

Overview of Renewable Energy

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Key concepts, technologies, benefits, challenges, and future outlook

1. What Is Renewable Energy?

Definition	Characteristics
Energy derived from natural processes that are replenished on a human timescale.	• Inexhaustible (sunlight, wind, water, biomass) • Low-carbon or carbon-neutral • Distributed generation possible • Often intermittent (except for some biomass and geothermal)

2. Main Renewable Energy Sources

Source	Primary Technology	Typical Applications	Global Share (2023)
Solar Photovoltaic (PV)	Solar panels (crystalline Si, thin-film)	Rooftop, utility-scale farms, off-grid	~30% of renewable electricity
Solar Thermal (CSP)	Mirrors, parabolic troughs, solar towers	Power-tower plants, industrial heat	<2%
Wind	Horizontal-axis turbines, offshore turbines	Utility-scale farms, community turbines	~35%
Hydropower	Dams, run-of-river, pumped storage	Base-load electricity, grid balancing	~16%
Biomass	Combustion, gasification, anaerobic digestion	Heat, electricity, bio-fuels	~5%
Geothermal	Dry steam, flash steam, binary cycle plants	Base-load electricity, district heating	~2%
Ocean (tidal, wave, OTEC)	Tidal barrages, submerged turbines, wave converters	Niche coastal projects	<1%

Overview of Renewable Energy

Numbers are approximate and vary by region.

3. How Renewable Energy Works – Core Principles

1. Energy Capture

- **Solar PV:** Photons excite electrons in semiconductor cells → DC electricity.
- **Wind:** Aerodynamic lift on blades → rotor → generator → AC electricity.
- **Hydro:** Water flow drives turbine → generator.

2. Conversion & Conditioning

- Inverters (PV) convert DC → AC.
- Gearboxes (wind) match turbine speed to generator speed.
- Power electronics control voltage/frequency for grid compatibility.

3. Integration

- **Grid-connected:** Synchronization with utility frequency, voltage regulation, fault ride-through.
- **Off-grid:** Battery storage, diesel backup, or microgrids.

4. Storage & Flexibility

- **Battery (Li-ion, flow, solid-state)** – short-term (seconds-hours).
 - **Pumped hydro, compressed air, thermal storage** – medium-to-long term.
 - **Hydrogen (electrolysis)** – long-term, sector coupling.
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4. Benefits of Renewable Energy

Category	Specific Advantages
Environmental	• Near-zero greenhouse gas emissions
	• Minimal air pollutants
	• Reduced water consumption (especially solar & wind)

Overview of Renewable Energy

Category	Specific Advantages
Economic	• Declining Levelized Cost of Energy (LCOE) – solar PV < \$0.04/kWh in many markets • Job creation in manufacturing, installation, O&M • Energy price stability (fuel-free)
Energy Security	• Diversifies supply, reduces dependence on imported fossil fuels • Enables local generation and resilience
Social	•