

# Recent Innovations and Trends in Renewable Energy for Offshore Structures

Rishabh D. Makwana<sup>1,\*</sup>, Darshan H. Bhalodia<sup>2</sup>, Milan M. Pankhaniya<sup>3</sup>, Paresh Sangadiya<sup>4</sup>

## Abstract

*The global transition to renewable energy is gaining significant momentum, driven by rapid technological advancements and the urgent need to mitigate climate change. Offshore renewable energy, in particular, is emerging as a critical component in achieving energy security and sustainability. This review provides a comprehensive analysis of recent trends and advancements in offshore renewable energy technologies, including offshore wind, solar, hydrogen, biofuels, and wave energy. Offshore wind energy has witnessed remarkable growth with the development of floating wind farms, larger and more efficient turbine designs, and improvements in aerodynamics and materials, significantly enhancing energy capture and reducing costs. In the solar sector, advancements such as perovskite-based solar cells, bifacial panels, and floating photovoltaic systems are increasing efficiency and enabling deployment in offshore environments. Additionally, green hydrogen production through renewable-powered electrolysis is gaining prominence as a sustainable energy carrier, with offshore wind and solar farms playing a crucial role in its large-scale production. Energy storage technologies are also evolving to support the integration of offshore renewables into the grid. Innovations in solid-state batteries, flow batteries, and offshore pumped hydro storage are improving energy storage capacity, stability, and reliability. Moreover, biomass from marine sources and wave energy technologies are diversifying the offshore renewable energy mix, offering sustainable solutions for power generation and industrial applications. These advancements collectively contribute to a cleaner, more sustainable, and resilient offshore energy infrastructure. This review highlights the latest breakthroughs and discusses the challenges and future prospects of offshore renewable energy, underscoring its pivotal role in the global energy transition.*

**Keywords:** Renewable energy, recent trends in energy, renewable energy, advancement, scope of renewable energy in India

## INTRODUCTION

The transition toward renewable energy has accelerated in recent years due to increasing global energy demand, the need to reduce carbon emissions, and advancements in technology. Offshore renewable energy, in particular, has emerged as a crucial solution for sustainable power generation, addressing the limitations of land-based energy sources while utilizing vast ocean resources. This shift is further supported by favorable policies, declining costs, and enhanced grid integration technologies.

Technological advancements are playing a significant role in shaping the future of offshore renewable energy. Innovations in solar, wind, hydrogen, and wave energy are leading to improved efficiency, reliability, and economic viability. Floating solar farms, offshore wind energy expansion, and advancements in marine biofuels are

### \*Author for Correspondence

Rishabh D. Makwana  
E-mail: rishabh.makwana@atmiyauni.ac.in

<sup>1-4</sup>Assistant Professor, Department of Mechanical Engineering and Automobile Engineering, Atmiya University, Rajkot, Gujarat, India

Received Date: March 07, 2025  
Accepted Date: March 27, 2025  
Published Date: April 02, 2025

**Citation:** Rishabh D. Makwana, Darshan H. Bhalodia, Milan M. Pankhaniya, Paresh Sangadiya. Recent Innovations and Trends in Renewable Energy for Offshore Structures. Journal of Offshore Structure and Technology. 2025; 12(2): 1–9p.

---

transforming offshore power generation and industrial applications. The development of high-efficiency energy storage solutions is also enabling better integration of offshore renewable sources into global energy grids.

Among these advancements, solar energy has seen remarkable progress, particularly with the rise of perovskite-based solar cells. These next-generation photovoltaics have shown great potential in improving efficiency while reducing manufacturing costs. Their lightweight and flexible nature make them a promising option for offshore solar farms, where conventional silicon-based panels face deployment challenges. However, further research is required to enhance their long-term stability and performance in harsh marine environments [1, 2].

## LITERATURE REVIEW

The growing global emphasis on renewable energy has led to rapid advancements in offshore energy technologies. Researchers and industry experts are focusing on harnessing solar, wind, hydrogen, and bioenergy to develop sustainable energy solutions for marine and coastal applications. This section reviews key developments in offshore renewable energy and explores the latest technological innovations [3].

### Offshore Solar Energy Developments

Solar energy plays a crucial role in offshore renewable energy production, with recent innovations improving efficiency and adaptability to marine environments. Floating solar farms have emerged as a promising solution for energy generation in coastal and offshore regions. New materials, such as perovskite-based solar cells, have gained attention due to their potential for higher efficiency and lower production costs compared to traditional silicon-based panels. However, challenges such as material degradation due to humidity and salt exposure remain key areas of research [4].

Bifacial solar panels have also gained prominence in offshore applications. These panels capture sunlight from both the front and rear surfaces, significantly increasing power output. When deployed over reflective water surfaces, they can generate more electricity than conventional panels. Ongoing research aims to improve their durability and integration with offshore energy infrastructure, making them more viable for large-scale deployment [5].

### Offshore Wind Energy Innovations

Offshore wind energy has experienced substantial growth, with the development of floating wind turbines expanding the possibilities for wind farm installations in deeper waters. Unlike traditional fixed-bottom turbines, floating wind turbines are mounted on buoyant platforms, allowing for deployment in locations with stronger and more consistent wind speeds. This innovation has the potential to enhance energy production while minimizing the impact on marine ecosystems [6].

Larger wind turbines with capacities exceeding 12 MW are being introduced to improve efficiency and reduce the overall cost of offshore wind projects. By increasing turbine size, developers can maximize power generation while reducing the number of installations required. However, stability and structural integrity in extreme weather conditions remain ongoing challenges in offshore wind turbine design.

### Green Hydrogen Production and Storage

Green hydrogen has gained significant interest as an alternative energy carrier, particularly in offshore applications where excess renewable energy can be used for hydrogen production. Hydrogen is produced through electrolysis, a process that splits water into hydrogen and oxygen using electricity generated from renewable sources such as offshore wind and solar. This approach offers a sustainable method for storing and transporting energy over long distances [7].

The integration of hydrogen storage and distribution systems with offshore energy infrastructure is a growing area of research. Efficient storage solutions, including compressed hydrogen, liquid hydrogen, and solid-state hydrogen carriers, are being explored to enhance feasibility and reduce energy losses during transportation. While green hydrogen presents a promising solution for decarbonizing industrial and maritime sectors, advancements in cost reduction and storage technology are required for large-scale adoption [8].

### **Offshore Bioenergy and Sustainable Fuels**

Bioenergy derived from marine biomass, such as algae, is gaining traction as a sustainable energy source for offshore applications. Unlike traditional biofuels that rely on land-based crops, marine biomass offers a renewable and low-carbon alternative that does not compete with food production. Algae-based biofuels have the potential to support offshore industries, including shipping and remote power generation for ocean-based operations [9].

A key focus in bioenergy research is achieving carbon neutrality by minimizing emissions throughout the production process. Improvements in biomass cultivation, transportation, and refining methods are helping to ensure that biofuels contribute to net-zero energy solutions. Additionally, integrating carbon capture technologies with bioenergy systems can further enhance their environmental benefits, making them more viable for large-scale implementation.

### **METHODOLOGY**

The paper primarily follows a review-based methodology, analyzing recent advancements in offshore renewable energy. The approach includes:

1. Literature Review:
  - Examines key developments in offshore energy, including wind, solar, hydrogen, biofuels, and wave energy.
  - Reviews past research papers, industry reports, and technological assessments to summarize trends.
  - Focuses on innovations such as floating wind farms, perovskite-based solar cells, and hydrogen production.
2. Technology Assessment:
  - Evaluates efficiency improvements in offshore energy technologies.
  - Compares the feasibility of different renewable energy solutions for marine environments.
  - Analyzes material advancements, storage techniques, and economic aspects of offshore energy deployment.
3. Challenges and Future Prospects:
  - Identifies technical, financial, and environmental challenges in offshore energy adoption.
  - Discusses emerging solutions such as AI-based energy forecasting and hybrid renewable models.

### **ADVANCEMENTS IN OFFSHORE SOLAR ENERGY**

#### **Perovskite Solar Cells**

Perovskite solar cells have emerged as a transformative technology in the field of photovoltaics, offering higher efficiency potential compared to conventional silicon-based solar cells. These cells are made from a unique class of materials that exhibit superior light absorption properties, allowing for greater energy conversion efficiency. Their lightweight and flexible nature make them particularly suitable for offshore applications, such as floating solar farms, where traditional panels may face structural and durability challenges.

Ongoing research is addressing key challenges associated with perovskite solar cells, including their stability, environmental resilience, and scalability for large-scale deployment. Scientists and engineers are developing protective coatings and hybrid materials to enhance their resistance to moisture,

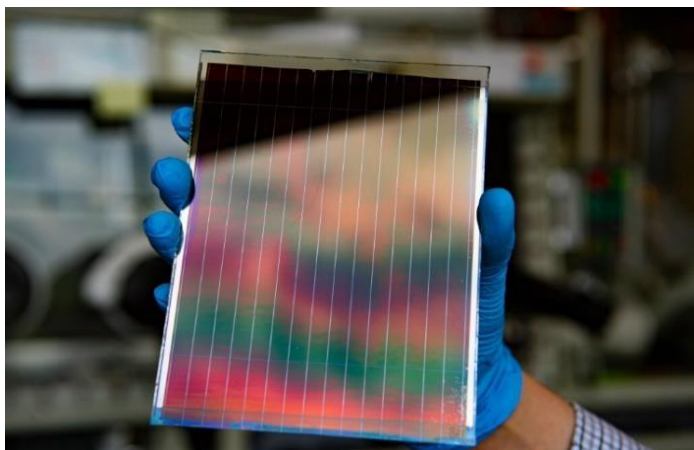
temperature fluctuations, and saltwater exposure—critical factors for offshore environments. Additionally, advancements in tandem solar cell technology, which combines perovskite with silicon or other materials, are further boosting energy output and operational efficiency.

With continuous improvements in material science and manufacturing techniques, perovskite solar cells are poised to become a viable alternative for offshore renewable energy systems. Their integration into offshore floating solar farms could contribute to the diversification of energy sources and support sustainable power generation for coastal and island communities, offshore industries, and marine operations (Figure 1).

### Bifacial Solar Panels

Bifacial solar panels represent a major breakthrough in photovoltaic technology, offering higher energy output by capturing sunlight on both the front and rear surfaces. Unlike conventional solar panels that absorb light only from one side, bifacial panels utilize reflected sunlight from surfaces such as water bodies, sand, or specialized coatings. This feature makes them particularly beneficial for offshore floating solar farms, where the ocean surface can enhance light reflection and improve energy yield.

The adoption of bifacial solar technology is increasing in large-scale renewable energy installations due to its improved efficiency and durability. These panels are often coupled with advanced tracking systems that optimize their orientation, further maximizing energy generation. As offshore solar technology matures, bifacial panels are expected to play a crucial role in expanding solar energy utilization in coastal and marine environments (Figure 2).



**Figure 1.** Perovskite solar cells.



**Figure 2.** Bifacial solar panels for offshore applications.

## **OFFSHORE WIND ENERGY**

### **Floating Wind Turbines**

Floating wind turbine technology is revolutionizing offshore wind energy by enabling wind farm installations in deeper waters where conventional fixed-bottom turbines are not feasible. Traditional offshore wind turbines are typically anchored to the seabed, limiting their deployment to shallow coastal regions. In contrast, floating wind turbines are mounted on floating platforms secured by mooring lines, allowing them to be deployed in deeper oceanic locations where wind speeds are higher and more consistent.

The development of floating wind technology opens vast new areas for wind energy generation, reducing spatial constraints and minimizing environmental impacts on coastal habitats. As engineering solutions improve, floating offshore wind farms are expected to become a key contributor to global renewable energy goals (Figure 3).

### **Large-Scale Wind Turbines**

The offshore wind industry is witnessing a shift toward large-scale turbines with capacities exceeding 12 MW. These next-generation wind turbines are designed with larger rotor diameters and taller towers to harness more wind energy per unit, significantly improving efficiency and reducing the cost of offshore wind farms.

Larger turbines not only increase energy generation but also reduce the number of units required for a given power capacity, leading to lower maintenance and installation costs. As offshore wind farms continue to expand, the deployment of high-capacity turbines is expected to enhance the cost-effectiveness and competitiveness of offshore wind energy (Figure 4).



**Figure 3.** Floating wind turbines.

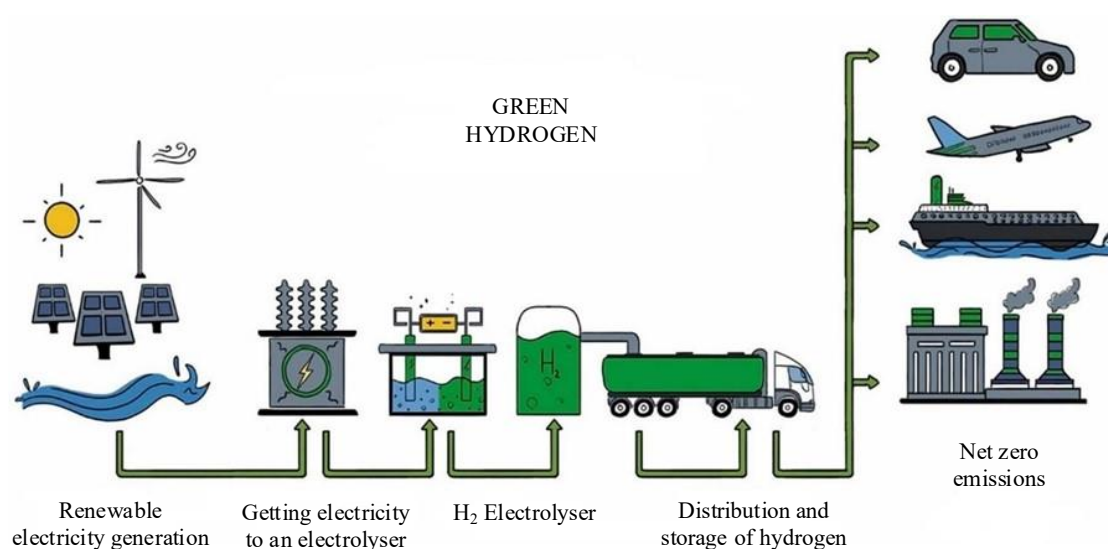
## **GREEN HYDROGEN PRODUCTION**

### **Electrolysis Using Renewable Power**

Green hydrogen production is emerging as a promising solution for decarbonizing industries and sectors that are challenging to electrify, such as heavy manufacturing and maritime transport.



**Figure 4.** Large-scale wind turbines.



**Figure 5.** Green hydrogen production and storage.

Hydrogen is produced through electrolysis, a process that splits water into hydrogen and oxygen using electricity. When powered by renewable energy sources such as offshore wind or solar, electrolysis produces green hydrogen—an environmentally friendly alternative to fossil fuels.

Offshore wind farms are increasingly being integrated with hydrogen production facilities, allowing surplus electricity to be used for electrolysis. This approach not only enhances the utilization of renewable energy but also supports energy storage by converting electricity into hydrogen for later use.

### Hydrogen Storage and Distribution

The development of efficient hydrogen storage and transportation solutions is critical for the widespread adoption of green hydrogen. Advances in compression, liquefaction, and solid-state hydrogen storage technologies are making it more feasible to store hydrogen for long durations and transport it across regions. Offshore facilities may play a significant role in hydrogen production and distribution, potentially establishing offshore hydrogen hubs that link renewable energy generation with industrial demand (Figure 5).

## BIOMASS AND BIOFUELS FOR OFFSHORE APPLICATIONS

### Advanced Biofuels

Biofuels are evolving beyond traditional crop-based sources to include more sustainable feedstocks such as algae, agricultural residues, and forest byproducts. These next-generation biofuels offer several advantages, including reduced competition with food production and lower environmental impact.

Marine-based biomass, such as algae, has gained particular interest for offshore energy applications. Algae can grow rapidly in ocean environments without the need for arable land or freshwater, making it a highly sustainable biofuel source. Additionally, advancements in biofuel processing technologies are improving the efficiency of converting biomass into usable fuels, supporting offshore industries and maritime transportation with cleaner alternatives to conventional fossil fuels.

By integrating advanced biofuels into offshore energy systems, industries can reduce their carbon footprint and enhance energy sustainability in marine operations. Continued research and innovation in biofuel production will further contribute to the diversification of offshore renewable energy sources (Figure 6).

## **CARBON-NEUTRAL BIOENERGY FOR OFFSHORE APPLICATIONS**

### **Carbon-Neutral Bioenergy**

As the renewable energy sector advances, increasing emphasis is being placed on ensuring that bioenergy solutions achieve true carbon neutrality. This involves minimizing greenhouse gas emissions at every stage of the bioenergy lifecycle, including feedstock cultivation, transportation, processing, and final energy conversion. By implementing sustainable agricultural practices, optimizing logistics, and utilizing carbon capture technologies, bioenergy can become a more viable and environmentally friendly alternative to conventional fossil fuels.

In offshore applications, carbon-neutral bioenergy can play a crucial role in powering marine operations, offshore platforms, and remote coastal communities. The integration of biofuels derived from marine biomass, such as algae, further enhances sustainability by reducing land-use competition and promoting resource efficiency. Continued research and technological advancements in biofuel production are expected to accelerate the adoption of carbon-neutral bioenergy in offshore energy systems (Figure 7).

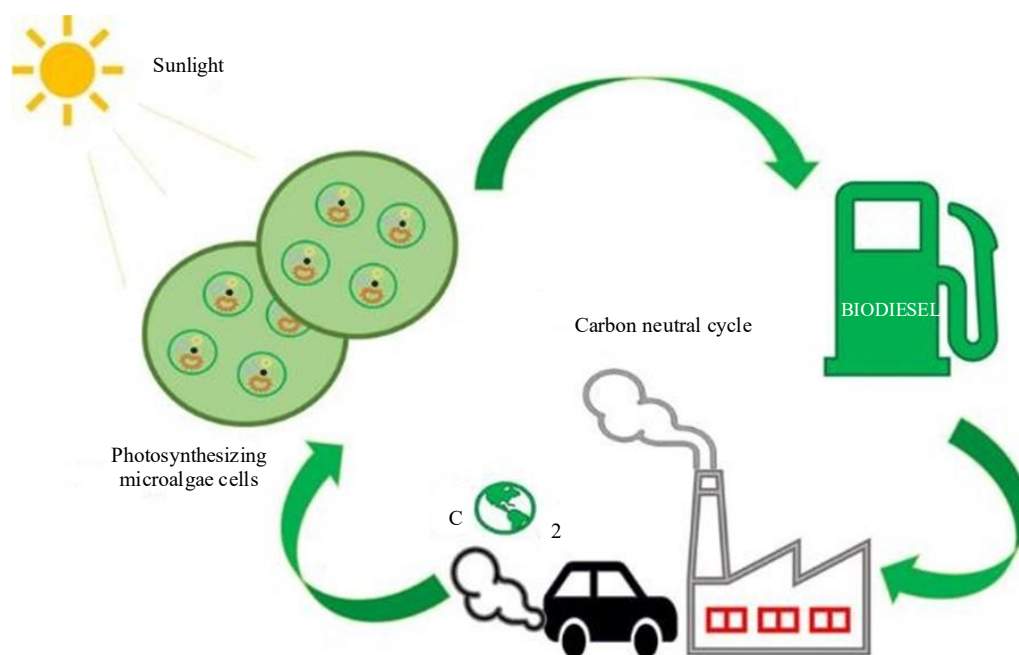
### **Results**

The paper highlights the following key findings:

1. Offshore Wind Energy
  - Growth of floating wind turbines, which allow for energy generation in deep waters.
  - Increase in turbine sizes beyond 12 MW, leading to greater efficiency and reduced costs.
2. Offshore Solar Energy
  - Perovskite-based solar cells and bifacial solar panels are improving efficiency.
  - Floating solar farms are being integrated into offshore energy systems.
3. Green Hydrogen Production
  - Electrolysis powered by offshore wind and solar is gaining traction as a clean hydrogen production method.
  - Advances in hydrogen storage and transportation improve feasibility.



**Figure 6.** Advanced biofuels from marine biomass.



**Figure 7.** Carbon-neutral bioenergy in offshore applications.

#### 4. Biofuels and Biomass

- Algae-based biofuels show promise for sustainable offshore energy.
- Carbon-neutral bioenergy solutions are emerging to support marine industries.

#### 5. Energy Storage Innovations

- Solid-state and flow batteries enhance offshore energy storage.
- Offshore pumped hydro storage is being explored as a large-scale solution.

### CHALLENGES AND FUTURE DIRECTIONS

Despite the promising advancements in offshore renewable energy, several challenges must be addressed to enable widespread deployment. The high initial costs of offshore energy infrastructure, exposure to harsh environmental conditions, and the need for efficient energy storage solutions are critical factors that influence project feasibility.

Future research is expected to focus on improving the durability of offshore energy systems, optimizing hybrid renewable energy models, and integrating artificial intelligence for predictive maintenance and energy forecasting. Additionally, policy frameworks and international collaboration will play a vital role in supporting the expansion of offshore renewable energy projects.

### CONCLUSION

The advancements in renewable energy technologies demonstrate the significant strides being made toward a cleaner and more sustainable energy future. Offshore renewable energy, in particular, has emerged as a critical component in addressing global energy demands while reducing dependence on fossil fuels. The integration of offshore solar, wind, hydrogen, and bioenergy solutions is transforming the energy landscape, enabling greater efficiency, resilience, and environmental sustainability.

Innovations such as floating solar farms, bifacial solar panels, large-scale wind turbines, and floating wind farms are enhancing offshore energy generation capabilities. Additionally, green hydrogen production and carbon-neutral bioenergy solutions are paving the way for more sustainable industrial and maritime applications. With ongoing research, technological advancements, and supportive policies, offshore renewable energy is poised to play a vital role in the global transition toward carbon neutrality.

As the offshore energy sector continues to evolve, further investment in research and development will be essential to optimize energy efficiency, reduce costs, and overcome technical challenges. By harnessing the vast potential of offshore renewable resources, the world can move closer to achieving a sustainable energy future with reduced environmental impact.

## REFERENCES

1. Somtochukwu Godfrey Nnabuife, Abdulhammed K. Hamzat, James Whidborne, *et al.* Integration of renewable energy sources in tandem with electrolysis: A technology review for green hydrogen production, *Int J Hydrog Energy*. 2024; 10(73): DOI:10.1016/j.ijhydene.2024.06.342.
2. Suparmaniam Uganeeswary, Lam Man, Lim, *et al.* Influence of environmental stress on microalgae growth and lipid profile: a systematic review. *Phytochem Rev*. 2022;22:1–24.
3. Douville T, Severy M, Eisdorfer J, He L, Pamintuan B. West Coast Offshore Wind Transmission Literature Review and Gaps Analysis. U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy; 2023 Feb 16. Available from: <https://www.ourenergypolicy.org/resources/west-coast-offshore-wind-transmission-literature-review-and-gaps-analysis/>
4. Oregon Department of Energy. Floating Offshore Wind Study Literature Review. Oregon Department of Energy; 2022. Available from: <https://www.oregon.gov/energy/Data-and-Reports/Documents/2022-DRAFT-FOSW-Lit-Review.pdf>
5. Nguyen DH, McKeogh E. Offshore Wind Energy: Technology Opportunities and Challenges. *Energy and Geotechnics*. 2018. Available from: [https://www.researchgate.net/publication/327869393\\_Offshore\\_Wind\\_Energy\\_Technology\\_Opportunities\\_and\\_Challenges\\_Energy\\_and\\_Geotechnics](https://www.researchgate.net/publication/327869393_Offshore_Wind_Energy_Technology_Opportunities_and_Challenges_Energy_and_Geotechnics)
6. Devine-Wright P. Public engagement with offshore renewable energy: a critical review. *Wiley Interdisciplinary Reviews: Climate Change*. 2011;2(1):51–61. Available from: <https://wires.onlinelibrary.wiley.com/doi/abs/10.1002/wcc.89>
7. Musial W, Beiter P, Schwabe P, Tian T. Offshore Wind Energy Resource Assessment for the United States. National Renewable Energy Laboratory; 2016 Sep. Report No.: NREL/TP-5000-66599. Available from: <https://www.nrel.gov/docs/fy16osti/66599.pdf>
8. Carbon Trust. Floating Offshore Wind: Market and Technology Review. Carbon Trust; 2015. Available from: <https://www.carbontrust.com/resources/floating-offshore-wind-market-and-technology-review>
9. Myhr A, Bjerkseter C, Ågotnes A, Nygaard TA. Levelised cost of energy for offshore floating wind turbines in a life cycle perspective. *Renew Energy*. 2014;66:714–28. Available from: <https://www.sciencedirect.com/science/article/pii/S0960148114002101>