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Role of chemistry in new energy technologies and fossil fuel reduction

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Abstract
This report analyses how chemical science underpins renewable energy technologies and strategies to reduce fossil-fuel dependence. It reviews the chemical principles, key materials and catalysts used in solar photovoltaics (including silicon, thin-film, perovskite and dye-sensitised cells), wind turbines (composites, corrosion-resistant alloys, lubricants), hydropower (turbine steels, coatings, hydroelectric storage) and alternative fuels (biofuels, green fuels, hydrogen). Electric-vehicle (EV) battery chemistry and recycling are also examined, including advances in electrolytes and solid-state systems.

Keywords: Renewable energy, green fuel, fossil fuel and electric vehicle.

Introduction

Current Energy Context

Fossil fuels remain the bedrock of global energy, supplying about 75%-80% of total primary energy. Oil and gas usage continues to grow in transport and industry, while global coal usage sees uneven regional trajectories. Fossil fuels still dominate global energy Chemistry is central to decarbonising energy: novel materials and reactions enable efficient renewable conversion and storage. Recent crises and climate targets underscore the urgency of replacing hydrocarbons. This demands rapid scaling of improved solar, wind, hydro and fuel technologies, guided by techno-economic analysis and supportive policy. [1-2]

Solar Energy Technologies

Solar power relies on semiconductor and molecular chemistry. Crystalline silicon (Si) photovoltaics (PVs) exploit p–n junctions in doped Si (bandgap 1.1 eV) to convert sunlight to electricity. Since the first practical Si cell (6% efficiency) in 1954, mono- and polycrystalline Si modules have reached ~20–26% efficiency. Advanced coatings (SiO_2 passivation, anti-reflective layers) and metallisation ensure efficient charge collection. Thin-film PVs (CdTe, CIGS) use complex chalcogenide alloys; their chemistry reduces material cost but raises toxicity and material-scarcity issues. Perovskite solar cells (PSCs) exemplify cutting-edge chemical innovation: hybrid organic–inorganic lead halide perovskites (ABX_3 structure) have soared from ~4% efficiency (2009) to over 25% [3]. Their chemistry yields strong sunlight absorption and tuneable bandgaps, enabling low-cost solution processing. However, PSCs face stability challenges (moisture/heat degrade the crystal) and toxicity concerns (lead content). Dye-sensitised solar cells (DSSCs), another third-generation PV, use organic or Ru-based dyes on mesoporous oxides (e.g. TiO_2) with a redox electrolyte. DSSCs remain lower-efficiency (~10–12%) but may offer low-cost, stable generation in niche applications [4].

Wind Energy

Wind turbines convert kinetic to electrical energy. Chemical/materials science ensures structural integrity and longevity. Turbine blades use glass- or carbon-fibre–epoxy composites; these high-strength polymers are engineered for fatigue resistance. Turbine towers and frames are usually steel; offshore machines face aggressive marine corrosion. Thus, corrosion-resistant alloys and coatings are critical: sacrificial zinc/aluminium-rich paints and cathodic-protection systems guard offshore steel against saltwater. For example, EN10025 S355 structural steel is common, but must be coated or galvanised for decades of operation [2]. Lubrication chemistry is another key: gearboxes and bearings rely on advanced greases and oil additives. Failures are dominated by bearing wear, and "the vast majority of wind turbine failures are due to bearings… and those are caused by lubrication" [5]. Tribology research (anti-wear additives, nanolubricants) seeks to extend life and reduce maintenance. Wind power is now mature: global installed capacity exceeds 700 GW, with capacity factors ~30–45% onshore. Offshore wind is growing rapidly due to better winds and lower intermittency.

Hydropower and Water Storage

Beyond generation, water enables storage. Pumped-storage hydropower (PSH) is the world's largest battery: ~160–200 GW installed (≈90–94% of global grid storage). [6-7] Excess renewable power (solar/wind) pumps water uphill; it is released through turbines when needed. PSH round-trip efficiency is ~80%, and it provides long-duration bulk storage. In addition, electrochemical approaches like water electrolysis convert renewable electricity to hydrogen ("green H_2"). Green hydrogen production (splitting water with >50% efficiency) uses catalysts (Pt, Ni, Ir) in electrolyzers. The hydrogen can be stored or used as fuel, effectively storing intermittent energy. Electrolytic hydrogen balances the grid, stabilises supply and can decarbonise hard-to-electrify sectors [8].

Green Fuels and Biofuels

Green fuels use biological or renewable carbon resources. First-generation biofuels (e.g. corn ethanol, soybean biodiesel) rely on edible crops; to avoid food–fuel conflicts, second-generation routes use lignocellulosic waste (wood, straw), waste oils and fats, or dedicated non-food crops. Third-generation fuels use algae or even CO_2 recycling. Key chemical processes include:

- **Ethanol (bioethanol):** Fermentation of sugars ($C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$) by yeast or engineered microbes. Catalysis is biochemical (enzymes). Advanced routes ferment cellulosic sugars or syngas from gasification.

- **Biodiesel (FAME):** Transesterification of triglycerides (from vegetable oils or waste fats) with methanol, using base catalysts (KOH/NaOH) or acid catalysts. Produces fatty-acid methyl esters (biodiesel) + glycerol.

- **Renewable Diesel (HVO/HEFA):** Hydroprocessing (hydrotreatment) of fats/oils over NiMo/CoMo catalysts to remove oxygen (deoxygenation), yielding alkanes (drop-in diesel).

- **Biogas:** Anaerobic digestion of biomass produces CH_4 + CO_2, usable in place of natural gas.

- **Bio-jet/Synthetic fuels:** Fischer–Tropsch (FT) synthesis of syn-gas ($CO+H_2$) from biomass (with Fe/Co catalysts), then hydrocracking to jet fuel. Alcohol-to-jet (ATJ) converts ethanol to kerosene.

Feedstocks vary: sugarcane, corn, oil palm for 1st gen; agricultural residues, woody biomass, municipal waste for 2nd gen; microalgae for 3rd gen (high CO_2 uptake). Algae can sequester >200 t CO_2/ha-year (far exceeding terrestrial crops) and need minimal land or fertilizer [1].

Life-cycle analysis is crucial. When waste or sustainably grown biomass is used, biofuels can offer large GHG savings (~50–90% lower than fossil fuels). For example, biodiesel from used cooking oil can approach net-zero emissions [9].

Modern biofuel demand is growing: today's global transport biofuel share is ~ 4–5% and rising [10]. Brazil leads with sugarcane ethanol and high-blend mandates, reducing oil imports and CO_2. Europe and the US also mandate blending (e.g. EU RED III sets 29% transport renewables by 2030, with caps on food-crop fuels) [11]. Policy drivers (mandates, incentives) are critical, as advanced biofuels currently cost 2–3× fossil equivalents. Nevertheless, advanced pathways (cellulosic ethanol, bio-FT, pyrolysis oils) are scaling up in pilot projects. Catalysts (e.g. engineered enzymes, heterogeneous catalysts for upgrading pyrolysis oil) and biorefinery integration will reduce costs. A notable case: the Bayou Fuels project (US) plans biomass gasification + FT with CO_2 capture for negative emissions [10].

Electric Vehicles and Battery Chemistry

Electrification of transport hinges on battery chemistry. Modern EVs overwhelmingly use lithium-ion batteries (LIBs). The electrode materials and electrolytes are chemical workhorses: common cathodes include nickel–manganese–cobalt oxides (NMC), nickel–cobalt–aluminium (NCA) or lithium iron phosphate (LFP); anodes are usually graphite. Liquid electrolytes are carbonate solvents with $LiPF_6$ salt. Battery design balances energy density, cost and safety. For example, LFP cathodes sacrifice some energy density but eliminate costly cobalt and offer better thermal stability.

Solid-state batteries (SSBs) replace liquid electrolytes with solid ionic conductors (ceramic or polymer). This chemical innovation can dramatically improve energy density and safety [12].

Battery costs have fallen dramatically – from over $1,100/kWh (2010) to about $137/kWh in 2020 [13]. This decline makes EVs increasingly cost-competitive. In 2024 EVs comprised >20% of new car sales globally [14].

Policy and Market Drivers

Government policy is a major driver for renewable chemistry. Carbon pricing and emissions standards (e.g. EU's fit-for-55, UK Carbon Budgets) raise the cost of fossil fuels, making renewables more attractive. Fuel standards (renewable fuel mandates) directly create markets: for instance, Brazil's ethanol blend mandates and the EU's Renewable Energy Directive drive biofuel production. [10-11] Subsidies, tax incentives and auctions have lowered renewable investment costs. In the US, the Inflation Reduction Act (2022) offers tax credits for clean energy and EVs, further stimulating demand and R&D.

International agreements set targets (e.g. net-zero by 2050), compelling industries to innovate. The private sector is also influential: many companies commit to 100% renewable electricity or develop low-carbon products (steel, cement, chemicals). Meanwhile, energy security concerns (diversifying away from oil/gas imports) motivate national strategies. Overall, policy and markets are aligning to reward low-carbon chemical technologies: 60+ countries now have advanced biofuel policies, and emerging standards (e.g. green hydrogen certificates) aim to scale up nascent industries.

Integrated Solutions and Proposed Strategies

No single technology can solve the energy crisis. Integrated, cross-disciplinary solutions are needed. Key approaches include:

- **Sector coupling:** Using electricity to decarbonise heat, transport and industry (e.g. green H_2 as chemical feedstock or fuel). For example, electrolytic hydrogen pairs renewables with ammonia production for fertilizers.

- **Grid integration:** Chemical energy storage (batteries, hydrogen, redox flow batteries) balances variable wind/solar. Demand-response and smart grids further improve utilisation.

- **Circular economy:** Recycling of PV panels, wind blades (chemical recycling of composites), batteries and bio-refinery co-products reduces material demand and emissions. Design-for-recycling (e.g. easier cell disassembly) is advocated.

- **Negative emissions:** Biomass combined with carbon capture (BECCS) can produce energy or fuels with net CO_2 removal. Chemical sequestration (mineralisation) of CO_2 is also explored.

- **Efficiency gains:** High-efficiency solar cells, LED lighting, and hydrogen fuel cells (for long-haul trucks) multiply the impact of renewable energy. For example, fuel cells (electrochemical) achieve >60% efficiency at vehicle wheels, far above combustion.

Conclusions

Chemistry is at the core of the renewable energy transition. Advances in semiconductor materials, catalysts, electrolytes and functional coatings are unlocking high-efficiency, low-cost renewable technologies. These requires continued R&D (e.g. non-toxic, abundant materials), life-cycle thinking (recycling and minimal environmental impact) and systemic solutions (sector coupling, smart grids). Policy actions (subsidies, carbon pricing, standards) and market forces must align to accelerate deployment. By integrating chemical science with engineering and policy, we can build a resilient, low-carbon energy system that vastly reduces dependence on fossil fuels.

References

1. Muhammad Waseem *et al*. Recent advances in chemical, thermochemical, and biochemical processing of algae. Frontiers in Environmental Chemistry,2026:7. https://doi.org/10.3389/fenvc.2026.1703150
2. Berenika Syrek-Gerstenkorn, Shiladitya Paul. Metallic coatings in offshore wind sector a mini review. npj Materials Degradation,2024:8:86.
3. Abniel Machín, Francisco Márquez. Advancements in Photovoltaic Cell Materials: Silicon, Organic, and Perovskite Solar Cells. Materials,2024:17(5):1165. https://doi.org/10.3390/ma17051165
4. Sultana Rahman *et al*. Research on dye sensitized solar cells: recent advancement toward the various constituents of dye sensitized solar cells for efficiency enhancement and future prospects. Royal Society of Chemistry Advances,2023:13:19508-19529. https://doi.org/10.1039/D3RA00903C
5. Han Peng *et al*. Review of Tribological Failure Analysis and Lubrication Technology Research of Wind Power Bearings. Polymers,2022:14(15):3041. https://doi.org/10.3390/polym14153041
6. International Energy Agency. Energy storage – IEA. https://www.iea.org/energy-system/electricity/grid-scale-storage
7. International Hydropower Association. Pumped storage hydropower explained: how it works and why it matters. https://www.hydropower.org/factsheets/pumped-storage
8. Alessandro Franco, Caterina Giovannini. Recent and Future Advances in Water Electrolysis for Green Hydrogen Generation: Critical Analysis and Perspectives. Sustainability,2023:15(24):16917. https://doi.org/10.3390/su152416917
9. IEA Bioenergy. Comparison of Biofuel Life Cycle Analysis Tools, Phase 2, Part 1: FAME and HVO/HEFA, 2019, 1-192. https://www.ieabioenergy.com/wp-content/uploads/2019/07/Task-39-CTBE-biofuels-LCA-comparison-Final-Report-Phase-2-Part-1-February-11-2019.pdf
10. International Energy Agency. Biofuels - Energy System -IEA. https://www.iea.org/energy-system/low-emission-fuels/biofuels
11. International Energy Agency. Bioenergy - IEA. https://www.iea.org/energy-system/renewables/bioenergy
12. Abniel Machín *et al*. Environmental Aspects and Recycling of Solid-State Batteries: A Comprehensive Review. Batteries,2024:10(7):255. https://doi.org/10.3390/batteries10070255
13. BusinessGreen News. Historic milestone: Battery pack prices fall under critical $100/kWh mark for first time. https://www.businessgreen.com/news/4025116/historic-milestone-battery-pack-prices-fall-critical-usd100-kwh-mark
14. International Energy Agency. Trends in electric car markets – Global EV Outlook 2025 – Analysis. https://www.iea.org/reports/global-ev-outlook-2025/trends-in-electric-car-markets-2