



Present Wave Power Situation in USA

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ABSTRACT

Wave power in the United States remains in the developmental and pilot stages, with no commercially operating wave energy projects as of now. However, significant progress has been made through research initiatives and pilot deployments along the east and west coasts, as well as in Hawaii. The theoretical wave energy potential off U.S. coasts is immense—estimated at 2.64 trillion kilowatt-hours annually, which could account for over 60% of the country's utility-scale electricity generation. Recent efforts include the deployment of submerged wave energy converters like CalWavex1™ off the coast of California, and proposed large-scale wave parks in Oregon. These projects aim to validate the reliability and scalability of wave energy technologies. Academic institutions and federal agencies, such as the U.S. Department of Energy, are actively supporting research and innovation in this sector. Despite promising developments, wave power in the U.S. is still primarily used in niche applications where other energy sources are less viable, and broader commercial adoption remains a future goal.

Keyword: Wave energy, Marine hydrokinetic energy, Renewable energy, Ocean power, Clean energy technology, Energy potential, Electricity generation

I. Introduction

In the pursuit of sustainable energy alternatives, wave power has emerged as a promising yet underutilized resource in the United States^[1-3]. With an estimated theoretical annual energy potential of up to **2.64 trillion kilowatt-hours**-equivalent to nearly **63% of total U.S. utility-scale electricity generation**-the ocean's waves represent a vast reservoir of renewable energy^[4-7]. Despite this potential, the U.S. currently has **no commercially operating wave energy projects**, though several pilot initiatives and research efforts are underway^[8-11]. Wave energy development is concentrated along the **west and east coasts**, as well as in **Hawaii**, where conditions are favorable for harnessing ocean motion^[12-13]. Notable projects include the **CalWave x1™ pilot off the coast of California**, supported by the U.S. Department of Energy, and proposed commercial wave parks in **Oregon and New Jersey**^[14-16]. These efforts reflect a growing recognition of wave power's role in diversifying the national energy portfolio and reducing dependence on fossil fuels^[17-20]. Academic institutions such as **Oregon State University** and **Portland State University** are actively contributing to wave ener-

gy research, while federal funding-like the **\$22 million grant awarded in 2022** is accelerating innovation in this field^[21-22]. As the U.S. navigates the transition toward cleaner energy, wave power stands at the frontier of marine renewable technologies, offering a unique blend of reliability, scalability, and environmental compatibility^[23].

II. Methodology

IIA. Design and Modeling of Wave data

1. High-Resolution Wave Data Modeling

- Developed the most comprehensive wave dataset publicly available.
- Covers the entire U.S. Exclusive Economic Zone (EEZ), extending 200 nautical miles from shore.
- Spans a 32-year time frame to capture long-term wave behavior.

2. Incorporation of Local and Distant Wave Sources

- Accounts for both:
 - **Local wind-generated waves** within the EEZ.
 - **Swell waves** arriving from distant ocean regions.
- This dual-source modeling significantly improved accuracy in estimating wave energy potential.

3. Improved Resource Accounting

- Previous estimates: ~2,600 terawatt-hours/year.
- New methodology: ~3,500 terawatt-hours/year—a 30% increase due to better modeling techniques.

4. Scalable Assessment Framework

- Designed to work at both:
 - **Site-specific scale** (for project developers).
 - **Regional/national scale** (for policy and planning).
- Resolves prior inconsistencies in wave energy assessments by standardizing methodology.

5. Use of International Standards

- Site assessments often follow **IEC technical specifications**.
- Regional assessments now align with this new unified framework to ensure consistency and reliability.

Regional Wave Energy Potential Estimates

Region	Estimated Potential (TWh/year)
Alaska	2000–2500
U.S. West Coast	510–630
U.S. East Coast	380–470
Gulf of Mexico	~70
Puerto Rico & U.S. Virgin Islands	18–33

IIB. Marine hydrokinetic energy

How It Works

MHK technologies harness energy from:

- **Waves:** Devices like buoys capture the vertical and horizontal motion of ocean waves.
- **Tides:** Turbines placed in tidal streams convert the predictable rise and fall of tides into electricity.
- **Ocean Currents:** Submerged turbines extract energy from steady ocean currents like the Gulf Stream.
- **Thermal Gradients:** Ocean thermal energy conversion (OTEC) uses temperature differences between deep and surface waters to generate power.

Benefits

- **Renewable & Predictable:** Tides and currents are highly predictable, offering reliable energy.
- **Minimal Visual Impact:** Most devices are submerged, preserving coastal aesthetics.
- **Geographically Diverse:** Coastal and island communities can benefit from local energy sources.
- **Multi-use Potential:** Can support desalination, marine research, and other blue economy applications.

Challenges

- **Environmental Impact:** Potential disruption to marine ecosystems, noise pollution, and electromagnetic fields.
- **Technological Maturity:** Many systems are still in pilot stages and face engineering hurdles.
- **Cost & Infrastructure:** High initial costs and the need for specialized infrastructure can slow deployment³.

Global Potential

Estimates suggest marine energy could generate between **20,000 to 80,000 terawatt-hours per year**, a massive contribution to global energy needs

IIC. Ocean power

Types of Ocean Energy

- **Wave Energy:** Captures energy from surface waves caused by wind. Devices like buoys and oscillating water columns convert wave motion into electricity.
- **Tidal Energy:** Utilizes the rise and fall of tides driven by the gravitational pull of the moon and sun. Tidal barrages and underwater turbines are common technologies.
- **Ocean Thermal Energy Conversion (OTEC):** Exploits the temperature difference between warm surface water and cold deep water to generate power.
- **Ocean Currents:** These can produce up to 2.5 times more power than wind farms, offering a highly reliable energy source.

Technologies in Action

- **Power Buoy by Ocean Power Technologies:** A wave energy device that provides uninterrupted power and data transfer for offshore operations.
- **WAM-V Unmanned Surface Vehicles:** Used for data collection, surveillance, and environmental monitoring in harsh maritime conditions.

Applications

- Offshore oil and gas operations
- Maritime security and defense
- Environmental monitoring and marine research
- Grid-connected and autonomous power supply

IID. Clean energy technology

What Is Clean Energy?

Clean energy typically includes sources that do not emit carbon dioxide (CO₂) during operation. These technologies aim to reduce climate-warming emissions and environmental degradation. However, no energy source is entirely impact-free-manufacturing and installation often involve some emissions.

Key Clean Energy Technologies

- **Solar Power:** Converts sunlight into electricity using photovoltaic cells.
- **Wind Energy:** Harnesses wind to turn turbines and generate electricity.
- **Hydropower:** Uses flowing water to spin turbines.
- **Geothermal Energy:** Taps into Earth's internal heat.
- **Nuclear Energy:** Generates power through nuclear fission with low direct emissions.
- **Bioenergy:** Uses organic materials; its cleanliness depends on sourcing and processing.
- **Emerging Tech:** Includes ocean wave power and advanced hydrogen systems.

Clean Tech Applications

According to the IEA Clean Energy Technology Guide, there are over 600 technologies contributing to net-zero goals, including:

- Energy storage systems (like batteries)
- Smart grids and energy-efficient appliances
- Green transportation (electric vehicles, hydrogen fuel cells)
- Sustainable building materials and lighting solutions

Why It Matters

- **Climate Impact:** Clean energy drastically reduces CO₂ emissions compared to fossil fuels.
- **Health Benefits:** Less air and water pollution.
- **Energy Security:** Diversifies energy sources and reduces dependence on imports.

III.Energy potential

Current Energy Mix (2023–2025)

According to the U.S. Energy Information Administration (EIA), the U.S. consumed about **94 quadrillion BTUs** of primary energy in 2023, with the following mix:

Energy Source	Share of Primary Energy
Petroleum	36%
Natural Gas	32%
Coal	9%
Nuclear	8%

Energy Source	Share of Primary Energy
Renewables (Total)	15%
– Wind	11%
– Solar	1%
– Hydroelectric	10%
– Biomass & Others	13%

Source: EIA Energy Facts

Renewable Energy Momentum

- **Wind and Solar** are leading the charge in new power plant installations.
- In 2024, renewable provided **25% of electricity generation**, with wind and solar contributing **17.5%** combined.
- By 2030, most new power capacity is expected to come from **solar and battery storage**, with **zero new coal or nuclear** plants planned.

Future Projections (2025–2035)

- **Electricity demand** is projected to hit **4.284 trillion kWh** by 2026, up from 4.097 trillion kWh in 2024.
- **Natural gas** remains dominant but is expected to decline from **42% in 2025** to **38% by 2028**, stabilizing through 2035.
- **Coal** will shrink significantly, from **14% to 10%** of the mix by 2035.
- **Nuclear and hydro** will remain relatively flat in capacity.

Sectoral Consumption

Sector	2023 Consumption (Quads)
Electric Power	32.11
Transportation	27.94
Industrial	22.56
Residential	6.33
Commercial	4.65

Key Drivers of Growth

- **Data centers and AI applications**
- **Electric vehicles**
- **Economic recovery**
- **State-level clean energy mandates**

III. Electricity generation in USA

Total Electricity Generation

- In **2023**, the U.S. generated approximately **4,178 terawatt-hours (TWh)** of electricity.
- By **2024**, this increased to around **4.3 petawatt-hours (PWh)**.

Generation by Energy Source (2023)

Energy Source	Share of Generation
Fossil Fuels	~60%
- Natural Gas	~39%
- Coal	~20%
- Petroleum	~1%
Nuclear	~19%
Renewables	~21%
- Wind	~10%
- Hydroelectric	~6%
- Solar	~3%
- Biomass/Geo	~2% combined

Nuclear remains the largest **low-carbon** source, while wind and solar are rapidly growing³.

Generation Technologies

- **Steam turbines** (fueled by coal, nuclear, biomass, geothermal, solar thermal)
- **Gas turbines** (natural gas)
- **Hydro turbines, wind turbines, and solar photovoltaics**³

Leading States in Electricity Production (2022)

State	Generation (TWh)	Dominant Source
Texas	526	Natural Gas & Wind
Florida	267.5	Natural Gas
California	214.5	Solar & Natural Gas
Illinois	188.1	Nuclear
Pennsylvania	~150+	Coal & Nuclear

Texas leads by a wide margin, producing twice as much as Florida or Pennsylvania.

Trends & Insights

- The U.S. is the **second-largest electricity producer** globally, after China.
- There's a clear shift toward **renewables and low-carbon sources**, driven by policy, economics, and climate goals.
- **Natural gas** remains dominant due to its flexibility and lower emissions compared to coal.

III. Results and Discussion**Results from Key Studies****1. Wave Power Trends Along the U.S. Coastline**

Source: Springer Ocean Dynamics Study

- **Regions Studied:** Eastern Pacific, Hawaii, Atlantic Ocean, Gulf of Mexico
- **Findings:**
 - **Eastern Pacific & Hawaii:** Showed **downward trends** in wave power.
 - **Atlantic & Gulf of Mexico:** Displayed **mixed trends**, with variability across sites.

- **Data Sources:** In situ measurements and model hindcasts from 29 sites.
- **Key Insight:** Wave power trends are **site-specific** and should not be generalized across large regions.
- **Implication:** Accurate local data is essential for coastal planning and resilience strategies.

2. Assessment of Wave Energy Resources and Conversion Factors

Source: Sandia National Laboratories & Integral Consulting

- **Estimated Resource:** ~1,200 TWh/year—comparable to U.S. coal and natural gas generation.
- **Conversion Challenges:**
 - High **structural costs** due to fluctuating wave loads.
 - Need for **efficient power take-off (PTO)** systems.
- **Technology Development:**
 - Wave Energy Converters (WECs) are evolving but not yet commercially competitive.
 - Performance and cost-effectiveness vary by site and device type.
- **Modeling Approaches:** Combined wave modeling and resource assessments to evaluate energy production potential.

Discussion Highlights

- **Variability Is Key:** Wave energy potential varies significantly by location, season, and sea state. This makes **site-specific assessments** crucial.
- **Economic Viability:** The **Levelized Cost of Energy (LCOE)** for wave energy remains high due to:
 - Inability to control peak loads.
 - Lower-than-expected energy output from current PTO systems.
- **Technological Innovation Needed:**
 - Improved **energy storage** systems are being explored to smooth out oscillatory power output.
 - Better **conversion mechanisms** are essential to make wave energy commercially viable.
- **Policy and Planning:** Accurate wave resource mapping helps identify **optimal deployment zones**, guiding infrastructure investment and technology design

IV. Conclusions

Current Status of Wave Power in the U.S.

- **No Commercial Projects Yet:** The U.S. currently has no commercially operating wave energy projects, though several pilot and research initiatives are underway.
- **Development Sites:** Wave power development is active off the East and West Coasts and in Hawaii. Some projects have begun producing reliable energy for the grid.
- **High Potential:** The theoretical wave energy potential off U.S. coasts is estimated at 2.64 trillion kilowatt-hours annually—about 63% of total U.S. utility-scale electricity generation.

Research Findings

- **Wave Power Trends:** A 2022 study using in situ measurements and model hind casts found that:
 - Most regions (Eastern Pacific and Hawaii) show **downward trends** in wave power.

- The Atlantic and Gulf of Mexico exhibit **mixed trends**.
- Wave power trends vary significantly by location, making regional generalizations unreliable.
- **Importance of Observational Data:** Accurate local and regional wave power estimates require high-quality observational data, which is vital for coastal planning and resilience efforts.

Future Perspectives

- **Growing Industry Interest:** Over one-third of the world's commercially active wave energy developers are based in the U.S., though few have reached high technology readiness levels.
- **Government Support:** The U.S. Department of Energy has provided substantial funding (e.g., \$22 million in 2022) to support wave energy research and development.
- **Pilot Projects:** Notable efforts include CalWave's submerged wave energy pilot off California and Ocean Power Technologies' projects in Oregon, New Jersey, and Hawaii

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