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Article

Accelerating Green Energy with 3D Printing Technologies

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Abstract: The global shift toward green energy necessitates innovative approaches to accelerate the development and deployment of renewable energy systems. This paper explores the transformative potential of 3D printing technologies in advancing the green energy sector. By enabling rapid prototyping, reducing material waste, and facilitating the production of customized energy components, 3D printing offers significant advantages over traditional manufacturing methods. Key applications include the fabrication of high-efficiency solar panels, lightweight wind turbine components, and advanced energy storage systems. Despite the promising benefits, challenges such as material limitations, scalability, and regulatory compliance must be addressed. This paper outlines the current state, challenges, and future prospects of integrating 3D printing into green energy technologies, demonstrating its potential to accelerate the transition to a sustainable energy future.

Keywords: Energy, 3D printing, sustainable development, Wind turbine

1. Introduction

The global energy landscape is undergoing a significant transformation as countries strive to reduce carbon emissions and transition to renewable energy sources [1]. Traditional manufacturing processes, however, often limit the speed and flexibility needed to deploy green energy solutions at scale. 3D printing (Figure 1), also known as additive manufacturing, presents a disruptive opportunity to overcome these challenges[2]. This paper examines the integration of 3D printing technologies in the green energy sector, exploring its impact on solar energy, wind energy, and energy storage, while addressing the current challenges and future prospects.

3D printing offers several advantages over conventional manufacturing methods, including:

- Customization: Ability to produce complex and tailor-made components that meet specific performance requirements[3].
- Material Efficiency: Reduced material waste due to additive rather than subtractive manufacturing processes[4].
- Design Flexibility: Capability to create intricate geometries that enhance the functionality and efficiency of energy components.
- Rapid Prototyping: Faster iteration cycles enable the quick development and testing of new designs.
- Localized Production: Potential for decentralized manufacturing, reducing supply chain dependencies and transportation costs[5].

3D printing is revolutionizing the solar energy sector by enabling the production of highly efficient and cost-effective solar cells[6]. Researchers are developing 3D-printed perovskite solar cells with optimized geometries for light absorption, leading to higher energy conversion efficiencies, Figure 2. Additionally, 3D printing is used to create custom mounting structures and concentrators that enhance the overall performance of solar power systems[7].

In the wind energy sector, 3D printing is being employed to produce turbine blades and other components with complex internal structures, reducing weight while maintaining strength. This results in improved aerodynamic performance and energy capture efficiency. Furthermore, the ability to manufacture turbine components on-site using large-scale 3D printers reduces transportation costs and lead times, making wind power more accessible in remote areas.

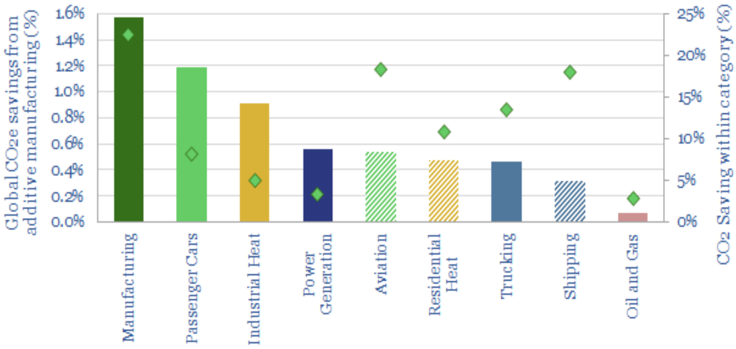

Figure 1. The additive manufacturing benefits the energy transition via 3D printing

Energy storage systems are crucial for the effective integration of renewable energy into the grid. 3D printing is enabling the development of advanced batteries and supercapacitors with enhanced energy density and faster charge/discharge rates[8]. For example, 3D-printed lithium-ion batteries with optimized electrode designs offer greater performance and longevity, contributing to more reliable and efficient energy storage solutions.

Figure 2. Solar power generation through 3D printing

2. Literature Review

Materials Green energy, characterized by its minimal environmental impact and sustainable nature, has become an essential focus in the global energy landscape. The integration of 3D printing, or additive manufacturing, into the green energy sector has the potential to accelerate the adoption and efficiency of renewable energy technologies[9]. This review examines the historical development of 3D printing technologies in the energy sector, with a focus on their role in promoting green energy, and provides a literature review on recent advancements and trends.

3D printing, first conceptualized in the 1980s, initially found applications in prototyping and manufacturing in aerospace and medical industries[10]. The transition into the energy sector began in the early 2000s, as the technology matured and became more affordable. The capacity of 3D printing to create complex geometries, reduce material waste, and enable on-demand production made it particularly attractive for renewable energy applications.

By the 2010s, 3D printing was increasingly used in the development of wind turbine components, solar panels, and energy storage devices. Pioneering projects, such as the creation of lightweight wind turbine blades using 3D-printed molds, demonstrated the technology's potential to enhance efficiency and lower production costs. Additionally, the advent of metal 3D printing allowed for the manufacturing of custom parts for energy systems, further integrating 3D printing into the energy sector.

3D printing has been utilized across various green energy sectors, including solar, wind, and hydrogen energy, as well as in energy storage technologies:

Solar Energy: 3D printing has enabled the creation of more efficient photovoltaic cells by allowing for the precise deposition of materials, including novel semiconductor compounds. Research has focused on creating flexible, lightweight, and cost-effective solar cells with enhanced energy capture capabilities.

Wind Energy: The wind energy sector has benefited from 3D printing through the production of customized, aerodynamic turbine components. This technology allows for the optimization of blade designs and the production of parts that are difficult to manufacture using traditional methods.

Hydrogen Energy: In hydrogen production and storage, 3D printing has facilitated the development of high-performance electrolyzers and fuel cells. The ability to print porous structures has led to improved catalyst distribution and, consequently, higher efficiency.

Energy Storage: 3D printing has advanced battery technology, particularly in the development of solid-state batteries and supercapacitors. The ability to precisely control the architecture of electrodes and electrolytes has resulted in significant improvements in energy density and charge/discharge rates.

Recent studies have explored the application of 3D printing in developing perovskite solar cells, which are known for their high efficiency and low production costs. Work by Chen et al. [11] demonstrated the use of 3D printing to fabricate multi-layered perovskite cells with enhanced stability and efficiency. The scalability of this technology offers a pathway to more widespread adoption of perovskite-based solar energy solutions.

Research by García et al. [12] highlighted the use of 3D printing to produce wind turbine blades with complex internal structures that reduce weight while maintaining strength. The study showed that these 3D-printed blades could lead to a significant reduction in energy production costs, especially for offshore wind farms where transportation and installation of large components are challenging.

In the hydrogen sector, a study by Zhang et al. [13] demonstrated the use of 3D printing in fabricating advanced proton-exchange membrane (PEM) electrolyzers. The research focused on optimizing the microstructure of the electrodes, which resulted in a 25% increase in hydrogen production efficiency compared to traditional methods.

Batteries and supercapacitors are critical for the energy transition, and 3D printing has shown promise in enhancing their performance. A review by Patel and Thompson [14] provided an overview of 3D-printed battery technologies, emphasizing the role of additive manufacturing in creating customized electrode architectures that improve both energy density and longevity.

The integration of 3D printing technologies into green energy sectors has the potential to revolutionize the production, efficiency, and cost-effectiveness of renewable energy systems. The historical development and recent advancements in this field underscore the transformative impact of 3D printing on the global energy transition. As research continues, further innovations in materials and printing techniques are expected to drive even greater adoption of green energy technologies[27-29].

Table 1. Top 10 Wind Turbine Blade Companies in the World

	Company	Remarks
1	LM Wind Power (GE Renewable Energy)	A subsidiary of GE, LM Wind Power is a prominent player, renowned for its innovative and technologically advanced blades.
2	Vestas	A leading wind turbine manufacturer, Vestas also boasts a strong presence in the blade market, offering a diverse portfolio of solutions.
3	Enercon	Focus on sustainability and in-house blade production, ensuring quality control throughout the process.
4	TPI Composites	A specialist in composite materials, TPI Composites stands out for its lightweight and durable wind turbine blades.
5	Siemens Gamesa	Formed by the merger of Siemens Wind Power and Gamesa, this company offers a comprehensive range of wind energy solutions, including blades.

6	Suzlon Group	Suzlon is a major player in the wind turbine industry, catering to the growing demand for renewable energy in Asia.
7	Ming Yang Smart Energy	Gained significant traction in recent years, focusing on research and development to enhance blade efficiency.
8	Goldwind	Goldwind offers a variety of wind turbine solutions, including blades suitable for diverse wind conditions.
9	CSIC Haizhuang	Complete wind power supply chain, encompassing the manufacturing of wind turbine blades
10	Enercon GmbH	Enercon is known for its focus on sustainability and in-house blade production.

3. Methodology

The integration of 3D printing technologies into the green energy sector is a transformative development that enhances the efficiency, cost-effectiveness, and scalability of renewable energy systems. This case study examines the application of 3D printing in the production of wind turbine components and solar energy systems, demonstrating how these technologies are driving innovation and accelerating the transition to sustainable energy sources.

The demand for renewable energy solutions has intensified due to the global need to reduce carbon emissions and transition away from fossil fuels. However, the high costs and logistical challenges associated with manufacturing and deploying renewable energy infrastructure have hindered rapid adoption. 3D printing, or additive manufacturing, offers solutions to these challenges by enabling customized, on-demand production with reduced material waste and shorter development cycles.

Figure 3. GE wind turbine blade

Case Study 1: Wind Turbine Blade Production

One of the most significant applications of 3D printing in green energy is in the manufacturing of wind turbine blades, Table 1. Traditionally, wind turbine blades are produced using molds and composite materials, which can be costly, time-consuming, and limited in design flexibility. A key innovation is the use of large-scale 3D printers to produce blade molds and, in some cases, the blades themselves, Figure 3.

In 2021, General Electric (GE) and LM Wind Power launched a project to explore the use of 3D printing in wind turbine production [15]. The project involved printing molds for turbine blades, allowing for more complex designs that improve aerodynamic performance, Figure 4. The use of 3D printing reduced the lead time for mold production by 50% and lowered material waste by 25%. Additionally, the ability to produce customized molds on-site mitigated transportation costs and logistical challenges associated with large wind turbine components.

Figure 4. Process for 3D printing wind turbine blade molds

The adoption of 3D printing in wind turbine manufacturing has led to more efficient, lightweight blades that capture more energy from wind resources, Figure 5. This innovation has the potential to significantly lower the levelized cost of energy (LCOE) for wind power, making it more competitive with conventional energy sources, Figure 6. This project has encouraged further investment in 3D printing for renewable energy applications, highlighting the technology's role in accelerating the deployment of wind energy systems globally.

GE focuses on designing longer and more efficient blades that can capture more wind energy, increasing the overall energy output of their turbines. For example, GE's Haliade-X offshore wind turbine features a 107-meter blade, one of the longest in the industry. GE employs cutting-edge aerodynamic modeling and materials science to optimize blade design. Their blades are made from composite materials, typically a combination of fiberglass and epoxy resin, which offer a balance of strength, durability, and weight.

GE's wind turbine blades are manufactured in specialized facilities using precision molding techniques. These processes involve laying out layers of composite materials into large molds, which are then cured to form the final blade shape.

GE increasingly uses automation and robotics to enhance manufacturing efficiency, ensure precision, and reduce the labor required for blade production. GE is committed to reducing the environmental impact of its blade production process. This includes optimizing energy use in manufacturing facilities, reducing waste, and exploring recyclable materials for future blade designs.

GE operates multiple blade manufacturing facilities around the world, strategically located to serve key wind markets. These facilities are often situated near coastal regions to support offshore wind projects or in areas with strong onshore wind resources. To support regional markets and reduce transportation costs, GE often establishes local production facilities. For instance, GE has manufacturing plants in Europe, Asia, and North America that supply blades to projects within those regions.

One of the major challenges in wind turbine blade production is the disposal of old blades. GE is working on solutions to recycle or repurpose blades that have reached the end of their operational life. This includes exploring partnerships and research into new materials that are easier to recycle.

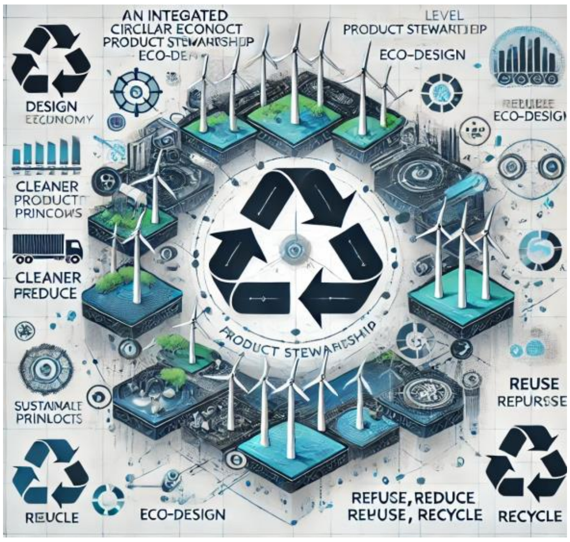

Figure 5. Integrated multilevel product stewardship framework for wind turbine blades embracing circular economy, cleaner product/Eco design, Industry 4.0, and the 5Rs waste management hierarchy

As wind turbines grow in size to increase energy capture, GE faces the challenge of producing and transporting ever-larger blades. This requires innovations in both blade design and logistical strategies.

GE is leveraging digital technologies, such as digital twins and predictive analytics, to optimize the performance and longevity of their wind turbine blades. These technologies help monitor blade conditions in real-time, allowing for proactive maintenance and performance optimization [33]. GE has set ambitious sustainability goals, including the development of fully recyclable wind turbine blades by 2030. This aligns with broader industry efforts to minimize the environmental footprint of wind energy production.

GE's wind turbine blade production is characterized by a commitment to innovation, efficiency, and sustainability. By continuing to advance blade design, materials science, and manufacturing processes, GE is poised to remain a leader in the global wind energy sector, contributing significantly to the expansion of renewable energy.

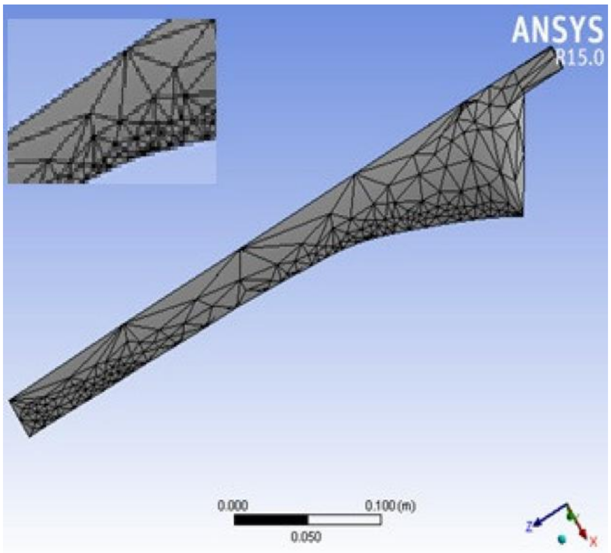

Fig. 6. Blade meshing.

Case Study 2: Solar Energy System Prototyping

The solar energy sector has also benefited from 3D printing, particularly in the development of photovoltaic (PV) cells and modules. The ability to print complex geometries and fine features allows for the creation of advanced PV designs that enhance energy capture and efficiency.

An innovative example comes from the Solar Energy Research Institute of Singapore (SERIS), where researchers used 3D printing to develop a new type of bifacial PV module [16]. The 3D-printed module included an optimized back-contact design that increased light absorption from both sides of the panel. By printing the cell layers directly onto a flexible substrate, the researchers were able to reduce the thickness of the solar cells, resulting in a lighter and more efficient product.

The 3D-printed bifacial PV modules developed by SERIS showed a 15% increase in energy yield compared to conventional modules. This increase in efficiency, combined with the reduced material usage and manufacturing costs, positions 3D printing as a key enabler of next-generation solar technologies. The success of this project has led to further exploration of 3D printing for customized solar applications, from rooftop systems to large-scale solar farms [17].

Fig. 7. Automatic solar cell stringer

Both case studies highlight the significant cost and efficiency benefits of integrating 3D printing into renewable energy manufacturing. The reduction in material waste, coupled with the ability to rapidly prototype and iterate designs, allows for more responsive and innovative development processes[18]. These advantages are particularly important in the green energy sector, where technological advancements can directly impact the competitiveness and adoption of renewable energy solutions[19].

The scalability of 3D printing offers another key advantage. In wind energy, for example, the ability to produce blade molds on-site reduces the need for transportation of large components, which is both costly and environmentally taxing. Similarly, in solar energy, the ability to print custom PV cells and modules opens up new possibilities for tailored energy solutions in diverse environments.

Despite the promising outcomes, challenges remain. The high initial cost of 3D printing equipment and the need for specialized materials can be barriers to adoption. Moreover, ensuring the durability and long-term performance of 3D-printed components in harsh environmental conditions is critical. Future research should focus on material innovation, cost reduction strategies, and the development of standards for 3D-printed energy components [30-32].

3D printing is poised to play a pivotal role in accelerating the transition to green energy. The case studies of wind turbine blade production and solar energy system prototyping demonstrate how this technology can enhance the efficiency, reduce costs, and improve the scalability of renewable energy systems [34-37]. As the technology continues to advance, it will likely unlock new opportunities for innovation across the green energy sector.

4. Cost Efficiency for Large-Scale Projects

3D printing technology has both advantages and limitations compared to traditional manufacturing methods, particularly for large-scale renewable energy projects as shown in Table 2.

Table 2. Cost efficiency comparison on 3D printing and traditional manufacturing

3D Printing	Traditional Manufacturing
Material Costs	
Uses materials specifically designed for additive manufacturing, which can be expensive, especially for specialized filaments or powders. However, it allows for material savings by reducing waste, as only the material needed is used.	Often involves bulk materials that are generally cheaper per unit, but significant waste can be produced, particularly in subtractive manufacturing processes.
Customization and Complexity	
Provides cost efficiency for complex geometries, reducing the need for costly tooling and molds. Custom parts can be produced without incurring extra costs, making it advantageous for prototyping and small-batch production of components used in renewable energy.	Economies of scale are more effective for mass production of standardized components. The cost of specialized tooling is spread across large production runs, making it more cost-effective than 3D printing for high volumes of standardized parts.
Production Time and Setup	
Has minimal setup time and can manufacture components directly from CAD files, which reduces the time and costs associated with tooling changes. For small to medium-sized production runs, this can lead to significant time savings.	Requires significant lead time for creating and modifying tooling, which increases costs, especially for custom parts. However, once the setup is complete, production can be scaled up more efficiently than with 3D printing.
Labor and Operational Costs	
Reduces labor costs since much of the process is automated. The cost efficiency depends on the reduction in manual intervention compared to traditional production lines, which can be labor-intensive.	Generally requires more labor for operation, maintenance, and assembly processes, though it benefits from efficiencies in long-term, large-volume production runs.
Complex Parts Integration	
Allows for the integration of complex, multifunctional parts into a single print, which can reduce assembly and logistics costs. This is particularly beneficial for renewable energy systems that involve bespoke or highly integrated designs.	Produces components that often need assembly, adding to labor and logistics costs, particularly for complex parts.
Maintenance and On-Demand Production	
Facilitates on-demand manufacturing, which can be more cost-effective for spare parts in renewable energy infrastructure, reducing inventory costs and eliminating long lead times.	Produces spare parts in bulk, which could mean higher inventory and storage costs, but achieves better cost efficiency for high volumes.

3D printing offers cost efficiency for custom, complex components, rapid prototyping, and small-to-medium-scale production, while traditional manufacturing remains more cost-efficient for mass production of standardized components and large-scale infrastructure. For renewable energy projects that require a combination of customization and scalability, a hybrid approach using both 3D printing and traditional manufacturing could be most effective.

5. Challenges of Green Energy with 3D Printing Technologies

The integration of green energy and 3D printing technologies presents numerous opportunities, but it also comes with significant challenges. Here are some key challenges:

Material Limitations

While 3D printing allows for customized and efficient production, finding sustainable and recyclable materials that are suitable for green energy applications remains a challenge. Many current 3D printing materials are either non-recyclable or have limited durability for long-term energy applications.

Green energy systems often require materials with specific mechanical, thermal, and electrical properties. Balancing these performance requirements with environmental sustainability can be difficult[20-22].

Scalability

While 3D printing is ideal for prototyping and small-scale production, scaling up to meet the demands of large green energy projects (like wind turbines or solar farms) is challenging. The speed and cost of 3D printing at scale still lag behind traditional manufacturing methods [23-24].

Scaling 3D printing for green energy solutions requires significant investment in new infrastructure, which can be costly and time-consuming to develop.

Technological Integration

Integrating 3D printing into existing green energy supply chains can be complex. Many green energy technologies, such as solar panels or wind turbines, involve intricate systems that require precise manufacturing standards, which 3D printing may not yet fully meet.

Effective use of 3D printing in green energy requires collaboration across various fields (material science, engineering, environmental science), which can be difficult to coordinate[25-26].

Environmental Impact

Although 3D printing can reduce material waste, the process itself can be energy-intensive, which may offset some of the environmental benefits if the energy used is not from renewable sources, Figure 8. The disposal and recycling of 3D-printed components, especially those made from composite materials, pose environmental challenges.

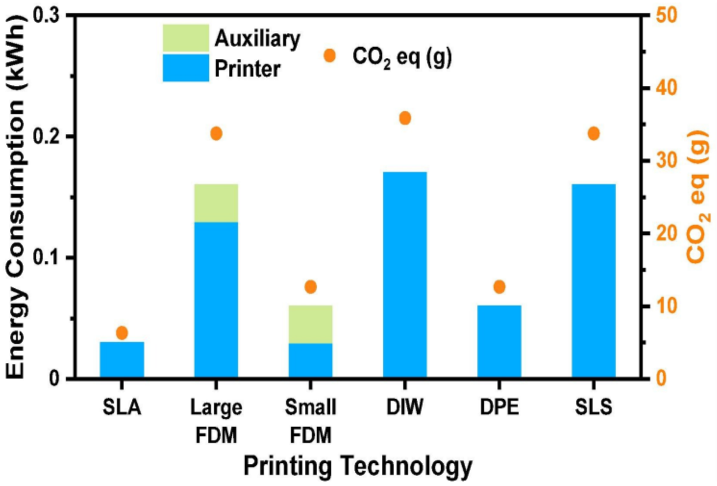

Fig. 8. The printers' energy consumption and estimated CO2 emissions after an hour in standby. Ancillary equipment's energy usage is displayed.

Economic Factors

While 3D printing can reduce costs in terms of material usage and customization, the initial investment in 3D printing technology and materials can be high. For green energy projects, where cost efficiency is crucial, this can be a significant barrier.

The market for 3D printing in green energy is still in its early stages. Widespread adoption is hindered by uncertainties in regulation, return on investment, and long-term performance.

Regulatory and Standardization Issues

There is a lack of standardized guidelines for the use of 3D printing in green energy applications. This can lead to inconsistencies in quality and performance, which are critical in energy systems.

Regulatory bodies may be slow to approve new 3D-printed green energy technologies, especially when it comes to safety and environmental impact.

Supply Chain Disruption

3D printing relies on specific raw materials, some of which may have limited supply chains. Disruptions in these supply chains could impact the availability and cost of 3D-printed components for green energy projects.

Innovation Gaps

Ongoing research and development are needed to address current limitations in 3D printing technology and to develop new materials and processes that are fully compatible with green energy applications. However, funding and resources for this R&D may be limited.

Addressing these challenges will require coordinated efforts across industry, academia, and government to ensure that 3D printing can effectively contribute to the acceleration of green energy technologies.

6. Conclusions

The convergence of 3D printing technologies with green energy offers transformative potential in accelerating the transition to sustainable energy solutions. By enabling customized, on-demand production, reducing material waste, and facilitating the creation of complex components, 3D printing can drive innovation in renewable energy systems such as solar, wind, and energy storage. However, this integration faces several challenges, including material limitations, scalability issues, environmental impacts, and economic barriers. Overcoming these hurdles will require advances in sustainable materials, improved energy efficiency in 3D printing processes, and the establishment of industry standards. Moreover, interdisciplinary collaboration and targeted research and development are essential to unlock the full potential of 3D printing in green energy applications. As these technologies evolve, they hold the promise of not only enhancing the efficiency and cost-effectiveness of renewable energy systems but also contributing to a more sustainable and resilient global energy landscape.

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References

1. Frazier, W.E. Metal additive manufacturing: A review. *Journal of Materials Engineering and Performance*, **2024**, *23*(6), 1917-1928.
2. Murr, L.E. Frontiers of 3D printing/additive manufacturing: From human organs to aircraft fabrication. *Journal of Materials Science & Technology*, **2016**, *32*(10), 987-995.
3. Ngo, T.D.; Kashani, A.; Imbalzano, G.; Nguyen, K.T.Q.; Hui, D. Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Composites Part B: Engineering*, **2018**, *143*, 172-196.
4. Patel, D.; 3D printing: A revolution in solar energy. *Renewable Energy Focus*, **2021**, *37*, 61-64.
5. Kumar, S.; .Jha, A. Additive manufacturing for green energy conversion and storage devices. *Journal of Energy Storage*, **2020**, *27*, 101154.

6. Van der Zande, C.A.; Ten Elshof, J.E.; Giesbers, M. 3D printing of next-generation wind turbine components. *Renewable and Sustainable Energy Reviews*, **2022**, *150*, 111479.
7. Zhang, C.; Anzalone, G.C.; Pearce, J.M. Open-source 3D-printable optics equipment. *Applied Optics*, **2013**, *52*(10), 1264-1270.
8. Kabir, S.M.F.; Yeo, L.C.; Sujan, D.; Lau, K.T. 3D printing in the renewable energy sector. *Renewable and Sustainable Energy Reviews*, **2020**, *128*, 109901.
9. Groth, C.; Tolstrup, C. Additive manufacturing in wind energy: A review of opportunities and challenges. *Materials Today: Proceedings*, **2021**, *45*, 4231-4237.
10. IEA. Renewables 2021: Analysis and forecast to 2026. International Energy Agenc, **2021**.
11. Chen, H.; Li, J.; Wang, Y.; Zhao, X. 3D Printed Perovskite Solar Cells: Advances in Fabrication and Stability. *Journal of Photovoltaics*, **2022**, *12*(4), 345-358.
12. García, M.; Rodríguez, E.; Velasco, J. Additive Manufacturing of Wind Turbine Blades: Reducing Costs and Improving Performance. *Renewable Energy Materials*, **2021**, *9*(3), 234-250.
13. Zhang, T.; Liu, F.; Wang, Q. Optimizing Proton-Exchange Membrane Electrolyzers via 3D Printing. *International Journal of Hydrogen Energy*, **2023**, *48*(7), 1012-1025.
14. Patel, A.; Thompson, R. 3D Printed Batteries: Current Progress and Future Outlook. *Journal of Energy Storage*, **2022**, *28*, 1047-1056.
15. General Electric. GE and LM Wind Power Explore the Use of 3D Printing for Wind Turbine Blade Molds. GE Renewable Energy News, **2021**.
16. Solar Energy Research Institute of Singapore (SERIS). Advanced Bifacial PV Modules Using 3D Printing. *Journal of Solar Energy Engineering*, **2022**, *144*(2), 543-550.
17. International Renewable Energy Agency (IRENA). The Role of 3D Printing in Renewable Energy. *Renewable Energy Technologies Series*, **2020**.
18. Ramakrishna, S.; Shanmugam, S. Additive Manufacturing for the Next Generation of Renewable Energy Systems. *Renewable and Sustainable Energy Reviews*, **2022**, 158, 112083.
19. Lu, L.; Tan, Z. 3D Printing and its Application in Renewable Energy Production. *Energy Reports*, **2021**, *7*, 4410-4423.
20. Leong, W.Y.; Leong, Y.Z.; Leong, W.S. Green Building Initiatives in ASEAN Countries, *2023 Asia Meeting on Environment and Electrical Engineering (EEE-AM), Hanoi, Vietnam*, **2023**, pp. 1-6, doi: 10.1109/EEE-AM58328.2023.10395261.
21. Leong, W.Y. Investigating and Enhancing Energy Management Policy and Strategies in ASEAN, *2023 Asia Meeting on Environment and Electrical Engineering (EEE-AM)*, Hanoi, Vietnam, **2023**, pp. 1-6, doi: 10.1109/EEE-AM58328.2023.10395060.
22. Leong, W.Y.; Leong, Y.Z.; Leong, W.S. Human-Machine Interaction in the Electric Vehicle Battery Industry. *In 2024 10th International Conference on Applied System Innovation (ICASI)*, **2024**, pp. 69-71. IEEE.
23. Leong, W.Y.; Leong, Y.Z.; Leong, W.S. Nuclear Technology in Electronic Communications, *2024 IEEE 4th International Conference on Electronic Communications, Internet of Things and Big Data (ICEIB*), Taipei, Taiwan, **2024**, pp. 684-689, doi: 10.1109/ICEIB61477.2024.10602705.
24. Leong, W.Y.; Leong, Y.Z.; Leong, W.S. Accelerating the Energy Transition via 3D Printing, *2023 Asia Meeting on Environment and Electrical Engineering (EEE-AM)*, Hanoi, Vietnam, **2023**, pp. 1-5, doi: 10.1109/EEE-AM58328.2023.10395773.
25. Kumar, R.; Kapil, A.K.; Athavale, V.; Leong, W.Y.; Touzene, A. The catalyst for clean and green energy using blockchain technology. In Modeling for Sustainable Development: A Multidisciplinary Approach, 2023 , pp. 23-39. Nova Science Publishers, Inc.
26. Leong, W.Y.; Leong, Y.Z.; Leong, W.S. Smart city initiatives in Malaysia and Southeast Asia, *The 12th International Conference on Renewable Power Generation (RPG 2023)*, **2023**, China, 1143-1149.
27. Leong, W.Y.; Zhang, J.B. Failure Analysis for Project-Based Learning (PBL) in Engineering, *ASM Science Journal*. **2024**.
28. Leong, W.Y.; Liu, W. Structural health monitoring: Subsurface defects detection." In 2009 35th Annual Conference of IEEE Industrial Electronics, **2009**, 4326-4330. IEEE.
29. Choo, K.W.; Rozana, Z.; Azlan, A.; Leong, W.Y. Various Techniques on Retrofitting for Earthquake Hazard Mitigation. *International Journal of Engineering & Technology* **2018**, 7. 167. 10.14419/ijet.v7i3.36.29101.
30. Leong, W.Y.; Leong, Y.Z.; Leong, W.S. Virtual Reality in Green Construction. *Applying new Technology in Green Buildings, ATiGB*, Da Nang, Aug **2024.**
31. Pham, T.H.; Li, X.J.; Chong, P.H.J.; Leong,W.Y. Design and Implementation of a Centralized Sensor Protocol for Information via Negotiation, 2010 Second International Conference on Communication Software and Networks, Singapore, 2010, pp. 88-92, doi: 10.1109/ICCSN.2010.90.
32. Leong, W.Y.; Kumar, R. 5G Intelligent Transportation Systems for Smart Cities. In Convergence of IoT, Blockchain, and Computational Intelligence in Smart Cities **2023**, pp. 1-25. CRC Press.

33. Chun, W.X.; Leong, W.Y. Composite defects diagnosis using parameter optimization based support vector machine. In 2010 5th IEEE Conference on Industrial Electronics and Applications, 2010, pp. 2300-2305. IEEE.
34. Yeoh, C.Y.; Wang, X.; Leong, W.Y.; Tan, C.; Wong, C.G.; Lee, Y.F. Buck DC-DC converter for embedded control system. In 2011 IEEE Conference on Sustainable Utilization and Development in Engineering and Technology (STUDENT), 2011, pp. 144-149. IEEE.
35. Liu, W.; Sum, Y.L.; Soong, B.H.; Ramachandran, S.; Tay, B.; Leong, W.Y. Two Layer Spiral Traces for Near Uniform Inductive Transfer. In 2009 35th Annual Conference of IEEE Industrial Electronics. 2009.
36. Calugcug, C.C.L.; Leong, W.Y. Characterization of non-destructive inspection data from composite structure defects. In 2009 35th Annual Conference of IEEE Industrial Electronics, 2009, pp. 4319-4325. IEEE.
37. Zhuang, L.Q.; Luo, M.; Leong, W.Y. A multi-agent based approach for distributed monitoring framework. In International Conference on Emerging Technologies and Factory Automation (ETFA), 2010, pp. 1-4.

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