific biomass parameters and the empirical data required for Tier 2 biomass and carbon stock estimation in perennial fruit production systems. The methodology integrates orchard stratification, standardized field measurements, plant level biometric characterization, component specific biomass assessment, dry matter determination, and conversion of individual-plant biomass to area-based estimates according to planting density. Particular emphasis is placed on establishing a consistent measurement protocol applicable across fruit species, orchard age classes, and production systems, while accounting for differences in plant architecture and management intensity.

The resulting dataset provides the empirical basis for developing and subsequently validating species- and production-system-specific allometric models using readily measurable biometric predictors, including trunk diameter, plant height, and crown dimensions. By linking standardized field measurements with biomass estimation and stratified aggregation, the proposed framework establishes a reproducible field to inventory methodology for developing country specific Tier 2 biomass and carbon-stock parameters for perennial fruit crops. This approach addresses key methodological limitations associated with the use of generalized Tier 1 parameters and may contribute to a more accurate representation of perennial fruit production systems within national Agriculture, Forestry and Other Land Use (AFOLU) greenhouse gas inventories. Its implementation could improve the accuracy and transparency of national biomass carbon-stock estimates and strengthen the assessment of the contribution of perennial fruit production systems to climate change mitigation.

Keywords: *above-ground biomass; below-ground biomass; carbon stock; perennial fruit crops; Tier 2 methodology*

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PEM-BASED SYSTEM FOR ENRICHING LOW-LEVEL TRITIUM IN ENVIRONMENTAL WATER SAMPLES

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Tritium is a radioactive isotope of hydrogen with a wide range of applications, including atmospheric and hydrogeological studies, authentication of natural products, and its use as an important parameter in nuclear monitoring programs. To improve the detection limits of tritium in low-level water samples, prior enrichment of the sample is required. The conventional method, alkaline electrolytic enrichment (AEC), presents several disadvantages, including its labor-intensive nature and the need to handle and safely store hazardous chemicals used during electrolysis and/or subsequent neutralization.

In this study, we propose an alternative to alkaline electrolytic enrichment: a tritium electrolytic enrichment system based on solid polymer electrolyte membranes (PEM), capable of enriching tritium in environmental water samples. Tritium enrichment is achieved by reducing a 1000 mL water sample to 10 mL through electrolysis under near-ambient conditions, followed by transfer of the enriched sample to a collector. The novel aspects of the PEM device include its simplicity in construction, maintenance, and operation.

Compared to conventional AEC systems, the proposed method eliminates the need for hazardous chemical electrolytes and neutralizing agents. The enriched sample does not require distillation prior to conventional liquid scintillation counting (LSC) and does not require the highly precise gravimetric control typical of AEC systems. Furthermore, it does not require costly thermal regulation or extensive hydrogen gas management infrastructure.

Keywords: *Tritium enrichment, LSC, environmental monitoring, proton exchange membrane*.

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FROM DEFAULT VALUES TO COUNTRY-SPECIFIC DATA: METHODOLOGICAL ADVANCES IN ROMANIA'S *AFOLU* GREENHOUSE GAS INVENTORY

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Romania's National Greenhouse Gas Inventory (NGHGI) for the Agriculture, Forestry and Other Land Use (AFOLU) sector is undergoing a progressive transition from approaches relying predominantly on default parameters and aggregated activity data towards country-specific datasets and higher-tier estimation methods, in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2006; IPCC, 2019). This transition is particularly relevant for agriculture and land use, land-use change and forestry (LULUCF), where greenhouse gas (GHG) emissions and removals are strongly influenced by national pedoclimatic conditions, land-use patterns, agricultural management practices and livestock production systems. improving their representation therefore requires coherent methodologies integrating experimental measurements, statistical and administrative information, geospatial datasets and uncertainty assessment.

An important framework for this process was established through Romanian Government Decision No. 1415/2024, which defines the responsibilities for the administration of the agriculture and LULUCF subdomains of the national GHG inventory. Within this framework, the National Research and Development Institute for Cryogenic and Isotopic Technologies - ICSI Râmnicu Vâlcea has responsibilities related to the technical and methodological development of both components, including the development and assessment of country-specific parameters, uncertainty evaluation, quality assurance/quality control (QA/QC), methodological documentation and technical support for their integration into INEGES.

For LULUCF, current developments address both activity data and carbon stock parameters. Land-use and land-use change representation is being improved through the integration of geospatial and high-resolution Earth observation datasets, aiming to increase the spatial accuracy and temporal consistency of land-use areas and transition matrices. Particular attention is given to non-forest land categories and to reducing artificial transitions generated by differences among data sources and classification systems.

In parallel, country-specific parameters are being developed to support tier 2 approaches for living biomass and soil organic carbon (SOC). For Cropland and Grassland, direct measurements of above- and below-ground biomass, carbon characterization and information on vegetation and management are integrated to derive parameters representative of Romanian conditions. For heterogeneous categories such as Settlements, the methodology differentiates impervious surfaces, turfgrass, gardens and wooded urban components and associates these classes with appropriate biomass and SOC information.

For Agriculture, the methodological framework combines experimental measurements, laboratory characterization, national statistics, farm-level information, surveys and process-based modelling. Studies focus primarily on parameters associated with enteric fermentation, manure management and agricultural soils. Livestock characterization includes animal categories, breed structure, live weight, production performance, feeding systems and feed characteristics, providing information required for higher-tier estimation of enteric fermentation emissions.

For manure management, experimental activities include determination of the maximum methane producing capacity (B_0) of cattle manure. representative sampling is combined with gravimetric characterization and controlled anaerobic digestion according to VDI 4630 principles. QA/QC procedures include blank correction, positive controls, replicate analyses and criteria for confirming test completion, providing an experimental basis for reducing reliance on default methane-production parameters.

A major research direction also concerns agricultural crop residues, representing an important methodological link between Agriculture and LULUCF subdomains. For representative annual crops, the main harvested product, above-ground residues and below-ground biomass are quantified, together with dry matter, carbon and nitrogen contents. These data support the derivation of country-specific parameters describing residue-to-product relationships, below-ground biomass and biomass composition. The approach also evaluates residue management pathways, including residues remaining on the field and those removed for feed, bedding, energy, construction or other uses, allowing generic assumptions to be progressively replaced by crop specific information representative of romanian agricultural systems.

For agricultural soils, methodological developments address nitrogen inputs and transformation pathways using national datasets and modelling approaches.

Nitrogen losses associated with agricultural management are investigated together with inputs from organic amendments, including sewage sludge and compost. Process based modelling integrates climate, soil and management information to account for the spatial variability of nitrogen related processes.

Overall, these developments establish a methodological chain linking primary measurements, laboratory characterization, statistical and geospatial information, country-specific parameters, uncertainty and QA/QC, and inventory integration. By combining nationally representative data with the methodological requirements of the 2006 IPCC guidelines and the IPCC 2019 refinement, this framework supports the transition from default Tier 1 assumptions towards Tier 2 approaches where national data allow. The resulting datasets and methodologies are intended for progressive integration into NGHGI, with several improvements supporting the 2027 reporting cycle and subsequent submissions. their implementation is expected to enhance the representativeness of AFOLU estimates while supporting the TACCC principles of transparency, accuracy, completeness, comparability and consistency, and to strengthen the scientific basis for higher-tier GHG reporting in Romania.

Keywords: *AFOLU; greenhouse gas inventory; Tier 2; country-specific parameters; LULUCF; Agriculture.*

Acknowledgments

This work was carried out within the framework established by Romanian Government Decision No. 1415/2024 for the national greenhouse gas inventory, Agriculture and LULUCF subdomains, and was financially supported by the Administration of the Environmental Fund (AFM), Romania, under Financing Agreement No. 800/M/30.12.2024. the authors acknowledge the Romanian institutions providing the statistical, administrative and geospatial datasets supporting the national GHG inventory activities addressed in this work.

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GRAPE POMACE VALORIZATION FOR A RESILIENT FUTURE: ADVANCING CIRCULAR PATHWAYS TOWARD VALUE-ADDED BIOPRODUCTS, CLIMATE ACTION AND ENVIRONMENTAL SUSTAINABILITY

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Grape pomace, the major solid by-product of the winemaking industry, represents an abundant yet underutilized biomass with significant potential for sustainable valorization. Its complex composition, rich in polyphenols, flavonoids, anthocyanins, and other bioactive compounds, makes grape pomace a promising feedstock for the development of high-value products while reducing the environmental burden associated with its disposal (Trif et al., 2026). Biofuels derived from biomass, including grape pomace, can contribute to climate-neutrality pathways by replacing fossil fuels, reducing greenhouse-gas emissions, and valorizing renewable carbon resources (Taifouris et al., 2023). By integrating resource recovery, renewable energy generation, and the production of high-value bioproducts, grape pomace valorization offers a promising pathway for advancing circular bioeconomy principles, reducing environmental burdens, and contributing to climate action and the resilience of agri-food systems (Sirohi et al., 2020).

This contribution explores innovative circular pathways for the integrated valorization of grape pomace within the framework of the circular bioeconomy. Particular emphasis is placed on the recovery of bioactive compounds and their conversion into value-added bioproducts for food, and cosmetic applications. The integration of green extraction technologies, biomass fractionation, bioconversion, and cascading valorization strategies is discussed as a means of maximizing resource efficiency and minimizing waste generation. In parallel, the residual lignocellulosic fraction can be further valorized for the production of renewable energy vectors, such as bioethanol and biohydrogen. The resulted residue can be used as soil amendments, supporting a zero-waste approach. Such integrated strategies can help mitigate greenhouse gas emissions, reduce reliance on fossil-derived resources, and foster more sustainable and resource-efficient agro-industrial production systems.

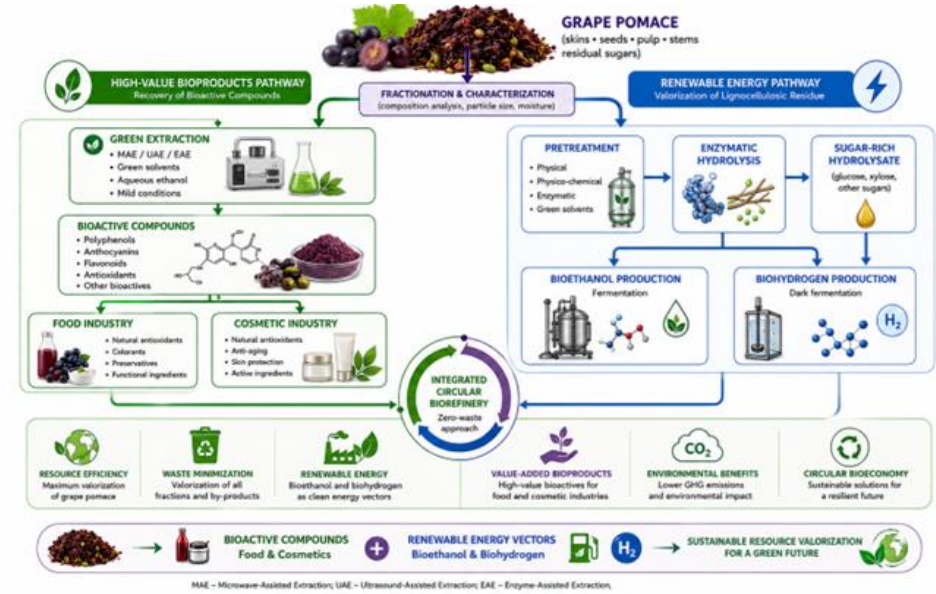


Figure 1. Integrated and sustainable biorefinery strategy for the cascade valorization of grape pomace

Polyphenolic ingredients derived from grape pomace were obtained through sequential enzymatic and microwave-assisted extraction, followed by extract purification and comprehensive characterization. The obtained polyphenolic extracts exhibited high extraction yields, reaching 1550 mg/100 g of white grape marc and 3150 mg/100 g of red grape marc. They were characterized by a high polyphenolic content and strong antioxidant activity, as well as antimicrobial activity against the tested bacterial strains, including S. aureus, E. faecalis, P. mirabilis, and P. aeruginosa. Moreover, the extracts exhibited good biocompatibility with the HaCaT human keratinocyte cell line, highlighting their potential for dermatological applications, particularly in chronic wound management (Geana et al., 2025).

Beyond the recovery of bioactive compounds, grape pomace was successfully converted into renewable energy carriers. Thus, bioethanol was obtained from grape pomace through ultrasound-assisted autohydrolysis pretreatment, followed by simultaneous enzymatic saccharification and fermentation (SSF) using hydrolytic and detoxification enzymes and *Saccharomyces cerevisiae*. The resulting fermentation mixture was separated by centrifugation, followed by bioethanol recovery through distillation and dehydration and subsequent determination of its purity. Bioethanol production from white grape pomace (*Vitis vinifera* L.) reached a yield of 0.21 mL/g dry grape pomace, with a final purity of 92.55%. Biohydrogen was produced from grape pomace through ultrasound-assisted autohydrolysis pretreatment, followed by enzymatic hydrolysis using hydrolytic enzymes. The resulting hydrolysate was subsequently subjected to dark anaerobic fermentation in the presence of *Clostridium beijerinckii*, and the generated gas mixture was collected and analyzed by GC-TCD. The

process allows for the production of biohydrogen with a yield of 52 NmL H_2/g dry grape pomace, the hydrogen content in the gas mixture being 56.26%.

These results highlight the significant potential of grape pomace as a valuable and versatile feedstock for the production of high-value bioactive compounds and renewable energy vectors. The recovery of polyphenolic ingredients with antioxidant and antimicrobial properties, together with the successful production of bioethanol and biohydrogen, demonstrates the feasibility of converting this agro-industrial by-product into products with applications in food, cosmetic, dermatological, energy, and mobility sectors. Such an integrated valorization approach can improve biomass resource efficiency, minimize waste generation and the associated environmental impacts. Moreover, the conversion of its organic fractions into renewable fuels can contribute to reducing dependence on fossil-derived resources and greenhouse gas emissions, while supporting the development of more sustainable mobility and energy systems. Overall, the valorization of grape pomace represents a promising pathway for advancing circular bioeconomy models, strengthening resource efficiency, and contributing to climate action and the transition toward more sustainable agro-industrial production systems.

Keywords: *winemaking by-product, value-added products, circular bioeconomy, biofuels*

Acknowledgments

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LIGNIN AS A NATURAL RESOURCE FOR INNOVATIVE MATERIALS: ADVANCING CIRCULAR BIOECONOMY, CLIMATE ACTION AND ENVIRONMENTAL SUSTAINABILITY

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Lignin, one of the most abundant natural aromatic polymers, represents a largely underutilized renewable resource with significant potential for the development of sustainable, value-added materials. As a major component of lignocellulosic biomass, lignin is generated in large quantities as a by-product of agricultural, forestry, and industrial bioprocesses, yet it is still predominantly used for low-value applications or energy recovery (Sethupathy et al., 2022). Unlike cellulose and hemicellulose, which form the polysaccharide fraction of lignocellulosic biomass, lignin is a complex aromatic polymer composed mainly of p-hydroxyphenyl, guaiacyl, and syringyl units derived from p-coumaryl, coniferyl, and sinapyl alcohols, respectively. Their proportions vary among biomass types, and their diverse interunit linkages form a complex three-dimensional polymer network (Liao et al., 2020). The valorization of lignin within integrated biorefinery systems can reduce biomass waste, promote resource efficiency, and create new value chains while decreasing dependence on fossil-derived raw materials. In this context, lignin-based materials offer a promising pathway toward circular bioeconomy models, contributing simultaneously to climate action, waste minimization, and long-term environmental sustainability (Tardy et al., 2023).

In our experiments, lignin was recovered from black liquor generated during the microwave-assisted organosolv and alkaline pretreatment of lignocellulosic biomass, specifically corn stalks and wheat straw. The cellulose fibers were separated by filtration from the alcoholic lignin-containing solution, after which lignin was recovered from the residual solution by precipitation with concentrated sulfuric acid followed by centrifugation at 6000 rpm. Characterization of separated solid has been made by elemental analysis, Fourier Transform Infrared Spectroscopy (FTIR), and Flame Atomic Absorption Spectroscopy.

The infrared spectra of lignin extracted by precipitation with sulfuric acid and dried in laboratory ambient is show in Fig. 1, while the elemental composition and

metals content are presented in Table 1. The FTIR spectrum of the extracted lignin (Fig. 1) exhibits the characteristic absorption bands associated with the aromatic and oxygenated functional groups of lignin, such as specific absorption of aliphatic and aromatic C-O bonds vibrations, at 1028 cm^{-1}, confirming the successful recovery of a lignin-rich fraction from the pretreatment liquor. The extracted lignin exhibits a high carbon content of 53.56%, confirming its predominantly carbonaceous and aromatic nature and supporting its potential as a renewable precursor for the production of value-added carbonaceous and polymeric materials. The hydrogen content of 6.34% is consistent with the presence of aliphatic and phenolic structures, while the relatively low nitrogen content (1.73%) indicates limited incorporation of nitrogen-containing compounds in the recovered lignin fraction. The sulfur content is very low (0.45%), suggesting a well removing of the sulfuric acid residue. The low concentrations of Ca, K and Fe suggest that the pretreatment and lignin-recovery procedures were effective in limiting the accumulation of several inorganic components in the recovered lignin. The presence of residual mineral elements is nevertheless expected, since lignocellulosic biomass naturally contains inorganic constituents and some may remain associated with lignin during precipitation and recovery.

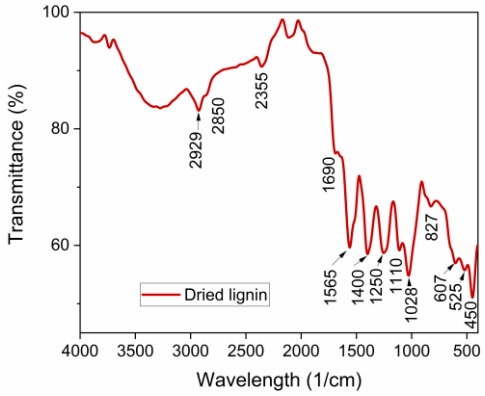


Figure 1. FTIR spectra of extracted lignin

Table 1. Elemental and mineral composition of lignin sample

Sample	Elemental analysis				Metal composition					
	%C	**%H**	**%N**	**% S**	**%Ca**	**%Mg**	**%Na**	**%K**	**%Fe**	**%Zn**
Lignin	53.56	6.34	1.73	0.45	0.029	0.017	0.68	0.11	0.028	0.003

Due to aromatic structure and functional groups attached to aromatic ring, lignin could be a precursor for energy storage materials in battery and capacitors (Trezza et al., 2025). As valuable additive in bio-plastics and cosmetics, lignin can increase the antioxidant, antimicrobial and UV-protective properties. Moreover, lignin-derived fertilizers and soil amendments are sustainable and cost-effective

solutions to improve soil health, enhance crop productivity, and address environmental challenges.

Keywords: *lignocellulosic biomass, lignin, renewable advanced material*

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PHYSICOCHEMICAL CHARACTERIZATION AND ECOLOGICAL RISK ASSESSMENT OF DIGESTATES DERIVED FROM THE ANAEROBIC DIGESTION OF PRETREATED LIGNOCELLULOSIC BIOMASS

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The transition toward a circular and sustainable bioeconomy requires the efficient use of renewable resources and the reduction of waste. Anaerobic digestion enables the conversion of organic residues into biomethane while simultaneously producing digestate, a nutrient-rich co-product with potential applications as an organic fertilizer or soil amendment. Lignocellulosic biomass represents an important resource for bioenergy production; however, its complex structure limits its biodegradability and conversion efficiency (Cai et al., 2021). For this reason, various pretreatment methods, including acidic, alkaline, oxidative, and organosolv processes, are employed to enhance biomethane production. Nevertheless, these treatments may also affect digestate composition by generating or leaving behind potentially toxic compounds (Li et al., 2026). The utilization of digestate in agriculture can support nutrient recycling, reduce dependence on synthetic fertilizers, and contribute to the development of circular biorefinery systems. However, its environmental suitability depends on its physicochemical composition, which can vary with feedstock characteristics, pretreatment methods, and anaerobic digestion conditions (Chojnacka & Moustakas, 2024). Therefore, ecological risk assessment is essential to complement physicochemical characterization and evaluate the environmental suitability of digestate valorization (Proskynitopoulou et al., 2026). In this context, the study aims to characterize the physicochemical and ecological risk assessment of digestates obtained through anaerobic digestion of pretreated lignocellulosic biomass (wheat straw, corn stalk, beech and spruce sawdust), mixed with sludge from the wastewater treatment plant. Digestates resulting from acidic, alkaline, oxidative and organosolv pretreatments were characterized by determining pH, electrical conductivity, nutrient content (K, total nitrogen, total phosphorus), mineral elements (Ca, Mg, Na), heavy metals (Mn, Fe, Zn, Cd, Ni, Pb, Cu, As and Cr) and polycyclic aromatic hydrocarbons. The potential ecological risk associated with the presence of heavy metals was assessed by the ecological risk factor (Er) and the

potential ecological risk index (PERI), according to the methodology proposed by Håkanson (Håkanson, 1980).

The analysis of physicochemical properties revealed that both the nature of the substrate and the pretreatment method significantly influenced the characteristics of the digestates. The heavy metal content varied according to both the substrate and pretreatment applied; however, the concentrations remained within ranges generally reported for organic materials derived from biological processes. In the solid fraction, Fe was the predominant element, whereas Cd, Pb, Ni, Cu, Zn, As, and Cr were detected at substantially lower concentrations. The pretreatments applied altered the distribution of metals between the liquid and solid phases without leading to significant accumulations of toxic elements. The assessment of potential ecological risk based on the Er (Fig. 1) and PERI (Fig. 2) indices indicated values corresponding to a low ecological risk for most of the samples analyzed. Although cadmium exhibited the highest individual risk factor due to the high toxicological risk attributed to this element, the total PERI index values remained below the threshold of 150, corresponding to a low ecological risk. These results demonstrate that the use of digestates derived from the analyzed lignocellulosic biomass does not pose a significant ecotoxicological risk under controlled agricultural application conditions.

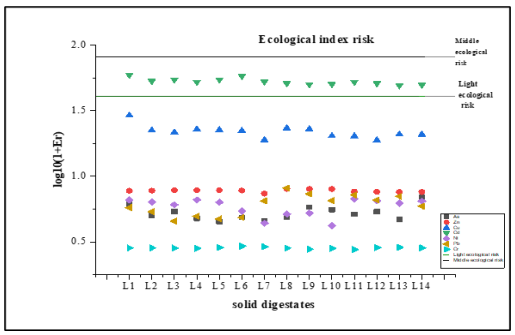


Fig. 1. Ecological Risk Index for the solid digestates

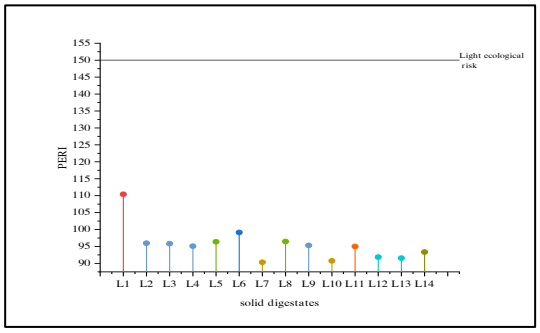


Fig. 2. Potential Ecological Risk Index for the solid digestates

Overall, the results highlight that pretreatment of lignocellulosic biomass is an effective tool for controlling the degradation of organic matter and for modifying the nutritional properties of digestates. The liquid fraction has high potential as a fertilizer due to its soluble nutrient content, particularly nitrogen and potassium, while the solid fraction can be utilized as an organic soil amendment due to its phosphorus, potassium, and stable organic matter content. Assessments of heavy metals and environmental risk confirm the safety of the resulting digestates, supporting their integration into sustainable agricultural practices and circular management strategies for residual biomass. The measured polycyclic aromatic hydrocarbons (PAHs) values in the digestates were within the normal values corresponding to soils, indicating the potential agricultural valorization of the digestate, as PAHs may pose environmental risks due to their

persistence, bioaccumulation potential, and adverse effects on soil organisms and plants. Overall, the results support the environmental compatibility and potential safe reuse of the solid digestate, although further assessment under long-term soil application conditions would be necessary to confirm its ecological safety.

The study investigates the influence of biomass pretreatment on key physicochemical properties, nutrient composition, residual organic matter, and the presence of potentially hazardous constituents. Furthermore, the ecological implications of digestate characteristics are evaluated to assess its environmental compatibility and potential for safe valorization, particularly in agricultural applications. By integrating resource recovery with environmental risk evaluation, this work seeks to contribute to the development of more sustainable and circular lignocellulosic biomass conversion pathways in which renewable energy production is coupled with the responsible management and valorization of anaerobic digestion residues.

Keywords: *lignocellulosic biomass, digestate, biofertilizers, soil amendments*

Acknowledgments

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MINERALOGICAL PROFILING AND CHEMICAL PARAMETER ASSESSMENT OF ROMANIAN HONEY: REGIONAL AND TEMPORAL VARIABILITY ANALYSIS

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Honey plays an important role in the human diet and also has traditional medicinal significance due to its antimicrobial properties and wound-healing effects. Honey ranks third among the most commonly adulterated products worldwide. Thus, mineral content can be used to verify honey's authenticity, which is vital for protecting this agricultural product with high market potential.

This study investigates the mineral composition and multivariate differentiation of honey samples collected from two major Romanian regions, Oltenia and Ardeal, with the aim of assessing the relative influence of botanical and geographical origin on their physicochemical characteristics. Six analytical parameters (Ca, Mg, Na, K, electrical conductivity, and pH) were quantified and interpreted using Principal Component Analysis (PCA), one-way ANOVA, and Tukey HSD post-hoc testing. PCA revealed that the first two principal components explained 81.6% of the total variance, with PC1 (59.8%) strongly associated with potassium, magnesium, and electrical conductivity—variables indicative of overall mineralization. Honeydew samples formed a distinct and well-defined cluster on the positive PC1 axis, reflecting their characteristically high mineral content. Floral honeys exhibited greater dispersion, particularly those from Oltenia, whereas samples from Ardeal formed a more compact group, suggesting compositional homogeneity.

ANOVA results indicated that sodium (Na) was the only parameter showing statistically significant regional differences ($p<0.01$), a finding confirmed by Tukey HSD post-hoc analysis. All other minerals and physicochemical parameters showed no significant variation between regions, highlighting the dominant role of botanical origin over geographical factors. Overall, the study demonstrates that mineral profiling combined with multivariate statistics provides a robust approach for differentiating honey types, particularly in distinguishing honeydew from floral honeys. The results further suggest that while regional influences exist, especially

for sodium, the botanical source remains the primary determinant of honey composition.

Keywords: *honey composition; mineral content; PCA; honey authentication; botanical origin.*

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VALIDATION AND APPLICATION OF A DNS METHOD FOR MONITORING REDUCING SUGAR CONSUMPTION DURING ANAEROBIC DARK FERMENTATION AND BIOHYDROGEN PRODUCTION

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Lignocellulosic agricultural residues such as wheat straw and corn cobs constitute abundant and renewable raw materials that can be valorised to biofuels through biological fermentation processes, offering a sustainable alternative to conventional feedstocks (Rajesh Banu et al., 2021). Reducing sugars, including monosaccharides and oligosaccharides (e.g. glucose, xylose, arabinose) released from cellulose and hemicellulose after pretreatment and hydrolysis — represent the readily fermentable carbon source directly assimilated by the fermentative microorganisms, their concentration in the substrate being directly correlated with biohydrogen yield and process efficiency. A key parameter for monitoring and optimising the upstream stages of this process is therefore the content of reducing sugars released after alkaline-oxidative pretreatment and enzymatic hydrolysis of the biomass (Liu et al., 2021). The present work reports the development and validation of a colorimetric method, based on the 3,5-dinitrosalicylic acid (DNS) reaction (Miller, 1959), for the quantification of reducing sugars in dark fermentation mixtures derived from lignocellulosic biomass.

Wheat straw (WS) and corn stalks (CS) were subjected to alkaline-oxidative pretreatment followed by enzymatic hydrolysis to release fermentable sugars. The resulting hydrolysates were subsequently subjected to anaerobic dark fermentation using *Clostridium beijerinckii* (CB) and Clostridium acetobutylicum (CA) strains. The DNS reaction was developed thermally at 99 °C using a Spectroquant® TR 320 thermoreactor, and the resulting absorbance was measured with a Spectroquant® Prove 300+ spectrophotometer. Calibration standards containing 0, 250, 500, 1000, 1500, 2000, 3000, 4000, and 5000 mg/L glucose were prepared by serial dilution of a 5 g/L glucose stock solution. The analytical method was validated in terms of linearity, limits of detection (LOD) and quantification (LOQ), precision (repeatability), accuracy, and recovery. The calibration curve demonstrated

excellent linearity across the concentration range of 0–5000 mg/L, described by the regression equation y = 0.0003426x + 0.0578, with an R^2 value of 0.9967 (Fig. 1). Based on five blank determinations, the LOD and LOQ were estimated at 248.21 mg/L and 293.03 mg/L, respectively. Repeatability was evaluated through seven replicate measurements of a glucose solution at approximately 1000 mg/L and yielded an RSD of 0.65%. Accuracy was assessed using a 2000 mg/L reference standard, resulting in a relative error of 1.84%. Recovery was evaluated by spiking an effluent sample with 500 mg/L glucose, corresponding to an initial concentration of 2647 mg/L. Analysis of five replicates resulted in a mean recovery of 83.68%, with individual recovery values ranging from 80.6% to 87.2%.

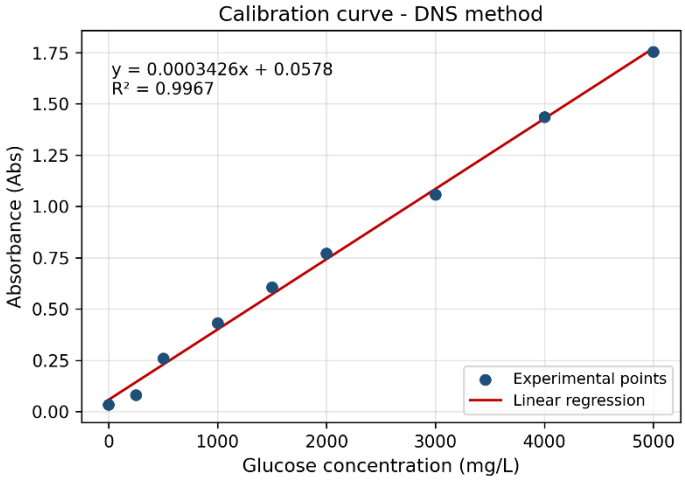


Figure 1. Calibration curve of the DNS method (glucose standards, 0–5000 mg/L).

Reducing sugar content was monitored throughout dark anaerobic fermentation using the validated DNS method, allowing substrate consumption to be correlated with biohydrogen yield and enabling comparison of substrate utilisation efficiency between the two Clostridium strains (Table 1).

Table 1. Reducing sugar consumption and biohydrogen production during anaerobic dark fermentation of lignocellulosic hydrolysates using Clostridium strains

	Reducing sugars (mg/L)		**Substrate consumption (%)**	**Volume of the resulted gas (NmL)**	**H_2 (%)**	**NmL H_2**
	initial	efluent				
WS-CB	15370	2730	82.23	1437.8	45.11	648.59
WS-CA	15350	2590	83.13	1353.2	43.83	593.11
CS-CB	12220	3320	72.83	1559.1	47.92	747.12
CS-CA	13550	3230	76.16	1254.3	38.96	488.68

WS - wheat straw; CS - corn stalks; CB - *Clostridium beijerinckii*; CA - *Clostridium acetobutylicum*

The results obtained after anaerobic dark fermentation demonstrate that both the type of lignocellulosic hydrolysate and the bacterial strain significantly affected substrate utilization and biohydrogen production. The initial reducing sugar concentrations ranged from 12.220 mg/L for CS-CB to 15.370 mg/L for WS-CB and decreased to 2.590–3.320 mg/L following fermentation, corresponding to substrate consumption of 72.83–83.13% and confirming the effective utilization of fermentable sugars by both CB and CA. Despite the higher substrate consumption observed for the wheat straw systems, the highest biohydrogen production was obtained from the corn stalk hydrolysate fermented with CB. The CS-CB system produced 1559.1 NmL of total gas, with a hydrogen concentration of 47.92%, corresponding to 747.12 NmL H_2. This was the highest hydrogen production among all tested variants. In comparison, WS-CB generated 1437.8 NmL of gas containing 45.11% H_2, corresponding to 648.59 NmL H_2. The CA-based systems showed lower performance, producing 593.11 NmL H_2 from wheat straw and only 488.68 NmL H_2 from corn stalks. The comparison between the two microorganisms indicates that CB was more effective than CA for biohydrogen production under the investigated conditions. For wheat straw, the use of CB resulted in an approximately 9.3% higher hydrogen production than CA, whereas for corn stalks the difference was considerably greater, with CB producing approximately 53% more hydrogen than CA. This pronounced difference suggests that CB may have exhibited better adaptation to the composition of the hydrolysates or a more favourable metabolic distribution of the consumed sugars toward hydrogen-producing pathways.

The results demonstrate that the developed DNS method is robust, accurate, linear over a wide concentration range (0–5000 mg/L) and suitable for routine monitoring of reducing sugars in complex fermentation matrices, providing a useful analytical tool for optimizing the technological flow of dark fermentation. The reliable and rapid quantification of reducing sugars allows real-time tracking of substrate depletion and supports process control decisions, such as adjusting the feeding strategy or hydraulic retention time, which are essential for increasing bioheterogeneous production from agricultural residues.

Keywords: *reducing sugars, DNS method, analytical validation, dark fermentation.*

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SUGAR CONVERSION AND ORGANIC METABOLITE FORMATION DURING THE DARK FERMENTATION OF LIGNOCELLULOSIC BIOMASS

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Lignocellulosic biomass including agricultural residues, agro-industrial by-products, and energy crops, represents one of the most important renewable sources of sustainable energy, which can be efficiently exploited by transforming it into energy vectors, such as bioethanol, biomethane, biohydrogen, biohytan and biodiesel (Ntunka et al., 2025). However, the complex and recalcitrant structure of lignocellulosic biomass limits the direct accessibility of fermentable carbohydrates to hydrogen-producing microorganisms. Therefore, an appropriate pretreatment step is generally required to disrupt the lignin–carbohydrate matrix, reduce biomass recalcitrance, increase the accessible surface area, and enhance the subsequent enzymatic or microbial conversion of cellulose and hemicellulose into fermentable sugars (Shanmugam et al., 2021). The resulting sugar-rich hydrolysate can be converted into biohydrogen through dark fermentation, an anaerobic process in which microorganisms metabolize carbohydrates to produce hydrogen and carbon dioxide, along with soluble fermentation metabolites such as volatile fatty acids, organic acids, and alcohols (Gull et al., 2025). Monitoring sugars and soluble organic metabolites during fermentation provides information on substrate utilization and metabolic evolution.

This study aims to investigate the conversion of soluble sugars and the formation of organic metabolites during the dark anaerobic fermentation of pretreated wheat straw (PG) and corn stalks (CP) for biohydrogen production. For that, sugars (xylose, arabinose, fructose, glucose, sucrose, and lactose) were analyzed by HPLC-CAD, organic acids (formic, lactic, acetic, succinic, propionic, and butyric acids) by HPLC-DAD, and alcohols (methanol, isopropanol, ethanol, isobutanol, propanol, and butanol) by GC-FID.

Apparent sugar consumption was calculated from the difference between initial and final total sugar concentrations (Figure 1). PG showed an initial total soluble sugar concentration of 12.79 g/L, mainly represented by glucose (8.75 g/L),

xylose (1.97 g/L) and fructose (1.78 g/L). After fermentation, residual sugars decreased to 1.19 g/L, corresponding to an apparent consumption of 90.7%. Glucose and fructose were no longer detected, while arabinose remained at 1.19 g/L. CP started with 11.47 g/L total soluble sugars, mainly glucose (7.40 g/L), xylose (2.13 g/L) and fructose (1.70 g/L). After fermentation, residual sugars decreased to 2.65 g/L, corresponding to an apparent consumption of 76.9%. Glucose and fructose were no longer detected and residual xylose was 1.47 g/L.

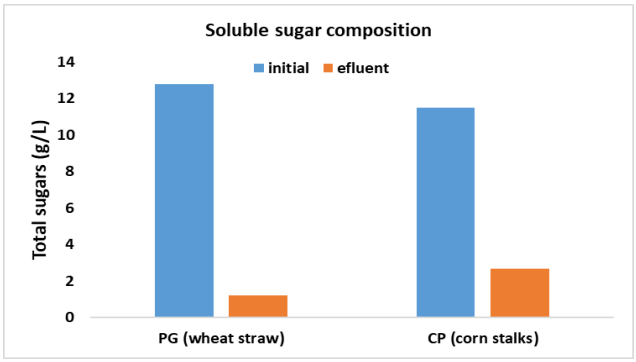


Figure 1. Total soluble sugars before and after fermentation.
Apparent consumption: PG = 94.4%; CP = 98.0%.

The profiles of organic acids differed markedly between the two experiments (Figure 2a). In the PG experiment, lactic acid decreased substantially from 4.87 to 1.16 g/L, while succinic acid declined from 1.60 to 0.12 g/L. In contrast, acetic and butyric acids increased, reaching final concentrations of 0.88 and 0.76 g/L, respectively. A more pronounced shift in the organic-acid profile was observed in the CP experiment, characterized primarily by the substantial accumulation of butyric acid, which increased from undetectable levels to 3.86 g/L. Lactic acid also decreased considerably, from 4.90 to 0.99 g/L, whereas acetic acid accumulated from 0.31 to 1.86 g/L. Overall, these results indicate distinct metabolic pathways and fermentation patterns in the two experimental systems.

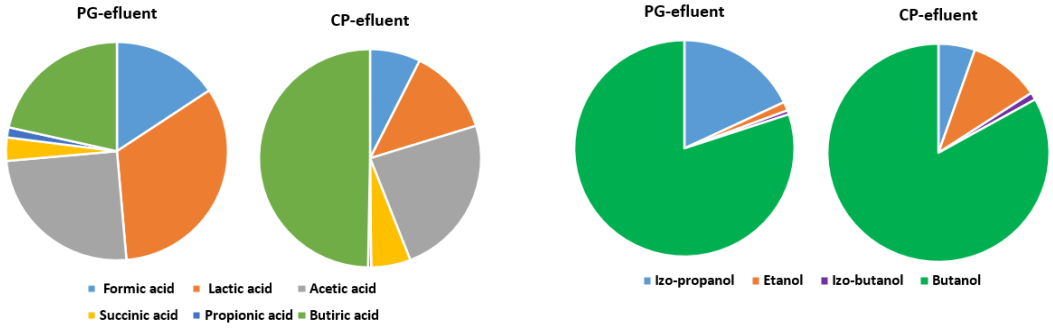


Figure 2. Profile of the organic metabolites in the dark fermentation effluents (PG – wheat straw, CP-corn stalks): (a) organic acids and (b) alcohols

The alcohol profile of the PG effluent after the hydrogen fermentation stage provides additional insight into the metabolic pathways involved in substrate conversion. A clear predominance of n-butanol was observed, reaching a concentration of 1.34 g/L, whereas the concentrations of isopropanol (0.30 g/L), ethanol (0.02 g/L), and isobutanol (0.01 g/L) remained comparatively low (Figure 2b). The alcohol profile of the CP effluent following the hydrogen fermentation stage was characterized by relatively low concentrations of all detected metabolites (Figure 2b). Among the alcohols identified, n-butanol was the predominant compound, reaching 0.401 g/L, followed by ethanol at 0.050 g/L, isopropanol at 0.026 g/L, and isobutanol at only 0.005 g/L. Although butanol remained the major alcohol product, its concentration was approximately 3.3-fold lower than that observed in the PG effluent, indicating a substantially lower contribution of solventogenic metabolism in the CP fermentation system. The preferential accumulation of butanol suggests that a significant fraction of the carbon derived from the fermentable substrate was directed toward solventogenic metabolism.

Both feedstocks showed substantial sugar utilization, 90.7% for PG and 76.9% for CP, but exhibited distinct metabolite profiles. CP showed a predominance of butyric acid, a pathway generally associated with hydrogen production, while PG exhibited stronger solvent formation, particularly butanol. These results highlight the importance of monitoring sugars, organic acids and alcohols to assess substrate conversion and fermentation pathways.

Keywords: *lignocellulosic biomass; wheat straw; corn stalks; dark anaerobic fermentation; organic metabolites*

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FTIR-BASED FINGERPRINTING OF SOIL, FEED, MILK AND CHEESE FOR TRACEABILITY ASSESSMENT IN TWO ROMANIAN DAIRY PRODUCTION REGIONS

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The growing consumer demand for the authentic, high-quality, and traceable food products has intensified the need for reliable analytical tools able to link the food characteristics with the geographical origin and production systems. The traditional dairy products are strongly influenced by the environmental conditions, local feed resources, animal management practices, and processing technologies. As a consequence, the identification of the analytical signatures able to describe the entire production chain represents an important step toward improving the food traceability and protecting the regional products. Fourier Transform Infrared (FTIR) spectroscopy has emerged as a rapid, non-destructive, and environmentally friendly analytical technique for the food authentication and quality assessment, while the chemometric approaches enable the extraction of relevant information from the complex spectral datasets [Saji et al., 2024].

The present study investigated the applicability of ATR-FTIR spectroscopy combined with multivariate statistical analysis for the characterization and traceability assessment of samples collected along the soil–feed–milk–cheese chain in two traditional Romanian dairy production regions: Ibănești–Gurghiu (Mureș County) and Vaideeni (Vâlcea County). These regions are characterized by distinct environmental conditions, feeding practices, and dairy processing traditions, providing an appropriate framework for evaluating the transfer of the compositional signatures throughout the production chain.

Representative soil, feed, milk, and cheese samples were analysed using ATR-FTIR spectroscopy in the mid-infrared region (4000–400 cm^{-1}). The obtained spectra revealed the characteristic absorption bands associated with the organic matter, proteins, lipids, carbohydrates, and mineral-related functional groups. In the dairy products, the major absorption features were observed in the regions corresponding to the O–H and N–H stretching vibrations (3600–3000 cm^{-1}), aliphatic C–H stretching of fatty acids (2950–2850 cm^{-1}), ester carbonyl groups (~1740 cm^{-1}), amide I and amide II bands (1700–1500 cm^{-1}), and carbohydrate-associated vibrations within the fingerprint region (1200–900 cm^{-1}). The differences of the band intensities and spectral profiles highlighted the compositional

variability among the investigated matrices and reflected the influence of environmental conditions and feed composition on dairy products.

To evaluate compositional relationships and traceability potential, Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were applied to the spectral dataset. PCA revealed that the first two principal components explained approximately 80% of the total spectral variance, indicating that the dominant sources of variability were effectively captured by the model. The resulting score distributions highlighted matrix-dependent clustering patterns and suggested the presence of region-specific compositional signatures. The observed clustering behaviour indicated that the FTIR fingerprints retained information associated with the production environment and may support the identification of traceability links between soil, feed, milk, and derived dairy products. Similar applications of FTIR spectroscopy combined with chemometric methods have successfully discriminated dairy products according to species and geographical origin [Tarapoulouzi et al., 2020; Duliński et al., 2025].

The results demonstrated that ATR-FTIR spectroscopy coupled with chemometric analysis may provide a rapid, cost-effective, and sustainable approach for investigating the complex agri-food systems. The proposed methodology may give valuable perspectives for the geographical authentication, quality control, and traceability assessment of traditional dairy products and may contribute to the development of integrated analytical strategies for protecting the regional food heritage.

Keywords: *ATR-FTIR spectroscopy; dairy products; milk; cheese; chemometrics; PCA; HCA; food authentication.*

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ELEMENTAL PROFILING AND ENVIRONMENTAL CONTAMINANT ASSESSMENT IN TOMATO-BASED PRODUCTS USING *ICP-OES* AND CHEMOMETRIC ANALYSIS

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Tomatoes and tomato-based products are worldwide extensively consumed and may represent an important pathway for the human exposure to environmental contaminants, including potentially toxic metals. Nevertheless, the occurrence and distribution of the trace and major elements across various tomato-derived products and geographical origins is still insufficiently characterized [Gabriella Lo Feudo, et al., 2010]. The research focused on the elemental composition and contamination patterns of the fresh tomatoes and processed products, including juices, tomato puree, tomato paste, and ketchup, originating from Romania, as well as from other European Union and non-European countries. Multi-element determination was performed using inductively coupled plasma optical emission spectrometry (ICP-OES), targeting essential elements (Fe, Zn, Cu, Mn, Co, Cr, and Li), potentially toxic metals (Cd, Pb, Ni, Hg, and As), and trace elements associated with the environmental and geographical variability (Sr and V). The results revealed significant variation within the elemental composition as a function of both geographical origin and processing degree. Samples originating from non-European regions exhibited higher concentrations of Cd, Pb, and Ni, revealing an increased influence of the environmental and agricultural contamination sources. In contrast, Romanian products exhibited elemental profiles comparable to those from other European Union countries, suggesting similar quality and exposure levels. Hg and As concentrations were generally low in all the samples, although one sample presented elevated Hg content, suggesting a potential localized contamination source. It was observed that the processing intensity strongly influenced the elemental accumulation [Rosaria Fragni, et al., 2018]. Essential elements concentration (Fe, Zn, Cu, and Mn) significantly increased from the fresh products to the concentrated matrices, with Zn concentration increasing from below 2 mg/kg in juices to over 15 mg/kg in tomato pastes, while Fe exceeded 80 mg/kg in highly processed samples. The ketchup samples exhibited lower concentrations due to the

formulation-related dilution effects. Multivariate statistical analysis demonstrated that the elemental variability was mainly associated with the processing intensity rather than with the contamination patterns. PCA highlighted Fe, Zn, Cu, and Mn as markers of the concentration effects, whereas Cd, Pb, and Hg were related to the contamination sources. Sr displayed a distinct behaviour, supporting its potential use as a geographical traceability marker.

Overall, the study demonstrated that the elemental profiling combined with the chemometric analysis may be applied as a robust approach for the monitoring environmental contaminants, assessing processing-related changes, and supporting authenticity and traceability evaluation in the tomato-based products [Alessandro Zappi, et al., 2022].

Keywords: food safety; environmental contamination; tomato-based products; chemometrics; PCA.

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PRELIMINARY RADIOCHEMICAL ASSESSMENT OF NATURAL MINERAL WATER SAMPLES FROM VÂLCEA COUNTY, ROMÂNIA: SPRING AND SUMMER 2026

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Vâlcea County, Romania, is known for its spa towns offering a variety of natural mineral water therapies. this study represents the first assessment of natural radioactivity in mineral waters from Vâlcea County, aiming to provide baseline radiological data and to evaluate the safety of these widely consumed waters for public use. a number of 20 samples (10 samples per season) of natural mineral water were collected from Băile Govora, Băile Olănești, Călimănești and Căciulata during the spring and summer seasons of 2026, with sampling for autumn and winter currently ongoing as part of a year-round monitoring campaign. Sampling locations were chosen for their accessibility to the general public.

Collected samples were analysed for the activity concentrations of ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K by gamma spectrometry, while ^{3}H was determined using liquid scintillation counting. For preliminary screening, gross alpha and gross beta activity concentrations were measured using a low-background alpha/beta radiometer. The annual effective dose due to ingestion by an adult (2 litres per day) was calculated for each naturally occurring radionuclide. Electrical conductivity and ph were also measured for each sample to establish the relationship between mineralization and radioactivity.

During spring and summer, activity concentrations ranged from below the minimum detectable activity (MDA) up to 2.06 Bq/L for ^{238}U, 0.85 Bq/L for ^{232}Th, 0.20 Bq/L for ^{226}Ra, and 2.04 Bq/L for ^{40}K. For ^{3}H the activity concentration varied from the detection limit (DL) to 7.24 TU. Gross alpha activity concentrations were consistently below the mda, whereas gross beta values ranged from the mda to 1.36 Bq/L. The corresponding annual effective doses due to ingestion reached a peak value of 0.12 mSv/yr, slightly above the 0.10 mSv/yr reference level of individual dose criterion, recommended by the world health organization (WHO). The

electrical conductivity ranged from 543 to 15,180 µS/cm, and the ph levels had a minor variation from 7.23 to 8.25.

A Positive correlation was observed between the electrical conductivity, the gross beta activity concentration, and the ^{40}K activity concentration, consistent with the increased radionuclide mobilization in the highly mineralized water samples.

The results indicate that the annual effective dose due to the ingestion of these natural mineral waters does not present a radiological health risk to consumers, considering that in order to reach the WHO reference level of individual dose criterion, an unrealistic consumption pattern would need to be achieved by the general population.

Keywords: *Natural mineral water, activity concentration, gamma spectrometry, tritium, liquid scintillation counting, effective dose.*

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THORIUM RECOVERY FROM DILUTE AQUEOUS SOLUTIONS BY NANOFILTRATION USING POLYMER–CROWN ETHER COMPOSITE MEMBRANES

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Water is one of the fundamental components of ecosystems and an indispensable resource for public health, agriculture, and industrial activities. Water quality can be affected by both chemical and biological contaminants, as well as by the presence of radioactive substances. Radionuclides can enter surface waters and, particularly, groundwater through natural processes such as the weathering and dissolution of rocks and minerals, as well as through anthropogenic activities, including mineral resource extraction, the nuclear industry, certain industrial activities, and the improper management of radioactive materials. The World Health Organization (WHO) indicates that naturally occurring radionuclides, originating primarily from the uranium and thorium decay series, may be present in rocks, soils, and water and can reach groundwater through leaching processes.

The presence of thorium and its decay products in water may result in human exposure through direct consumption of contaminated water, as well as indirectly through its use in food preparation or through the transfer of radionuclides to living organisms and their subsequent incorporation into the food chain. In the case of radionuclides that emit ionizing radiation, internal exposure is of particular concern, as radionuclides entering the human body may be absorbed, transported, and deposited in specific tissues, where they can cause prolonged irradiation over extended periods.

The significance of this issue is further emphasized by the fact that radioactively contaminated water does not necessarily exhibit visible or sensory changes. In most cases, radionuclides cannot be detected based on the color, odor, or taste of water, making it impossible to assess water safety solely through organoleptic methods. Therefore, water quality monitoring must include analytical methods capable of detecting and quantifying the radionuclides present. Such monitoring is particularly important for groundwater sources, where naturally occurring radionuclides

derived from rocks and minerals may be encountered more frequently than in surface waters.

In this context, the separation of radionuclides from water represents an essential step toward reducing radiological risk and obtaining water with a high degree of purity. Treatment processes should aim not only to remove suspended particles and conventional chemical contaminants, but also to reduce the concentration of radionuclides present in dissolved form or associated with particulate matter. The efficiency of the separation process depends on the chemical speciation of the radionuclide, pH, water composition, the presence of competing ions, and the interactions between radionuclides and solid surfaces.

Various technologies can be employed for the removal of radionuclides from water, including adsorption, ion exchange, membrane processes, coagulation–flocculation, precipitation, filtration, and combinations thereof. The selection of an appropriate technology should be based on the characteristics of the water matrix and the nature of the target radionuclides. In the case of thorium, its chemical properties and tendency to associate with particles and mineral surfaces can be exploited in separation processes based on adsorption or solid–liquid separation. Consequently, the development of adsorbent materials and selective filtration systems for thorium may represent an important approach for the treatment of contaminated water.

Regardless of the nature of the systems from which thorium originates, natural waters that come into contact with rare-earth ores or composite metal-containing industrial wastes may contain thorium, which therefore needs to be recovered, removed, separated, rejected, or retained. Thorium can be recovered from dilute aqueous solutions by nanofiltration using polymer–crown ether composite membranes.

One possible approach is the recovery (rejection) of thorium from aqueous solutions with concentrations comparable to the background levels found in regions where rare-earth elements are exploited (10^{-4}–10^{-7} mol/L) or in composite metal-containing industrial wastes (10^{-3}–10^{-6} mol/L).

Thorium recovery can be achieved by nanofiltration using either integral polymeric membranes or composite membranes.

An integral polymeric membrane based on sPEEK and a composite membrane incorporating sPEEK and a crown ether (ABCE), whose cavity radius is comparable to the ionic radius of thorium, were prepared.

Both membranes were fabricated by an immersion–precipitation process from polymer solutions in sulfuric acid.

Comprehensive morphological, structural, and comprehensive morphological, structural, and process-related characterization demonstrated that the composite membrane exhibited superior performance.

Thorium recovery (rejection) exceeded 90%, indicating that the membranes have potential for application at an industrial pilot scale.

Other complexing agents may also be investigated to further enhance the performance of the nanofiltration process, representing a potential direction for future research.

The results obtained can be explained by an adsorption–complexation separation mechanism.

Keywords: *thorium; nanofiltration; composite membranes; crown ether; recovery*

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ASH CONTENT IN CATTLE MANURE: STATISTICAL ASSESSMENT AND DEVELOPMENT OF A COUNTRY-SPECIFIC PARAMETER FOR ROMANIA

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The study aimed to determine and statistically substantiate a national "country-specific" parameter for the ash content (Ash, %) of cattle manure (cattle and buffalo), in the context of developing the parameters required for the Agriculture sector of the Romanian National Greenhouse Gas Inventory (INEGES) (IPCC, 2019). Ash content represents the inert mineral fraction of the substrate and is a relevant indicator for characterizing the physicochemical properties of manure, as well as for assessing the organic fraction available for anaerobic degradation processes and CH_4 production (Font-Palma, 2019; Nasir et al., 2021; Yu et al., 2021).

The determinations were performed on an experimental dataset comprising 55 cattle manure samples selected to reflect the main farming conditions and production systems investigated in Romania. Physicochemical characterization of the samples included the determination of total solids (TS) by drying at 105 °C to constant mass and volatile solids (VS) by ignition at 550 °C, using standard gravimetric methods. Ash content was determined indirectly based on these measurements. To ensure representativeness and assess potential sources of variability, the analytical results were associated with information on animal species and breed, age category, farming system, climatic zone, and sampling season.

The statistical assessment of Ash (%) aimed to identify potential differences among the subgroups defined by the investigated factors and to determine whether data stratification was required for deriving the national parameter. The analysis included descriptive statistics and boxplot representations to characterize central tendency, data dispersion, and extreme values, as well as the Shapiro–Wilk test to assess distribution normality. Given the predominantly non-Gaussian nature of some distributions, the

unequal sizes of certain subgroups, and the presence of extreme values, the influence of the investigated variability factors was assessed using non-parametric statistical methods. The Mann–Whitney U test was used to compare cattle and buffalo samples, whereas the Kruskal–Wallis test and, where appropriate, Dunn's post-hoc test were applied to factors comprising multiple categories.

The results revealed descriptive differences in the dispersion and distributional structure of Ash (%) among some of the investigated categories; however, the statistical tests did not identify significant differences according to species, breed, age category, farming system, climatic zone, or sampling season ($p > 0.05$). The observed variability was predominantly characterized by within-group heterogeneity, which exceeded the variability between the investigated subgroups. Consequently, the results did not support the use of these factors as separate stratification criteria for deriving the national *country-specific* parameter.

Based on these findings, all 55 valid experimental observations were integrated into a single statistical population. Considering the predominantly non-Gaussian distribution of the data, the presence of extreme values, and the sensitivity of the arithmetic mean to such observations, the global median was used as a robust estimator of central tendency. Accordingly, the national "country-specific" parameter for the ash content of cattle and buffalo manure was established at Ash = 12.54%. The variability associated with this parameter was characterized using robust measures of dispersion, resulting in Q1 = 10.94% and Q3 = 14.63% corresponding to an interquartile range (IQR) of 3.69%.

The results provide an experimental and statistical basis for a representative national "country-specific" parameter for the ash content of cattle manure in Romania and support the subsequent stages of uncertainty assessment and comparison of the national value with the default values provided by the IPCC 2006 Guidelines and the 2019 Refinement, with a view to using the parameter in Romania's national greenhouse gas inventory reporting.

Keywords: *cattle manure; ash content; country-specific parameter; greenhouse gas inventory; statistical analysis*

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INTEGRATING EARTH OBSERVATION INTO *LULUCF MRV* IN ROMANIA: FROM SPATIALLY EXPLICIT LAND MONITORING TO TIER 2 CARBON STOCK ASSESSMENT

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Earth Observation (EO) is becoming an increasingly important component of Monitoring, Reporting and Verification (MRV) for the Land Use, Land-Use Change and Forestry (LULUCF) sector, particularly where national greenhouse gas inventories require spatially explicit, transparent and reproducible activity data. This work presents Romania's current framework for integrating EO, geospatial, administrative and statistical information in the monitoring of non-forest land categories and examines how the same spatial infrastructure can support the transition from Tier 1 to country specific Tier 2 carbon stock assessment. Romania's annual land use matrix is generated through a hybrid approach. For the period 2007 onward, Cropland and Grassland activity data are primarily supported by Approach 3 geospatial information, with the Land Parcel Identification System (LPIS) providing annual parcel level information for approximately 75% of these categories and Corine Land Cover/CLC+ datasets contributing to national coverage and the characterization of non-agricultural land. The resulting Explicit Geospatial Map harmonizes land use polygons spatially and thematically, applies quality-control procedures, and enables annual extraction and querying of areas according to Intergovernmental Panel on Climate Change (IPCC) land use classes.

Beyond activity data estimation, the framework is being extended toward carbon stock characterization. Spatial overlay of the land use map with the national soil classification dataset enables identification and allocation of organic soils by land use category. In parallel, intersection with European Commission/Joint Research Centre climate zone information provides a spatial basis for stratifying

cropland and permanent grassland, designing representative biomass sampling, and developing country specific parameters for aboveground biomass, belowground biomass and dead organic matter. EO therefore functions not only as a source of land use information, but as an integrating layer linking spatial representativeness, field measurements and inventory calculations. The analysis also identifies key methodological constraints: heterogeneous EO and institutional datasets, temporal discontinuities associated with changes in data sources and methods, and the absence of a fully unified national MRV architecture. Further progress requires improved temporal harmonization, standardized spatial inputs and stronger integration of EO, statistical and institutional components. The Romanian experience demonstrates that a progressively integrated geospatial framework can strengthen transparency, consistency and national specificity in LULUCF reporting while providing the operational basis for higher tier carbon stock methodologies.

Keywords: *Earth Observation; LULUCF; MRV; land use matrix; geospatial monitoring; Tier 2*

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This work was carried out within the framework established by Romanian Government Decision No. 1415/2024 for the national greenhouse gas inventory, LULUCF sector, and was financially supported by the Administration of the Environmental Fund (AFM), Romania, under Financing Agreement No. 800/M/30.12.2024. The authors acknowledge the Romanian institutions providing the statistical, administrative and geospatial datasets supporting the national LULUCF inventory.

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2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

BIOCHEMICAL METHANE POTENTIAL OF CATTLE MANURE: AN EXPERIMENTAL FRAMEWORK TOWARDS A ROMANIAN REFERENCE PARAMETER

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Manure management is a major source of methane emissions from livestock systems, and accurate national greenhouse gas inventories require parameters that reflect local production and management conditions. Romanian estimates still rely in part on default factors, while experimentally supported data on cattle manure under national conditions remain limited. This study evaluates the Biochemical Methane Potential (BMP) of cattle manure and develops a traceable experimental basis for a future Romanian reference parameter. In the Intergovernmental Panel on Climate Change (IPCC) manure-management methodology, B_o denotes the maximum methane-producing capacity of manure and is one of several inputs required for Tier 2 estimates. Measured BMP is therefore not assumed to be directly equivalent to B_o; it may instead support the development, substantiation, or validation of a country-specific value (IPCC, 2019).

Fifty-nine cattle-manure samples were collected from 13 sampling locations across eight Romanian counties (Arad, Călărași, Dolj, Iași, Ilfov, Maramureș, Mureș, and Vâlcea), covering three climatic zones and all four seasons. The traceability scheme recorded breed, animal age, feeding regime, housing system, season, sampling location, and climatic zone. Samples were sealed, transported at 4 ± 1 °C, and submitted to initial analyses within 72 h of collection. All samples were characterized for pH, total solids (TS), volatile solids (VS), and ash. TS were determined by oven drying at 105 °C for 20 h, followed by VS determination through ignition at 550 °C for 2 h. Complementary investigations included elemental carbon, hydrogen, nitrogen, and sulfur (CHNS) analysis, selected metals, lignocellulosic composition, and calorific value.

Batch BMP assays were conducted in 500 mL borosilicate reactors using an Automatic Methane Potential Test System III (AMPTS III) and anaerobically digested sewage sludge from the municipal wastewater treatment plant in Râmnicu Vâlcea as inoculum. After nitrogen purging, reactors were incubated at 37 ± 0.5 °C with programmed mixing. Carbon dioxide was removed in 3 M sodium hydroxide before automated volumetric methane measurement. Quality control included inoculum blanks and microcrystalline cellulose as a positive control; methane production was blank-corrected and normalized to substrate VS, consistent with established BMP practice (Raposo et al., 2011). The prespecified endpoint was daily methane production below 1% of cumulative production for three consecutive days, with an indicative assay duration of 30–35 days. Gas produced during anaerobic digestion was also collected in gas-sampling bags and characterized using a Varian CP-3800 gas chromatograph equipped with thermal conductivity and flame ionization detectors.

The integrated workflow supports structured evaluation of BMP in relation to recorded sample characteristics and the assessment of data suitability for developing a country-specific reference value, without assuming national representativeness. The resulting dataset is intended to inform, not independently determine, a national reference parameter and to complement the other activity data and model inputs required for IPCC Tier 2 estimates. Its future integration into the Romanian National Greenhouse Gas Emissions Inventory (INEGES), within the institutional context established by Government Decision No. 1,415/2024 (Government of Romania, 2024), could help reduce inventory uncertainty and inform sustainable anaerobic-digestion strategies for cattle manure. Broader sampling, interlaboratory validation, and explicit criteria linking BMP measurements to inventory B_o remain necessary before national adoption.

Keywords: *cattle manure; biochemical methane potential; anaerobic digestion; country-specific B_o; IPCC Tier 2; greenhouse gas inventory*

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FROM STATIC ACCOUNTING TO DYNAMIC *LCA* THROUGH IoT INTEGRATION IN SUSTAINABLE FOOD VALUE CHAINS

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Conventional Life Cycle Assessment (LCA) generally relies on static or temporally aggregated Life Cycle Inventory (LCI) datasets, which may insufficiently represent short-term variations in resource consumption, process efficiency, yield, and product losses. This limitation is particularly relevant for food and agricultural systems, where environmental performance may vary substantially between production periods, batches, processing conditions, and storage scenarios. Recent developments in Internet of Things (IoT), machine learning, blockchain-based data management, and automated monitoring provide new possibilities for generating continuous, traceable, and temporally resolved environmental data [Popowicz, M. et al., 2025; Ajakwe, I.U. et al., 2025; Li, C. and Lao, W., 2025]. IoT-based monitoring has demonstrated its potential for continuous acquisition and predictive interpretation of environmental and operational parameters [Baena-Navarro, R. et al., 2025], while real-time energy-monitoring architectures confirm the feasibility of continuously acquiring and transmitting energy-related data for decision support [ur Rehman, A. et al., 2025]. This work proposes a conceptual IoT-to-LCA integration framework designed to transform heterogeneous, time-stamped sensor and process measurements into dynamically updated LCI parameters. At agricultural level, potential IoT variables include soil moisture and temperature, air temperature, relative humidity, electrical conductivity, irrigation volume, energy consumption, and crop yield. At processing level, monitoring may include electrical power, cumulative energy demand, water flow, process temperature, processing duration, mass flows, equipment operating state, production yield, and product losses. Depending on the application, sensing systems may include temperature and humidity probes, soil-moisture and conductivity sensors, smart electricity meters, water-flow meters, pressure sensors, load cells, optical or spectral sensors, and environmental monitoring nodes connected through IoT gateways. The proposed data architecture separates raw sensor acquisition from LCA-compatible inventory generation. Sensor observations are time-stamped, validated, filtered,

synchronized, converted to standardized units, and associated with metadata describing sensor identity, location, process stage, batch, sampling frequency, calibration status, and data-quality indicators. Such standardization is essential for interoperability and for establishing explicit links between digital measurements and life-cycle inventory flows [Popowicz, M. et al., 2025]. Validated observations are subsequently mapped to foreground LCI flows, allowing irrigation volumes, energy use, production yield, processing losses, and material flows to be converted into time-dependent activity data. Inventory parameters can then be classified as static, periodically updated, or high-frequency dynamic variables. Dynamic foreground data are combined with conventional background datasets and characterization factors to periodically or event-wise update environmental indicators, while maintaining the fundamental life-cycle perspective of conventional LCA [Kaynak, E. et al., 2025]. The proposed approach may support dynamic evaluation of global warming potential, cumulative energy demand, water use, resource efficiency, and yield- or product-loss-related environmental impacts. Process-specific energy, material, and operational data are particularly relevant when comparing alternative processing technologies [Bashiri, B. et al., 2025]. By continuously updating selected foreground parameters, IoT-integrated LCA could enable batch-specific environmental assessment, identification of temporal hotspots, detection of inefficient operating conditions, and comparison with predefined reference scenarios. The environmental burden associated with sensors, communication networks, gateways, data storage, and computational infrastructure should also be considered when evaluating the net sustainability benefits of digital monitoring [Li, C. and Lao, W., 2025]. Overall, the proposed framework provides a methodological basis for future implementation and validation of dynamic LCA in sustainable food value chains by transforming high-frequency monitoring data into traceable, quality-controlled, and decision-relevant environmental indicators.

Keywords: *Life Cycle Assessment; Internet of Things; dynamic Life Cycle Inventory; environmental monitoring; sustainability assessment; food value chains*

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STABLE ISOTOPES AS ANALYTICAL ANCHORS IN PROTEIN TRACEABILITY SYSTEMS

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The increasing complexity of food supply chains has accelerated the development of digital traceability systems capable of recording product identity, transformation and chain-of-custody information. However, digital systems primarily preserve declared information and cannot independently verify whether the physical product is consistent with its documented origin or production history. Stable isotope ratio analysis (SIRA) provides a complementary source of evidence, since naturally occurring isotopic variations integrate information related to environmental conditions, water sources, agricultural inputs, feed composition and biological processes (Suzuki, 2021).

This work discusses, from a conceptual and application-oriented perspective, the potential of stable isotope fingerprints to act as analytical anchors in protein traceability systems, drawing on published applications across animal- and plant-derived food chains. Particular attention is given to $\delta^{13}C$, $\delta^{15}N$, $\delta^{2}H$, $\delta^{18}O$ and $\delta^{34}S$ and to the transfer of isotopic information along the environment/feed–organism–raw material–food product continuum. Carbon isotope ratios may reflect photosynthetic pathways and dietary carbon sources, $\delta^{15}N$ is influenced by nitrogen inputs and trophic processes, while hydrogen and oxygen isotope ratios are associated with water sources and hydroclimatic conditions. Sulfur isotopes can provide additional information related to geographical and dietary factors. The combined interpretation of these markers, particularly through chemometric approaches, enables the construction of multi-isotope fingerprints with greater discriminatory potential than individual isotope markers (Dinca et al., 2015; Suzuki, 2021).

The relevance of this principle for protein chains is demonstrated by experimental studies on different matrices. In rainbow trout, relationships between the isotopic composition of feed, rearing water and fish tissue showed that $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ can

retain dietary information, while hydrogen and oxygen isotopes provide complementary environmental information, supporting geographical discrimination (Camin et al., 2018). Along the *Mozzarella di Bufala Campana* production chain, carbon and nitrogen isotope signatures provided links between feed, milk and cheese, while processing-related effects were observed for oxygen isotopes (Altieri et al., 2020). These studies illustrate both the persistence of isotopic information through successive stages of protein production and the importance of accounting for biological and technological fractionation.

Beyond individual protein matrices, analytical food-authentication studies demonstrate the value of combining isotope ratios with complementary analytical descriptors and multivariate statistics. Multi-isotope fingerprints coupled with chemometrics have been successfully applied to geographical and botanical discrimination (Dinca et al., 2015), while $\delta^{13}C$ combined with physicochemical and compositional parameters has supported authenticity assessment (Geana et al., 2020). Similarly, the integration of ^{1}H nuclear magnetic resonance profiling with carbon isotope discrimination has shown the potential of multimarker fingerprints for differentiating plant materials according to geographical and genetic origin (Popescu et al., 2019). Together, these approaches provide a methodological basis for extending analytical fingerprints from product authentication towards traceability-oriented verification.

Despite this analytical potential, analytical verification and digital chain-of-custody are still largely developed as parallel rather than fully integrated components of food traceability systems. Stable isotope analysis remains predominantly focused on authenticity and provenance verification, while its systematic integration into digital traceability architectures is still limited (Suzuki, 2021). We therefore propose a conceptual workflow linking production environment/feed → isotopic fingerprint → protein product → analytical verification → digital batch record. Within this framework, stable isotope measurements would not replace conventional traceability but would act as independent analytical checkpoints, enabling consistency testing between selected product claims and measurable intrinsic characteristics.

Translation of this concept into operational traceability requires representative reference datasets, harmonized sampling and analytical protocols, validated chemometric models, consideration of spatial, temporal and processing-related isotope variability, and robust mechanisms linking sample-level analytical evidence to batch-level digital records. Addressing these requirements could enable stable isotope fingerprints to evolve from predominantly authenticity-oriented tools towards analytical anchors supporting evidence-based and integrated protein traceability systems.

Keywords: *stable isotopes; protein traceability; isotopic fingerprinting; food authenticity; analytical verification; digital traceability*.

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ABOUT AN ELECTRICAL RECTIFICATION EQUIPMENT USED IN ELECTROLYSIS IN THE 1980^{s}

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In the 1980s, the widespread introduction of power electronics in the most diverse branches of the romanian economy led to the creation of modern, reliable installations, similar to those manufactured by companies abroad.

In electrolysis and electrometallurgy installations, semiconductor rectifiers with currents of the order of ka and ma and continuous voltages of the order of tens and hundreds of volts were used [Dan, 1975]. these rectifiers must ensure the constant maintenance of the current, at a voltage variation between 0 and the nominal value according to the requirements of the technological process [Iosif et al., 1984].

The electrical equipment for the rectifier installation with alternating voltage varistor, type eie-002 was designed to supply 4 lines (in series) with direct current through two rectifier groups (one active and one backup) that are automatically connected only from the control panel [Certificat de inovator nr. 470/1987].

From a constructive point of view, the equipment consisted of:

- electrolysis control panel type pce-01;
- electrolysis variator cabinet type dfc-vty6_002;
- electrolysis rectifier type rtdo-003;
- three-phase it transformer type ttu 1600 kva 6/0.66 kv;
- three-phase lv transformer type onan 2/1 mva, 0.66/0.11-0.11 kv;
- interphase transformer type tma-068;
- single-pole separator with asi-2 type smi 1.2 kv/3150 a;
- filter compensation equipment type ecf-0.66-450/1000.

Continuous voltage modification was achieved with the ac varistor introduced into the primary circuit of the transformer of jt.

In order to reduce the harmonic content, a 12-pulse rectification was obtained, by operating in parallel two rectifiers rtdo-03 with the inputs connected to the secondary windings of the transformer of jt with three windings (the primary

winding had the delta connection, and one secondary winding had the star connection and the other winding had the delta connection).

The technical solution adopted for the realization of the electrical equipment for the rectifier installation had the following advantages the following advantages:

- continuous regulation;
- high response speed, due to the use of electronic control;
- high reliability due to the use of semiconductor elements in the power circuit;
- high efficiency due to the reduction of losses by the use of semiconductor elements.

The technical characteristics of the equipment are the following:

- nominal continuous current 10000 c.c.;
- nominal continuous voltage 120 v d.c.;
- it supply voltage 3 x 6 kv;
- voltage frequency 50 hz;

The equipment was put into operation from a pce-01 type control panel.

In conclusion, the presented equipment aimed to increase the number of modern rectifier installations, at that time, this installation being a novelty nationally in the 1980s.

Keywords: *electrolysis equipment, power electronics, rectifier, 80s*

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RECYCLING AND RECOVERY OF WASTE FROM COMPOSITE INSULATORS

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The use of composite insulators in electrical transmission and distribution networks has seen significant growth due to their advantages over conventional ceramic or glass insulators, such as low weight, high mechanical strength, and favorable performance under polluted conditions. however, the increasing number of composite insulators in service leads to a growing volume of waste generated when they are decommissioned. their multi-material structure—comprising primarily a silicone rubber housing and sheds, a fiberglass-reinforced composite core, and metal fittings—makes the application of conventional recycling methods difficult.

This paper presents an analysis of the main options for managing and valorizing waste from composite electrical insulators, focusing on the mechanical, thermal, and chemical methods used to separate and recover constituent materials. it examines recycling possibilities for silicone rubber and glass-fiber-reinforced composite materials, as well as the recovery of mineral and metallic fractions. particular attention is paid to the potential for reusing recovered materials as fillers, components of new composite materials, or secondary raw materials. the analysis highlights both the advantages of various recovery methods and their main technological and economic limitations. in this context, the development of efficient recovery and reuse solutions can contribute to reducing waste and integrating circular economy principles into the field of electrotechnical equipment and materials.

Keywords: *Composite insulators, electrotechnical waste, silicone rubber, glass fiber-reinforced polymer (GFRP) composites, recycling, recovery, circular economy***.**

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IRON OXIDE-MODIFIED BIOCHAR FROM POTATO PEELS FOR THE ADSORPTION OF ORGANOCHLORINE PESTICIDES FROM CONTAMINATED WATER

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The contamination of water resources with persistent pesticide residues represents an important environmental concern, particularly in agricultural areas where runoff can facilitate the transport of organochlorine compounds into aquatic systems. Adsorption using carbonaceous materials derived from agricultural residues represents a promising approach for pesticide removal due to the favourable porosity, aromatic structure and surface functionalities of biochar (Liu et al., 2018; Khalid et al., 2020). Surface modification with inorganic phases, particularly iron-containing species, can further improve the adsorption performance of biochar by introducing additional active sites and modifying surface interactions with pesticide molecules (Dong et al., 2024).

The present study investigated the preparation, characterization and pesticide adsorption performance of an iron-modified biochar composite, denoted FeO/BCC450, using potato-peel-derived biochar as a carbonaceous support. The composite was prepared by contacting 1 g BCC450 with 50 mL of an iron precursor solution containing $FeCl_3$ and $FeSO_4 \cdot 7H_2O$, followed by adjustment of the suspension to pH 9–11 using NaOH. The mixture was maintained under continuous magnetic stirring overnight, after which the resulting black precipitate was isolated by filtration and dried under vacuum at 80 °C. The obtained FeO/BCC450 material was characterized by scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM–EDS), Fourier-transform infrared spectroscopy (FTIR) and Raman spectroscopy.

The SEM observations revealed a heterogeneous mesoporous carbon structure with slit-like pores, microcracks and dispersed iron-containing clusters on the surface. EDS analysis confirmed the presence of Fe in the modified material, with

an iron content of approximately 1.93%. FTIR spectra indicated changes in oxygen-containing surface groups and the appearance or strengthening of Fe-O-related bands, supporting the incorporation of iron-containing species onto the carbonaceous surface. These structural and chemical modifications are consistent with the enhanced adsorption behaviour reported for functionalized and metal-modified biochars (Dong et al., 2024; Chen et al., 2023).

The adsorption performance was evaluated in batch experiments using a mixture of six organochlorine pesticides: α-HCH, Aldrin, Dieldrin, p,p'-DDD, p,p'-DDE and p,p'-DDT. The initial pesticide concentration was 10 µg/mL, and samples were collected after 5, 8 and 24 h. Pesticide concentrations before and after adsorption were determined by gas chromatography with electron-capture detection (GC-ECD). The FeO/BCC450 composite showed substantially improved pesticide removal compared with the unmodified BCC450. After 24 h, removal efficiencies of approximately 55.2% for α-HCH and 69.3% for Aldrin were obtained, while complete removal was observed for Dieldrin, p,p'-DDD, p,p'-DDE and p,p'-DDT under the investigated conditions. The enhanced performance of the iron-modified material is consistent with the ability of metal-modified biochars to provide additional surface interactions and adsorption sites for organic contaminants (Liu et al., 2018; Chen et al., 2023; Dong et al., 2024).

The results demonstrated that FeO modification substantially enhanced the adsorption performance of the potato-peel-derived carbonaceous material towards persistent organochlorine pesticides. The FeO/BCC450 composite therefore represents a promising low-cost and potentially sustainable adsorbent for the treatment of pesticide-contaminated water. The valorisation of agro-food residues into functionalized adsorbents also provides an attractive approach for integrating waste valorisation and environmental remediation within circular-economy strategies.

Keywords: *FeO/BCC450; biochar; iron oxide modification; organochlorine pesticides; adsorption; agricultural runoff; water remediation*.

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SUSTAINABLE VALORIZATION OF PLANT BY-PRODUCTS AND EXTRACTS IN FUNCTIONAL FERMENTED BEVERAGES: AN INTEGRATED PILOT-SCALE CHEMICAL AND IN SILICO ASSESSMENT

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The valorization of agro-food by-products and plant-derived materials offers an opportunity to develop functional ingredients while improving resource efficiency within the food chain. The present work investigated pilot-scale fermented beverages to evaluate the effects of fermentation conditions and botanical enrichment on their bioactive and mineral composition. Water kefir was produced over 24–120 h, either without supplementation or with 1.5% grape pomace, whereas kombucha formulations were prepared with different plant-derived enrichments.

The phenolic composition of the samples was characterized by ultra-high-performance liquid chromatography coupled with mass spectrometry (UHPLC–MS/MS). Trace and potentially toxic elements were determined by inductively coupled plasma optical emission spectrometry (ICP-OES), whereas Ca, Mg, Na and K were quantified by flame atomic absorption spectrometry (AAS). More than 35 phenolic compounds were included in the analytical evaluation. Experimental data were further complemented by an in silico assessment based on chemical and bioactivity databases, ADMET-related information and the analysis of potential molecular targets.

Clear differences were observed according to fermentation time, beverage matrix and the plant material used for enrichment. In water kefir, the addition of grape pomace produced marked changes in the phenolic profile, particularly for catechin, epicatechin and syringic acid. These differences became more evident during the later stages of fermentation. The evolution of the phenolic composition over time also indicated

progressive release and transformation of compounds initially associated with the plant matrix, consistent with microbial and enzymatic processes occurring during fermentation.

Kombucha showed a different phenolic pattern, largely reflecting the contribution of the black-tea substrate. Nevertheless, supplementation with botanical extracts substantially modified this profile. Quince leaves, raspberry-derived materials and grape pomace contributed different groups of phenolic acids and flavonoids, resulting in distinct but complementary compositions among the investigated formulations. These findings suggest that the final phenolic fingerprint is determined not only by the initial botanical source but also by its interaction with the fermentation process.

The mineral composition was similarly dependent on the type of fermented matrix. Water kefir was characterized by comparatively higher concentrations of Ca, Mg and K, while grape pomace supplementation contributed to the enrichment of selected bioessential elements. In kombucha, K and Mg remained the predominant macroelements, reflecting the mineral contribution of the black-tea substrate. Thus, plant supplementation altered selected components of the mineral profile without disrupting the characteristic mineral pattern of each beverage.

The in silico evaluation provided complementary information on the possible biological relevance of the phenolic compounds detected experimentally. Gallic acid, syringic acid, catechin and epicatechin were among the compounds showing the most relevant predicted interactions with molecular targets involved in oxidative and inflammatory processes. Although these predictions require experimental confirmation, they provide a useful basis for selecting compounds and formulations for subsequent biological validation.

Taken together, the results show that fermentation conditions and botanical enrichment can be used to tailor the phenolic and mineral composition of water kefir and kombucha. In particular, the use of grape pomace and other plant-derived materials illustrates the potential of agro-food secondary resources as ingredients for functional fermented beverages. Combining targeted chemical characterization with computational evaluation also provides a practical framework for selecting promising formulations prior to further technological optimization and scale-up.

Keywords: *functional fermented beverages; grape pomace; plant extracts; phenolic compounds; mineral profile; in silico assessment*

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This work was carried out within project ADER 17.1.2, "Research on the development of sustainable technologies for obtaining and valorizing innovative food ingredients and products for the nutritional balance of the modern consumer's diet", funded under the Sectoral Plan for Agricultural and Rural Development Research 2023–2026 – ADER 2026, Ministry of Agriculture and Rural Development, Romania.

FishROrigin: INTEGRATED ISOTOPIC AND MOLECULAR APPROACHES FOR FRESHWATER FISH ORIGIN AND AUTHENTICITY

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Seafood authenticity and traceability remain important challenges for food control, sustainable aquaculture and biodiversity conservation. Although stable isotope analysis and elemental fingerprinting are increasingly used to investigate the origin and production history of marine species, freshwater fish are still comparatively underrepresented in authenticity studies, particularly in the Danube Basin and Carpathian regions. Against this background, the FishROrigin – Integrated Isotopic and Profiling Methods for Freshwater Fish Authentication project, developed within the International Atomic Energy Agency Coordinated Research Project D52046 – "Seafood Origin and Authenticity using Nuclear and Related Technologies", aims to establish an integrated analytical framework for verifying the geographical origin and production system of freshwater fish.

The project focuses on two sturgeon species, *Acipenser ruthenus* and *Acipenser gueldenstaedtii*, together with brown trout (*Salmo trutta fario*), and considers both wild and aquaculture production systems. A harmonized sampling strategy will link fish specimens with their environmental context by collecting tissues together with associated water samples from the Danube, aquaculture facilities, mountain rivers and alpine lakes. Different biological matrices, including muscle, fatty tissue, fins, bones and sturgeon thorns, will be investigated in order to capture complementary environmental, trophic and metabolic information.

The analytical approach combines stable isotope ratio mass spectrometry (IRMS) for the determination of $\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$ and $\delta^{2}H$ with multi-element and strontium isotope profiling by ICP-MS/OES. Particular attention will be given to collagen and bioapatite as potential long-term indicators of habitat and environmental exposure. An additional innovative component will explore the combined use of IRMS and Site-Specific Natural Isotope Fractionation Nuclear

Magnetic Resonance (SNIF-NMR) for $\delta^{13}C/\delta^{2}H$ characterization of fatty-acid fractions. In parallel, high-resolution ^{1}H-NMR profiling will be used to investigate muscle metabolites associated with diet and production system.

The isotopic, elemental and molecular information generated through these complementary approaches will be integrated using chemometric and machine-learning methods to identify the variables with the greatest discriminatory value. These markers will support the development of a hierarchical screening-to-confirmation strategy, in which rapid screening can highlight atypical samples and guide the use of more targeted confirmatory analyses.

By bringing together environmental, isotopic, elemental and molecular information within a common analytical framework, FishROrigin seeks to strengthen the scientific basis for freshwater fish authentication in Romania. The project will also contribute to improved traceability, more sustainable aquaculture practices and the conservation of vulnerable freshwater species within the Danube Basin.

Keywords: *freshwater fish authentication; stable isotopes; IRMS; SNIF-NMR; elemental profiling; traceability*

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PRELIMINARY FEASIBILITY ASSESSMENT OF SALT-MINE MATURATION FOR DRY-CURED MEAT PRODUCTS: EXPERIMENTAL EVIDENCE FROM OCNELE MARI SALT MINE, ROMANIA

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Dry-curing and maturation are critical stages in the development of the physicochemical, microbiological and sensory characteristics of meat products. Temperature, relative humidity, air circulation and drying conditions influence water loss, biochemical transformations and product stability during maturation (Baldini et al., 2000). Natural underground environments are therefore of particular interest as potential maturation systems because they may provide distinctive and comparatively stable microclimatic conditions. A relevant Romanian precedent is Țaga, also known as Năsal cheese, which is traditionally matured in a natural cave at approximately 14–15°C and 90–95% relative humidity. microbiological and biochemical monitoring of this product demonstrated progressive changes during the 25–30-day cave-ripening process, illustrating the potential technological importance of a naturally defined underground maturation environment (Criste et al., 2020).

The regional context of ocnele mari provides an additional rationale for investigating salt-mine maturation of meat products. The European Union documentation for the registered protected geographical indication (PGI) "cârnați din topor din Vâlcea" specifies the use of food-grade rock salt extracted from the Ocnele Mari Salt Mine. The product specification associates its distinctive characteristics partly with dry-salting maturation and with the macroelement (Ca, Mg, Na, K) and microelement (Fe, Cu, Zn, Mn, Co) profile of the Ocnele Mari salt (European Commission, 2025). Although this traditional practice involves the use of salt originating from the mine rather than maturation inside the mine itself, it establishes a strong geographical and technological relationship between Ocnele Mari mineral resources and local meat-product processing.

Against this background, the present preliminary study assessed the practical feasibility of using the underground environment of the ocnele mari salt mine, romania,

for the maturation of dry-cured meat products. Experimental batches of dry-cured sausages, pork loin, pork neck, pork belly and tenderloin were produced by AVI-GIIS S.R.L., and selected products were subjected to preliminary testing under salt-mine maturation conditions. The experimental activity was photographically documented, and representative products were subjected to organoleptic, physicochemical and microbiological characterization.

Physicochemical analyses included moisture, fat, sodium chloride, protein and nitrite contents, together with hydrogen sulfide identification and the Kreiss reaction. Two experimental dry-cured sausage batches (P1 and P2) showed comparable compositional characteristics. Batch P1 contained 26.1% moisture, 45.3% fat, 4.4% NaCl and 25.4% protein, whereas P2 contained 27.5% moisture, 43.5% fat, 4.2% NaCl and 25.6% protein. nitrite contents were 1.1 and 0.9 mg/100 g, respectively. Hydrogen sulfide and Kreiss reactions were negative for both batches, and the products exhibited characteristic taste and odour without foreign sensory notes. Additional analyses confirmed the feasibility of physicochemical characterization of the experimental pork loin, pork neck, pork belly and tenderloin products.

Microbiological testing of the dry-cured sausages included Escherichia coli, salmonella spp. and listeria monocytogenes. E. coli counts were below 100 CFU/g, while Salmonella spp. and L. monocytogenes were not detected in the analysed samples.

These preliminary findings demonstrate the practical feasibility of producing, exposing and analytically characterizing dry-cured meat products under salt-mine maturation conditions. However, the exploratory study was not designed to establish a causal relationship between the salt-mine microclimate and the observed product characteristics. Further controlled research should combine continuous temperature, relative-humidity and airflow monitoring with paired conventional and salt-mine maturation batches, time-resolved sampling, water activity and pH measurements, mass-loss kinetics, microbiological evolution and advanced compositional and volatile profiling. Such an approach could determine whether the Ocnele Mari underground environment induces reproducible physicochemical, microbiological and sensory modifications and could support the development of a scientifically validated and controlled salt-mine maturation technology.

Keywords: *dry-cured meat; salt-mine maturation; ocnele mari; underground microclimate; meat quality; experimental validation*

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INFLUENCE OF BIOCOMPOSITE FERTILIZATION ON *CNO* ISOTOPE FINGERPRINTS OF RASPBERRIES IN CONTRASTING AGROECOSYSTEMS

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Stable isotope ratios integrate information related to plant physiology, nutrient sources, water availability and environmental conditions and have therefore become valuable markers for food authentication and for characterizing agricultural production systems (Camin et al., 2011; Laursen et al., 2013; Marshall et al., 2007). In particular, $\delta^{13}C$ can reflect plant responses to water availability and photosynthetic processes, $\delta^{15}N$ is closely related to nitrogen sources and soil–plant nitrogen cycling, while $\delta^{18}O$ is strongly influenced by the isotopic composition of source water and subsequent evaporative processes. In this context, understanding whether innovative soil amendments modify the natural isotopic signature of agricultural products is important for both sustainable crop management and the development of reliable isotope-based traceability systems.

This study investigated the influence of two biocomposite fertilizers on the CNO isotopic fingerprint ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$) of two raspberry (*Rubus idaeus* L.) cultivars, Opal and Delniwa, grown during the 2025 production season in two contrasting experimental agroecosystems: an agroforestry system located in Vlădești, Vâlcea County, and an organic production system established at INMA Bucharest. The two cultivars were monitored under unfertilized control conditions and following application of biochar–digestate-based (BCD) and organo-mineral biocomposite (OMB) amendments. These fertilizers originate from the valorization of biomass and agro-industrial residues and were investigated as sustainable alternatives for improving soil properties, nutrient availability and water retention. A total of 95 raspberry samples were collected throughout the harvesting period. Carbon and

nitrogen isotope ratios were determined by EA-IRMS, while $\delta^{18}O$ was measured in water extracted from raspberry fruits using CF-IRMS coupled with an equilibration system.

The results demonstrated that the production environment represented a stronger source of variation in the overall isotopic fingerprint than biocomposite fertilization, in agreement with previous observations on raspberry production systems (Ionete et al., 2026). The most pronounced differentiation between the two experimental agroecosystems was observed for $\delta^{15}N$. Raspberry fruits from the agroforestry system showed predominantly negative mean $\delta^{15}N$ values, ranging from approximately −1.65 to −0.16‰ across cultivars and treatments, whereas samples from the organic system were consistently enriched in ^{15}N, with mean values between approximately +4.32 and +5.32‰. This marked shift indicates distinct nitrogen cycling and nitrogen-source characteristics between the two environments and highlights $\delta^{15}N$ as a particularly informative component of the isotopic fingerprint.

Differences were also observed for $\delta^{18}O$, reflecting the contrasting hydroclimatic and soil–plant water conditions of the two experimental sites. Mean $\delta^{18}O$ values in the organic system were relatively similar among treatments, ranging from approximately +4.18 to +4.59‰, while the agroforestry samples showed a broader response, from approximately +1.53 to +3.72‰. Temporal profiles further revealed short-term changes following fertilizer application, particularly during periods characterized by high summer temperatures and limited water availability. In several treatments, fertilizer-induced $\delta^{18}O$ shifts gradually approached those of the corresponding control plants later in the harvesting period, suggesting that environmental control over the oxygen isotope signal remained predominant.

The $\delta^{13}C$ values displayed comparatively smaller differences between production systems and treatments, but cultivar- and fertilizer-dependent responses were nevertheless observed. In the agroforestry system, BCD application to Opal was associated with ^{13}C depletion relative to the corresponding control, while Delniwa showed a more limited response. Fertilization effects on $\delta^{15}N$ were likewise cultivar-dependent: BCD-treated Opal in the agroforestry system showed an increase of approximately 1‰ in mean $\delta^{15}N$ compared with the control, whereas only minor changes were observed for Delniwa. These responses suggest that biocomposite amendments can temporarily affect nutrient and water dynamics in the soil–plant system, but do not override the broader isotopic signal associated with the production environment.

Overall, the combined $\delta^{13}C$–$\delta^{15}N$–$\delta^{18}O$ fingerprint effectively captured differences between contrasting raspberry agroecosystems while simultaneously revealing smaller, treatment- and cultivar-dependent effects of biocomposite fertilization. The results demonstrate the importance of accounting for agricultural management as a potential source of within-site isotopic variability and support

multi-isotope profiling as a complementary tool for characterizing production systems and developing robust authenticity and traceability frameworks for berry fruits.

Keywords: *raspberry; CNO stable isotopes; biocomposite fertilizers*

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GRAPEVINE WATER RELATIONS REVEALED BY STABLE ISOTOPES UNDER DIFFERENT CLIMATIC CONDITIONS

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Romania has a long tradition in grape cultivation and wine making with a significant impact in agricultural sector. Thus, the environmental conditions during plant growth and grape ripening are critical to grapevine do to their effect on yield and wine sensory characteristics. In this study, we evaluated the stable isotopes efficacy in environmental monitoring to prevent drought stress, by collecting and analysing precipitation and plant tissue samples during 2 years at a Sauvignon Blanc vineyard located in Valcea county, Romania. The stable isotope composition of leaves was highly sensitive to atmospheric evaporative demand. Specifically, leaf $\delta^{18}O$ showed a strong negative correlation with relative humidity and a strong positive correlation with evapotranspiration. These results verify that low humidity and high evapotranspiration accelerate the accumulation of $\delta^{18}O$ in leaf water, demonstrating a classic isotopic response to atmospheric stress. Lower sensivity was observed for leaf $\delta^{2}H$. Shallow soil moisture correlated moderately with leaf $\delta^{18}O$, whereas deeper layers showed negative correlations with leaf $\delta^{2}H$. These distinct relationships suggest a progressive down-shift in root water uptake from shallow to deeper soil horizons as conditions dried. From principal component analysis, the relative positioning of $\delta^{2}H$ and $\delta^{18}O$ confirms their utility as tracers of short-term evaporative conditions. In contrast, $\delta^{13}C$ and $\delta^{15}N$ serve as indicators of longer-term physiological integration. While $\delta^{13}C$ and $\delta^{15}N$ align with metrics of cumulative drought intensity (evapotranspiration and soil water tension), the $\delta^{2}H$ and $\delta^{18}O$ associate strongly with atmospheric drivers and surface heat dynamics. These dual-isotopic systems trace rapid atmospheric forcing and cumulative soil-plant feedbacks, providing a framework for vineyard drought assessment.

Keywords: *grapevine, drought, isotopes, evapotranspiration, humidity*

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SAFE HYDROGEN FUTURE FOR RELIABLE AND GREEN POWER SUPPLY

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Metal hydride technology provides a safe, compact and efficient way to store hydrogen for long periods.

Hydrogen is stored within a solid metal-hydride structure, enabling very high volumetric storage density at relatively low pressure.

Its high level of safety makes the technology suitable for industrial, infrastructure and potentially urban applications.

Metal hydride storage represents an important missing link in green energy management, complementing batteries with long-duration and seasonal storage.

Surplus solar and wind electricity can be converted into hydrogen and stored until renewable production is insufficient.

We will disclose one integrated solutions for dense hydrogen storage and flexible hydrogen utilization.

Stored hydrogen can be converted back into electricity and heat when required.

It can also be used for biogas enrichment, synthetic methane production, turbines, burners and CHP applications.

This creates a flexible energy carrier connecting the electricity, gas, heat and industrial energy sectors.

Metal hydride hydrogen storage can therefore play an important role in future grid balancing, seasonal energy storage and energy security.

SENSOR ARRAY FOR MICROCLIMATE MONITORING IN A MINI-GREENHOUSE

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Controlled-environment agriculture requires continuous, reliable monitoring of the microclimate, since air humidity, temperature and gas composition (CO_2, O_2, volatile organic compounds) directly influence plant growth and crop quality. Low-cost sensor arrays offer an attractive alternative to expensive reference instrumentation, but their response is affected by cross-sensitivity, especially the interference of humidity and temperature with the signal of chemiresistive gas sensors [Corona et al., 2024].

In this work, an array of sensors was implemented in a mini-greenhouse, combining commercial sensors with laboratory-developed chemiresistive sensors based on graphene/carbon nanotube layers deposited on interdigitated electrodes [Iordache et al., 2025; Caramizoiu et al., 2025]. The array was connected to a microcontroller-based acquisition unit enabling real-time data logging and wireless transmission to an IoT platform. The response of the sensors was monitored under varying relative humidity, temperature and gas mixture composition. The sensors were evaluated in terms of sensitivity, response and recovery times and cross-sensitivity to humidity and temperature, and their readings were compared with those of the commercial sensors. Simultaneous monitoring of humidity and temperature allows the compensation of their influence on the gas sensor signals, making the proposed array a promising low-cost solution for microclimate monitoring in greenhouses.

Keywords: *sensor array; mini-greenhouse; chemiresistive gas sensors; humidity; temperature; IoT monitoring*

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Our three technical divisions – Microscopy, Spectrometry & Diffractometry; Analytical; Test, Measurement & Calibration – with a specialized sales and service team trained by the equipment producers through more than 500 courses, covering all three conference themes.

THEME 1
Integrated energy systems & circular energy infrastructure

Battery, PV and functional materials, from structure to surface:

SEM, DualBeam (FIB-SEM) and TEM (**Thermo Fisher Scientific**) with EDS/EBSD (EDAX), EELS (Gatan) and nanomanipulation (Kleindiek); confocal-microscopy Raman, spectro-fluorescence and FTIR (Edinburgh Instruments); contact angle and surface tension (KRÜSS); X-ray fluorescence (Rigaku); microwave synthesis (Milestone).

Energy systems:

Power-quality analyzers, thermal imaging, PV-installation and EV-charger testers (**Fluke**, Seaward, Thermoteknix); power-quality and grid monitoring (Elspec, Powerside); electrical test and battery analyzers (Fluke).

Delivered:

ICER – Institute for Renewable Energy Research, Politehnica University of Timișoara (laboratories of four faculties); predictive monitoring and disturbance analysis for the Southern Transylvania electricity distribution network (Sibiu).

THEME 2
Hydrogen isotopes, nuclear & advanced energy applications

Materials for extreme conditions:

FIB-SEM cross-sections, EBSD and TEM (**Thermo Fisher Scientific**, EDAX, Gatan) for hydrogen embrittlement, membranes, coatings and radiation damage; thin films and membranes, spin coating (Laurell) and electrospinning (Tong Li).

Cryogenic and process metrology:

Temperature, pressure and electrical calibration (**Fluke Calibration**); an argon triple-point system (83.8058 K, an ITS-90 defining fixed point) commissioned by Ronexprim at Medisol & Lives International.

Energy assets:

Oil condition monitoring (Spectro Scientific); fuel and lubricant testing to ASTM, ISO and EN methods (Stanhope-Seta).

Delivered:

Design and micro-assembly of advanced solid targets for high-intensity experiments at ELI-NP, Măgurele; advanced electron microscopy for Ro-HydroHub, the national hydrogen hub led by ICSI; Metron Focșani reference calibration centre (temperature, electrical, pressure);

THEME 3
Environmental systems, climate action & water-energy-food nexus

Traceable results, from sample to certificate:

SEM & TEM (**Thermo Fisher Scientific**) and Raman microscopy (Edinburgh Instruments) for particles and microplastics; microwave digestion, extraction, ashing and mercury analysis (Milestone); cryogenic grinding (Cole-Parmer); certified reference materials (LGC); combustion elemental analysis (Trace Elemental Instruments); X-ray fluorescence (Rigaku) and near-infrared analysis (Zeltex); water-quality and VOC-emission monitoring.

Delivered:

ASPIRE, POLITEHNICA Bucharest – supercritical CO_2 extraction system recovering high-value compounds such as beta-carotene from bioresources.

Contracted (2026):

DANUBIUS-RI Hub, Murighiol (INCDSB) – electron microscopy (**Thermo Fisher Scientific**), Raman (Edinburgh Instruments) and AFM for the Romania-led European Strategy Forum on Research Infrastructures on river–sea systems.

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- **INFLPR "Photoplasmat", Măgurele –** photonics and plasma innovation center linking research with industry
- **Bosch and Emerson, Cluj –** automated calibration laboratories for industrial sensors
- **Petroleum-Gas University of Ploiești –** crude oil, fuel and lubricant laboratories
- **National Metrology Institute, Republic of Moldova –** biomedical metrology laboratory
- **PNTS – National Platform for Semiconductor Technologies (2024–2029) –** knowledge contributor

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Where we are - Arbor Group



Under the leadership of Managing Director Thomas Freund, the Arbor Group has grown into an internationally active group of authorized Swagelok Sales and Service Centers with more than 50 employees across Austria, Hungary, and Romania.

Since 2016, AA Solutions GmbH has been serving customers from its location in Wiener Neudorf, Austria. In 2025, AA Solutions Kft. in Hungary and AA Solutions RO S.R.L. in Romania joined the group. Together, our local teams support customers with technical expertise, tailored fluid system solutions, and professional service.

Why Swagelok

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Our Target Markets

Swagelok Romania supports customers across a wide range of demanding industries and applications. From high-pressure and high-purity systems to critical energy and clean energy applications, our fluid system solutions are designed to meet demanding requirements for safety, reliability, and performance.

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4

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Founded in 1992, OF Systems is a Romanian provider of equipment, integrated solutions and technical services for laboratory and industrial applications.

For more than three decades, the company has been equipping and supporting some of Romania's most advanced laboratories and production facilities, providing access to leading international technologies together with the local expertise required for their implementation, operation and long-term maintenance.

From research and quality control laboratories to complex production environments, OF Systems supports its customers throughout the entire lifecycle of their equipment - solution selection and installation, qualification, calibration, maintenance and technical service.

With nationwide coverage, OF Systems serves organizations operating in industries such as Pharmaceutical & Biopharmaceutical, Food & Beverage, Chemical & Petrochemical, Research & Academia, Environmental, Retail, Automotive and Manufacturing.

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The OF Systems portfolio covers a broad range of applications, from routine laboratory activities and advanced analytical processes to quality control and production environments.

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OF Systems collaborates with more than 40 international manufacturers, providing customers in Romania with access to some of the best solutions for laboratory and industrial applications.

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STORAGE CAPACITY	How much hydrogen can the material store?
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