



Original Article

Chemistry of Renewable Fuels

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Manuscript ID:
IBMIIRJ -2025-021208

Submitted: 05 Nov. 2025

Revised: 10 Nov. 2025

Accepted: 06 Dec. 2025

Published: 31 Dec. 2025

ISSN: 3065-7857

Volume-2

Issue-12

Pp. 33-36

December 2025

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Quick Response Code:



Web: <https://ibrj.us>



DOI: [10.5281/zenodo.18357806](https://doi.org/10.5281/zenodo.18357806)

DOI Link:

<https://doi.org/10.5281/zenodo.18357806>



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Abstract

Chemistry plays a central role in the development and advancement of renewable fuels and sustainable energy technologies. As the global demand for clean and low-carbon energy increases, chemical innovations are driving progress in solar energy conversion, green hydrogen production, biofuel generation, fuel cell technology, and carbon capture systems. This paper highlights key chemical contributions to renewable energy, focusing on perovskite solar cells, electrochemical water splitting for green hydrogen, algae-based biofuels, advanced catalysts for fuel cells, and electro-catalysis for carbon dioxide utilization. Recent advancements in materials chemistry, nanotechnology, and catalysis have significantly improved energy efficiency, cost-effectiveness, and environmental sustainability. The paper also discusses practical applications of these technologies across residential, industrial, transportation, agricultural, and energy storage sectors, including solar photovoltaics, lithium-ion batteries, wind energy, and geothermal systems. By integrating chemical science with renewable energy engineering, these innovations offer promising pathways toward reducing greenhouse gas emissions and achieving a resilient, sustainable energy future.

Keywords: Perovskite Solar Cells, Green Hydrogen Production, Biofuels from Algae, Advanced Catalysts for Fuel Cells, Electro-catalysis for Carbon Capture.

Introduction

Chemistry is behind many important changes in renewable energy. It helps create new ideas in areas like solar power, storing energy, and making fuels that do not produce carbon emissions. As we move towards cleaner energy to fight climate change and reduce our use of fossil fuels, chemical science gives us important tools to build more efficient systems for clean energy. This section looks at some of the key chemical advances and how they are making a difference in the renewable energy field.

Innovations: Chemical innovations are setting the stage for future sustainable energy technologies. Some of the most important ones include

1. Perovskite Solar Cells

Perovskite-based solar cells are a big step forward in making solar power more effective. These materials are better at turning sunlight into electricity than traditional silicon-based solar cells and can be made at a lower cost. Plus, they can be used in different ways, like making lightweight or even clear solar panels. When perovskite is combined with silicon, it makes a tandem solar cell that can capture more sunlight and convert it into electricity than either material alone. This is because two layers of materials are stacked together. Perovskite solar cells have improved a lot in recent years. Their efficiency has gone up from about 3% in 2009 to over 26% today, especially for small devices. Perovskite-silicon tandem cells have even reached an efficiency of nearly 34.85%.

2. Green Hydrogen Production

Chemistry is key to creating efficient catalysts for making green hydrogen through water electrolysis. This uses renewable electricity, like from solar or wind, to split water into hydrogen and oxygen. This produces hydrogen that does not create any emissions, making it a clean fuel for energy storage, transportation, and industry. Green hydrogen is made by using electricity from renewable sources to break down water molecules. This process produces hydrogen and oxygen, and it is carbon-neutral because it doesn't use fossil fuels and produces no greenhouse gases.

The electrolysis process works by using direct current to separate the water into its parts, with hydrogen collecting at the negative electrode and oxygen at the positive one.

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How to cite this article:

Jadhav, V. V. (2025). Chemistry of Renewable Fuels. *InSight Bulletin: A Multidisciplinary Interlink International Research Journal*, 2(12), 33–36. <https://doi.org/10.5281/zenodo.18357806>

Green hydrogen can help replace fossil fuels in industries that are hard to change to cleaner options, like fertilizer production, oil refining, and steelmaking. It can also be used for long-distance transportation.

3. **Biofuels from Algae**

Algae are excellent for producing biofuels because they have high oil content and can grow very fast. They do not need agricultural land, which is a big plus. Algae biofuels are renewable and can be used as biodiesel or bioethanol. The process starts with growing algae, harvesting it, extracting the oils, and then turning those oils into fuels. Even though algae biofuels have a lot of potential, challenges like cost and efficiency are still holding them back from being widely used. One advantage is that they produce fewer greenhouse gases. New chemical processes, like hydrothermal liquefaction, are helping to make algae biofuels easier and cheaper to produce. Advanced Catalysts for Fuel Cells Fuel cells generate electricity by using hydrogen and oxygen. New platinum-free catalysts are helping to make fuel cells cheaper and more efficient.

4. **Advanced Catalysts for Fuel Cells**

These advanced catalysts use Nano-materials and new structures to improve performance, often using less platinum and more durable alternatives. Innovations include using platinum-nickel alloys and carbon-based materials like graphene and nanotubes. These materials have better surface area, stability, and can replace expensive precious metals. These improvements are bringing fuel cells closer to being used in everyday applications, like powering electric vehicles and providing backup power for renewable energy systems.

5. **Electro-catalysis for Carbon Capture**

Electro-catalysis is being explored as a new way to capture and use carbon dioxide. Innovative catalysts can help turn captured CO₂ into useful products, like chemicals or fuels, which can help reduce greenhouse gas emissions and support a circular carbon economy. This can help with climate change and also create new energy sources. CO₂ is usually captured from places like industrial flue gas or the atmosphere using solutions like amines or potassium-based compounds. The captured CO₂ is then reduced at the cathode, a process that uses electricity, ideally from renewable sources. Depending on the catalyst and conditions, CO₂ can be turned into various products, such as carbon monoxide, formic acid, methane, ethylene, and ethanol. At the same time, an oxidation reaction, like the oxygen evolution reaction, happens at the anode to complete the process.

Applications:

Some of the important applications include the following.

Solar Energy and Photovoltaic Cells

Residential and commercial

- **On-grid and off-grid power:** PV systems can be connected to the power grid to lower electricity costs and even allow surplus energy to be sold back. They can also be used in off-grid setups to provide independent power. These systems can directly power homes, businesses, and factories. Solar panels on rooftops in housing societies can power common areas, reducing costs for all residents. They are especially useful in remote areas without grid access or for that seeking total energy independence.
- **Public and Community Infrastructure:** Solar-powered streetlights and traffic signals help save electricity and power signage. Government buildings, schools, and hospitals are installing solar panels on rooftops to cut energy costs and ensure a reliable power supply, which is important during emergencies.
- **Community Solar Projects:** These projects let many homes and businesses share the benefits of a single solar setup located away from their homes. This helps people who can't install solar panels on their own property, like renters, to use solar energy. You can find out about local programs by checking with the US Department of Energy or contacting your local utility company.
- **Transportation and Portable Power:** Solar panels can also be used to provide extra power for cars and boats. For example, solar sunroofs can power onboard devices or slowly charge batteries. Solar power is being used more in public transport, such as solar powered buses and trains. Lightweight solar panels can even be used on airplane wings for high-altitude flights. Thin-film solar panels are portable and durable, making them good for charging devices in the field.
- **Agriculture and Remote Areas:** In farming, solar pumps are used to help with irrigation by moving water. Solar panels also power remote equipment like navigation systems, telecommunication stations, and monitoring systems. In places without access to clean water, solar can help purify water through desalination systems or solar stills, which create fresh water.
- **Space and Specialized Applications:** Solar power is important in space, like for satellites, the International Space Station, and rovers on the Moon and Mars. Researchers are also working on new uses, like using solar panels to receive signals for Li-Fi, a wireless communication system that could bring internet access to remote areas.
- **Energy Storage System:** An energy storage system saves energy from different sources so it can be used later. It helps balance the way electricity is supplied and used. These systems can store energy in different forms, such as electricity (like in batteries), heat, motion (like in pumped water systems), and chemicals. This stored energy can be released when needed to help the power grid work.

- better and support the use of renewable energy.
- **Lithium-Ion Batteries:** These batteries have improved in design, making them more efficient and longer-lasting.
- They are used in electric vehicles and for storing energy on a bigger scale. The chemical parts of these batteries, like
- the electrolytes and materials used in the positive electrode, help them work better.

Solid-state batteries, which replace liquid electrolytes with solid materials,

could offer even more storage and safer use in electric vehicles. Lithium-ion batteries have higher energy density than other types, like lead-acid batteries, and can produce around 3.6 volts, which is more than most other batteries. They are low-maintenance and don't need regular charging to last longer. They don't have a 'memory effect', which can reduce a battery's capacity if it's not fully charged and discharged regularly. They also don't contain harmful materials like lead or cadmium. These batteries are especially useful in electric vehicles and for flying electric planes.

Biofuels and Biomass

Conversion: Ethanol and biodiesel are made through processes like fermentation and transesterification, which help improve the production of fuel from plants and waste materials.

These fuels can be used in both transportation and power generation.

Types of Biofuels:

- First-generation biofuels are made from food crops like corn or sugarcane, but they may affect food supplies and
- are less sustainable.
- Second-generation biofuels- come from non-food waste, like agricultural leftovers or trash from cities.
- Third-generation biofuels are made from algae, which is a more sustainable source of fuel.

Wind Energy:

Wind energy uses wind turbines to turn the wind's movement into electricity. When the wind blows, it turns the turbine blades, which spin a generator to produce power.

This is a clean and renewable way to generate electricity that helps reduce our reliance on fossil fuels. It can be produced in onshore and offshore wind farms.

How It Works:

- **Kinetic Energy to Mechanical Energy:** Wind flows over turbine blades, creating lift that makes them spin.
- This changes the wind's energy into mechanical energy.
- **Mechanical Energy to Electrical Energy:** The spinning blades turn a shaft that spins a generator, which produces electricity.

Benefits

- **Renewable and Clean:** Wind is an endless resource,
- and producing electricity this way doesn't create air or water pollution or require water for cooling, unlike traditional power plants.
- **Cost-Effective:** On a large scale, wind energy is one of the cheapest ways to get electricity, and as technology improves, the cost continues to drop.
- **Low Carbon Footprint:** Using wind energy instead of fossil fuels helps reduce carbon dioxide
- and other harmful gas emissions.
- **Community Benefits:** Wind projects can provide local tax payments and land lease money, which helps communities.

Geothermal Energy:

Geothermal energy is the heat from inside the Earth, generated by the core and radioactive decay.

This heat is a renewable and clean source that can

be used to heat buildings or generate electricity by tapping into underground reservoirs of hot water or steam.

How It Works:

- **Source of Heat:** The Earth's core is very hot, from the heat left over from when
- the planet formed and ongoing radioactive decay.
- **Heat Transfer:** This heat travels outward, warming rocks and water underground.
- **Geothermal Reservoirs:** This process creates pools of hot water and steam beneath the surface.
- In some places, this can form hot springs or geysers.
- **Extraction:** Geothermal power plants can drill wells to bring steam and hot water to the surface

Applications:

- **Electricity Generation:** The steam from the wells can spin turbines to make electricity.
- **Direct Use Heating:** Hot water can be used directly for heating homes, cooking, and bathing.
- **Cooling:** Some systems can also be used for cooling buildings.

Advantages:

- Renewable: Geothermal energy is a continuous and sustainable source because the Earth's heat is always being produced.
- Low Emissions: It's a clean energy source with very little greenhouse gas emissions compared to burning fossil fuels.
- Small footprint: Geothermal plants have a smaller physical footprint compared to other power plants.

Conclusion

Chemistry is a propeller that has pushed innovations in renewable energy technologies. From improvements in efficiency for solar cells, with better batteries, to sustainable biofuel development, up to optimized designs for wind turbines, chemistry has been quite ubiquitous and priceless. The removal of barriers to renewable energy adoption would have to persist in relying on the sciences in chemistry as a requirement for the pursuit of a cleaner energy future to become more sustainable and resilient in the energy landscape of the future.

Acknowledgment

I would like to express my sincere gratitude to the Department of Science and Humanities, K.B.P. Polytechnic, Satara, for providing the necessary facilities and academic environment to carry out this work. I am thankful to my teachers and mentors for their valuable guidance, encouragement, and constructive suggestions throughout the preparation of this paper. I also extend my appreciation to my classmates and friends for their support and discussions, which contributed to the successful completion of this work. Finally, I am grateful to my family for their constant motivation and support.

Financial support and sponsorship

Nil.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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