Review

Progress in Green Energy and Fuel for Sustainability

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Abstract: Developing green energy and sustainable fuels is crucial to overcoming the environmental and resource challenges posed by fossil fuel consumption and dependence. To provide a comprehensive insight into the progress in green energy and fuels, including solar, wind, bioenergy, hydropower, marine, and geothermal energy, this study explores significant advancements and ongoing challenges in various renewable energy sectors. This study also highlights the development of green fuels such as biofuels, hydrogen, ammonia, and synthetic fuels, emphasizing their potential to achieve carbon neutrality and integration into existing infrastructures. Key challenges are identified, such as improving the efficiency and performance of renewable technologies, addressing high initial investment costs, and overcoming policy and social acceptance barriers. The environmental impacts of renewable energy production and resource availability are also discussed. The research underscores the necessity of collaborative efforts, supportive policies, and public engagement to overcome these challenges and achieve a sustainable energy future. This comprehensive overview provides insights into the current state and future prospects of green energy and fuel research for sustainability.

Keywords: green energy and fuel; biofuel; biochar; hydrogen; sustainability; net zero

1. Global Community for Sustainability

Fossil fuels have enormously contributed to our demands for heating, power, and chemical products. However, these resources are nonrenewable, have limited amounts, and have led to severe environmental pollution problems worldwide after the Industrial Revolution. These problems include air pollution, thermal pollution, acid rain, etc. In particular, on account of vast emissions of carbon dioxide, the primary byproduct of burning fossil fuels, into the atmosphere, people are encountering more severe environmental challenges, such as the deteriorated atmospheric greenhouse effect, global warming, and climate change [1]. The rising CO_2 concentration and accumulation in the atmosphere even lead to ocean acidification [2], another noticeable issue impacting marine ecosystems.

The global community has made many efforts to solve these environmental and resource challenges. Significant milestones and collaborative initiatives have pushed these efforts toward sustainability, as shown in Figure 1. Beginning with the Earth Summit in 1992, this pivotal event laid the groundwork for international environmental governance. It emphasized the need for sustainable development and set the stage for subsequent collaborative efforts. The United Nations Framework Convention on Climate Change (UNFCCC) was established in 1995 to combat global climate change. In the same year, the first Conference of the Parties (COP1) in Berlin paved the way for international cooperation on climate action. Kyoto Protocol, held in 1997, set binding emission reduction targets for developed countries. It aimed to mitigate greenhouse gas emissions and promote sustainable practices. Re100, launched in 2014, was a global initiative that united influential businesses, such as 3M, Apply, Adobe, Airbnb, IKEA, TSMC, and Intel, committed to using 100% renewable electricity. Then, the 2015 Paris Agreement sought to curb global warming by ensuring that the rise in average temperature remains below 2 °C compared to pre-industrial levels. It encouraged countries to submit nationally determined contributions (NDCs) outlining their emission reduction actions and adaptation measures. This landmark agreement entered into force in 2016. Subsequently, all United Nations Member States adopted the Sustainable Development Goals (SDGs) in 2015. The 17 SDGs, along with 169 targets, were outlined in the outcome document titled “Transforming our world: the 2030 Agenda for Sustainable Development.” The 17 global objectives addressed poverty, inequality, climate change, and other critical challenges to create a more sustainable and equitable world. Of the 17 SDGs, SDG 7 (affordable and clean energy) is directly related to green energy and fuel development. The newest conference of the parties (COP) event, COP28, was held in Dubai, UAE, in 2023. Representatives from different countries gathered to address critical climate challenges, implement the Paris Agreement, and accelerate efforts to control global temperature rise to 1.5 °C by the end of this century.

In addition to the events mentioned above, "net zero emissions (or simply net zero)" is also worth paying attention to for sustainability. Net zero is defined as the state where the amount of greenhouse gases emitted by human activities is entirely offset by carbon removal from the atmosphere. The net zero concepts for climate change and greenhouse gas emissions started gaining significant attention around the early to mid-2000s. However, it wasn't until the late 2010s that it became a prominent goal within climate policy discussions and corporate sustainability strategies. The Paris Agreement of 2015 played a crucial role in elevating the prominence of net zero. It underscored the significance of restricting global warming to significantly less than 2 °C and trying to confine it to 1.5 °C above the levels recorded before the industrial era [3]. Since then, the net zero target has become increasingly adopted by governments, businesses, and organizations worldwide as a vital approach for addressing climate change and attaining enduring sustainability.

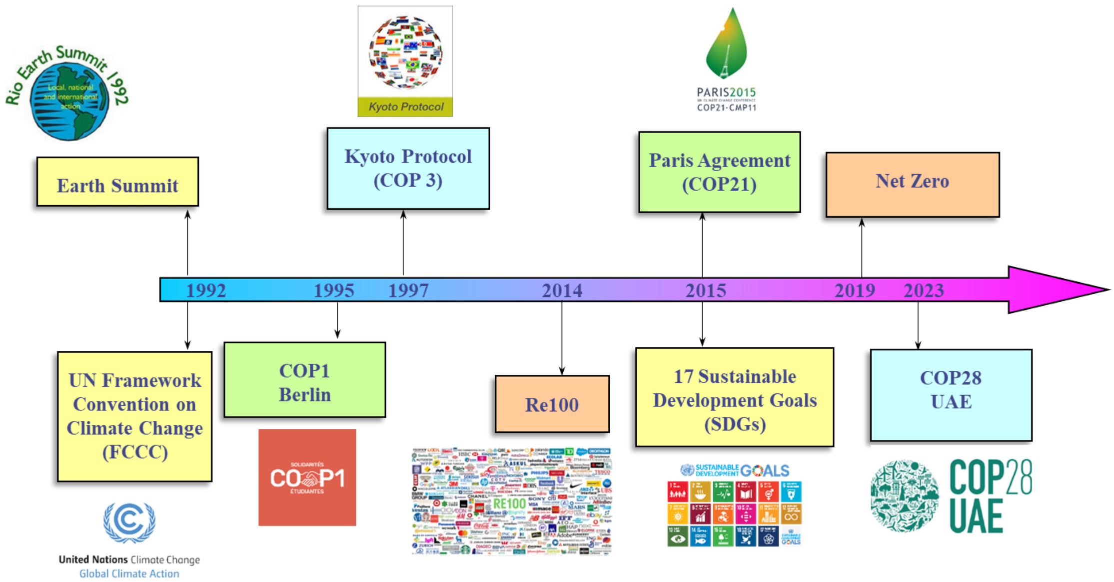

Figure 1. Global community efforts for sustainability.

2. Green Energy

As described earlier, burning fossil fuels to gain energy is the primary reason causing environmental problems. For this reason, many countries have spurred a shift toward renewable energy sources like solar, wind, marine, biomass, geothermal, and hydropower to mitigate global warming. While people grapple with the challenges posed by fossil fuels, the transition to green energy becomes essential for a sustainable future. Green energies comprise solar, wind, biomass, hydropower, marine, and geothermal. No CO_2 is emitted into the atmosphere when utilizing these green energies, so carbon neutralization and decarbonization can be achieved.

2.1. Solar Energy

Solar energy is recognized as a sustainable alternative energy source that is inexpensive, inexhaustible, and widely accessible. Solar energy consists of solar photovoltaic (PV) and concentrating solar power (CSP). Solar energy used for global electricity production is still low, at around 3.6% [4]. Nevertheless, there was a significant surge of around 22% in the installed solar energy capacity from 2021 to 2022. In recent years, considerable progress has been made in materials and systems within solar energy technology to improve efficiency and lower costs [5]. Besides power generation, solar energy can also be applied to materials processing, metallurgy and materials, the cement industry and ceramics, and the recycling of materials' wastes [6].

2.2. Wind Energy

Like solar energy, wind energy is a mature technology and has been highly commercialized. It directly converts wind mechanical energy into electricity, so it is a promising renewable energy source, offering clean and relatively affordable usage [7]. There is ample potential for expansion in installed wind power capacity, evidenced by the substantial global increase in onshore wind capacity. For instance, in 2010, the capacity stood at a mere 178 GW, whereas by 2021, it had surged to 769 GW [8]. Wind turbines can be classified as horizontal and vertical axis wind turbines in accordance with design. To effectively harvest wind energy for electricity generation, much effort has been made in wind turbine design [9] and wind farm array optimization [10].

2.3. Bioenergy

In contemporary times, bioenergy ranks as the fourth most significant primary energy source, following oil, coal, and natural gas [11]; it is also the largest renewable energy resource. Unlike solar and wind energy, which primarily contribute to electricity generation, bioenergy is focused mainly on producing biofuels. These biofuels can be applied to heating, power generation, and transportation. Through biorefinery, biomass can be converted to a variety of biofuels and chemicals. Moreover, waste valorization and a circular bioeconomy [12] can be achieved when biomass wastes are employed as feedstocks. Much attention has recently focused on the relationship between bioenergy and carbon neutrality [13].

2.4. Hydropower

Hydropower, or hydroelectric power, is a sustainable energy source that harnesses power by manipulating natural water flow using dams or diversion structures in rivers or other water bodies. Hydropower globally supplies around 62% of all renewable electricity [14] and around 16% of global electricity demand [15]. At the heart of a hydropower plant lies the hydro turbine, pivotal in converting water's potential energy into mechanical energy, propelling the generator to produce electricity. Turbines are categorized into two main types: impulse and reaction turbines [16]. Recently, small-scale and micro hydropower development has been an important research topic, particularly for its applications in rural and remote areas [17].

2.5. Marine Energy

Marine energy, also called ocean energy, consists of ocean currents, tides, wave energy, ocean thermal energy conversion (OTEC), and salinity gradient energy. Because the ocean covers approximately 71% of the Earth's surface, marine energy resources are abundant and geographically distributed. Theoretical estimates suggest that marine energy sources could offer a potential of approximately 151,300 terawatt-hours per year [18]. However, most marine energy technologies are still in the pre-commercial phase, and substantial advancements are needed in research and development and in demonstrating and validating these technologies [19]. These efforts aim to enhance their performance and reliability, ultimately reducing the associated levelized cost of energy (LCoE). To make marine energy more efficient and ready for commercialization, more efforts are needed on energy converter design and optimization [20], the deployment of tidal turbines and generators [21], and the development of materials and structures to withstand harsh marine environments [22].

2.6. Geothermal Energy

It is estimated that the Earth's core temperature is around 5700 °C, so a tremendous amount of heat is contained in the Earth's interior. Geothermal energy is also a renewable and sustainable energy resource and is reliable and stable when harvesting geothermal energy. It was reported that 88 countries have directly utilized geothermal energy [23]. Geothermal energy, manifested as hot water and steam, can be used for power generation, greenhouse and space heating, aquaculture pond and raceway heating, industrial applications, etc. Due to heat in the deep underground, resource assessment is the most crucial work for developing geothermal energy. Developing efficient and cost-effective geothermal power plants [24] and heat pump systems [25] is also paramount. Moreover, geothermal energy production's environmental, economic, and social impacts also attract much attention to geothermal sustainability [26].

3. Green Fuels

Green fuels intrinsically are sustainable fuels. They are alternatives to traditional fossil fuels and are characterized by no net carbon emissions. So, green fuels can reduce greenhouse gas emissions and mitigate global warming and climate change. They can even promote the energy security of a country. Some common examples of green fuels include biofuels, hydrogen, and synthesis fuels.

3.1. Biofuels

Biofuels are produced from biomass. Biomass is an abundant resource, mainly lignocellulosic and algal biomass [27,28]. Organic wastes such as crop residues are also crucial for developing bioenergy. Raw biomass, like wood, can be consumed or burned directly for bioenergy. However, its utilization efficiency is low. Solid, liquid, and gas biofuels can be produced through various conversion technologies, such as physical (grinding, palletization, compression or densification, etc.), thermochemical (combustion, gasification, pyrolysis, torrefaction, liquefaction, etc.), chemical (transesterification), or biological (fermentation, digestion, etc.) conversion [11]. The classification of biofuels in terms of their phases is shown in Figure 2.

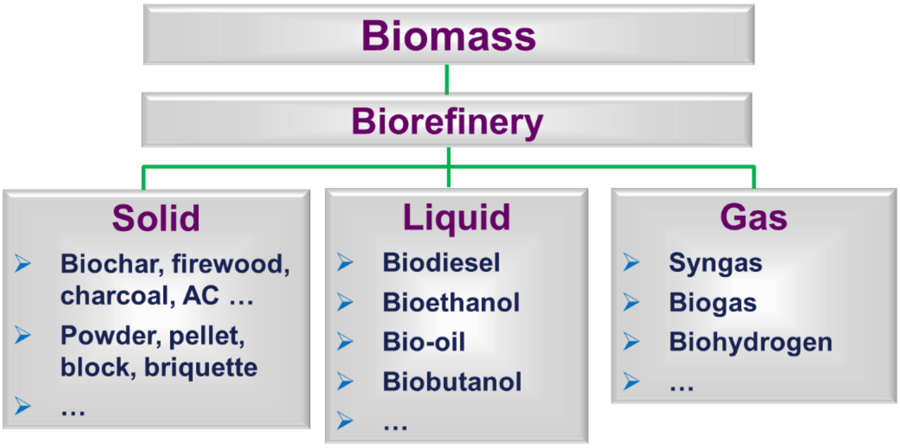

Figure 2. Classification of biofuels.

3.1.1. Solid Biofuel

Wood as a solid biofuel has been consumed for a long time. Wood pellets from the densification of sawdust, wood shavings, or other wood residues are widely used for heating, cooking, power generation, and combined heat and power (CHP) plants [29]. Furthermore, charcoal from carbonization has been widely employed because of its higher energy density. Recently, biochar production through torrefaction and pyrolysis has been extensively investigated [30,31]. In addition to fuel usage, biochar can be used for wastewater treatment to remove dyes, heavy metals, antibiotics, etc. [32], achieving environmental remediation. Moreover, biochar can also be applied to soil amendment and even to the target of carbon negativity.

3.1.2. Liquid Biofuel

Biodiesel and bioethanol production techniques are mature, and the two biofuels have been widely used for vehicles. Biodiesel, a non-toxic and biodegradable fuel, is made from vegetable oils, animal fats, or recycled cooking oils through transesterification. Though biodiesel has been commercialized, research on feedstock selection, catalyst development, fuel stability, and storage for biodiesel quality deserves further investigation [33,34]. Alternatively, bioethanol is made from fermenting sugars or starches in corn, sugarcane, wheat, barley, etc. However, to avoid food storage problems from bioethanol production, using food waste and lignocellulosic biomass as feedstocks is a growing field of research. When using lignocellulosic biomass as a feedstock for bioethanol production, choosing effective pretreatment methods for breaking down complex recalcitrance carbohydrates into fermentable sugars is also a critical topic [35]. Bio-oil is produced from biomass pyrolysis and contains various organic compounds, including phenols, acids, aldehydes, ketones, furans, etc. [28]. Bio-oil can be used as a feedstock to produce high-valued chemicals, solvents, and resins. However, bio-oil has a high water content and is unstable; therefore, upgrading bio-oil is crucial for its application [36]. Another liquid biofuel is biobutanol, which can be produced through the microbial fermentation of biomass-derived sugars, starches, or cellulose [37].

3.1.3. Gas Biofuel

Syngas (synthesis gas), composed of hydrogen and carbon monoxide, produced from biomass gasification is called bio-syngas. Bio-syngas can be burned for heat and power generation in gas turbines, steam boilers, or as a fuel in fuel cells. It can be further processed to produce methanol, dimethyl ether (DME), and liquid transportation fuels such as synthetic gasoline) [38,39]. Bio-syngas cleanup to remove impurities such as sulfur compounds, ammonia, tars, and particulates is an essential issue for biomass gasification development and scale-up. Biogas is generated when microorganisms anaerobically digest organic materials in an oxygen-free environment. It primarily comprises CH_4 and CO_2, along with small amounts of H_2S, N_2, and trace impurities. Process optimization is a potential topic for enhancing biogas production [40]. Biogas purification and upgrading are also essential for producing biomethane [41]. Bio-hydrogen is a biologically produced hydrogen generated from biological processes using renewable biomass as a feedstock. Bio-hydrogen can be produced through dark fermentation, photo-fermentation, and water photolysis [42]. Suitable and advanced microbial strain selection and engineering, reactor design, process optimization, substrate selection and pretreatment, and hydrogen purification play essential roles in bio-hydrogen development [43,44].

3.2. Hydrogen

The evolution of fuel usage is highly related to the atomic caron-to-hydrogen ratio in fuel. Humans' fossil fuel consumption proceeded with coal, petroleum, and natural gas. Coal has an atomic carbon-to-hydrogen ratio of around 10, gasoline has a ratio of around 0.5 (close to wood), and CH_4 has a ratio of 0.25. Hydrogen is gaining significant attention worldwide as a clean fuel and an energy carrier. Since hydrogen has no carbon in gas hydrogen (its atomic carbon-to-hydrogen ratio is 0), using it is conducive to achieving net zero and decarbonization targets [45].

Hydrogen is classified into (1) grey hydrogen, produced from fossil fuel without incorporating carbon capture and storage (CCS) technology; (2) blue hydrogen, produced from natural gas with CCS [46]; (3) green hydrogen, produced via water electrolysis using green power like wind or solar energy; (4) turquoise hydrogen, produced from methane pyrolysis or thermal decomposition to produce pure hydrogen and carbon [47]; (5) pink hydrogen, produced by water electrolysis powered by nuclear energy [46]; and (6) white hydrogen, also known as "natural," "gold," or "geologic" hydrogen, is a naturally occurring form of hydrogen found in the Earth's crust [48].

The future of the hydrogen economy is promising and is expected to play a significant role in the global energy transition. The critical tasks to overcome to approach the hydrogen economy include lowering green hydrogen production costs, hydrogen delivery development, innovative hydrogen storage technology, and hydrogen utilization (fuel cell vehicles, aviation, power production, railway, etc.) [49,50].

3.3. Ammonia

Ammonia has been widely applied in the industry for fertilizer, chemicals, cleaners and sanitizers, refrigerators, pharmaceuticals and healthcare, food additives, water and metal surface treatment, etc. Due to the net-zero target, ammonia, a carbon-free fuel, has also gained significant global interest as a candidate for the transition toward renewable energy [51]. Ammonia is a hydrogen carrier. Compared to hydrogen, ammonia is easy to store and deliver. The first step in the ammonia supply chain is green ammonia production [52], which involves water electrolysis to produce green hydrogen using renewable electricity (green power) and the Haber-Bosch process to synthesize ammonia. Currently, high production costs and scale-up are the main obstacles to green ammonia production [51]. Like hydrogen, ammonia has no carbon, so no carbon dioxide is produced and emitted when burning ammonia. Ammonia can be applied to internal combustion engines, gas turbines, power generation, etc. It can also be blended with other fuels (CO, syngas, dimethyl ether, diethyl ether, coal) to be combusted for industrial applications. Although NH_3 combustion does not emit CO_2, it has pronounced barriers such as high NO_x emissions, low burning velocity, and lower stability [53].

3.4. Synthetic Fuel and Renewable Natural Gas (RNG)

Synthetic fuels are also known as e-fuels or power-to-liquid fuels. Synthetic fuels are produced from the combination of hydrogen, stemming from water electrolysis using renewable electrolysis, and carbon dioxide, whether extracted from the atmosphere or generated by industrial activities. Synthetic fuels include synthetic e-methane, e-methanol, e-ammonia, e-gasoline, e-diesel, and e-jet fuel [54]. E-gasoline, e-diesel, and e-jet fuel can be produced from e-Fischer-Tropsch synthesis (e-FT), implying that Fischer-Tropsch (FT) synthesis uses green electricity to convert syngas and CO_2 to liquid fuels. Though e-fuels appear to be a promising solution for the future of green mobility, they still face several challenges, such as high production costs, energy conversion efficiency and loss, and significant infrastructure development fuel [55].

Renewable natural gas (RNG) or biomethane is the biogas produced from organic waste's anaerobic digestion or thermochemical processes followed by purification. Therefore, unlike biogas containing methane, carbon dioxide, and other small amounts of gases, RNG is a nearly pure form of methane, generated either by upgrading biogas or by gasifying solid biomass and then methanating it. The resulting RNG has a methane content of at least

90%. So, RNG can be used as a direct replacement for natural gas in heating, electricity generation, and transportation, reducing methane emissions from waste. The concerns of RNG development include production costs, feedstock, upgrading technology, environmental impact, and efficiency [56,57].

4. Perspectives and Challenges in Green Energy and Fuel Research

4.1. Perspectives

Green energy and fuel research encompasses various perspectives, focusing on developing sustainable and renewable energy sources to replace fossil fuels. Key areas of research and perspectives aim to address global energy needs while reducing environmental impacts and improving energy security. Some perspectives are described as follows.

(1) Advanced biofuels: Research in this area focuses on developing biofuels from renewable biological sources such as third-generation feedstocks (i.e., macroalgae and microalgae). These biofuels offer a sustainable alternative to conventional fossil fuels, with ongoing studies addressing these technologies' challenges and future potential [58]. Developing advanced biofuel combining waste valorization, biorefinery, and circular bioeconomy is promising [12].

(2) Market and economic perspectives**:** To fulfill the transition to a sustainable society, it is necessary to analyze the market dynamics and economic viability of green energy technologies, exploring multiple perspectives to understand the business case for renewable energy investments [59].

(3) Emerging materials in energy applications: Integrating nanomaterials, such as graphene, into energy technologies is a rapidly advancing field. These materials can enhance the efficiency and performance of solar cells, fuel cells, and batteries [60]. Perovskites are another emerging material with a specific structure that has received a great deal of attention recently. Perovskites can be used in solar cells, batteries, supercapacitors, thermoelectric materials, energy storage, photocatalysis, lighting emitting diodes (LEDs), solid oxide fuel cells (SOFCs), hydrogen evolution reaction, and oxygen evolution reaction [61,62].

(4) Renewable energy integration: It involves adopting and optimizing renewable energy resources, such as solar, wind, hydrogen, geothermal, etc, to create sustainable energy systems [63].

(5) Artificial intelligence (AI) applications: AI is playing a pivotal role in green energy and fuel research, significantly enhancing the development and utilization of renewable energy sources. Through data analysis, evolutionary computation, machine learning, and optimization algorithms, AI technologies can effectively improve the efficiency of green energy and fuel forecasting and management [64,65].

4.2. Challenges

Green energy and fuel research faces several significant challenges. These challenges range from technical and economic issues to policy and social acceptance hurdles. They are described below.

(1) Technical challenges: One of the primary technical challenges is improving the efficiency and performance of renewable energy technologies. For instance, solar panels and wind turbines need advancements in material science to enhance energy conversion efficiency. Storing energy efficiently remains a significant hurdle. Technologies like batteries and supercapacitors need further development to provide reliable storage solutions that balance the intermittent nature of renewable energy sources [66].

(2) Economic challenges: The initial investment for renewable energy infrastructure is often high. While the long-term benefits and operational costs might be lower, the upfront costs can be prohibitive for widespread adoption [66]. Meanwhile, renewable energy markets are influenced by various factors, including subsidies for fossil fuels, market demand, and the economic viability of renewable energy projects [59].

(3) Social and acceptance challenges: Public acceptance is crucial for successful renewable energy projects. Community opposition to renewable energy installations like wind farms or solar parks can delay or even halt projects. Increasing public awareness and understanding of the benefits and necessity of renewable energy is essential for gaining broader acceptance [67].

(4) Environmental and resource challenges: While renewable energy is generally environmentally friendly, the production and disposal of renewable energy technologies can have environmental impacts that need to be managed [68]. Meanwhile, the availability of resources needed for renewable energy technologies, such as rare earth elements for batteries and solar panels, can pose significant challenges [69].

5. Conclusions

The transition to green energy and sustainable fuel sources is essential to mitigate the adverse environmental impacts caused by the reliance on fossil fuels. This research has highlighted the significant strides made in various green energy sectors and outlines the challenges that must be addressed to advance these technologies further. Considerable advancements have been made in solar, wind, bioenergy, hydropower, marine, and geothermal technologies. Each of these sectors offers promising avenues for sustainable energy generation with varying degrees of maturity and commercial readiness. Solar and wind energies have substantially increased capacity and efficiency improvements, while marine and geothermal energy still require extensive research and development to become commercially viable. The development of biofuels, hydrogen, ammonia, and synthetic fuels represents a crucial component of the green energy landscape. Biofuels from lignocellulosic and algal biomass, hydrogen production through electrolysis using renewable energy, and the synthesis of fuels from carbon capture and renewable electricity are highlighted as key focus areas. Each fuel type presents unique advantages, such as carbon neutrality and potential integration into existing infrastructure. Improving the efficiency and performance of renewable energy technologies, along with addressing energy storage issues, are identified as primary technical challenges. Economically, the high initial investment costs and market dynamics, including subsidies for fossil fuels, pose significant barriers to widespread adoption. Effective regulatory frameworks and supportive policies are critical for advancing green energy technologies. In addition, public acceptance and awareness are essential to overcoming resistance and ensuring the successful implementation of renewable energy projects. While renewable energy technologies generally have lower environmental impacts, producing and disposing of these technologies can still pose environmental and ecological challenges. The availability of critical resources, such as rare earth elements, is also a concern that needs to be addressed. The transition to green energy and sustainable fuels is a multifaceted endeavor that requires continued innovation, supportive policies, and public engagement. In summary, research with a collaborative approach to overcoming the existing challenges and realizing the full potential of renewable energy technologies for a sustainable future still needs much effort.

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References

1. Paraschiv, S.; Paraschiv, L.S. Trends of carbon dioxide (CO_2) emissions from fossil fuels combustion (coal, gas and oil) in the EU member states from 1960 to 2018. *Energy Rep.* **2020**, *6*, 237–242.
2. Iida, Y.; Takatani, Y.; Kojima, A.; et al. Global trends of ocean CO_2 sink and ocean acidification: An observation-based reconstruction of surface ocean inorganic carbon variables. *J. Oceanogr.* **2021**, *77*, 323–358.
3. Van Soest, H.L.; den Elzen, M.G.; van Vuuren, D.P. Net-zero emission targets for major emitting countries consistent with the Paris Agreement. *Nat. Commun.* **2021**, *12*, 2140.
4. Pourasl, H.H.; Barenji, R.V.; Khojastehnezhad, V.M. Solar energy status in the world: A comprehensive review. *Energy Rep.* **2023**, *10*, 3474–3493.
5. Dada, M.; Popoola, P. Recent advances in solar photovoltaic materials and systems for energy storage applications: A review. *Beni-Suef Univ. J. Basic Appl. Sci.* **2023**, *12*, 66.
6. Fernández-González, D. A state-of-the-art review on materials production and processing using solar energy. *Miner. Process. Extr. Metall. Rev.* **2023**, 1–43.
7. Zhang, Z.; Liu, X.; Zhao, D.; et al. Overview of the development and application of wind energy in New Zealand. *Energy Built Environ.* **2023**, *4*, 725–742.
8. Jung, C.; Schindler, D. Efficiency and effectiveness of global onshore wind energy utilization. *Energy Convers. Manag.* **2023**, *280*, 116788.
9. Hand, B.; Kelly, G.; Cashman, A. Aerodynamic design and performance parameters of a lift-type vertical axis wind turbine: A comprehensive review. *Renew. Sustain. Energy Rev.* **2021**, *139*, 110699.

10. Azlan, F.; Kurnia, J.; Tan, B.; et al. Review on optimisation methods of wind farm array under three classical wind condition problems. *Renew. Sustain. Energy Rev.* **2021**, *135*, 110047.
11. Chen, W.-H.; Lin, B.-J.; Lin, Y.-Y.; et al. Progress in biomass torrefaction: Principles, applications and challenges. *Prog. Energy Combust. Sci.* **2021**, *82*, 100887. https://doi.org/10.1016/j.pecs.2020.100887.
12. Ubando, A.T.; Felix, C.B.; Chen, W.-H. Biorefineries in circular bioeconomy: A comprehensive review. *Bioresour. Technol.* **2020**, *299*, 122585.
13. Saravanakumar, A.; Vijayakumar, P.; Hoang, A.T.; et al. Thermochemical conversion of large-size woody biomass for carbon neutrality: Principles, applications, and issues. *Bioresour. Technol.* **2023**, *370*, 128562.
14. Shaktawat, A.; Vadhera, S. Risk management of hydropower projects for sustainable development: A review. *Environ. Dev. Sustain.* **2021**, *23*, 45–76.
15. Wasti, A.; Ray, P.; Wi, S.; et al. Climate change and the hydropower sector: A global review. *Wiley Interdiscip. Rev. Clim. Chang.* **2022**, *13*, e757.
16. Kumar, K.; Saini, R. A review on operation and maintenance of hydropower plants. *Sustain. Energy Technol. Assess.* **2022**, *49*, 101704.
17. Elbatran, A.; Yaakob, O.; Ahmed, Y.M.; et al. Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review. *Renew. Sustain. Energy Rev.* **2015**, *43*, 40–50.
18. Taveira-Pinto, F.; Rosa-Santos, P.; Fazeres-Ferradosa, T. Marine renewable energy. *Renew. Energy* **2020**, *150*, 1160–1164.
19. Bhuiyan, M.A.; Hu, P.; Khare, V.; et al. Economic feasibility of marine renewable energy. *Front. Mar. Sci.* **2022**, *9*, 988513.
20. Garcia-Teruel, A.; Forehand, D. A review of geometry optimisation of wave energy converters. *Renew. Sustain. Energy Rev.* **2021**, *139*, 110593.
21. Walker, S.; Thies, P. A review of component and system reliability in tidal turbine deployments. *Renew. Sustain. Energy Rev.* **2021**, *151*, 111495.
22. Qu, F.; Li, W.; Dong, W.; et al. Durability deterioration of concrete under marine environment from material to structure: A critical review. *J. Build. Eng.* **2021**, *35*, 102074.
23. Lund, J.W.; Toth, A.N. Direct utilization of geothermal energy 2020 worldwide review. *Geothermics* **2021**, *90*, 101915.
24. Hackstein, F.V.; Madlener, R. Sustainable operation of geothermal power plants: Why economics matters. *Geotherm. Energy* **2021**, *9*, 10.
25. Farzanehkhameneh, P.; Soltani, M.; Kashkooli, F.M.; et al. Optimization and energy-economic assessment of a geothermal heat pump system. *Renew. Sustain. Energy Rev.* **2020**, *133*, 110282.
26. Soltani, M.; Kashkooli, F.M.; Souri, M.; et al. Environmental, economic, and social impacts of geothermal energy systems. *Renew. Sustain. Energy Rev.* **2021**, *140*, 110750.
27. Chen, W.-H.; Lin, B.-J.; Huang, M.-Y.; et al. Thermochemical conversion of microalgal biomass into biofuels: A review. *Bioresour. Technol.* **2015**, *184*, 314–327. https://doi.org/10.1016/j.biortech.2014.11.050.
28. Chen, W.-H.; Ho, K.-Y.; Aniza, R.; et al. A review of noncatalytic and catalytic pyrolysis and co-pyrolysis products from lignocellulosic and algal biomass using Py-GC/MS. *J. Ind. Eng. Chem.* **2024**, *134*, 51–64.
29. Sarker, T.R.; Nanda, S.; Meda, V.; et al. Densification of waste biomass for manufacturing solid biofuel pellets: A review. *Environ. Chem. Lett.* **2023**, *21*, 231–264.
30. Chen, W.-H.; Peng, J.; Bi, X.T. A state-of-the-art review of biomass torrefaction, densification and applications. *Renew. Sustain. Energy Rev.* **2015**, *44*, 847–866. https://doi.org/10.1016/j.rser.2014.12.039.
31. Li, Y.; Gupta, R.; Zhang, Q.; et al. Review of biochar production via crop residue pyrolysis: Development and perspectives. *Bioresour. Technol.* **2023**, *369*, 128423.
32. Chen, W.-H.; Hoang, A.T.; Nižetić, S.; et al. Biomass-derived biochar: From production to application in removing heavy metal-contaminated water. *Process Saf. Environ. Prot.* **2022**, *160*, 704–733.
33. Mohiddin, M.N.B.; Tan, Y.H.; Seow, Y.X.; et al. Evaluation on feedstock, technologies, catalyst and reactor for

sustainable biodiesel production: A review. *J. Ind. Eng. Chem.* **2021**, *98*, 60–81.
34. Hazrat, M.; Rasul, M.; Khan, M.; et al. Techniques to improve the stability of biodiesel: A review. *Environ. Chem. Lett.* **2021**, *19*, 2209–2236.
35. Ocreto, J.B.; Chen, W.-H.; Ubando, A.T.; et al. A critical review on second-and third-generation bioethanol production using microwaved-assisted heating (MAH) pretreatment. *Renew. Sustain. Energy Rev.* **2021**, *152*, 111679.
36. Zhang, M.; Hu, Y.; Wang, H.; et al. A review of bio-oil upgrading by catalytic hydrotreatment: Advances, challenges, and prospects. *Mol. Catal.* **2021**, *504*, 111438.
37. Ndaba, B.; Chiyanzu, I.; Marx, S. n-Butanol derived from biochemical and chemical routes: A review. *Biotechnol. Rep.* **2015**, *8*, 1–9.
38. Huang, M.-H.; Lee, H.-M.; Liang, K.-C.; et al. An experimental study on single-step dimethyl ether (DME) synthesis from hydrogen and carbon monoxide under various catalysts. *Int. J. Hydrog. Energy* **2015**, *40*, 13583–13593.
39. Galadima, A.; Muraza, O. From synthesis gas production to methanol synthesis and potential upgrade to gasoline range hydrocarbons: A review. *J. Nat. Gas Sci. Eng.* **2015**, *25*, 303–316.
40. Djimtoingar, S.S.; Derkyi, N.S.A.; Kuranchie, F.A.; et al. A review of response surface methodology for biogas process optimization. *Cogent Eng.* **2022**, *9*, 2115283.
41. Mulu, E.; M'Arimi, M.M.; Ramkat, R.C. A review of recent developments in application of low cost natural materials in purification and upgrade of biogas. *Renew. Sustain. Energy Rev.* **2021**, *145*, 111081.
42. Xu, X.; Zhou, Q.; Yu, D. The future of hydrogen energy: Bio-hydrogen production technology. *Int. J. Hydrog. Energy* **2022**, *47*, 33677–33698.
43. Akhlaghi, N.; Najafpour-Darzi, G. A comprehensive review on biological hydrogen production. *Int. J. Hydrog. Energy* **2020**, *45*, 22492–22512.
44. Yahaya, E.; Lim, S.W.; Yeo, W.S.; et al. A review on process modeling and design of biohydrogen. *Int. J. Hydrog. Energy* **2022**, *47*, 30404–30427.
45. Nnabuife, S.G.; Oko, E.; Kuang, B.; et al. The prospects of hydrogen in achieving net zero emissions by 2050: A critical review. *Sustain. Chem. Clim. Action* **2023**, *2*, 100024.
46. Shirizadeh, B.; Quirion, P. Long-term optimization of the hydrogen-electricity nexus in France: Green, blue, or pink hydrogen? *Energy Policy* **2023**, *181*, 113702.
47. Teso, A.; Cloete, S.; del Pozo, C.A.; et al. Integration assessment of turquoise hydrogen in the European energy sector. *Energy Convers. Manag.* **2024**, *307*, 118334.
48. Hand, E. *Hidden Hydrogen*; Science: New York, NY, USA, 2023; Volume 379, pp. 630–636.
49. Man, J.; Ma, T.; Yu, Y.; et al. Levelized costs and potential production of green hydrogen with wind and solar power in different provinces of mainland China. *J. Renew. Sustain. Energy* **2024**, *16*, 025902.
50. Qureshi, F.; Yusuf, M.; Khan, M.A.; et al. A State-of-The-Art Review on the Latest trends in Hydrogen production, storage, and transportation techniques. *Fuel* **2023**, *340*, 127574.
51. El-Shafie, M.; Kambara, S. Recent advances in ammonia synthesis technologies: Toward future zero carbon emissions. *Int. J. Hydrog. Energy* **2023**, *48*, 11237–11273.
52. Olabi, A.; Abdelkareem, M.A.; Al-Murisi, M.; et al. Recent progress in Green Ammonia: Production, applications, assessment; barriers, and its role in achieving the sustainable development goals. *Energy Convers. Manag.* **2023**, *277*, 116594.
53. Kang, L.; Pan, W.; Zhang, J.; et al. A review on ammonia blends combustion for industrial applications. *Fuel* **2023**, *332*, 126150.
54. Nemmour, A.; Inayat, A.; Janajreh, I.; et al. Green hydrogen-based E-fuels (E-methane, E-methanol, E-ammonia) to support clean energy transition: A literature review. *Int. J. Hydrog. Energy* **2023**, *48*, 29011–29033.
55. Shi, K.; Guan, B.; Zhuang, Z.; et al. Perspectives and Outlook of E-fuels: Production, Cost Effectiveness, and Applications. *Energy Fuels* **2024**, *38*, 7665–7692.

56. Du, G.; Shami, H.O.; Mostafa, L.; et al. Life cycle cost and life cycle environmental analysis of the different waste-to-renewable natural gas pathways: An effort to identify an optimal pathway under different Multi-criteria decision-based scenarios. *Process Saf. Environ. Prot.* **2024**, *183*, 1082–1101.
57. Hoffman, A.; Kurumbail, U.; Rhodes, N.; et al. Renewable natural gas: A case study of Minnesota. *Biomass Bioenergy* **2024**, *183*, 107163.
58. Mathushika, J.; Gomes, C. Development of microalgae-based biofuels as a viable green energy source: Challenges and future perspectives. *Biointerface Res. Appl. Chem.* **2022**, *12*, 3849–3882.
59. Qadir, S.A.; Al-Motairi, H.; Tahir, F.; et al. Incentives and strategies for financing the renewable energy transition: A review. *Energy Rep.* **2021**, *7*, 3590–3606.
60. Salahdin, O.D.; Sayadi, H.; Solanki, R.; et al. Graphene and carbon structures and nanomaterials for energy storage. *Appl. Phys. A: Mater. Sci. Process.* **2022**, *128*, 703.
61. Monama, G.R.; Ramohlola, K.E.; Iwuoha, E.I.; et al. Progress on perovskite materials for energy application. *Results Chem.* **2022**, *4*, 100321.
62. Fakharuddin, A.; Gangishetty, M.K.; Abdi-Jalebi, M.; et al. Perovskite light-emitting diodes. *Nat. Electron.* **2022**, *5*, 203–216.
63. Alzahrani, A.; Ramu, S.K.; Devarajan, G.; et al. review on hydrogen-based hybrid microgrid system: Topologies for hydrogen energy storage, integration, and energy management with solar and wind energy. *Energies* **2022**, *15*, 7979.
64. Chen, W.-H.; Eng, C.F.; Lin, Y.-Y.; et al. Two-step thermodegradation kinetics of cellulose, hemicelluloses, and lignin under isothermal torrefaction analyzed by particle swarm optimization. *Energy Convers. Manag.* **2021**, *238*, 114116.
65. Chen, W.-H.; Lu, C.-Y.; Chou, W.-S.; et al. Design and optimization of a crossflow tube reactor system for hydrogen production by combining ethanol steam reforming and water gas shift reaction. *Fuel* **2023**, *334*, 126628.
66. Elavarasan, R.M.; Shafiullah, G.; Padmanaban, S.; et al. A comprehensive review on renewable energy development, challenges, and policies of leading Indian states with an international perspective. *IEEE Access* **2020**, *8*, 74432–74457.
67. Gareiou, Z.; Drimili, E.; Zervas, E. Public acceptance of renewable energy sources. In *Low Carbon Energy Technologies in Sustainable Energy Systems*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 309–327.
68. Sharma, H.B.; Vanapalli, K.R.; Barnwal, V.K.; et al. Evaluation of heavy metal leaching under simulated disposal conditions and formulation of strategies for handling solar panel waste. *Sci. Total Environ.* **2021**, *780*, 146645.
69. Jyothi, R.K.; Thenepalli, T.; Ahn, J.W.; et al. Review of rare earth elements recovery from secondary resources for clean energy technologies: Grand opportunities to create wealth from waste. *J. Clean. Prod.* **2020**, *267*, 122048.