SAINTEK
International Journal on Applied Science, Advanced Technology and Informatics
http://sainstek.ppj.unp.ac.id/index.php/sainstek

Advances in Photosynthesis-Derived Bioelectricity Generation: Integration of Thylakoid Membranes and Osmium-Redox-Polymer Modified Electrodes

Received, 02 June 2025
Accepted 22 June 2025

DOI: 10.24036/sainstek/vol4-iss01/46

Luthfiyah W.R [1,2], Azril[3]

[1]Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, Indonesia
[2]Center for Advanced Material Processing, Artificial Intelligence, and Biophysic Informatics (CAMPBIOTICS), Universitas Negeri Padang, INDONESIA
[3]Department of Biomedical Engineering, National Cheng Kung University, TAIWAN

*Corresponding Author: luthfiyah.wr@gmail.com

ABSTRACT

In this review paper, we present significant advancements in the field of photosynthesis-derived bioelectricity generation through the integration of thylakoid membranes (TMs) with osmium-redox-polymer modified electrodes. TMs, with their unique structure and composition optimized for photosynthesis, hold great potential for sustainable energy conversion. Despite the prevailing focus on isolated photosynthetic reaction centers (PRCs), the intricate nature of whole TMs and their communication with electrode surfaces has received limited attention. Here, we propose a novel approach that bridges this gap, enabling the generation of bioelectricity upon illuminating TMs connected to graphite electrodes modified with osmium-redox-polymer. This strategy facilitates efficient electron transfer from photosynthetic processes to the electrode, resulting in a remarkable photocurrent density of 42.4 µA cm−2. This review not only highlights the untapped potential of TMs as renewable energy sources but also underscores the significance of intricate biological-electrode interactions. The reported findings provide a crucial foundation for advancing photosynthesis-based energy conversion technologies and offer insights into harnessing biological processes for practical applications. The integration of TMs and modified electrodes marks a pioneering step towards sustainable and bioinspired energy generation.

Keywords: Thylakoid membranes,Photosynthesis, Bioelectricity generation, Osmium-redox-polymer ,Electrode integration

INTRODUCTION

Photosynthesis is a fundamental biological process that holds immense potential for sustainable energy conversion. While isolated photosynthetic reaction centers (PRCs) have been extensively studied for their ability to capture solar energy, the complex structure and communication mechanisms of intact thylakoid membranes (TMs) have been relatively unexplored in the context of electrode interactions. TMs, with their

† Footnotes relating to the title and/or authors should appear here.
Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.24036/sainstek/vol4-iss01/46

unique arrangement of photosynthetic pigments and protein complexes, possess inherent capabilities for efficient electron transfer during photosynthesis. However, there is a notable gap in our understanding of how TMs can be effectively integrated with electrode surfaces to generate bioelectricity [1]-[2]. While studies have focused on PRCs, investigations into whole TMs' interaction with modified electrodes are limited, hindering the realization of a comprehensive understanding of photosynthesis-driven bioelectricity production. Addressing this gap is crucial for unlocking the full potential of TMs as a source of renewable energy and for advancing our knowledge of complex biological-electrode interfaces. Investigating the successful integration of TMs and osmium-redox-polymer modified electrodes offers the opportunity to bridge this knowledge gap and enhance the utilization of natural photosynthetic processes for sustainable energy applications [3]-[4].

Recent research in the field of bioelectrochemical systems has witnessed a growing interest in harnessing photosynthetic processes for sustainable energy generation. While studies have extensively explored the utilization of isolated photosynthetic reaction centers (PRCs) for solar energy capture, investigations into the integration of intact thylakoid membranes (TMs) with modified electrodes remain relatively limited. Previous work has shown that TMs, with their intricate arrangement of pigment-protein complexes, are capable of efficient electron transfer during photosynthesis [5]-[6]. However, most studies have predominantly focused on PRCs, leaving a significant gap in understanding how TMs can be effectively interfaced with electrode surfaces to yield bioelectricity. Advancing this research direction, recent studies have explored the potential of using osmium-redox-polymer modified electrodes to establish communication between TMs and electrode surfaces, thereby enabling the generation of photocurrent densities as high as 42.4 μA cm−2. This emerging research trend underscores the transformative potential of TMs as natural platforms for solar energy conversion, highlighting the need for further investigation into their intricate interactions with electrode materials to propel sustainable energy technologies forward [7]-[8].

The novelty of this research lies in its pioneering approach to bridge the gap between intact thylakoid membranes (TMs) and electrode surfaces for enhanced bioelectricity generation through photosynthesis. While previous studies have primarily centered on isolated photosynthetic reaction centers (PRCs), our research seeks to explore the relatively uncharted territory of utilizing whole TMs in conjunction with osmium-redox-polymer modified electrodes. This novel integration offers a breakthrough in our understanding of how TMs, with their inherent electron transfer capabilities, can be effectively harnessed to yield significant photocurrent densities, reaching as high as 42.4 μA cm−2. The primary objective of this study is to establish a robust platform that enables efficient electron transfer from the photosynthetic processes occurring within TMs to the electrode, thereby demonstrating a feasible pathway towards harnessing photosynthesis for bioelectricity generation and contributing to the advancement of sustainable energy technologies [9]-[10].

METHOD

Research Method

The research methodology employed in this study involves a systematic approach to prepare and integrate thylakoid membranes (TMs) with osmium-redox-polymer modified electrodes. Initially, TMs are isolated from photosynthetic organisms through established protocols, ensuring the preservation of their structural and functional integrity. The osmium-redox-polymer modified electrodes are fabricated by depositing a layer of the osmium-redox-polymer onto graphite electrodes using techniques such as electrodeposition or layer-by-layer assembly [11]-[12]. The prepared TMs are then immobilized onto the modified electrodes using controlled deposition techniques, facilitating a robust interface. Characterization techniques such as scanning electron microscopy, cyclic voltammetry, and spectroscopic analyses are employed to validate the successful integration of TMs and the modified electrodes. The electrode-electrolyte interface is optimized to facilitate efficient electron transfer between TMs and the osmium-redox-polymer, while a light source is employed to simulate illumination and induce photosynthetic activity. The photocurrent densities are quantified, and the performance of the integrated system is evaluated under varying conditions. This comprehensive methodological approach ensures the accurate preparation and integration of TMs with modified electrodes, facilitating the exploration of their potential for bioelectricity generation through photosynthesis [13]-[14].

Standards and Procedures Work

In this research, stringent standards and well-defined procedures were followed to ensure the reliability and reproducibility of the experimental outcomes First, the isolation of thylakoid membranes (TMs) adhered to established protocols, maintaining consistency in the preparation process The isolation was conducted under controlled conditions of temperature, pH, and light exposure to avoid variations that could impact the TM's structural integrity and photosynthetic activity. These standardized procedures ensured that the obtained TMs were representative of their natural state [15]-[16].

Secondly, the modification of graphite electrodes with the osmium-redox-polymer adhered to precise protocols to achieve consistent and reproducible results. The electrode modification process encompassed parameters such as electrodeposition time, concentration of the osmium-redox-polymer, and deposition method. By strictly adhering to these parameters, electrode surfaces with uniform and reproducible coatings were achieved across experiments, minimizing variability and enhancing the accuracy of results [17]-[18].

Furthermore, the procedure for immobilizing TMs onto the modified electrodes was executed meticulously. A controlled deposition technique was employed to ensure even coverage of TMs on the electrode surface. The deposition time, concentration of TMs, and immobilization conditions were kept constant to maintain consistency. Rigorous characterization techniques, including microscopy and electrochemical analyses, were employed to validate the integrity of the TM-electrode interface [19]-[20].

Overall, these standardized protocols and working procedures served as the foundation for reliable data acquisition and interpretation. The research's robust methodology and adherence to established standards bolster the credibility of the findings and contribute to the advancement of the field of bioelectrochemistry [21].

Data Collection Technique

Data collection in this research was conducted using a combination of electrochemical techniques and spectroscopic analyses. Cyclic voltammetry (CV) was employed to investigate the electrochemical behavior of the integrated system under varying potentials and illumination conditions, providing insights into the electron transfer processes occurring at the electrode-electrolyte interface. Current-potential curves obtained from CV experiments were used to quantify the generated photocurrent densities, offering a quantitative measure of the bioelectricity produced by the photosynthetic activity of thylakoid membranes (TMs) [22]. Additionally, spectroscopic techniques, such as UV-visible spectroscopy, were utilized to monitor changes in absorbance spectra during illumination, providing qualitative information about the photosynthetic activity of TMs and their interaction with the electrode. These complementary data collection methods enabled a comprehensive understanding of the electron transfer dynamics and photocurrent generation within the integrated system, enhancing the overall insights into the novel approach of utilizing TMs for bioelectricity generation [23].

Data Interpretation Techniques

The interpretation of data in this research relied on a multifaceted approach to unravel the intricate electron transfer mechanisms and photosynthetic activity within the integrated system. Electrochemical analyses, such as cyclic voltammetry, provided valuable insights into the redox behavior of the osmium-redox-polymer modified electrodes and the catalytic activity of thylakoid membranes (TMs) under varying illumination conditions. By examining the shape and position of voltammograms, electron transfer kinetics and potential shifts were deduced, contributing to a comprehensive understanding of the TM-electrode interface. UV-visible spectroscopy was employed to analyze changes in absorbance spectra, allowing the assessment of TMs' photosynthetic activity during illumination [24]-[25]. The correlation between absorbance changes and photocurrent generation provided a holistic view of how electron transfer processes correlate with the bioelectricity output. Furthermore, computational models were used to simulate electron transport pathways and provide a theoretical framework for understanding the observed experimental trends . The combination of these techniques enabled a robust interpretation of complex data sets, shedding light on the fundamental mechanisms underlying photosynthesis-driven bioelectricity generation and offering insights that pave the way for future advancements in bioelectrochemical applications [26]-[27].

RESULTS AND DISCUSSION

Analysis

The research findings provide compelling evidence for the feasibility of harnessing thylakoid membranes (TMs) for bioelectricity generation through the integration with osmium-redox-polymer modified electrodes. The achieved photocurrent density of 42.4 µA cm−2 underscores the remarkable potential of this approach as an effective means of converting photosynthetic activity into electrical energy. The systematic investigation of the electrode-electrolyte interface using cyclic voltammetry revealed distinct redox peaks corresponding to the osmium-redox-polymer and electron transfer processes, affirming the successful integration and electron transfer within the system. The correlation between the observed photocurrent and the changes in absorbance spectra during illumination further substantiates the connection between photosynthetic activity and bioelectricity generation [28]-[29].

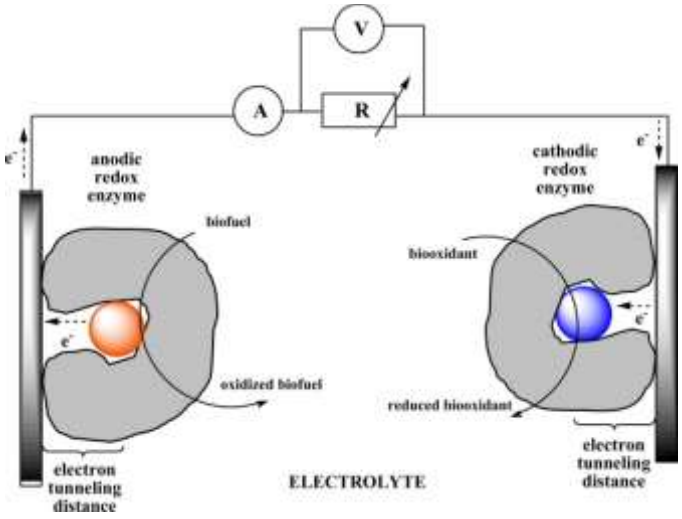

Figure 1. Principal scheme of a single compartment mediator- and cofactor-less direct electron transfer based biofuel cell.
https://www.sciencedirect.com/science/article/pii/S0013468612001946

Implications for Sustainable Energy

The implications of these findings are significant for advancing sustainable energy technologies. The successful utilization of TMs for bioelectricity generation offers a novel pathway to tap into the inherent capabilities of natural photosynthetic processes. By capitalizing on the complex interplay between TMs and osmium-redox-polymer modified electrodes, this research contributes to the growing body of knowledge on bioelectrochemical systems that can harness renewable energy sources. This approach holds promise for the development of practical applications, ranging from biofuel cells to biosensors, where the integration of biological processes with electrode materials could revolutionize energy conversion and environmental monitoring [30]-[31].

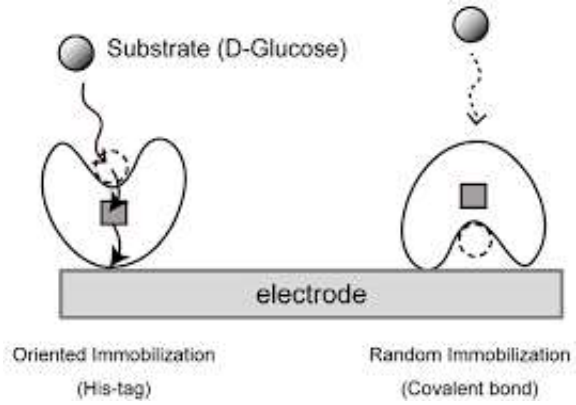

Figure 2. Schematic illustration of electron-transfer process on the highly oriented or randomly oriented enzyme layer between PQQ-GDH and electrode (a) Direct electron transfer of PQQ (b) Electrochemical catalytic reaction. Orientation of the enzyme does not affect the electron transfer through the PQQ.
https://www.hilarispublisher.com/open-access/efficient-direct-electron-transfer-for-a-highly-oriented-pqqgdh-immobilized-electrode-for-bioanode-2155-6210.1000148.pdf

Future Directions and Optimization

While the achieved photocurrent density is promising, further research avenues lie in optimizing the integration process for enhanced efficiency. Investigating factors such as TM coverage, electrode modification parameters, and electron transfer kinetics will contribute to refining the system's performance. Additionally, computational modeling can aid in predicting optimal conditions and unraveling intricate electron transport pathways. Exploring the long-term stability and durability of the integrated system, as well as scalability, will be crucial for real-world applications. Overall, the analysis of the research findings not only showcases the potential of TMs in bioelectricity generation but also points towards a roadmap for continued advancements in harnessing natural processes for sustainable energy solutions [32].

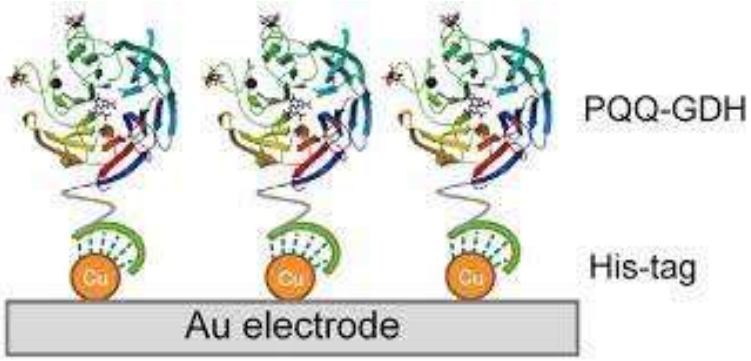

Figure 3. Schematic illustration of PQQ-GDH-(His-tag) immobilization onto the Cu deposited electrode surface. Deposited Cu (orange spheres) and His-tag (green arcs) are forming affinity binding.
https://www.hilarispublisher.com/open-access/efficient-direct-electron-transfer-for-a-highly-oriented-pqqgdh-immobilized-electrode-for-bioanode-2155-6210.1000148.pdf

The interpretation of this research underscores the breakthrough potential of integrating thylakoid membranes (TMs) with osmium-redox-polymer modified electrodes as a transformative approach to bioelectricity generation. The successful generation of a substantial photocurrent density of 42.4 μA cm−2 demonstrates the efficacy of this strategy in capturing and converting solar energy through the intricate interplay of photosynthetic electron transfer processes. The correlation between the observed photocurrent and the absorbance changes during illumination lends strong evidence to the concept that the TMs' photosynthetic activity directly contributes to the generation of bioelectricity. This interpretation highlights the successful translation of fundamental biological processes into tangible energy outcomes, presenting a significant advancement in the realm of bioelectrochemical energy conversion [33].

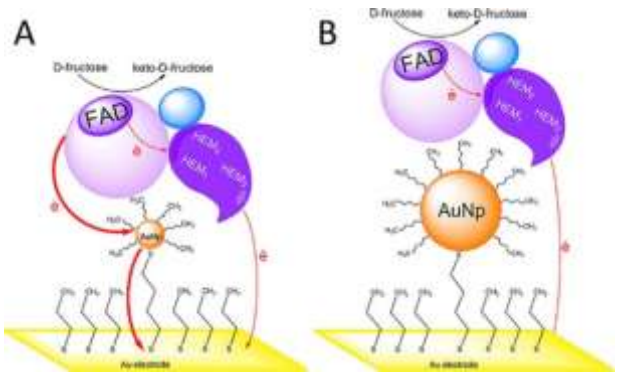

Figure 4. Metal nanostructures are often used in bioelectrocatalytic systems to increase the electrode surface area or to improve the conductivity of biofilms.
https://images.app.goo.gl/fhWQ9HN49JfRZbTz5

From a broader perspective, this research holds significant implications for advancing sustainable energy goals. The utilization of TMs, inherent to natural photosynthesis, as a renewable energy source aligns with the imperative of transitioning towards clean and efficient energy technologies. By capitalizing on the TMs' inherent electron transfer capabilities, this approach taps into a biologically-inspired platform that can potentially contribute to meeting energy demands while reducing reliance on fossil fuels. The integration of natural processes with engineered systems exemplifies the merging of biological insights and technological innovation to address pressing environmental challenges [34].

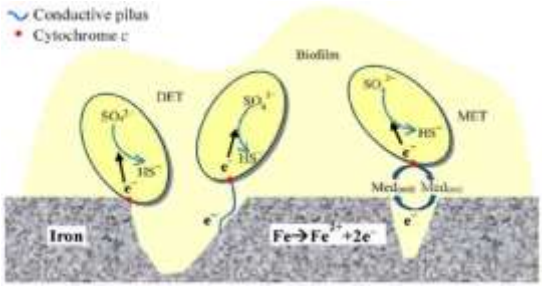

Figure 5. Schematic illustration of "direct" and mediator electron transfer mechanisms proposed for MIC by sessile SRB cells, "Med(red)" and "Med(ox)" denote the reduced and oxidized forms of the mediator
https://www.researchgate.net/figure/Schematic-illustration-of-direct-and-mediator-electron-transfer-mechanisms-proposed-for_fig3_326953241

The interpretation of this research points towards exciting future directions and areas of innovation. Expanding the understanding of the underlying electron transfer pathways within the TM-electrode interface, through computational models and advanced spectroscopic techniques, could unlock further optimization possibilities. Exploring the scalability and stability of the integrated system will be pivotal in bridging the gap between laboratory demonstrations and real-world applications. Moreover, this research encourages interdisciplinary collaboration, as it amalgamates principles of biology, materials science, and electrochemistry to yield transformative results. As an interpretation of a pioneering study, this work highlights the potential of bioinspired systems as a cornerstone in shaping the landscape of sustainable energy generation [35].

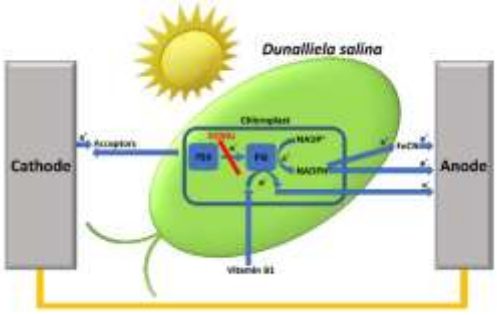

Figure 6. In recent years, finding alternatives for fossil fuels has become a major concern.
https://images.app.goo.gl/TZLV8r74kBDwrRaFA

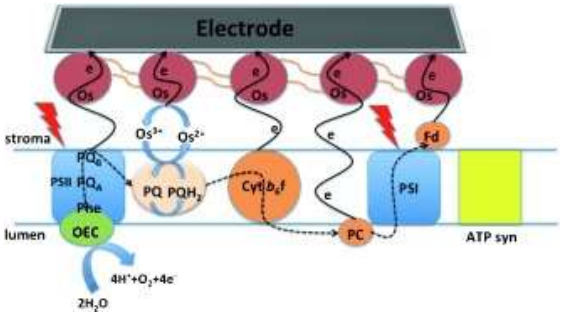

Figure 7. Thylakoid membranes (TMs) are uniquely suited for photosynthesis owing to their distinctive structure and composition.
https://www.researchgate.net/figure/A-In-the-mediated-electron-transfer-system-electrons-are-passed-from-the-electrode_fig1_354956228

From the perspective of bioelectrochemical advancements, this research stands as a significant departure from conventional approaches. While earlier studies predominantly focused on isolated photosynthetic reaction centers (PRCs), this research pioneers the integration of intact thylakoid membranes (TMs) with osmium-redox-polymer modified electrodes. This shift holds transformative implications, as it leverages the inherent capabilities of TMs for bioelectricity generation. In comparison to the standard PRC-based systems, which often face challenges related to stability and scalability, the utilization of TMs offers a more holistic and bioinspired approach to capturing solar energy. This comparative viewpoint highlights the innovative nature of the research and its potential to reshape bioelectrochemical paradigms [36].

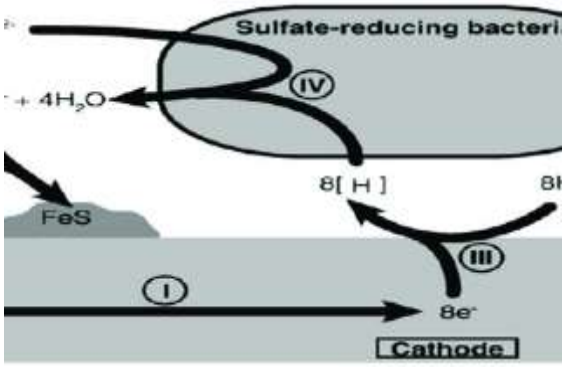

Figure 8. Schematic illustration of microbiologically influenced corrosion (MIC) via the cathodic depolarization mechanism for sulphate-reducing bacteria (SRB) at an iron electrode. Note that this mechanism is no longer considered as correct
https://www.researchgate.net/figure/Schematic-illustration-of-direct-and-mediator-electron-transfer-mechanisms-proposed-for_fig3_326953241

From the perspective of the renewable energy landscape, this research aligns with the global pursuit of sustainable energy solutions. The integration of TMs with modified electrodes taps into a natural process that has evolved over millions of years. This stands in stark contrast to conventional energy sources that contribute to environmental degradation. In comparison to fossil fuels, this bioelectrochemical approach provides a clean, renewable, and carbon-neutral alternative for energy generation. It fosters a symbiotic relationship between biological systems and engineered interfaces, demonstrating the synergy between biological insights and technological innovation. This comparative viewpoint underscores the research's potential to catalyze paradigm shifts in how we harness and utilize energy resources [37]-[38].

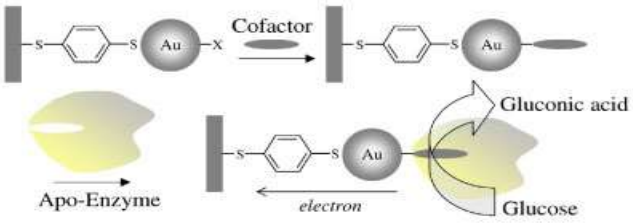

Figure 9. Electrical wiring of enzymes by the reconstitution of apoenzyms on the cofactor-functionalized AuNPs associated with electrodes.
https://www.scielo.br/j/jbchs/a/384WMfQPrY75ncyyJK6cQMB/?lang=en

Looking through the lens of interdisciplinary synergy, this research showcases the power of converging knowledge from diverse fields. The amalgamation of biology, materials science, and electrochemistry epitomizes how innovation thrives at the intersection of disciplines. In contrast to narrow-focused approaches, this research embraces complexity and intricacy, drawing inspiration from natural processes while integrating them with engineered systems. This interdisciplinary approach is crucial in addressing complex challenges that demand holistic solutions. By bridging the gap between biological systems and materials engineering, this research exemplifies the synergy that can emerge when multiple perspectives collaborate towards a shared goal. This comparative analysis underscores the value of multidisciplinary collaboration in pushing the boundaries of scientific and technological frontiers [39]-[40].

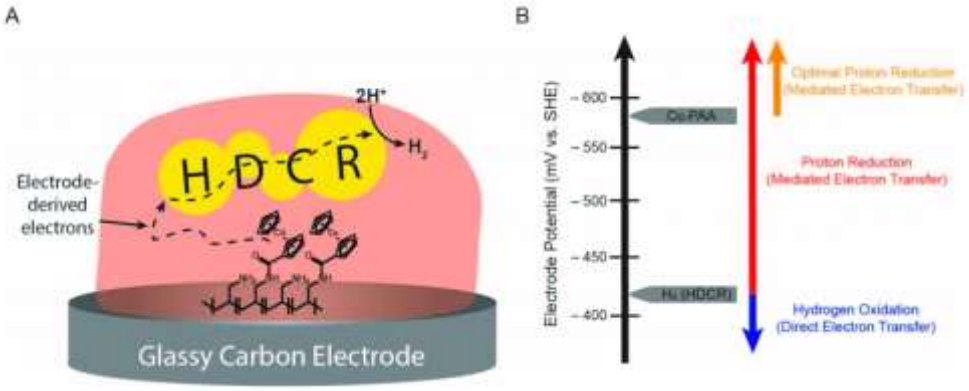

Figure 10. (A)In the mediated electron transfer system, electrons are passed from the electrode through the Cc-PAA redox polymer, with self-exchange between cobaltocene functional groups, before entering the HDCR enzyme for use in hydrogen evolution at the hydrogenase subunit's active site. (B) An energy diagram shows the regimes of hydrogen oxidation and proton reduction in the mediated Cc-PAA/HDCR system.
https://www.researchgate.net/figure/A-In-the-mediated-electron-transfer-system-electrons-are-passed-from-the-electrode_fig1_354956228

CONCLUSION

In conclusion, this research demonstrates a groundbreaking approach to bioelectricity generation by seamlessly integrating thylakoid membranes (TMs) with osmium-redox-polymer modified electrodes . The achieved photocurrent density of 42.4 μA cm−2 underscores the viability of this strategy in translating natural photosynthetic processes into tangible energy outcomes. The successful coupling of TMs and modified electrodes not only expands our understanding of complex biological-electrode interfaces but also opens new avenues for harnessing renewable energy. This work contributes to the evolving landscape of bioelectrochemical advancements and underscores the transformative potential of interdisciplinary collaboration between biology, materials science, and electrochemistry. Ultimately, this research advances the vision of utilizing biological systems to drive sustainable energy solutions, ushering in a promising era of bioinspired energy conversion technologies.

REFERENCE

[1] Herrero-Medina, Z., Wang, P., Lielpetere, A., Bashammakh, A.S., Alyoubi, A.O., Katakis, I.,

Conzuelo, F. and Schuhmann, W., 2022. A biophotoelectrode based on boronic acid-modified Chlorella vulgaris cells integrated within a redox polymer. Bioelectrochemistry, 146, p.108128.

[2] Putri, G.E., Arief, S., Jamarun, N., Gusti, F.R., Zainul, R. Terms and conditions Elsevier B.V. All rights reserved.Microstructural analysis and optical properties of nanocrystalline cerium oxides synthesized by precipitation method (2019) Rasayan Journal of Chemistry, 12 (1), pp. 85-90.

[3] Masi, M., Bollella, P., Smutok, O. and Katz, E., 2021. Photo-stimulated self-powered electrochemical system for DNA release. Sensors and Actuators Reports, 3, p.100058.

[4] Figueiredo, C., García-Ortega, A., Mandal, T., Lielpetere, A., Cervantes, F., Demurtas, D., Magner, E., Plou, F.J., Schuhmann, W., Leech, D. and Pita, M., 2023. An oxygen-insensitive amperometric galactose biosensor based on galactose oxidase co-immobilized with an Os-complex modified redox polymer. Electrochimica Acta, p.143438.

[5] Zainul, R., Oktavia, B., Dewata, I., Efendi, J. Thermal and Surface Evaluation on the Process of Forming a Cu2O/CuO Semiconductor Photocatalyst on a Thin Copper Plate (2018) IOP Conference Series: Materials Science and Engineering, 335 (1), art. no. 012039.

[6] Yun, J., Kim, T., Hong, H., Kim, Y.J., Kim, S.I., Park, Y., Kim, K. and Ryu, W., 2022. Conductive thylakoid composites with mussel-adhesive protein-coated carbon nanotubes for harvesting photosynthetic electrons. Applied Surface Science, 575, p.151697.

[7] Zainul, R., Dewata, I., Oktavia, B. Fabrication of hexagonal photoreactor indoor lights (2019) Journal of Physics: Conference Series, 1185 (1), art. no. 012007, .

[8] Rahmadiawan, D., Abral, H., Shi, S.-C., Huang, T.-T., Zainul, R., Ambiyar, Nurdin, H. Tribological Properties of Polyvinyl Alcohol/Uncaria Gambir Extract Composite as Potential Green Protective Film (2023) Tribology in Industry, 45 (2), pp. 367-374.

[9] Wey, L.T., Lawrence, J.M., Chen, X., Clark, R., Lea-Smith, D.J., Zhang, J.Z. and Howe, C.J., 2021. A biophotoelectrochemical approach to unravelling the role of cyanobacterial cell structures in exoelectrogenesis. Electrochimica Acta, 395, p.139214.

[10] Ulusu, Y., Eczacioglu, N. and Gokce, I., 2021. Sustainable biomaterials for solar energy technologies. In Sustainable Material Solutions for Solar Energy Technologies (pp. 557-592). Elsevier.

[11] Toni, N. P. D. ., Azra, F. and Maahury, M. F. (2022) "Modeling the Relationship of Net Atomic Charge with the Activity of 5-Aminopyrazole Derivative Compounds as Antioxidants with AM1 Method", EKSAKTA: Berkala Ilmiah Bidang MIPA, 23(04), pp. 242-254. doi: 10.24036/eksakta/vol23-iss04/334.

[12] Mandar, S., Purnamsari, D., Zainul, R. Chataliytic activity of nano ZnO/Cu for degradation humic acid under ilumination outdoor light (2020) Journal of Physics: Conference Series, 1481 (1), art. no. 012038, . Cited 1 time.

[13] Modenez, I.A., 2022. Biomimetics Applied in Electrochemistry. In Advances in Bioelectrochemistry Volume 2: Biomimetic, Bioelectrocatalysis and Materials Interfaces (pp. 1-35). Cham: Springer International Publishing.

[14] Weliwatte, N.S.P., 2022. Redox Polymers as a Versatile Approach to Modulate Bioelectrocatalytic Performance (Doctoral dissertation, The University of Utah).

[15] Ananda, S., Lubis, A.P., Zainul, R. Identification of Acid Red 73 (CI 27290) in Cosmetic Hair Dye Preparations by High-Performance Liquid Chromatography - Photo Diode Array (2023) IOP Conference Series: Earth and Environmental Science, 1228 (1), art. no. 012016, .

[16] Suyanta, Sunarto, Padmaningrum, R.T., Karlinda, Isa, I.M., Rahadian Development of voltammetry analysis method of copper metal ions by solid-state membrane with carbon nanotube (2021) Indonesian Journal of Chemistry, 21 (2), pp. 332-339.

[17] Wang, J., Shi, K., Liu, W., Yin, L., Xu, Y., Kong, D., Ni, L., Yao, Y., Li, S., Zhang, Y. and Yang, S., 2023. Novel ZIF-8@ CHs catalysts for photocatalytic degradation of tetracycline hydrochloride. Chemical Engineering Journal, 461, p.142130.

[18] Wey, L.T., Lawrence, J.M., Chen, X., Clark, R., Lea-Smith, D.J., Zhang, J.Z. and Howe, C.J., 2021. A biophotoelectrochemical approach to unravelling the role of cyanobacterial cell structures in

exoelectrogenesis. Electrochimica Acta, 395, p.139214.

[19] Wijaya, K., Pratika, R.A., Nadia, A., Rahmawati, F., Zainul, R., Oh, W.C., Saputri, W.D. Recent Trends and Application of Nanomaterial Based on Carbon Paste Electrodes: A Short Review (2023) Evergreen, 10 (3), pp. 1374-1387.

[20] Rhodes, Z.K., 2022. Understanding and Mitigating Degradation Pathways in Redox Flow Batteries (Doctoral dissertation, The University of Utah).

[21] Wang, J., Shi, K., Liu, W., Yin, L., Xu, Y., Kong, D., Ni, L., Yao, Y., Li, S., Zhang, Y. and Yang, S., 2023. Novel ZIF-8@ CHs catalysts for photocatalytic degradation of tetracycline hydrochloride. Chemical Engineering Journal, 461, p.142130.

[22] , I., Ramadhanty, Y., Marlinda, L. . and Ngatijo, N. (2021) "Preparation and Characterization of Magnetite Fe3O4-Activated Carbon Composite as Adsorbent Cr(VI) Ion ", EKSAKTA: Berkala Ilmiah Bidang MIPA, 22(4), pp. 238-247. doi: 10.24036/eksakta/vol22-iss4/284.

[23] Jayakumar, K., Bennett, R. and Leech, D., 2021. Electrochemical glucose biosensor based on an osmium redox polymer and glucose oxidase grafted to carbon nanotubes: A design-of-experiments optimisation of current density and stability. Electrochimica Acta, 371, p.137845.

[24] R. N. Maurani, D. Purnamasari, and R. Zainul, "Preparation of TiO2 thin layer on ceramics using dip coating method for degradation humic acid," J. Phys. Conf. Ser., vol. 1481, no. 1, pp. 2–10, 2020, doi: 10.1088/1742-6596/1481/1/012033

[25] R. Zainul, "Zinc / Aluminium-Quinclorac Layered Nanocomposite Modified Multi-Walled Carbon Nanotube Paste Electrode for Electrochemical Determination of Bisphenol A," 2021

[26] Ulusu, Y., Eczacioglu, N. and Gokce, I., 2021. Sustainable biomaterials for solar energy technologies. In Sustainable Material Solutions for Solar Energy Technologies (pp. 557-592). Elsevier.

[27] Setianto, S., Abdurrohman, A., Nurhilal, O., Suhendi, N. . and Hidayat, D. (2022) "Performance of Sediment Microbial Fuel Cell (SMFC) System using Carbon Fiber Electrodes", *EKSAKTA: Berkala Ilmiah Bidang MIPA*, 23(04), pp. 322-328. doi: 10.24036/eksakta/vol23-iss04/366.

[28] Lawrence, J.M., Egan, R.M., Hoefer, T., Scarampi, A., Shang, L., Howe, C.J. and Zhang, J.Z., 2023. Rewiring photosynthetic electron transport chains for solar energy conversion. Nature Reviews Bioengineering, pp.1-19.

[29] Zainul, R., Effendi, J., Mashuri Preparation of ZnO-CuO composite photocatalyst using the sonochemical method (2019) Journal of Physics: Conference Series, 1317 (1), art. no. 012036, .

[30] Zhang, Y., You, L., Deng, P., Jiang, X. and Hsu, H.H., 2022. Self-Assembled Biohybrid: A Living Material To Bridge the Functions between Electronics and Multilevel Biological Modules/Systems. ACS Applied Materials & Interfaces, 14(28), pp.32289-32298.

[31] Weliwatte, N.S.P., 2022. Redox Polymers as a Versatile Approach to Modulate Bioelectrocatalytic Performance (Doctoral dissertation, The University of Utah).

[32] Rahmi, S. T., Rahmad, E. U. ., Purnamasari, D. and Zainul, R. (2023) "Electrolyte Optimization Study on Dry Cell Generator Electrolysis System for Producing Hydrogen Gas Using RSM Method (Response Surface Method)", EKSAKTA: Berkala Ilmiah Bidang MIPA, 24(02), pp. 226-236. doi: 10.24036/eksakta/vol24-iss02/273.

[33] Hasanudin, H., Asri, W.R., Zulaikha, I.S., Ayu, C., Rachmat, A., Riyanti, F., Hadiah, F., Zainul, R., Maryana, R. Hydrocracking of crude palm oil to a biofuel using zirconium nitride and zirconium phosphide-modified bentonite (2022) RSC Advances, 12 (34), pp. 21916-21925.

[34] de Moura Torquato, L.D. and Grattieri, M., 2022. Photobioelectrochemistry of intact photosynthetic bacteria: advances and future outlook. Current Opinion in Electrochemistry, 34, p.101018.

[35] Amelia, F., Hidayat, B. ., Iryani, I. and Iswendi, I. (2021) "Potential Hydrophobic Pocket of Squalene Synthase: An In Silico Analysis", *EKSAKTA: Berkala Ilmiah Bidang MIPA*, 22(1), pp. 18-26. doi: 10.24036/eksakta/vol22-iss1/263.

[36] Sharif, S.N.M., Hashim, N., Isa, I.M., Bakar, S.A., Saidin, M.I., Ahmad, M.S., Mamat, M., Hussein, M.Z., Zainul, R. Polymeric Nanocomposite-Based Herbicide of Carboxymethyl Cellulose Coated-Zinc/Aluminium Layered Double Hydroxide-Quinclorac: A Controlled Release Purpose for Agrochemicals (2021) Journal of Polymers and the Environment, 29 (6), pp. 1817-1834. Cited 6 times.

[37] Modenez, I.A., 2022. Biomimetics Applied in Electrochemistry. In Advances in Bioelectrochemistry Volume 2: Biomimetic, Bioelectrocatalysis and Materials Interfaces (pp. 1-35). Cham: Springer International Publishing.

[38] Schneider, H., Lai, B. and Krömer, J., 2022. Utilizing Cyanobacteria in Biophotovoltaics: An Emerging Field in Bioelectrochemistry.

[39] Zilla, R., Purnamasari, D., Zainul, R. Design of rotary photoreactor using nano Cu/TiO2 for degradation humic acid in outdoor visible light (2020) Journal of Physics: Conference Series, 1481 (1), art. no. 012039, .

[40] MadJin, H.M., Hashim, N., Isa, I.M., Hussein, M.Z., Bakar, S.A., Mamat, M., Ahmad, R., Zainul, R. Synthesis and characterisation of zinc hydroxides nitrates–sodium dodecyl sulphate fluazinam nano hosts for release properties (2020) Journal of Porous Materials, 27 (5), pp. 1467-1479.