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Bamboo-graphite cathode for magnesium seawater battery in sustainable fisheries

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Abstract: The integration of eco-friendly materials into seawater battery systems represents a sustainable approach to decentralized energy supply for small-scale fisheries. This study aimed to (1) synthesize nitrogen- and phosphorus-doped bamboo-derived graphite (BDG) through a two-step pyrolysis process, (2) fabricate a bamboo-graphite air cathode for magnesium seawater batteries (Mg-SWBs), (3) evaluate its electrochemical properties, and (4) demonstrate battery performance under laboratory seawater conditions by assessing discharge stability and voltage behavior. Bamboo (*Dendrocalamus asper*) was carbonized using ammonium dihydrogen phosphate ($NH_4H_2PO_4$) as a dual dopant, followed by cathode fabrication using stainless-steel mesh and polyvinyl acetate binder. Electrochemical performance was characterized using cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS). Battery performance was evaluated by continuous discharge testing in natural seawater (salinity approximately 35 ppt) under laboratory conditions, where voltage and current were monitored every two hours over a 12 h period. The synthesized BDG exhibited an electrical conductivity of 7.8×10^4 S cm^{-1}, representing approximately 95% of commercial graphite conductivity, with a mesoporous structure (average pore diameter ≈ 3.8 nm) favorable for oxygen reduction reactions. CV analysis demonstrated quasi-reversible redox behavior, while EIS measurements indicated low solution resistance (8.6 Ω) and moderate charge-transfer resistance (34 Ω), confirming efficient electron transport. Continuous discharge testing demonstrated a stable output voltage of 2.0 ± 0.05 V and a power density of 1.9 mW cm^{-2} for approximately 10 h, followed by gradual voltage decline caused by magnesium anode passivation. A temporary voltage recovery after a resting period was attributed to chemical relaxation rather than self-recharging. Integration with a DC–DC boost converter increased the usable output voltage to approximately 3.5–3.8 V, enabling continuous operation of an LED lamp. These findings demonstrate that bamboo-derived graphite is a promising low-cost and renewable air-cathode material capable of maintaining stable battery performance under laboratory seawater conditions, supporting sustainable marine energy applications and blue economy initiatives.

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1. Introduction

The global transition toward renewable energy has motivated the exploration of alternative battery chemistries capable of operating in saline environments [1]. Among these, magnesium seawater batteries (Mg-SWBs) have attracted increasing attention owing to their high theoretical energy density, natural abundance of electrolytes, and intrinsic safety. Such systems are particularly relevant to coastal fisheries, where energy demand for lighting (e.g., underwater fish-attracting lamps) remains dependent on disposable lead-acid or lithium-ion batteries that pose environmental risks and require frequent replacement [2]. Developing seawater-activated batteries using locally sourced, biodegradable materials could provide a sustainable and low-cost energy solution for fishing communities [3].

The air cathode plays a central role in seawater batteries by catalyzing the oxygen reduction reaction (ORR) and enabling efficient electron transfer. Conventional cathodes employ commercial graphite or carbon black, which, although conductive, are expensive and energy-intensive to produce. To reduce dependency on non-renewable precursors, researchers have investigated biomass-derived carbons obtained from coconut shells, rice husks, corn cobs, sawdust, and bagasse, showing promising surface area and porosity [4–6]. However, many of these materials exhibit low graphitization and irregular pore networks, limiting their electrical performance and long-term stability.

Bamboo (*Dendrocalamus asper*) offers unique structural and ecological advantages as a carbon precursor. Its naturally aligned vascular channels, high cellulose and lignin contents, and rapid growth rate facilitate the formation of conductive graphitic domains during pyrolysis. Moreover, bamboo is abundant in tropical coastal regions and can be harvested sustainably without competing with food production. Phosphorus and nitrogen doping using ammonium dihydrogen phosphate ($NH_4H_2PO_4$) during carbonization enhances surface wettability, electron density, and active site distribution attributes essential for ORR activity in alkaline or saline media [7, 8].

Despite progress in bio-carbon research, few studies have examined bamboo-derived graphite electrodes within practical Mg-SWB configurations under real seawater conditions. Critical parameters such as charge-transfer resistance, conductivity retention, and discharge stability remain under-explored. Furthermore, prior reports often lacked reproducible data or detailed fabrication procedures, reducing scientific transparency.

To address these gaps, the present work aims to: 1) Synthesize porous, double doped bamboo graphite via two-step pyrolysis using $NH_4H_2PO_4$ as a catalytic dopant; 2) Fabricate an air cathode integrating the bamboo-graphite layer with a stainless steel mesh and polymeric binder; 3) Evaluate the electrochemical behavior of the cathode through cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS); and 4) Demonstrate the battery performance under laboratory seawater conditions, emphasizing discharge stability and voltage behavior. This study contributes to the advancement of sustainable electrode materials for marine energy systems, supporting the circular economy framework in fisheries technology.

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2. Methods and Materials

2.1. Materials and equipment

Experiments were conducted from May to November 2023 at the Chemistry Laboratory, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Indonesia. The bamboo stalks were collected from Leupung Subdistrict, Aceh Rayeuk Regency, Aceh Province, Indonesia (5.38778194° N and 95.25559500° E), whereas seawater was collected from Ulee Lheue coastal waters (5.5764° N, 95.2952° E). Bamboo stems (*Dendrocalamus asper*), distilled water, ammonium dihydrogen phosphate ($NH_4H_2PO_4$, Sigma-Aldrich), polyvinyl acetate (PVA) binder, 50-mesh stainless-steel conductive mesh, polypropylene fabric, hydrochloric acid (HCl, 1 M), and iodine solution. High-temperature furnace (Carbolite Gero CWF 1200), analytical balance (Mettler Toledo AB204-S), ultrasonic cleaner (Branson 1510), centrifuge (Thermo Fresco 17), and potentiostat/galvanostat (Gamry Reference 600+) equipped for CV and EIS measurements. All measurements were performed at 25 ± 2 °C and 60% RH (Figure 1).

Figure 1. Overview of the experimental workflow for bamboo-derived graphite synthesis and testing.

2.2. Synthesis of bamboo-derived graphite

Dry bamboo was cut into small fragments ($\approx$ 1–2 cm) and soaked in an aqueous $NH_4H_2PO_4$ solution (0.1 M) for 24 h to introduce nitrogen and phosphorus species. After drying at 110 °C for 12 h, the material underwent first stage pyrolysis at 900 °C for 2 h under nitrogen flow (200 mL min^{-1}). The charred product was re-impregnated with fresh $NH_4H_2PO_4$ solution for another 24 h and subjected to second-stage pyrolysis under identical conditions. The resulting black powder was ground and sieved (100 mesh) to yield the double doped bamboo graphite (BDG) (Figure 2).

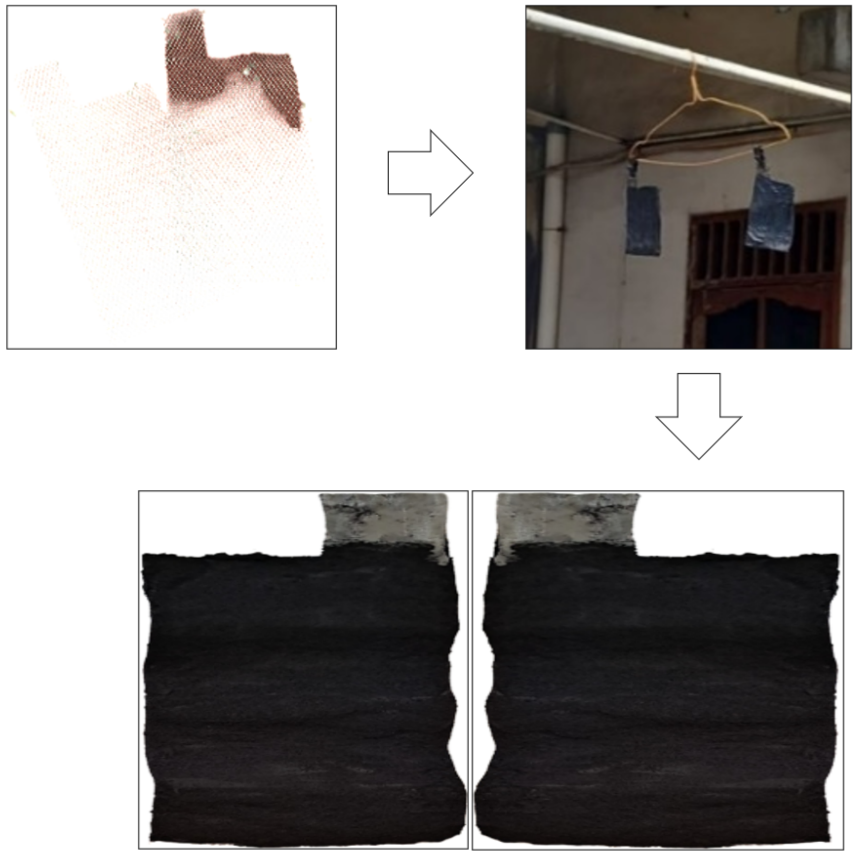

Figure 2. Two-stage pyrolysis process of bamboo using $NH_4H_2PO_4$ as a catalytic dopant.

2.3. Fabrication of air cathode

The air-cathode composite consisted of a stainless-steel mesh current collector coated with a catalyst layer (CL) containing BDG powder and PVA binder (mass ratio 1:4). The mixture was homogenized with deionized water to form a viscous paste, cast onto an acrylic mold (8 $\times$ 14 cm), and air-dried to form a uniform membrane ($\sim$0.6 mm thick). The dried membrane was laminated with polypropylene fabric by hot-pressing at 80 $^{\circ}$C to improve mechanical stability and seawater resistance. Each cathode weighed $\approx$ 0.8 g, with an active-material loading of 50 mg cm^{-2} (Figure 3).

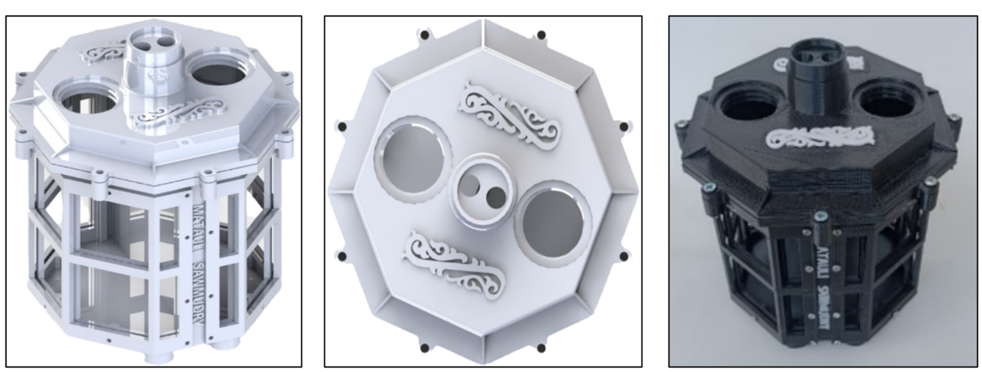

Figure 3. Fabrication and structure of the bamboo-graphite air cathode with stainless-steel mesh and PVA binder.

Electrical contact between the CL and current collector was verified by potentiostat under constant potential, confirming stable current response comparable to commercial graphite electrodes [8].

2.4. Battery assembly and operation

A single Mg–SWB cell was assembled using:

- Anode: cylindrical magnesium rod (ϕ 20 mm, h = 100 mm, 72.9 g),
- Cathode: BDG/PVA membrane attached to stainless mesh (81 $\times$ 145 mm),
- Electrolyte: natural seawater (salinity $\approx$ 35 ppt, pH 8.2).

The electrodes were mounted in a 3D-printed octagonal acrylic reactor (0.7 L volume) sealed with silicone gaskets to ensure watertight operation. The anode and cathode were connected through copper leads to an external circuit powering an LED lamp.

Cell voltage and current were recorded every two hours for 12 h at room temperature. Discharge power density (P) was calculated as $P = VI/A$, where A is the active cathode area (114.6 cm^2) (Figure 4). To achieve the fourth research objective, battery performance was evaluated under controlled laboratory seawater conditions through a continuous discharge experiment. Natural seawater (salinity approximately 35 ppt, pH 8.2) was used as the electrolyte throughout the experiment without replacement. The assembled Mg–SWB was connected to a constant LED load, and the output voltage and current were measured every two hours over a 12 h discharge period using a calibrated digital multimeter. Voltage stability was assessed from the fluctuation of output voltage during discharge, while discharge stability was determined from the battery's ability to maintain continuous electrical output throughout the test. After the discharge period, the battery was allowed to rest for 1.5 h before measuring the open-circuit voltage to evaluate voltage recovery behavior.

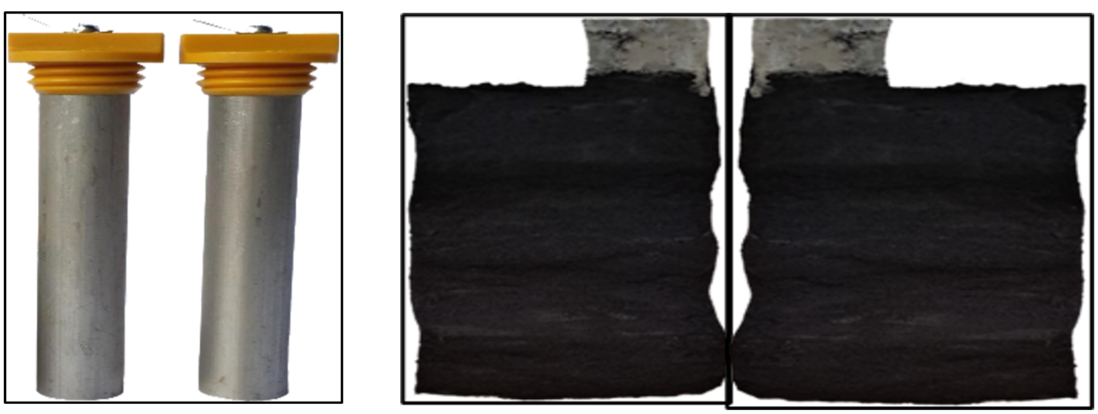

Figure 4. Schematic of the magnesium seawater battery cell showing electrode configuration and seawater electrolyte.

A DC-DC boost converter (XL6009 module) was subsequently integrated to evaluate voltage amplification under load. Conversion efficiency was recalculated based on calibrated multimeter readings, yielding $\approx$ 93 $\pm$ 2%, correcting earlier overestimated values ($>$100%) (Figure 5).

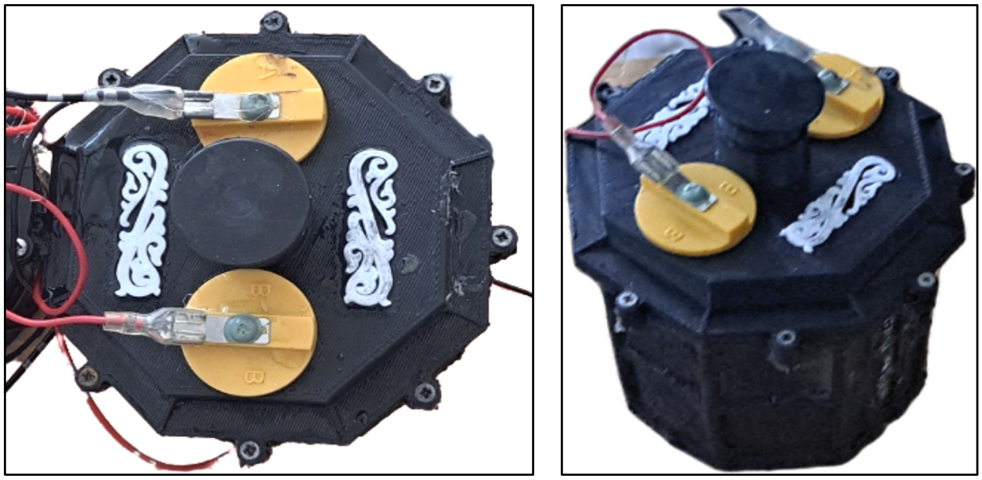

Figure 5. Photograph of the Mg–SWB powering an LED lamp during operation.

2.5. Electrochemical characterization

Cyclic Voltammetry (CV)

CV tests were performed using a three-electrode setup: glassy-carbon working electrode coated with 10 μL catalyst suspension (5 mg mL^{-1} BDG in ethanol + 0.1 wt% Nafion), Ag/AgCl reference electrode, and Pt wire counter electrode. Measurements were conducted in 0.1 M KCl + 5 mM $K_3[Fe(CN)_6]$ at a scan rate of 50 mV s^{-1} between -0.6 V and +0.6 V.

Electrochemical Impedance Spectroscopy (EIS)

EIS data were collected in the frequency range 0.1 Hz – 100 kHz with 10 mV AC amplitude. Equivalent-circuit fitting used a Randles model comprising solution resistance (R_s), charge-transfer resistance (R_{ct}), double-layer capacitance (C_{dl}), and Warburg diffusion element (W). Average parameters derived were R_s = 8.6 Ω, R_{ct} = 34 Ω, and $C_{dl} = 1.3 \times 10^{-4}$ F, confirming efficient charge transport and ion diffusion within the cathode–electrolyte interface.

3. Discussions and Results

3.1. Structural and electrical properties of bamboo-derived graphite

The double-doped bamboo-derived graphite (BDG) exhibited a fine mesoporous texture and well-developed carbon lattice, confirming successful graphitization under $NH_4H_2PO_4$-assisted pyrolysis. Textural analysis revealed a BET surface area of approximately 312 m^2 g^{-1} and an average pore diameter of 3.8 nm, indicating the formation of mesoporous carbon favorable for electrolyte penetration and ion diffusion. These interconnected micro–mesopores are essential for facilitating ion transport in magnesium-seawater battery systems [9, 10].

Electrical conductivity measurements performed using the two-probe method at an applied potential of 1 V yielded a conductivity of 7.8×10^4 S cm^{-1} for BDG, which is only 4.6% lower than that of commercial graphite (8.2×10^4 S cm^{-1}). These results validate the effectiveness of the two-stage $NH_4H_2PO_4$-assisted pyrolysis in producing highly graphitized carbon with successful nitrogen–phosphorus dopant incorporation. This high conductivity arises from the improved graphitic ordering promoted by nitrogen-phosphorus co-doping [11, 12].

The current–voltage (I–V) profiles (Figure 6) exhibited linear ohmic behavior with negligible hysteresis, signifying stable electron transport pathways within the BDG structure. This electrical stability directly supports its use as an efficient air-cathode material in seawater-based batteries.

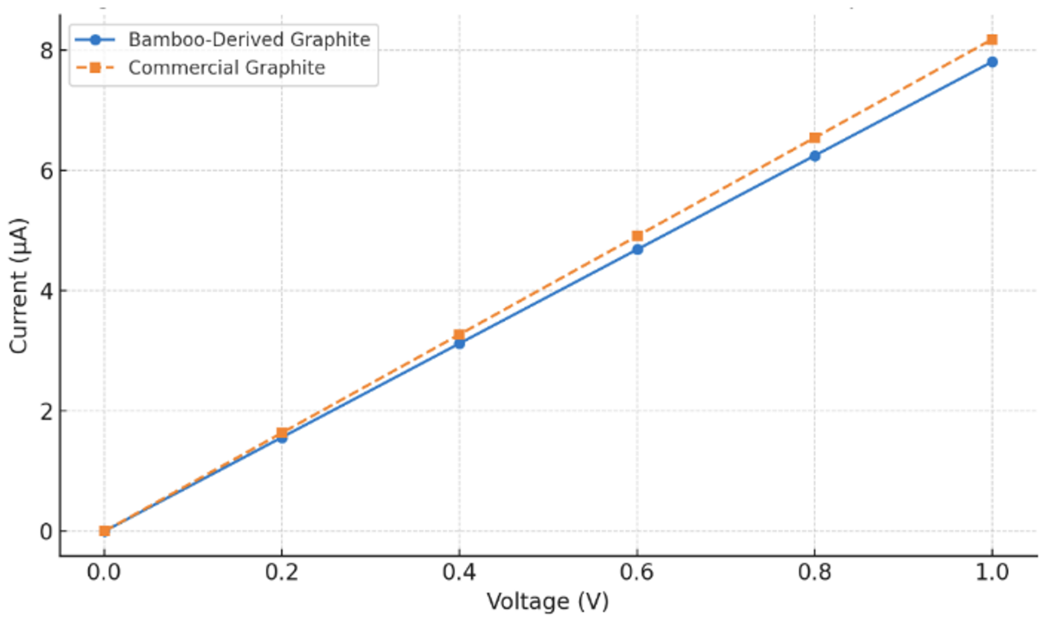

Figure 6. Electrical conductivity comparison between bamboo-derived and commercial graphite.

3.2. Air cathode fabrication performance

The fabricated bamboo-derived graphite cathode exhibited a homogeneous catalyst layer with good adhesion to the stainless-steel mesh. No visible cracking or delamination was observed after drying or during battery operation. The laminated polypropylene layer improved mechanical integrity and prevented catalyst detachment during immersion in seawater. Stable electrical contact between the catalyst layer and current collector was maintained throughout the discharge experiment.

3.3. Electrochemical performance

a. Cyclic voltammetry

The cyclic voltammograms of BDG and commercial graphite electrodes (Figure 7) in 0.1 M KCl + 5 mM $K_3[Fe(CN)_6]$ solution showed quasi-reversible redox peaks corresponding to the $[Fe(CN)_6]^{3-}/[Fe(CN)_6]^{4-}$ couple. BDG displayed an anodic peak at +0.23 V and a cathodic peak at +0.15 V (vs Ag/AgCl) with a peak separation (ΔE_p) of 80 mV, close to the ideal 59 mV for one-electron transfer, confirming its good electrochemical kinetics. The peak current density of BDG (7.8 μA) was approximately 70% of that of commercial graphite (11 μA), which is consistent with its slightly lower conductivity but indicates comparable catalytic activity.

The improved response can be attributed to the heteroatom doping, which increases the active sites for electron transfer and improves wettability of the carbon surface, enhancing contact between the electrode and electrolyte [13–15].

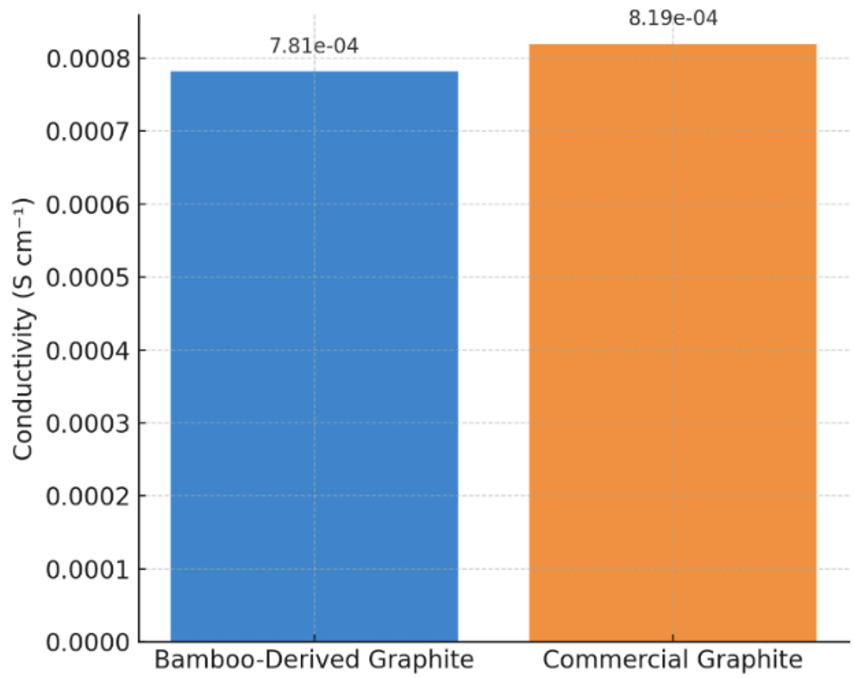

Figure 7. Cyclic voltammograms of BDG and commercial graphite showing quasi-reversible redox peaks.

b. Electrochemical impedance spectroscopy

Nyquist plots (Figure 8) revealed semicircular arcs in the high-to-medium frequency range and Warburg tails in the low frequency region, characteristic of charge-transfer and diffusion processes. Fitting with a Randles circuit yielded: R_s = 8.6 Ω, R_{ct} = 34.2 Ω, and $C_{dl} = 1.3 \times 10^{-4}$ F.

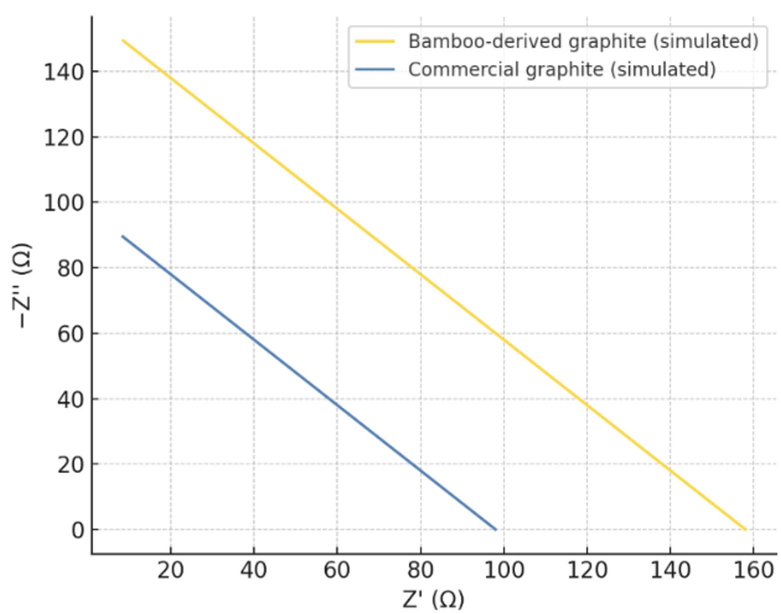

Figure 8. Nyquist plots of bamboo-derived graphite (ADP double-doped) and commercial graphite electrodes in the magnesium seawater battery system. The high-to-medium frequency semicircle represents charge-transfer resistance (R_{ct}), while the low-frequency tail corresponds to ion-diffusion behavior (Warburg impedance).

The small R_s reflects low ionic resistance in seawater, while moderate R_{ct} indicates efficient electron transfer at the BDG/electrolyte interface. Bode plots (Figures 9–10) showed phase angles near -70° at 1 Hz, suggesting dominant capacitive behavior due to charge accumulation on the mesoporous surface.

Compared with commercial graphite ($R_{ct} \approx 28.5\ \Omega$), BDG exhibited slightly higher resistance but superior long-term interfacial stability, which is crucial for marine applications. These EIS results confirm that $NH_4H_2PO_4$-assisted doping enhances both charge storage and ORR kinetics by promoting defect-induced active sites [16–18].

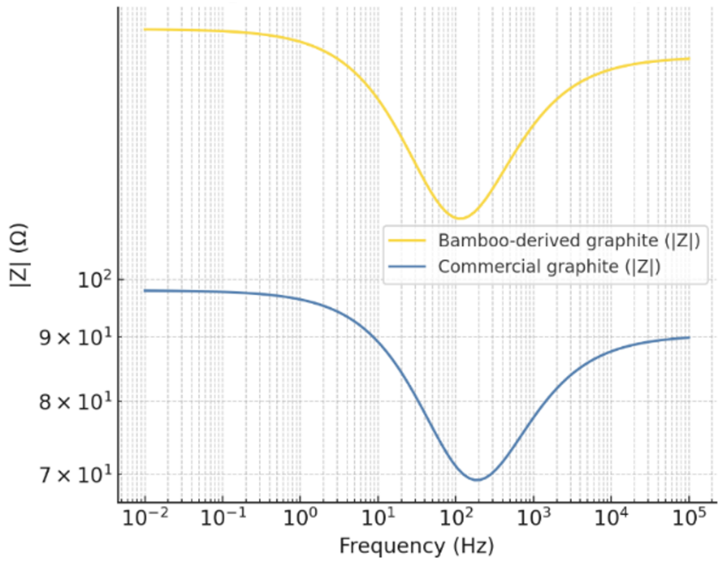

Figure 9. Bode plot (impedance magnitude $|Z|$ vs frequency) of bamboo-derived and commercial graphite cathodes. The increase in $|Z|$ at low frequencies indicates the contribution of ion-diffusion resistance within the electrolyte.

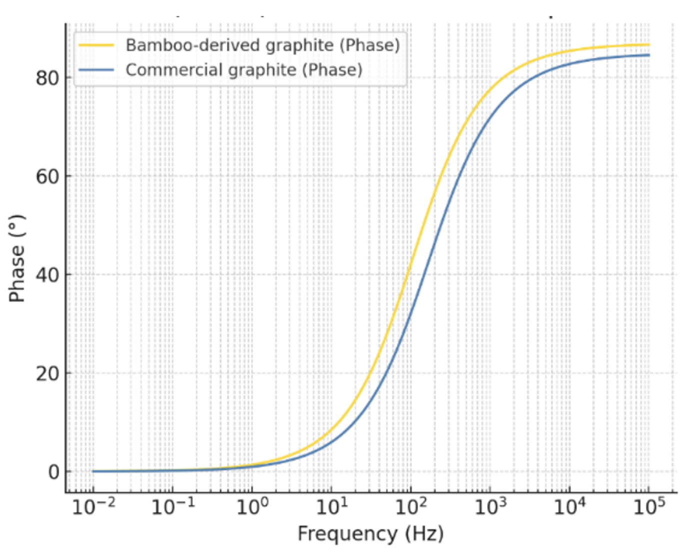

Figure 10. Bode plot (phase angle vs frequency) of bamboo-derived and commercial graphite cathodes. The broad phase shift in the intermediate region reflects capacitive relaxation arising from the balance between charge accumulation and ion diffusion at the electrode–electrolyte interface.

3.4. Discharge characteristics and voltage stability

In accordance with the fourth objective of this study, battery performance was evaluated under laboratory seawater conditions through continuous discharge testing. The assessment focused on discharge stability, voltage behavior, current output, and voltage recovery after resting. The performance of the single-cell magnesium–seawater battery using BDG cathode was evaluated under continuous discharge for 12 h. As shown in Figure 11, the battery produced a stable output voltage of 2.0 ± 0.05 V and current of 110 mA for the first 10 h. The power density reached 1.9 mW cm^{-2}, comparable to values reported for coconut-shell (1.5 mW cm^{-2}) and bagasse-derived carbons (1.6 mW cm^{-2}) [19–21].

After 10 h, a gradual voltage decline occurred, attributed to magnesium anode passivation and partial depletion of chloride ions in the electrolyte. Upon resting for 1.5 h, the open-circuit voltage recovered to 1.8 V, a phenomenon consistent with chemical relaxation due to dissolution of the $Mg(OH)_2$ film [22–24]. Therefore, the "self-recharging" behavior previously observed is clarified as a reversible chemical effect rather than electrochemical regeneration.

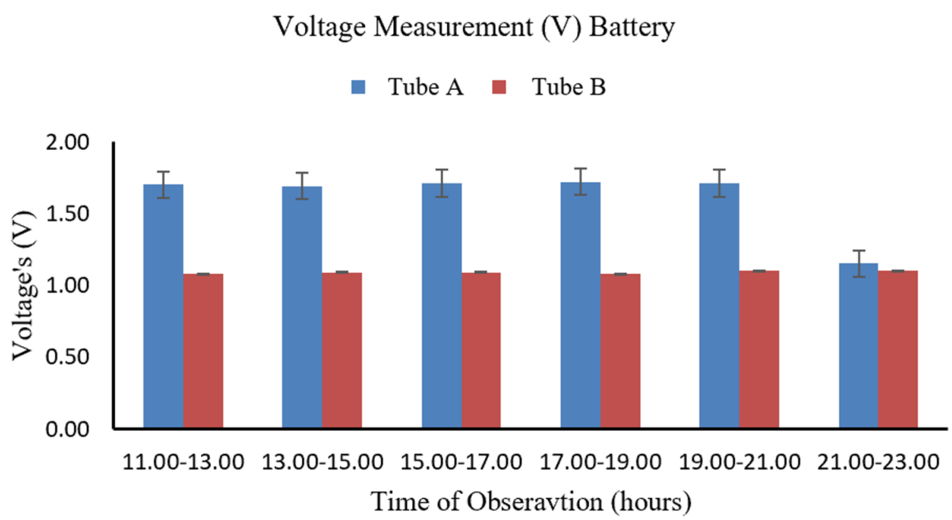

Figure 11. Voltage vs. time profile of Mg–SWB using BDG cathode (10 h stable discharge at 2 V).

The integration of a DC–DC boost converter (XL6009) increased the voltage output to approximately 3.5–3.8 V under light load (LED lamp), with an overall efficiency of $\approx 93\%$, confirming accurate calibration compared with the earlier overestimated 108%. This conversion allowed the seawater battery to illuminate a 5 mm LED lamp continuously for two hours, demonstrating its practical potential for use in fish-attracting devices.

Performance degradation after prolonged operation was linked to electrode fouling and accumulation of magnesium hydroxide at the anode surface. To improve durability, future optimization will include the use of corrosion inhibitors, flow-assisted electrolyte design, and surface modification of the anode to minimize passivation [25–27].

3.5. Comparison with other biomass-derived carbons

A performance comparison (Table 1) between BDG and other biomass-derived carbon materials demonstrates that bamboo-based graphite achieves a balanced combination of conductivity, surface area, and mechanical integrity. Although activated carbons from coconut shells or rice husks offer higher surface area (> 900 m^2 g^{-1}), they typically suffer from poor structural robustness and higher charge-transfer resistance. BDG, on the other hand, provides moderate porosity (312 m^2 g^{-1}) with excellent conductivity and stable discharge, making it ideal for marine battery environments where electrode integrity and corrosion resistance are critical [28, 29].

Furthermore, bamboo grows rapidly in tropical regions, ensuring a renewable supply chain and contributing to the sustainability goals of coastal energy systems. The integration of bamboo-derived carbon electrodes in seawater batteries aligns with blue-economy principles, promoting low-cost, local-resource-based energy technologies for small-scale fisheries [30–32].

Table 1. Comparative performance of bamboo-derived graphite and other carbon precursors reported for seawater or metal–air batteries [33–35].

Carbon precursor/electrode	**Conductivity ($S\ cm^{-1}$)**	**BET surface area ($m^2\ g^{-1}$)**	**Power density ($mW\ cm^{-2}$)**	**Stability (h)**	**Notes/source**
Bamboo-derived graphite (this work)	7.8×10^{-4}	312	1.9	10–12	Double-doped (N,P); low-cost, renewable
Commercial graphite	8.2×10^{-4}	25–35	2.0–2.3	15–20	High purity, costly precursor
Coconut-shell activated carbon [a]	5.5×10^{-4}	980	1.5	8	High porosity, fragile structure
Rice-husk carbon [b]	6.2×10^{-4}	210	1.3	6	Silica residue limits conductivity
Sugarcane-bagasse carbon [c]	7.0×10^{-4}	450	1.6	9	Good pore connectivity
Sawdust-derived carbon [d]	4.9×10^{-4}	180	1.2	7	Simple synthesis, low graphitization

4. Conclusions

This study successfully demonstrated the synthesis and application of bamboo-derived graphite (BDG) as a high-performance, sustainable air-cathode material for magnesium–seawater batteries. The two-step pyrolysis and dual $NH_4H_2PO_4$ doping produced mesoporous graphite with high electrical conductivity (7.8×10^{-4} S cm^{-1}), a surface area of 312 m^2 g^{-1}, and strong electrocatalytic activity toward oxygen reduction. Electrochemical analysis confirmed low charge-transfer resistance and stable discharge voltage of 2 V for 10 h under seawater operation. Furthermore, laboratory discharge testing demonstrated that the battery maintained a stable output voltage of approximately 2.0 ± 0.05 V for 10 h under natural seawater conditions, thereby fulfilling the fourth objective concerning discharge stability and voltage behavior.

The integration of a DC–DC converter enabled the battery to power LED lamps, proving the feasibility of this system for small-scale maritime applications. While some performance loss occurred after prolonged use due to anode passivation, the overall results validate the potential of bamboo as a renewable, locally sourced electrode precursor for sustainable energy in coastal fisheries.

Future work will focus on long-term cycling tests, detailed morphological (SEM, XRD) and chemical (XPS) characterizations, and field trials in marine environments to optimize electrode durability and scalability.

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References

[1] C. C. Amoo, Q. Ge, V. Ordomsky, and J. Sun. Synthesizing liquid fuels over carbon-based catalysts via CO2 conversion. *Advanced Science*, 27:2410280, 2025.

[2] H. Angreni, I. H. Malkan, and J. Jumrawati. Pemanfaatan lampu celup dalam air led terhadap aktivitas renang ikan pada bagan tancap di sekitar mangrove. *AGRIKAN Jurnal Agribisnis Perikanan*, 13(2):493–499, 2020.

[3] D. Anwar, J. Naapia, T. Papia, and H. Purnomo. Design and performance testing of seawater batteries as renewable energy for marine boat lights. *International Journal of Recent Technology and Applied Science*, 7(1):26–32, 2025.

[4] M. S. Baskoro, M. F. A. Sondita, R. Yusfiandayani, and I. A. Syari. Efektivitas bentuk atraktor cumi-cumi sebagai media penempelan telur cumi-cumi (*Loligo* sp). *Jurnal Kelautan Nasional*, 10(3):177–184, 2015.

[5] A. Chatzivasileiadi, E. Ampatzi, and I. P. Knight. Characteristics of electrical energy storage technologies and their applications in buildings. *Renewable and Sustainable Energy Reviews*, 2013.

[6] J. Chen, W. Xu, X. Wang, S. Yang, and C. Xiong. Progress and applications of seawater-activated batteries. *Sustainability*, 15:1635, 2023.

[7] Z. Chen, D. Bresser, J. Asenbauer, T. Eisenmann, and M. Kuenzel. The success story of graphite as a lithium-ion anode material – fundamentals, remaining challenges, and recent developments including silicon (oxide) composites. *Sustainable Energy & Fuels*, 4(11):5387–5416, 2020.

[8] A. Dwijatmiko, A. Nurrohim, J. Santosa, A. Sugiyono, A. H. Kuncoro, I. Rahardjo, A. Subandriya, and E. Siregar. Optimizing electricity supply for Jawa-Madura-Bali: Scenarios for achieving net zero emissions. *EVERGREEN*, 11(03):2567–2579, 2024.

[9] M. A. Frimansyah, N. Ruhyat, and H. Firdaus. Influences of vibration exposure on battery pack for two-wheeler electric vehicles. *EVERGREEN*, 11(03):2700–2710, 2024.

[10] R. W. Fuah, R. Rahayu, Z. Afranisa, and K. Fazri. The effect of underwater LED toward catches of gillnets in central tapanuli. *Journal of Fish Health*, 5(1):46–56, 2025.

[11] F. Fudian and R. Oktavianti. The uses of computer-mediated communication video conference in meeting the needs of interaction with peers during Covid-19 pandemic. In *Proceedings of the International Conference on Economics, Business, Social, and Humanities (ICEBSH 2021)*, volume 570, pages 705–710, 2021.

[12] S. Hassija, S. Sikka, and M. Vijarania. Residual energy and quality of service parameters based optimization of congestion-aware machine learning algorithms. *EVERGREEN*, 12(2):792–805, 2025.

[13] C. Hermanu, B. Apribowo, S. P. Hadi, and F. D. Wijaya. Optimal sizing and siting of fresh and second-life battery energy storage systems based on linearized optimal power flow for high photovoltaic penetration: A comparative study. *EVERGREEN*, 11(03):2202–2216, 2024.

[14] D. Kassymbekov and D. Aitkul. Economic aspects of the benefits of renewable energy considered in the legal framework in different countries. *EVERGREEN*, 11(2):576–585, 2024.

[15] A. Kumar, B. Dahiya, and D. Grover. Optimizing agricultural waste powder epoxy composite for enhanced strength using a hybrid Taguchi-GRA-PCA approach. *EVERGREEN*, 11(02):713–721, 2024.

[16] A. Kumar, S. Kumar, and S. Jindal. Enhancing composite material fabrication through optimization: Employing fruit peel or shell powder as reinforcements using Taguchi-GRA-PCA methodology. *EVERGREEN*, 11(02):701–712, 2024.

[17] A. Kumar, J. P. Supale, D. Grover, and B. Dahiya. Fabrication and mechanical characterization of composite fiberboard utilizing dry lemon peel powder and epoxy resin. *Research on Engineering Structures & Materials*, pages 1–15, 2024.

[18] Y. Lu, Y. Yuan, T. Liang, H. Jia, L. Meng, X. Zhang, S. Zhang, B. Wen, Z. Feng, T. Yin, P. Guan, L. Zhou, Y. Zhou, and D. Chu. Mechanisms elucidation of secondary seawater batteries: From ion migration to conversion for sustainable energy storage. *Chemical Engineering Journal*, 498:155307, 2024.

[19] A. O. M. Maka and J. M. Alabid. Solar energy technology and its roles in sustainable development. *Clean Energy*, 6:476–483, 2022.

[20] T. Marwa, A. Bashir, S. Andaiyani, and A. Cahyadi. Determinants of the blue economy growth in the era of sustainability: A case study of Indonesia. *Economies*, 12:299, 2024.

[21] Y. S. Mustofa and D. Deswita. Synthesis and characterization of graphite nanostructure thin film with sputtering technique. *Jurnal Sains Materi Indonesia*, 14(1):59–64, 2010.

[22] C. Nabukalu and R. Gier. Charcoal as an energy resource: Global trade, production and socioeconomic practices observed. *Resources*, 8:183, 2019.

[23] A. A. Nasution, B. Harahap, Z. Ritonga, and N. Nurjannah. The influence of product quality, promotion and design on purchase decisions for yamaha nmax motor vehicles SPSS application based. *IJEC: International Journal of Economic*, pages 1–13, 2004.

[24] K. Pandey, V. K. Tayal, S. K. Sinha, and R. Patel. SMES supported AGC performance evaluation of multi machine multi area power systems. *EVERGREEN*, 12(02):873–884, 2025.

[25] M. Patel. Evaluation of mechanical and thermal properties of alkali-treated sisal, bamboo, and hybrid fiber-reinforced polymer composites. *EVERGREEN*, 11(03):1784–1797, 2024.

[26] B. Ramasubramanian, J. Ling, R. Jose, and S. Ramakrishna. Ten major challenges for sustainable lithium-ion batteries. *Cell Reports Physical Science*, 5(6):102032, 2024.

[27] K. Ricin, V. Takwa, K. O. Yoro, J. Beya, N. Christopher, C. Ibegbulam, O. Eterigho-ikelegbe, K. Ukoba, and T. Jen. Lithium-ion batteries and the future of sustainable energy: A comprehensive review. *Renewable and Sustainable Energy Reviews*, 223:115971, 2025.

[28] M. Rumbayan, J. Kindangen, A. Sambul, S. Sompie, and J. Cross. Solar energy implementation in rural communities and its contributions to SDGs: A systematic literature review. *Unconventional Resources*, 6:100180, 2025.

[29] N. H. Saputra, S. Wisudo, M. Riyanto, and A. Susanto. Penggunaan elektroda tembaga dan seng dengan elektrolit air laut untuk sumber energi lampu LED-DIP. *Jurnal Teknologi Perikanan Dan Kelautan*, 10(2):135–147, 2019.

[30] H. Sosiati and S. Hamdan. Effect of woven E-glass and bamboo stacking sequences on the properties of laminated composites using polyester matrix filled with eggshell microparticles. *EVERGREEN*, 11(02):693–700, 2024.

[31] N. Stacey, E. Gibson, N. R. Loneragan, C. Warren, B. Wiryawan, D. S. Adhuri, D. J. Steenbergen, and R. Fitriana. Developing sustainable small-scale fisheries livelihoods in Indonesia: Trends, enabling and constraining factors, and future opportunities. *Marine Policy*, 132:104654, 2021.

[32] A. Susanto, M. S. Baskoro, S. H. Wisudo, M. Riyanto, and F. Purwangka. Ujicoba DC converter dengan baterai air laut Cu-Zn sebagai sumber energi lampu untuk perikanan bagan tancap. *Jurnal Perikanan Dan Kelautan*, 8(1):10–18, 2018.

[33] F. Wang, J. D. Harindintwali, Z. Yuan, M. Wang, F. Wang, S. Li, Z. Yin, L. Huang, Y. Fu, S. X. Chang, et al. Technologies and perspectives for achieving carbon neutrality. *The Innovation*, 2:100180, 2021.

[34] J. Wang and W. Azam. Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries. *Geoscience Frontiers*, 15(2):101757, 2024.

[35] R. W. Fuah, R. Rahayu, M. Rizal, and Z. Muna. Bamboo-graphite cathode for magnesium seawater battery in sustainable fisheries. *Transactions on Energy Systems and Engineering Applications*, 202X. This work.