Bio-inspired Nanomaterial's for Energy Harvesting and Storage: A Green Approach

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Abstract. The advent of bio-inspired nanomaterials (BINMs) has the potential to address the global demand for sustainable and green energy technology. From osmotic power membranes to bio-hybrid light harvesting devices, BINMs mimic the complex systems and mechanisms found in nature. The assessment discusses a wide range of BINMs, including their synthesis, properties, applications, as well as their effects on the environment and manufacturing requirements, which have led to their increasing popularity. It focuses particularly on bio-inspired synthesis techniques, bioinspired electrode functionality, and the effectiveness of green chemistry in nanomaterial production. The advancement of renewable energy technologies and the enhancement of this promising field are highlighted as bio-inspired nanomaterials are explored and enhanced in energy programs, and their value is highlighted as they contribute to the advancement of renewable energy technologies.

Keyword-: Nanomaterials, energy harvesting, energy conversion. Biomaterials.

1 Introduction

A bioinspired nanomaterial (BINM) mimics the complex structures present in naturally occurring biological systems. A wide range of ecological, technological, and scientific problems can be addressed with these materials, allowing a new direction for material science [1]. Biomimetic nanomaterials, which are sourced from biological things such as proteins, DNA, cells, and creatures, have the ability to generate nanoscale patterns and structures, as shown in Fig.1. Biosynthesis and molecular self-assembly are two methods that can be used to create BINMs. BINMs continue to be a promising field of study despite obstacles like

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controlling the synthesis and assemblage procedures and possible negative effects on the ecosystem and human health. It is anticipated that developments in biology and nanotechnology will expand the potential for creating unique and significant BINMs [2]. Using water motion to create electricity is known as "water motion harvesting," and it is a viable strategy for becoming carbon neutral. However, because they are distributed, traditional hydroelectric techniques have difficulties. The liquid-solid behaviors of naturally occurring living things are used by bio-inspired electricity generators to effectively convert the interaction between water and solid matter into electrical output [3]. The fundamental nature of these generators is still unclear notwithstanding their rapid progress. Self-powered sensors and wearable electronics are examples of practical uses; yet, producing electricity on a big scale is still a difficulty.

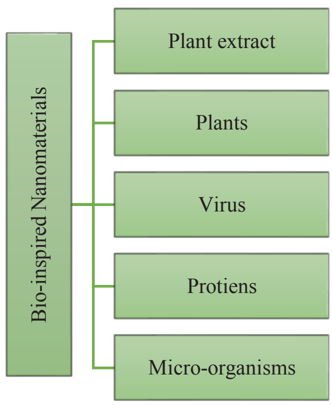

Fig. 1. Types of bio inspired nanomaterials

With an emphasis on biotemplating synthesis and biomimetic artificial fabrication, the application of bio-organisms in electrode design is investigated IN [4]. It draws attention to the special qualities of biotemplates, such as their ability to be structurally designed, their metabolism, and their genetically adjustable traits. Improved electrodes' physical properties, wetting, mass transportation, electron/charge transfer, and catalytic activity are all improved by recent advances in bio-prototypes. The utilization of bioderived and biomimetic electrode materials in electrochemical energy preservation and conversion systems has led to improvements in electro catalytic and charging/discharging performances. Through a variety of uses, nanotechnology has transformed environmentally friendly advancements and made greener, more sustainable economic growth possible. Green techniques have been used to develop nanomaterials for environmentally beneficial uses, such as MOFs and MeOs. In fuel cell and hydrogen electro catalysts, these materials enhance electrocatalytic activity, being absorbed, and stability. Moreover, fuel cells and supercapacitors—two types of energy storage and conversion devices—have included nanotechnology [5]. To evaluate the sustainability, efficacy, and application of nanotechnologies in practical settings, more research is required.

2 Bio-inspired Nanomaterial’s for Energy Harvesting

A dependable renewable power source with little fluctuation is osmotic energy. On the other hand, membranes need to have both long-term durability in seawater and effective ion rectification along with elevated ionic flux. These problems can be solved by using soft biological tissue-inspired membranes with nanocomposite components. Despite pressure decreases and salinity gradients, the multilayer membranes made of BN nanosheets and aramid nanofibers exhibit remarkable stiffness and tensile strength. Over wide areas, the overall produced power density was more than 0.6 W m2, and it was maintained for up to 20 cycles (200 h), exhibiting remarkable robustness. Additionally, they function well in osmotic energy harvesting throughout a broad temperature and pH range [6]. The quick growth of electronic devices that are worn, such e-skins, requires self-powered sensing in order to identify signals from the body as well as harvest bioenergies. The development of a new, flexible, and biocompatible hybrid nan generator combining triboelectric, piezoelectric, and pyroelectric processes has produced ultra-high transmission rates of up to 99% and sheet resistances as low as 1.4 Ω sq−1. With this novel design, mechanical and thermal energy can be produced by scavenging a maximum open-circuit output voltage of 55 V and 86 V. For real-time vital sign tracking, the translucent hybrid nanogenerator can be conformally hooked up to a variety of bodily areas. With possibilities for use in wearable electronics, healthcare surveillance, energy conversations, and device dimension shrinking, this research increases self-powered sensing in devices that are worn [7]. In the realm of bio-hybrid nanomaterials, material the production has emerged as a significant research area, especially in light harvesting devices. Recognizing photosynthetic systems, energy transfer, charge storage spaces. And quantum coherent processes is essential as the world's climate changes and demands the use of alternate energy sources. These characteristics are used to create artificial substitutes for photo-electrochemical processes. Narrow bandgap semiconductors' optical characteristics and bio-hybrid structures' self-assemblage capabilities have been researched for use in photocatalysis, hydrogen production, and water desalination. The article offers a strong foundation for ideas that could be developed into practical uses, such as DNA assembly, photosynthetic antennae, marine seashells, and tea leaf stains [8]. For the first time, a multipurpose energy harvester constructed using PVDF and bioinspired vitamin B2 (VB2) has been developed. It can gather significant amounts of electrical energy from various energy sources within a single device. The entirely organic-based piezoelectric nanogenerator (PNG) has a high output current of 12.2 μ A and a voltage of roughly 61.5 V. It can generate wind, sound, and mechanical energy. With a maximum power density of roughly 9.3 mW/cm3 and an exceptionally high energy conversion effectiveness of 62%, the gadget can power over 100 LEDs directly and charge mobile devices and CD motors via capacitor charging. Additionally, the gadget may be used as an artificially acoustic ultra-sensor, opening up new possibilities for e-healthcare surveillance and next-generation multifunction developing power sources [9]. An eight-day continual power output utilizing an average voltage of 0.6 V and a maximum power density of 1.6 μW cm−2 is possible with the tri-layered poly-ionic membrane (TL-PIM), which was motivated by plant transpiration mechanisms [10]. The TL-PIM has better repeatability since it may be used for at least 70 cycles at a steady voltage. Targeted and effective bromide ion shuttles are made possible by stable nanochannels made of hydrophilic polymeric material, 2D nanosheets in shape and poly-ionic liquids (PILs) throughout the processes of power production and discharge. The great environmental flexibility of the TL-PIM is demonstrated by its capacity to generate power in a wide variety of humidity and temperature levels, even outside. Triboelectric nanogenerators (TENGs) are a potential class of electric energy harvesting devices that use environmental mechanical excitement to generate clean, energy from renewable sources. Pressure sensors, battery charging appliances, and biological devices are just a few of the uses for which these devices can be adapted [11]. With the use of biocompatible and environmentally safe materials, triboelectric energy harvesting has advanced. Dry leaf/polyvinylidene fluoride-based TENG devices have the ability to produce up to 14 mW of electricity. These results highlight the special abilities of plants to produce electricity for a range of uses. The triboelectric nanogenerator (BITENG) described in [12] is a bio-inspired device that uses wave motion to generate energy, much like kelp. Energy harvesting operates at frequencies of vibration as low as 1 Hz and is both steady and efficient. Having a density of power of 25 μW•cm−2, the unit can power at least 60 LEDs with an output voltage of 260 V and current of 10 μA. Table 1 bio-inspiration presents a novel approach to wave energy gathering.

Table 1: Advanced Bio-inspired Nanomaterials for Energy Harvesting and Storage

Feature	Osmotic Energy Membranes	Hybrid Nanogenerator	Bio-hybrid Nanomaterials	Organic-based PNG	TL-PIM	Dry Leaf-based TENG	BITENG
Material Type	BN nanosheets and aramid nanofibers	Triboelectric, piezoelectric, and pyroelectric processes	DNA, photosynthetic antennae, marine seashells, tea leaf stains	PVDF and vitamin B2 (VB2)	Hydrophilic polymeric material, 2D nanosheets, poly-ionic liquids	Dry leaf/polyvinylidene fluoride	Bio-inspired (like kelp)
Energy Source	Pressure decreases and salinity gradients	Mechanical and thermal energy	Light	Wind, sound, mechanical energy	Humidity changes (inspired by plant transpiration)	Environmental mechanical excitement	Wave motion
Power Density	> 0.6 W/m²	-	-	9.3 mW/cm³	1.6 μW cm−2	14 mW	25 μW•cm −2
Voltage/Current	Not specified	55 V (open-circuit), 86 V (max)	-	12.2 μA, 61.5 V	0.6 V	-	260 V, 10 μA
Durability/ Cycle Life	20 cycles (200 h)	-	-	Can power over 100 LEDs	70 cycles	-	Not specified
Temperature and pH Range	Broad	-	-	Not specified	Variety of humidity and temperature levels	-	Low frequencies (1 Hz)
Applications	Osmotic energy harvesting	Wearable electronics, healthcare surveillance	Photocatalysis, hydrogen production, water desalination	E-healthcare surveillance, power sources	Environmental energy harvesting	Pressure sensors, battery charging	Wave energy harvesting

3 Bio-inspired Nanomaterials for Energy Storage

One very effective method for creating complex nanostructures that is both sustainable and high-efficiency is bio-inspired synthesis. This method offers special benefits and superior qualities by imitating electrode materials at the nanoscale. A library of intricate resembling building with high-order, hierarchical porosity, bionic function, and improved electrochemical properties, as well as the development of bio-templates and bio-resources, are some of the recent developments in bio-inspired synthesis of nanomaterials and innovative structures in the fields of energy storage and conversion that are covered [13].

Environmental damage is being caused by electrical appliance generation of non-biodegradable e-waste. Nanomaterials based on biopolymers could be a viable way to develop sustainable, environmentally friendly electronics. Gelatin/single walled carbon nanotube (Gel/SWCNT) nano-composites were the subject of a study in [14] that revealed enhanced SWCNT-gel matrix interaction. The surface wettability of the nanocomposites shifted from hydrophilic to hydrophobic, which and there was a four-fold decrease in DC resistivity. Additionally, particular capacitance and pseudo-capacitance were raised by SWCNTs. With a capacitive retention of 98% after 2000 charging/discharging cycles, the nanocomposite demonstrated cyclic stability. Because it degrades in water in 12 hours, it is a good option for applications involving temporary energy storage. This shows that the Gel/SWCNT nanocomposite might present a fresh approach to biodegradable, portable, and environmentally friendly electronics. In an effort to improve current systems, researchers are looking toward greener nanosystems with special qualities. Bioinspired graphene nanosystems are high-performing nanostructures with abundant interfacial interactions and hierarchical micro/nanoscale structure that are taken from nature. These nanosystems are scalable, highly electrically charged, working, flexible, and living-being-adaptable [15]. Electronic gadgets, batteries for energy sensors, and their uses in the medical sciences can all benefit from them. Nevertheless, there is a lack of general knowledge regarding bio-inspired graphene nan systems and their possible uses. This mini-review seeks to inspire researchers to create and develop new bio-inspired graphene nanosystems for next-generation biomedical equipment that are more inexpensive, scalable, and environmentally friendly. Anemone-like transition-metal chalcogenides (VS4), a bio-inspired nanotechnologies structure composed of nanorods with 30-100 nm diameter and 1-2 µm length, is presented in [16]. Three- and two-electrode systems were used to assess the nanomaterial's electrochemical efficiency as a super capacitor electrode. The anemone-like VS4 showed remarkable durability during cycling with 93.8% retention of capacity after over 12,000 galvanostatic charge-discharge cycles at an electrical current density of 6 A g^{-1}, a high specific capacitance of 617 F g^{-1} at a current density of 0.4 A g^{-1}, and an outstanding energy density of 113.6 W h kg^{-1} at a power density of 720 W kg^{-1}. Polydopamine (PD) serves as a strong metal binder, functionalize, and decreasing agent in a bio inspired hydrogen-holding medium. Three-dimensionally linked graphene foam's specific surface area can be regulated by varying the degree of functionalized PD on graphene. Furthermore, the amount, size, and arrangement of platinum (Pt) nanoparticles painted on the foam are influenced by the the functionalization degree of polyethylene (PD) [17]. The Pt-decorated PD-functionalized graphene (rGO/PD_Pt), considered to be the best for hydrogen storage medium with the greatest hydrogen uptake per unit particular surface area, exhibits a high hydrogen storage capacity of 3.19 wt% at room temperatures and 100 bar through the combination of a high surface area with an evenly distributed distribution of small sized Pt nanoparticles. Since bismuth-based compounds have a larger volumetric capacity and a greater operational potential than graphite, they are appealing as anode materials in energy storage devices such as batteries that are rechargeable. Maintaining this high capacity over time is still difficult, though. A polypyrrole shell encasing bismuth sulfide nanowires forms the yolk-shell composite used in a bio-inspired material engineering technique [18]. The resulting composite outperforms earlier bismuth-based materials with its improved Li storage the cyclability (99% for 500 cycles) and high rate capability (337 mAh g^{-1} at 10 C). In addition, it provides a good endurance for Na storage and a high reversal capacity of 591 mAh g^{-1} as shown in Table 2.

Table 2: Bio-Inspired Nanomaterials for Sustainable Energy Solutions

Aspect	**Bio-Inspired Synthesis**	**Gel/SWCNT Nanocomposite**	**Bioinspired Graphene Nanosystems**	**Anemone-like VS4**	**PD-functionalized Graphene Foam**	**Yolk-Shell Bi-S Nanowires**
Synthesis Method	Sustainable, high-efficiency creation of complex nanostructures	Biopolymer-based sustainable approach	Scalable, nature-inspired with hierarchical structure	Bio-inspired nanorods	Bioinspired hydrogen storage medium	Bio-inspired material engineering approach
Structure and Properties	High-order, hierarchical porosity; bionic function; enhanced electrochemical properties	Hydrophilic to hydrophobic surface shift; lowered DC resistivity	Highly electrically charged; abundant interfacial interactions	Nanorods with 30-100 nm diameter and 1-2 µm length	3D graphene foam; controllable surface area and Pt nanoparticle distribution	Yolk-shell structure with polypyrrole shell and bismuth sulfide nanowires
Electrochemical Performance	Not specified	Specific and pseudo-capacitance enhancement by SWCNTs	Not specified	617 F g−1 capacitance at 0.4 A g−1; 113.6 W h kg−1 energy density at 720 W kg−1 power density	High hydrogen storage capacity (3.19 wt% at room temperature and 100 bar)	High Li storage capacity and rate capability (337 mAh g−1 at 10 C)
Cycling Stability	Not specified	98% capacitive retention after 2000 cycles	Not specified	93.8% capacity retention after 12,000 cycles	Not specified	99% capacity retention for 500 cycles
Environmental Impact	Sustainable and environmentally friendly	Biodegradable in water within 12 hours	Environmentally friendly	Not specified	Not specified	Higher volumetric capacity, greater operational potential
Potential Applications	Energy storage and conversion	Temporary energy storage; biodegradable electronics	Electronics, energy sensors, biomedical applications	Supercapacitor electrodes	Hydrogen storage	Rechargeable battery anodes

4 Green Chemistry Approaches in Nanomaterial Production

Despite their tiny size, nanoparticles have several uses, and one of those uses is in the synthesis process. Green synthesis presents a viable, economical, and ecologically responsible substitute for conventional techniques [19-23]. Natural materials and physiologically active substances are used in this one-step synthesis as capping, stabilizing, and reducing agents. Sustainable chemistry is a viable method for the effective and environmentally conscious synthesis of nanoparticles since it has less of an impact on the environment and improves safety. Because of its sustainability and possible uses in environmental cleanup, consumer goods, and medicinal research, green synthesis of nanomaterials (NMs) has drawn interest [24-27]. But there are issues with present methods: choosing a safe solvent, process parameters, cytotoxicity of nanomaterials, bulk manufacturing, and control over morphology, laborious maintenance, and lack of understanding. Future research should concentrate on comprehending the internal workings of synthesis processes, finding more biological as well as chemical agents, advancing the viability of green synthesis at an industrial level, and enhancing factors impacting the synthesis process in order to increase the utilization of biogenic NMs [28-30].

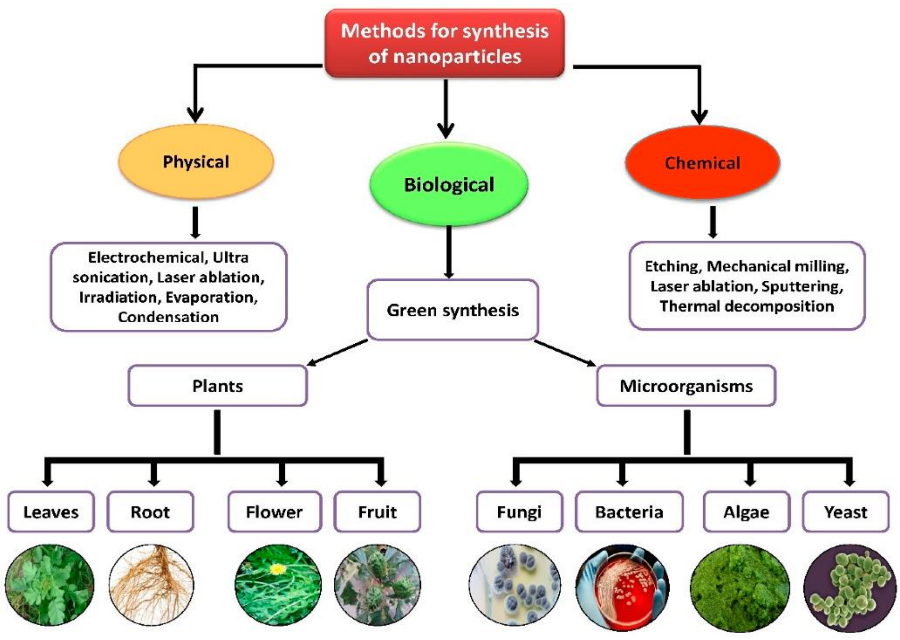

Fig. 2: Different methods for synthesis of nanoparticles

Production that satisfies current needs while preserving the capacity of future generations to satisfy their own needs is known as sustainable development[30]. A growing area called "green chemistry" encourages the use of ideas meant to lessen the usage and manufacture of hazardous chemicals [31-33]. Greener methods therefore reduce the negative environmental effects of industrial labor [34]. These techniques have been created by researchers as prospective solutions to the costly procedures and hazardous materials discovered when using conventional synthesis techniques. The best way to lessen the negative effects of its production and application is through green nanomaterial synthesis, which also lowers the risk associated with nanotechnology [35-37]. Green nanotechnology uses the physicochemical properties of materials to produce environmentally friendly and energy-efficient solutions. It can boost energy availability and lessen the requirement for conventional raw materials in the energy sector [38]. Nonetheless, lawmakers, business leaders, and consumers may find it unclear. It is imperative that scientists and engineers stop weak legislation, fight greenwashing initiatives, and educate the general public about environmentally friendly synthesis and nanotechnology [39-42]. They ought to encourage sustainable nanotechnology investigation, incorporating toxicological assessments and societal repercussions, and explain the uses and implications of new technologies [43-48].

5 Conclusion

Bio-inspired nanomaterials (BINMs) have proven tremendous promise in the realm of sustainable energy solutions, leveraging nature-inspired systems to enhance energy harvesting and storage technologies. The synthesis and application of these materials offer a greener alternative to standard energy assets, aligning with worldwide sustainability desires. However, the path forward requires addressing demanding situations in scalability, environmental impact, and integration into present systems.

- Revolutionary energy solutions: BINMs offer innovative techniques to energy harvesting and storage, inspired by means of natural systems, leading to better performance and novel functionalities.
- Sustainability and Environmental effect: The improvement of BINMs is aligned with green chemistry ideas, promoting environmentally friendly options to conventional energy resources.
- Demanding situations and opportunities: even as promising, BINMs face demanding situations which include large-scale manufacturing, ecological safety, and the complexity of bio-inspired designs, which want to be addressed to recognise their full capability.
- Destiny instructions: endured research and improvement are crucial to overcome modern obstacles and explore new applications of BINMs in sustainable energy technology.

References

1. Dwivedi, Naveen, and Shubha Dwivedi. "Bio-Inspired Nanomaterials: Applications in Artificial Photosynthesis and Energy Generation." In Bionanotechnology towards Green Energy, 33-58. CRC Press, 2023.
2. Harun-Ur-Rashid, Mohammad, Israt Jahan, Tahmina Foyez, and Abu Bin Imran. "Bio-Inspired Nanomaterials for Micro/Nanodevices: A New Era in Biomedical Applications." Micromachines 14, 9 (2023): 1786.
3. Suganthi, S. T., Vinayagam, A., Veerasamy, V., Deepa, A., Abouhawwash, M., & Thirumeni, M. (2021). Detection and classification of multiple power quality disturbances in Microgrid network using probabilistic based intelligent classifier. Sustainable Energy Technologies and Assessments, 47, 101470.
4. Wang, Kaiqiang, Wanghuai Xu, Wei Zhang, Xiong Wang, Xiao Yang, Jianfeng Li, Hanli Zhang, Jinjin Li, and Zuankai Wang. "Bio-inspired water-driven electricity generators: From fundamental mechanisms to practical applications." Nano Res. Energy 2, 1 (2023): e9120042.
5. Ramu, G. (2018). A secure cloud framework to share EHRs using modified CP-ABE and the attribute bloom filter. Education and Information Technologies, 23(5), 2213-2233.
6. Guo, Xingmei, Junhao Zhang, Lei Yuan, Baojuan Xi, Fei Gao, Xiangjun Zheng, Ruiyu Pan et al. "Biologically assisted construction of advanced electrode materials for

electrochemical energy storage and conversion." Advanced Energy Materials 13, 24 (2023): 2204376.

7. Prakash, S., Somiya, G., Elavarasan, N., Subashini, K., Kanaga, S., Dhandapani, R., ... & Sujatha, V. (2021). Synthesis and characterization of novel bioactive azo compounds fused with benzothiazole and their versatile biological applications. Journal of Molecular Structure, 1224, 129016.
8. Fuku, Xolile, Xoliswa Dyosiba, and Faiza Jan Iftikhar. "Green prepared nanomaterials from various biodegradable wastes and their application in energy." Nano-Structures & Nano-Objects 35 (2023): 100997.
9. Chen, Cheng, Dan Liu, Li He, Si Qin, Jiemin Wang, Joselito M. Razal, Nicholas A. Kotov, and Weiwei Lei. "Bio-inspired nanocomposite membranes for osmotic energy harvesting." Joule 4, 1 (2020): 247-261.
10. Anusha, P., M. Naga Swapna Sri, S. Vijayakumar, TV Janardhana Rao, Prabhu Paramasivam, S. Jeyakrishnan, and Kuldeep Kumar Saxena. "Design and optimization the wear characteristics for Al7178/TiO2/B4C/FA central hybrid composite." International Journal on Interactive Design and Manufacturing (IJIDeM) (2023): 1-9.
11. Sun, Jian-Guo, Tse-Ning Yang, Chiu-Yen Wang, and Lih-Juann Chen. "A flexible transparent one-structure tribo-piezo-pyroelectric hybrid energy generator based on bio-inspired silver nanowires network for biomechanical energy harvesting and physiological monitoring." Nano Energy, 48 (2018): 383-390.
12. Saxena, Shatakshi, Fuhar Dixit, Goutam Kumar Dalapathi, Satheesh Krishnamurthy, and Balasubramanian Kandasubramanian. "Bioengineered solar harvesting systems for next generation applications." Solar energy 231 (2022): 857-879.
13. Padmaja, B., Prasad, V. R., & Sunitha, K. V. N. (2018). A machine learning approach for stress detection using a wireless physical activity tracker. International Journal of Machine Learning and Computing, 8(1), 33-38.
14. Yadav, G. Praveen Kumar, Din Bandhu, B. Vijay Krishna, Nakul Gupta, Panchanand Jha, Jay J. Vora, Subhash Mishra, Kuldeep Kumar Saxena, Karrar Hazim Salem, and Sherzod Shukhratovich Abdullaev. "Exploring the potential of metal-cored filler wire in gas metal arc welding for ASME SA387-Gr. 11-Cl. 2 steel joints." Journal of Adhesion Science and Technology 38, 2 (2024): 163-184.
15. Karan, Sumanta Kumar, Sandip Maiti, Anand Kumar Agrawal, Amit Kmar Das, Anirban Maitra, Sarbaranjan Paria, Aswini Bera et al. "Designing high energy conversion efficient bio-inspired vitamin assisted single-structured based self-powered piezoelectric/wind/acoustic multi-energy harvester with remarkable power density." Nano Energy 59 (2019): 169-183.
16. Kathpalia, Renu, and Anita K. Verma. "Bio-inspired nanoparticles for artificial photosynthesis." Materials Today: Proceedings 45 (2021): 3825-3832.
17. Slabov, Vladislav, Svitlana Kopyl, Marco P. Soares dos Santos, and Andrei L. Kholkin. "Natural and eco-friendly materials for triboelectric energy harvesting." Nano-Micro Letters 12 (2020): 1-18.
18. Ding, Mei, Gen Chen, Weichuan Xu, Chuankun Jia, and Hongmei Luo. "Bio-inspired synthesis of nanomaterials and smart structures for electrochemical energy storage and conversion." Nano Materials Science 2, 3 (2020): 264-280.
19. Alam, Md Absar, Rajan Kumar, Deepen Banoriya, Anil Singh Yadav, Geetesh Goga, Kuldeep K. Saxena, Dharam Buddhi, and Ravindra Mohan. "Design and development of thermal comfort analysis for air-conditioned compartment." International Journal on Interactive Design and Manufacturing (IJIDeM) 17, 5 (2023): 2777-2787.
20. Alam, Rabeya Binta, Md Hasive Ahmad, and Muhammad Rakibul Islam. "Bio-inspired gelatin/single-walled carbon nanotube nanocomposite for transient electrochemical

energy storage: An approach towards eco-friendly and sustainable energy system." Heliyon 7, 7 (2021).

21. Yogananda, H. S., Basavaraj, R. B., Darshan, G. P., Prasad, B. D., Naik, R., Sharma, S. C., & Nagabhushana, H. (2018). New design of highly sensitive and selective MoO3: Eu3+ micro-rods: Probing of latent fingerprints visualization and anti-counterfeiting applications. Journal of colloid and interface science, 528, 443-456.
22. Kumar, K. Y., Saini, H., Pandiarajan, D., Prashanth, M. K., Parashuram, L., & Raghu, M. S. (2020). Controllable synthesis of TiO2 chemically bonded graphene for photocatalytic hydrogen evolution and dye degradation. Catalysis Today, 340, 170-177.
23. Li, Hong-Yi, Jun-Kai Feng, Liao Xiang, Jie Huang, and Bing Xie. "Facile synthesis of bio-inspired anemone-like VS4 nanomaterials for long-life supercapacitors with high energy density." Journal of Power Sources 457 (2020): 228031.
24. Kalyani, G., Janakiramaiah, B., Karuna, A., & Prasad, L. N. (2023). Diabetic retinopathy detection and classification using capsule networks. Complex & Intelligent Systems, 9(3), 2651-2664.
25. Malagavelli, V., Angadi, S., Prasad, J. S. R., & Joshi, S. (2018). Influence of metakaolin in concrete as partial replacement of cement. Int J Civil Eng Technol, 9(7), 105-111.
26. Bhukya, L., Kedika, N. R., & Salkuti, S. R. (2022). Enhanced maximum power point techniques for solar photovoltaic system under uniform insolation and partial shading conditions: a review. Algorithms, 15(10), 365.
27. Vijayakumar, Y., Nagaraju, P., Yaragani, V., Parne, S. R., Awwad, N. S., & Reddy, M. R. (2020). Nanostructured Al and Fe co-doped ZnO thin films for enhanced ammonia detection. Physica B: Condensed Matter, 581, 411976.
28. Telagam, N., Kandasamy, N., & Nanjundan, M. (2017). Smart sensor network based high quality air pollution monitoring system using labview. International Journal of Online Engineering (iJOE), 13(08), 79-87.
29. Chaudhury, S., Krishna, A. N., Gupta, S., Sankaran, K. S., Khan, S., Sau, K., ... & Sammy, F. (2022). Effective image processing and segmentation-based machine learning techniques for diagnosis of breast cancer. Computational and Mathematical Methods in Medicine, 2022.
30. Liang, Haichen, Jiangfeng Ni, and Liang Li. "Bio-inspired engineering of Bi2S3-PPy yolk-shell composite for highly durable lithium and sodium storage." Nano Energy 33 (2017): 213-220.
31. Gómez-López, Paulette, Alain Puente-Santiago, Andrés Castro-Beltrán, Luis Adriano Santos do Nascimento, Alina M. Balu, Rafael Luque, and Clemente G. Alvarado-Beltrán. "Nanomaterials and catalysis for green chemistry." Current opinion in Green and sustainable Chemistry 24 (2020): 48-55.
32. Vandana, C. P., & Chikkamannur, A. A. (2021). Feature selection: An empirical study. International Journal of Engineering Trends and Technology, 69(2), 165-170.
33. Villaseñor, Mª Jesús, and Ángel Ríos. "Nanomaterials for water cleaning and desalination, energy production, disinfection, agriculture and green chemistry." Environmental chemistry letters 16 (2018): 11-34.
34. Asiya, S. I., K. Pal, S. Kralj, G. S. El-Sayyad, F. G. De Souza, and T. Narayanan. "Sustainable preparation of gold nanoparticles via green chemistry approach for biogenic applications." Materials Today Chemistry 17 (2020): 100327.
35. Sridhara, V., Gowrishankar, B. S., Snehalatha, & Satapathy, L. N. (2009). Nanofluids—a new promising fluid for cooling. Transactions of the Indian Ceramic Society, 68(1), 1-17.
36. Huston, Matthew, Melissa DeBella, Maria DiBella, and Anisha Gupta. "Green synthesis of nanomaterials." Nanomaterials 11, 8 (2021): 2130.

37. Ram, J. P., Pillai, D. S., Ghias, A. M., & Rajasekar, N. (2020). Performance enhancement of solar PV systems applying P&O assisted Flower Pollination Algorithm (FPA). Solar Energy, 199, 214-229.
38. Cheruvu, A., Radhakrishna, V., & Rajasekhar, N. (2017, May). Using normal distribution to retrieve temporal associations by Euclidean distance. In 2017 International Conference on Engineering & MIS (ICEMIS) (pp. 1-3). IEEE.
39. Kumar, K. U., Babu, P., Basavapoornima, C., Praveena, R., Rani, D. S., & Jayasankar, C. K. (2022). Spectroscopic properties of Nd3+-doped boro-bismuth glasses for laser applications. Physica B: Condensed Matter, 646, 414327.
40. Eckelman, Matthew J., Julie B. Zimmerman, and Paul T. Anastas. "Toward green nano: E-factor analysis of several nanomaterial syntheses." Journal of Industrial Ecology 12, 3 (2008): 316-328.
41. Gurunathan, Sangiliyandi, JaeWoong Han, Jung Hyun Park, and Jin-Hoi Kim. "A green chemistry approach for synthesizing biocompatible gold nanoparticles." Nanoscale research letters, 9 (2014): 1-11.
42. Cinelli, Marco, Stuart R. Coles, Mallikarjuna N. Nadagouda, Jerzy Błaszczyński, Roman Słowiński, Rajender S. Varma, and Kerry Kirwan. "A green chemistry-based classification model for the synthesis of silver nanoparticles." Green Chemistry 17, no. 5 (2015): 2825-2839.
43. Awasthi, A., Saxena, K. K., & Arun, V. (2021). Sustainable and smart metal forming manufacturing process. Materials Today: Proceedings, 44, 2069-2079.
44. Falsini, S., U. Bardi, A. Abou-Hassan, and S. Ristori. "Sustainable strategies for large-scale nanotechnology manufacturing in the biomedical field." Green chemistry 20, 17 (2018): 3897-3907.
45. Raghu, M. S., Kumar, C. P., Prashanth, M. K., Kumar, K. Y., Prathibha, B. S., Kanthimathi, G., ... & Osman, S. M. (2021). Novel 1, 3, 5-triazine-based pyrazole derivatives as potential antitumor agents and EFGR kinase inhibitors: Synthesis, cytotoxicity, DNA binding, molecular docking and DFT studies. New Journal of Chemistry, 45(31), 13909-13924.
46. Jayabal, R., Subramani, S., Dillikannan, D., Devarajan, Y., Thangavelu, L., Nedunchezhiyan, M., ... & De Poures, M. V. (2022). Multi-objective optimization of performance and emission characteristics of a CRDI diesel engine fueled with sapota methyl ester/diesel blends. Energy, 250, 123709.
47. García-Quintero, Angélica, and Manuel Palencia. "A critical analysis of environmental sustainability metrics applied to green synthesis of nanomaterials and the assessment of environmental risks associated with the nanotechnology." Science of The Total Environment 793 (2021): 148524.
48. Parashuram, L., Sreenivasa, S., Akshatha, S., & Udayakumar, V. (2019). A non-enzymatic electrochemical sensor based on ZrO2: Cu (I) nanosphere modified carbon paste electrode for electro-catalytic oxidative detection of glucose in raw Citrus aurantium var. sinensis. Food chemistry, 300, 125178.