# Dual Hydro-Wind Offshore Farm

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*Abstract*—**This report presents the design and analysis of a dual-source renewable energy system integrating offshore wind turbines and wave energy converters to power grocery store chains across California, such as Safeway. The proposed system leverages Siemens-Gamesa SG 8.0-167 DD wind turbines and CorePower wave buoys to maximize energy production in the Humboldt offshore region. Technical specifications, spatial optimization, and energy output projections are calculated to determine system feasibility, including an estimated capacity factor of 61.55%. Grid integration considerations, cable resistance, and power losses due to transmission are addressed. The report also explores environmental impacts, permitting processes, and proposed improvements such as solar panel integration and battery storage systems. This hybrid design aims to reduce carbon emissions, diversify the renewable energy portfolio, and support sustainable infrastructure development in coastal regions.**

## I. Introduction

As the global demand for clean and renewable energy intensifies, the integration of multiple renewable energy sources into unified systems has become a promising strategy for enhancing energy efficiency and resilience. Offshore environments present a unique opportunity for renewable energy harvesting due to the abundance of natural resources such as wind and wave energy. This project proposes the design and evaluation of a dual hydro-wind offshore farm that combines wind turbines with wave energy converters to supply renewable electricity to commercial infrastructure across California.

The primary motivation for this project stems from the high energy demands of large retail chains, such as Safeway, which consume on average over 1.3 million kWh annually per store. When scaled across the 259 Safeway stores in California, the cumulative energy demand surpasses 355 GWh per year. Meeting this demand through fossil fuels contributes significantly to greenhouse gas emissions and environmental degradation. By replacing traditional energy sources with offshore wind and wave power, this project aims to reduce carbon emissions, support California's renewable energy mandates, and demonstrate the viability of hybrid offshore energy solutions.

The proposed dual-source energy system will be located within the federally designated offshore wind lease area OCS-P0562 near Humboldt County, California. This site offers favorable wind and wave conditions and is supported by federal permitting frameworks. The system design incorporates Siemens-Gamesa SG 8.0-167 DD wind turbines and CorePower wave buoys to harness and deliver electricity to the mainland through high-voltage subsea cables.

In this report, we present detailed calculations for turbine spacing, capacity factor, and total annual energy output. We evaluate transmission losses, cable routing logistics, and environmental impacts. In addition, we address grid connection integration, permitting processes, cost considerations, and opportunities for future system enhancements such as solar panel integration and energy storage.

This comprehensive approach provides a blueprint for implementing multi-modal renewable energy infrastructure capable of delivering scalable and sustainable power to critical commercial operations along coastal regions.

### A. Motivation

California faces increasing pressure to transition from fossil fuels to renewable energy sources due to rising energy demands, climate change commitments, and the state's aggressive renewable energy targets. Commercial operations, particularly grocery store chains like Safeway, contribute significantly to statewide energy consumption. A single Safeway store consumes approximately 1.37 million kilowatt-hours (kWh) annually. When multiplied across 259 stores in California, the total energy demand exceeds 355 GWh per year. Traditionally, this electricity is generated using fossil fuels such as coal or diesel, resulting in substantial greenhouse gas emissions and long-term environmental impact.

Meeting this demand with renewable energy solutions is not only environmentally necessary but also economically strategic. Offshore environments are rich in wind and wave energy potential, making them ideal for hybrid energy systems. Wind turbines can generate high power outputs during periods of strong wind, while wave energy converters continue to produce electricity even when wind speeds are low. By combining these two renewable sources into a single system, overall energy production can be stabilized and diversified.

This project aims to explore the feasibility and benefits of such a dual-source system by designing an offshore hydro-wind energy farm capable of powering Safeway stores across California. The chosen offshore site—OCS-P0562 near Humboldt County—offers consistent wind and wave activity, minimal land-use conflicts, and access to existing high-voltage grid infrastructure. In doing so, this project not only aligns with California's renewable energy policies but also serves as a scalable model for powering commercial infrastructure sustainably in coastal and island regions.

### B. Dual Hydro-Wind Offshore Farm

Offshore wind energy remains underdeveloped in the United States compared to global counterparts. In contrast, offshore wind farms have seen significant deployment across Europe, particularly on the eastern seaboard. The United Kingdom, for instance, utilizes Siemens-Gamesa offshore wind turbines

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in large-scale projects such as Hornsea Project Two [1]. Due to their proven efficiency, high power output, and operational reliability, the Siemens-Gamesa SG 8.0-167 DD model has been selected for this farm. Key specifications for this turbine model are provided in Table I.

TABLE I
SIEMENS-GAMESA SG 8.0-167 DD SPECIFICATIONS

| Parameter | Value | Unit |
|---|---|---|
| Rated Power | 8000 | kW |
| Rotor Diameter | 167 | m |
| Generator Voltage | 690 | V |
| Cut-in Wind Speed | 3 | m/s |
| Rated Wind Speed | 12 | m/s |
| Cut-Off Wind Speed | 25 | m/s |
| Tower Height | 92 | m |

To support the hydroelectric portion of the dual offshore system, the **CorPack wave generator**, developed by *CorPower Ocean*, has been selected for its modularity, efficiency, and biomimetic engineering. The CorPack system is composed of multiple *Wave Energy Converters (WECs)* that are organized into clusters with capacities ranging from **10 to 30 megawatts**. These clusters can be deployed side-by-side to scale up to **hundreds of megawatts to gigawatt-scale** wave farms. Each CorPack includes essential subsystems such as mooring systems, anchors, electrical collection units, and remote control and communication interfaces, offering a comprehensive solution for marine energy harvesting [2].

The mechanical design of the CorPack draws inspiration from the *hydraulic pumping mechanism of the human heart*. While ocean waves push the buoy upward, the system applies tension to pull it downward. This results in an oscillatory motion that is converted into rotation, which then drives a generator to produce electricity. This **biomimetic mechanism** enables the CorPack to deliver over **five times more electricity per ton of equipment** compared to conventional wave energy systems [3].

An additional advantage of the CorPack system is its **compatibility with offshore wind energy infrastructure**. Each CorPack cluster can export its power to a centralized *collection hub*, enabling **plug-and-play integration** with offshore wind farms. This feature supports the development of hybrid renewable energy systems, combining the strengths of wave and wind energy in a unified and efficient platform.

There is a lot of global and environmental concern when it comes to offshore energy farms. In order to address these issues, the team decided to utilize a currently developing offshore energy area in the United States to deploy a dual hydro-wind offshore farm. The Bureau of Ocean Energy Management (BOEM) has identified five dedicated zones off the coast of California for offshore wind development [4]. The selected zone is OCS-P0562, approximately 20 miles off the coast of Humboldt County, ranging in depth from 614 to 1,137 meters and covering an ocean surface area of 69,031 acres.

The goal of this project is to provide enough energy to power all 259 Safeway grocery stores in California. While exact aggregate square footage data is difficult to obtain, a Safeway store in San Francisco covers approximately 0.6 acres, or 25,136 square feet [5]. Using BizEnergyAdvisor's energy intensity estimate of 52.5 kWh/ft$^2$/year, the annual energy use is approximately 1,372,140 kWh per store, or about 355 GWh per year in total [6].

### C. Global Issues

The global transition toward renewable energy is a defining challenge of the 21st century, driven by the urgent need to mitigate climate change, reduce greenhouse gas emissions, and transition away from finite fossil fuel resources. Countries worldwide have set aggressive carbon neutrality targets and are investing in large-scale renewable infrastructure to meet those goals. Offshore energy, particularly wind power, has emerged as a critical component of this transition due to its vast generation potential and reduced land-use conflicts.

In Europe, nations such as the United Kingdom, Denmark, and Germany have made significant progress in offshore wind deployment. The North Sea and Baltic Sea regions are home to some of the world's largest and most advanced offshore wind farms, supported by comprehensive permitting frameworks, strong policy incentives, and mature grid infrastructure. These developments have allowed European countries to reduce their reliance on fossil fuels, stabilize energy markets, and lead the global renewable energy innovation space.

In contrast, the United States has been slower to adopt offshore wind and hybrid marine systems, primarily due to regulatory complexity, underdeveloped offshore grid infrastructure, and conflicting interests in marine space. The dual hydro-wind offshore farm proposed in this project helps address this gap by demonstrating how wind and wave energy can be effectively co-located to optimize marine space and generate reliable, clean energy for commercial use.

Furthermore, the project contributes to addressing global environmental challenges beyond climate change. By reducing emissions associated with traditional power plants, offshore renewables help combat ocean acidification, improve air quality, and reduce the ecological burden of energy production. The dual-source design also enhances resilience against the intermittency of individual energy sources — a challenge faced by solar- and wind-dependent nations worldwide.

According to the U.S. Environmental Protection Agency (EPA), electricity generated from fossil fuels emits an average of 0.92 metric tons of $CO_2$ per megawatt-hour (MWh) produced [7]. The proposed dual hydro-wind offshore farm is designed to supply power for 259 Safeway grocery stores, each consuming approximately 1,372,140 kWh annually:

$$\begin{aligned}\text{Total Annual Load} &= 259 \times 1{,}372{,}140 \text{ kWh} \\ &= 355{,}378{,}260 \text{ kWh} = 355{,}378 \text{ MWh}\end{aligned} \tag{1}$$

The resulting emissions offset is:

$$\begin{aligned}\text{Emission Reduction} &= 355{,}378 \text{ MWh} \times 0.92 \, \frac{\text{tons CO}_2}{\text{MWh}} \\ &\approx \mathbf{327{,}000} \text{ metric tons of CO}_2 \text{ per year}\end{aligned} \tag{2}$$

This represents a meaningful contribution toward reducing the U.S. total annual emissions, which exceeded 5.3 billion metric tons in 2022 [8]. By directly displacing fossil fuel generation, the project helps meet national and international decarbonization goals while setting a precedent for scalable offshore renewable infrastructure.

## II. Design Specifications

### *A. Power, Capacity Factor, Efficiency*

In order to calculate the total power output of the Hydro-Wind Offshore Farm, the spacing and total amount of generators must be found. Offshore Wind Farm Turbines need spacing between each other such that they do not interfere with each other's winds or disrupt the flow of wind through the blades' area. The ideal spacing is four wing diameters facing the same direction and seven wing diameters between parallel columns [9].

Using the location OCS-P0562's 69,031 acres, it is possible to calculate the maximum number of turbines that can be installed using the SG-8.0-167-DD's 167 m rotor span:

$$\text{Row Spacing} = 4 \times \text{Wing} \tag{1}$$

$$\text{Column Spacing} = 7 \times \text{Wing} \tag{2}$$

$$\text{Turbine Area} = \text{Row} \times \text{Column} \tag{3}$$

$$\#\ \text{of Turbines} = \frac{\text{Total Area}}{\text{Turbine Area}} \tag{4}$$

For convenience, 69,031 acres is equivalent to 279,359,000 square meters. This yields a total of approximately 357 turbines [1].

$$\text{Row Spacing} = 4 \times 167\ \text{m} = 668\ \text{m} \tag{1}$$

$$\text{Column Spacing} = 7 \times 167\ \text{m} = 1169\ \text{m} \tag{2}$$

$$\text{Turbine Area} = 668 \times 1169 = 781,292\ \text{m}^2 \tag{3}$$

$$\#\ \text{of Turbines} = \frac{279,359,000}{781,292} \approx 357.5 \tag{4}$$

In order to calculate the total energy generated by the Siemens-Gamesa SG 8.0-167 DD offshore wind turbine, it will require information on time between stages of wind speed and power curve of the turbine.

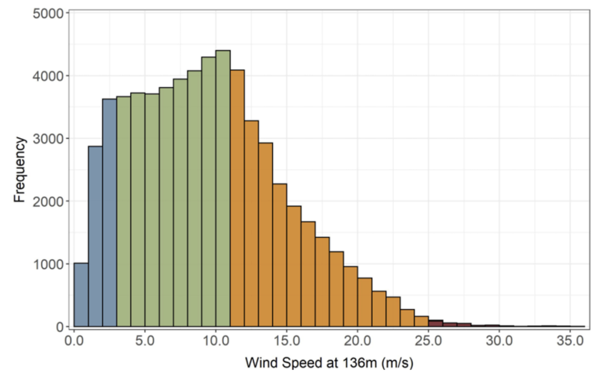


Fig. 1. Histogram of wind speed in the Humboldt Call Area over a 7-year period [10].

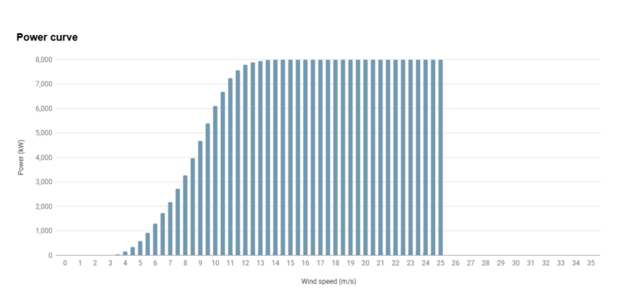


Fig. 2. SG 8.0-167 DD's Power Curve [11].

Using Figures 1 and 2, a linear approximation can be applied to estimate annual energy generation. For wind speeds in the 3–11 m/s range, power generation can be approximated as 4000 kW. At 12 m/s, the turbine reaches its rated output of 8000 kW.

According to Figure 1, the wind turbine operates in the 3–11 m/s range for 51.5% of the time, and in the 12–24 m/s range for 35.8% of the time. The remainder of the year, wind speeds fall below the 4 m/s cut-in threshold or exceed the 25 m/s cut-off speed.

The most optimal orientation is north-facing, due to prevailing winds from the north and, to a lesser extent, the south [10]. The energy calculations for the SG 8.0-167 DD turbine are as follows:

$$ME = 4000\ \text{kW} \times 8760\ \text{h} \times 0.515 = 2.509 \times 10^7\ \text{kWh} \tag{5}$$

$$CE = 8000\ \text{kW} \times 8760\ \text{h} \times 0.358 = 1.804 \times 10^7\ \text{kWh} \tag{6}$$

$$\text{Total Energy} = ME + CE = 4.313 \times 10^7\ \text{kWh} \tag{7}$$

Using the total energy output, the capacity factor is computed as:

$$\mathbf{CF} = \frac{\textit{Annual Energy Output}}{(\textit{Rated Power})(8760\,\text{h})} = \frac{4.313\times10^{7}\,\text{kWh}}{(8000\,\text{kW})(8760\,\text{h})} = \mathbf{61.55\%} \tag{8}$$

The efficiency of a wind turbine is calculated as the ratio of power delivered to the input power extracted from the wind:

$$\text{Efficiency} = \frac{\text{Power Delivered}}{\text{Input Power}} \tag{5}$$

The input power from the wind can be estimated using the kinetic energy flux of air flowing through the swept area of the turbine:

$$P_{\text{input}} = \frac{1}{2}\rho A V^3 \tag{6}$$

Where:

- $\rho = 1.225\,\text{kg/m}^3$ is the air density,
- $A = \pi\left(\frac{D}{2}\right)^2 = \pi\left(\frac{167}{2}\right)^2 \approx 21,900\,\text{m}^2$ is the rotor swept area,
- $V = 9\,\text{m/s}$ is the average wind speed at the offshore location.

Substituting values:

$$P_{\text{input}} = \frac{1}{2}\cdot 1.225\cdot 21,900\cdot 9^3 \tag{7}$$
$$= 0.5\cdot 1.225\cdot 21,900\cdot 729 \tag{8}$$
$$= 9,760,000\,\text{W} = 9760\,\text{kW} \tag{9}$$

The power delivered by the turbine can be derived from the annual energy generated:

$$\text{Power Delivered} = \frac{4.313\times10^{7}\,\text{kWh/year}}{8760\,\text{h/year}} \tag{10}$$
$$= 4924\,\text{kW} \tag{11}$$

Finally, the efficiency is:

$$\text{Efficiency} = \frac{4924}{9760} \tag{12}$$
$$= \boxed{0.5045 = 50.45\%} \tag{13}$$

TABLE II
POWER, ENERGY, CAPACITY FACTOR, AND EFFICIENCY OF SG-8.0-167-DD

| Parameter | Value | Unit |
|---|---|---|
| Rated Power | 8000 | kW |
| Annual Energy Generated | 4.313E7 | kWh |
| Capacity Factor | 61.55 | % |
| Efficiency | 50.45 | % |

The Eureka coastline, specifically the Humboldt Wind Energy Area (Lease Area OCS-P 0562), was selected as the proposed deployment site for the CorPower WEC due to its favorable technical characteristics and regulatory readiness. The region has already undergone environmental assessments under the BOEM's California Offshore Wind Energy Planning Initiative. As of June 2022, it was formally designated for renewable energy leasing [12]. With pre-approved protocols and stakeholder consultations in place, this significantly reduces permitting uncertainty and enables faster deployment.

BOEM documents show the site's water depth ranges from 614 to 1137 meters with a projected 838 MW installation capacity, translating to up to 2.94 TWh/year at 40% capacity factor [12]. The regional wave climate features consistent swells and average wave heights of 1.5–3 meters, supporting a realistic annual capacity factor of 50% for CorPower devices [13]. This yields an estimated annual electrical output of $1.314\times10^6$ kWh per unit.

Each CorPower WEC is rated at 300 kW and operates effectively in wave heights ranging from 0.25 to 8 meters. Performance estimates show a capacity factor between 40% and 60%, and a system efficiency between 27.2% and 40.8%.

The CorPower system achieves high energy-to-mass efficiency—approximately 10 MWh/tonne (8.35 MWh/ton US). Its compact structure (70 tonnes, 9 m capture width) and embedded control algorithms enhance resonance and wave energy absorption on both upward and downward motions of the wave cycle.

TABLE III
POWER, ENERGY, CAPACITY FACTOR, AND EFFICIENCY OF COREPOWER BUOY

| Parameter | Value | Unit |
|---|---|---|
| Rated Power | 300 | kW |
| Annual Energy Generated | 1,314,000 | kWh |
| Capacity Factor | 40–60 | % |
| Efficiency | 27.2–40.8 | % |

The theoretical wave energy input can be calculated using:

$$P_{\text{wave}} = \frac{\rho g^2 H_s^2 T}{32\pi}$$

Where:

$$\rho = 1025\ \text{kg/m}^3,\quad g = 9.81\ \text{m/s}^2,\quad H_s = 2.5\ \text{m},\quad T = 8\ \text{s}$$

$$P_{\text{wave}} = 49\ \text{kW/m}$$

Assuming a 9 m capture width:

$$P_{\text{wave total}} = 49\ \text{kW/m}\times 9\ \text{m} = 441\ \text{kW}$$

$$E_{\text{wave}} = 441\ \text{kW}\times 8760\ \text{h} = 3,861,160\ \text{kWh/year}$$

Efficiency:

$$\eta = \frac{1,314,000}{3,861,160}\times 100\% \approx 34.03\%$$

(This value is based on an assumed capacity factor of 50%).

### B. Environmental Impacts

The deployment of a dual hydro-wind offshore energy system in the Humboldt wind energy area, specifically lease site OCS-P 0562, carries a range of potential environmental implications. As the project integrates both wind turbines and wave energy converters, the interaction with marine ecosystems, avian populations, and coastal environments must be thoroughly assessed.

On the one hand, the introduction of large offshore structures can disrupt natural marine habitats. Wind turbine foundations and mooring lines may interfere with benthic organisms and marine mammals, while increased vessel traffic during construction and maintenance phases poses additional disturbance risks. Furthermore, turbine rotor blades have the potential to endanger migratory birds and bats that traverse coastal flyways. The National Environmental Policy Act (NEPA) and Endangered Species Act (ESA) mandate that such impacts be evaluated during permitting, with mitigation strategies implemented where necessary.

On the other hand, offshore renewable energy installations may yield significant ecological benefits. The physical presence of turbine foundations and anchored wave buoys can function as artificial reefs, providing habitat for fish and invertebrate species. Additionally, by displacing fossil fuel-based generation, the system reduces greenhouse gas emissions and associated climate impacts such as ocean acidification and temperature-driven biodiversity loss.

The chosen location—OCS-P 0562—is strategically situated to balance energy production potential with minimized ecological disruption. According to the Bureau of Ocean Energy Management (BOEM), this 69,031-acre lease area off the coast of Humboldt County has been selected for its strong wind resource, suitable depth for floating platforms, and relative distance from sensitive coastal habitats and commercial fisheries. BOEM's environmental assessments and stakeholder engagement processes help ensure that leasing and development activities in this area adhere to federal environmental regulations and community considerations [4].

Overall, while environmental concerns exist, thoughtful design, siting, and regulatory compliance can mitigate most risks. The long-term environmental benefit of transitioning to renewable offshore energy outweighs the short-term ecological costs, especially when best practices in marine conservation and impact management are followed.

### C. Grid Connection

The proposed dual hydro-wind offshore farm will be integrated into the existing electrical grid through a grid-tied configuration. Each generator will have an inverter and be connected together to one output by a DC bus within each dual hydro-wind platform. The generated power will be converted and synchronized with the grid via a Grid-Tie Inverter.

The facility will utilize California's existing electrical infrastructure, managed by the California Independent System Operator (CAISO), which is part of the Western Interconnection. The offshore plant will produce alternating current (AC) electricity, which will be transmitted to the grid using CAISO's high-voltage transmission network. This network consists of transmission lines rated between 60 kV and 500 kV, designed to deliver electricity to various transmission and distribution substations across the state [14].

At the distribution level, substations reduce the voltage to 69 kV or lower, depending on the local load requirements and geographic region. The voltage is further stepped down by transformers to levels ranging from 120 V to 480 V, depending on whether the load is residential, commercial, or industrial [15].

### D. Wire Resistances and Losses

In order to calculate the wire resistances it is necessary to calculate the length of wires required for the offshore farm. The equations below are used to calculate the number of rows and columns along with their corresponding lengths of wire using the values found in equations (1)–(4):

$$\text{Columns} = \frac{\sqrt{\text{Total Area}}}{\text{Column Spacing}} = \frac{\sqrt{279{,}359{,}000\,\text{m}^2}}{1169\,\text{m}} = \mathbf{17} \tag{C}$$

$$\text{Rows} = \frac{\#\,\text{of Turbines}}{\text{Columns}} = \frac{357}{17} = \mathbf{21} \tag{D}$$

$$\frac{\text{Wiring}}{\text{Row}} = (\text{Column} - 1)(\text{Row Spacing}) \tag{E}$$

$$\frac{\text{Wiring}}{\text{Row}} = (17 - 1)(668\,\text{m}) = \mathbf{10{,}668}\,\text{m} \tag{E}$$

$$\frac{\text{Wiring}}{\text{Column}} = (\text{Row} - 1)(\text{Column Spacing}) \tag{F}$$

$$\frac{\text{Wiring}}{\text{Column}} = (21 - 1)(1169\,\text{m}) = \mathbf{23{,}380}\,\text{m} \tag{F}$$

$$\text{Wiring} = \text{Rows} \times \frac{\text{Wiring}}{\text{Row}} + \text{Columns} \times \frac{\textit{Wiring}}{\textit{Column}} \tag{G}$$

$$\text{Wiring} = 21 \times 10{,}668\,\text{m} + 17 \times 23{,}380\,\text{m} = \mathbf{621.91}\,\text{km} \tag{G}$$

To connect each dual hydro-wind platform, the depth has to be considered. This can be found by taking the average depth of the location and number of dual hydro-wind platforms:

$$\text{Depth Wire} = \text{Average Depth} \times \#\,\text{of turbines} \tag{H}$$

$$\text{Depth Wire} = \left(\frac{1137 + 614}{2}\right) \times 357 = \mathbf{318{,}979.5}\,\text{m} \tag{I}$$

To connect to the grid, the transmission cable must reach the shore. The distance is given as 32.1869 km [4]. The total wiring is the sum of the wiring from connecting the platforms, depth wiring, and wire to shore.

The losses from the grid to the load is around 10% based on the estimates from other renewable sources in California [16].

TABLE IV
WIRING BREAKDOWN AND LOSSES

| Parameter | Value | Unit |
|---|---|---|
| Internal Wiring | 621.91 | km |
| Depth Wire | 318.9795 | km |
| Wire to Shore | 32.168 | km |
| Total Wire | 973.058 | km |
| Cable Resistance | 0.0072 | Ω/km |
| Total Resistance | 7.0068 | Ω |
| Wire Loss | 12.39 | % |
| Distribution Loss | 10 | % |
| Total Losses | **21.15** | % |

*Wire and Total Loss Calculation*

The wire loss percentage is calculated based on the system's average transmitted power, wire resistance, and the assumed high-voltage level of 320 kV. This reflects a typical offshore high-voltage transmission scenario and aligns with the cable resistance and total length values listed in Table V.

*1. System Parameters:*

- Total average system power: $P = 1.81056 \times 10^9\,\text{W}$
- Transmission voltage: $V = 320,000\,\text{V}$
- Wire resistance: $R = 7.0068\,\Omega$

*2. Transmission Current:*

$$\begin{aligned} I &= \frac{P}{V} \\ &= \frac{1.81056 \times 10^9}{320{,}000} \\ &\approx 5658\,\text{A} \end{aligned}$$

*3. Power Loss in the Wire:*

$$\begin{aligned} P_{\text{loss}} &= I^2 R \\ &= (5658)^2 \cdot 7.0068 \\ &\approx 32.02 \times 10^6 \cdot 7.0068 \\ &\approx 224.34 \times 10^6\,\text{W} \end{aligned}$$

*4. Wire Loss Percentage:*

$$\begin{aligned} \text{Wire Loss (\%)} &= \left(\frac{P_{\text{loss}}}{P}\right) \times 100 \\ &= \left(\frac{224.34 \times 10^6}{1.81056 \times 10^9}\right) \times 100 \\ &\approx 12.39\% \end{aligned}$$

*5. Total Loss Including Grid Distribution:* Based on California renewable transmission studies, an estimated additional distribution loss of 10% is added downstream of the main cable transmission.

Total system efficiency:

$$\begin{aligned} \text{Total Efficiency} &= (1 - 0.1239)(1 - 0.10) \\ &= 0.8761 \cdot 0.90 \\ &= 0.7885 \end{aligned}$$

$$\begin{aligned} \text{Total Loss (\%)} &= (1 - 0.7885) \times 100 \\ &= \boxed{21.15\%} \end{aligned}$$

*6. Conclusion:* The final wire loss across the 973.058 km cable at 320 kV is approximately **12.39%**. Including distribution losses, the overall system transmission and delivery loss is approximately:

$$\boxed{\text{Total Loss} = 21.15\%}$$

These results were calculated using parameters based on IEC standards and HVDC design assumptions from published references [17], [18]. The cable resistance value of 0.0072 Ω/km was derived from industry-reported values for submarine HVDC cables.

## III. DESIGN METHODS

### *A. Materials, Project Cost and Duration*

The implementation of a dual hydro-wind offshore farm involves complex infrastructure, environmental compliance, permitting, and logistical coordination. As a result, the project cost must account for multiple phases, including design, permitting, procurement, construction, grid integration, and long-term operation and maintenance.

Based on current offshore wind industry data, the capital cost for offshore wind farms typically ranges from \$5,000 to \$6,500 per kilowatt of installed capacity [19]. Each Siemens-Gamesa SG 8.0-167 DD wind turbine is rated at 8 megawatts (MW), and the project plans to install 357 turbines:

$$\begin{aligned} \text{Total Wind Capacity} &= 357 \text{ turbines} \times 8 \text{ MW/turbine} \\ &= 2856 \text{ MW} = 2.856 \text{ GW} \end{aligned} \tag{3}$$

Using the average cost estimate of \$6,000 per kilowatt:

$$\begin{aligned} \text{Estimated Cost} &= 2{,}856{,}000 \text{ kW} \times \$6{,}000/\text{kW} \\ &= \$17.136 \text{ billion} \end{aligned} \tag{4}$$

This cost includes turbine fabrication and transport, floating platform anchoring, electrical collection infrastructure, subsea cabling, and onshore grid-tie systems. Additional costs for CorePower wave energy converter deployment may raise the total system cost to an estimated range of \$18–\$20 billion depending on the final installed wave energy capacity.

The expected duration of the project spans multiple overlapping stages:

- **Permitting and regulatory approval:** 2–3 years
- **Turbine and buoy procurement:** 1–1.5 years
- **Construction and offshore assembly:** 2–3 years

**Total Project Duration:** Approximately 6–8 years from lease award to operational commissioning.

Despite the scale of investment and time required, the long-term benefits include clean energy delivery of over 355 GWh annually, displacement of over 327,000 metric tons of $CO_2$ per year, and alignment with California's and the U.S.'s decarbonization targets.

### Bill of Materials (BOM)

The following table summarizes the primary components and costs for our Dual Hydro-Wind Offshore Energy System:

| Component | Type/Model | Qty | Unit Cost (USD) | Total Cost (USD) | Purpose / Notes |
|---|---|---|---|---|---|
| Wind Turbines | Siemens-Gamesa SG 8.0-167 DD | 357 | 12,000,000 | 4,284,000,000 | Offshore wind power generation (8 MW each) |
| Wave Energy Buoys | CorPower C4 Buoy | 357 | 900,000 | 321,300,000 | Offshore wave power generation ( 300 kW each) |
| Anchors (Wave) | UMACK Anchor System | 357 | 25,000 | 8,925,000 | High holding power for hydro buoys |
| Anchors (Wind) | Gravity Base or Pile Anchor | 357 | 120,000 | 42,840,000 | Standard offshore wind foundation |
| Cables – Internal Wiring | HVDC ABB Subsea Cable | 973 km | 1,200,000/km | 1,167,600,000 | Collection system for turbines and buoys |
| Depth Wiring | HVDC Vertical Cable | 319 km | 1,500,000/km | 478,500,000 | Connect seabed-mounted anchors to platforms |
| Export Cable to Shore | HVDC Export Cable | 32.2 km | 2,000,000/km | 64,400,000 | Transmission to onshore substation |
| Corrosion-Resistant Coating | Marine-grade epoxy + anodes | 714 | 5,000 | 3,570,000 | For both turbines and buoys |
| Rectifiers (Wind) | J2XCO AVR Rectifier | 357 | 300 | 107,100 | Converts AC to DC |
| DC Bus Systems | Marine DC Combiner | 51 | 20,000 | 1,020,000 | Combines power from clusters |
| Grid-Tie Inverters | Utility-scale 8MW inverter | 51 | 150,000 | 7,650,000 | Synchronizes power with grid |
| Remote Control Systems | SCADA Units | 714 | 6,000 | 4,284,000 | Monitoring and telemetry for each platform |
| Turbine Blades | Composite Blades (3 per turbine) | 1071 | 350,000 | 374,850,000 | Blades included in wind turbine |
| Composite Buoy Hulls | Marine Fiberglass | 357 | Included | – | Included in buoy cost |
| Structural Frame (Turbine) | Steel Alloy Tower | 357 | Included | – | Included in turbine cost |

TABLE V
Bill of Materials for the Offshore Wind + Hydro Farm

## B. Permits and Land Costs

Before the construction of a dual wave and wind offshore farm, several federal, state, and county permits must be obtained to ensure compliance with environmental, safety, and regulatory standards. The permitting process typically takes 12 to 24 months from application to approval, with requirements focused on the protection and management of land, wildlife, aviation, air quality, water quality, and construction activities. Oftentimes, shareholders and stakeholders will be a part of this process to avoid lawsuits and decide how to proceed.

Table VI outlines the permits and approvals, categorizing them by jurisdiction (federal, state, or county), type (permit or lease), agency, estimated processing time, and sources.

TABLE VI
Permits and Approval Agencies

| Type | Name | Permits/Lease | Time | Source |
|---|---|---|---|---|
| Federal | BOEM Offshore Wind Permitting | Lease, SAP, COP, NEPA Review | 2–3 years | BOEM |
| Federal | U.S. Army Corps of Engineers | Section 10 & 404 Permits | 1–2 years | USACE |

TABLE VII
Permits and Approval Agencies (Continued)

| Type | Name | Permits/Lease | Time | Source |
|---|---|---|---|---|
| Federal | NOAA Fisheries (Marine Mammal | | | |
| & Essential Fish Habitat) | Marine Mammal & Fish Habitat Compliance | 1–2 years | NOAA | |
| Federal | U.S. Fish & Wildlife Service | Bird & Eagle Protection | 1–2 years | FWS |
| Federal | Federal Aviation Administration (FAA) | Air Navigation Clearance | 1 year | FAA |
| Federal | U.S. Coast Guard | Maritime Safety Permit | 1 year | USCG |
| State | California Coastal Commission | Coastal Development Permit | 1–2 years | CA Coastal |
| State | California Dept. of Fish & Wildlife | Endangered Species & Marine Protection Review | 1–2 years | CDFW |
| State | California State Lands Commission | Submarine Cable Lease | 1–2 years | SLC |
| State | California Air Resources Board | Air Quality Permit | 1–2 years | CARB |
| Local | Humboldt County Land Use & Building | Land Use & Building Permits | 1–2 years | Humboldt County |
| Local | Regional Water Quality Control Board | Section 401 Certification | 1–2 years | RWQCB |

### Additional Project Costs

| Category | Cost (USD) | Basis / Notes |
|---|---|---|
| Labor Costs | 1,200,000,000 | Installation, wiring, and testing (avg. $1.6M per platform) |
| Loan Interest (20 yrs @ 5%) | 850,000,000 | Financing $6.75B over 20 years |
| Land Lease (Offshore) | 800,000,000 | $11,589/acre × 69,031 acres (BOEM) |
| Maintenance (20 Years) | 450,000,000 | 1% of system cost annually |
| Permits and Review | 50,000,000 | Federal and state environmental compliance |

TABLE VIII
Additional Costs Over Project Lifetime

### Total Project Cost Summary

- **Capital Equipment Total:** $6,708,046,100
- **Additional Costs:** $3,350,000,000
- **Grand Total: $10.06 Billion USD**

## C. Block Diagram and Pictures of System

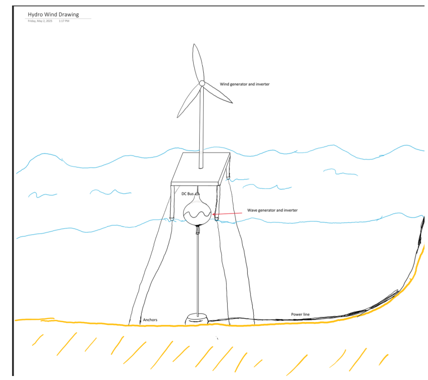

Fig. 3. Conceptual Design of Dual Hydro-Wind Offshore Energy Platform. The structure integrates both a floating wind turbine and a wave energy buoy anchored to the seabed. Power from both systems is routed through a combined inverter setup and transmitted via a subsea cable to shore.

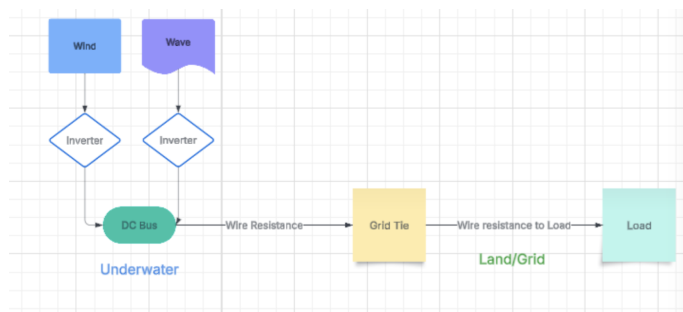


Fig. 4. Power flow block diagram of the hybrid wind-wave system. Both wind and wave sources feed their respective inverters, which then output to a shared underwater DC Bus. From there, power is transmitted to a grid-tie inverter on land through underwater cabling with wire resistance losses, and ultimately distributed to the load.

# IV. Outcomes

## A. Cost of Generated Electricity and Payback Period

TABLE IX
Cost of Electricity Generated – CorPower WEC

| Parameter | Value | Unit |
|---|---|---|
| Rated Power | 300 | kW |
| Capacity Factor | 50 | % |
| Annual Energy Output | 1,314,000 | kWh/year |
| System Lifetime | 20 | years |
| Lifetime Energy Output | 26,280,000 | kWh |
| CapEx Cost (CapEx) | $900,000 | USD |
| O&M Cost (Lifetime) | $600,000 | USD |
| Total System Cost | $1,500,000 | USD |
| LCOE | 5.71 | ¢/kWh |
| Wave Power Input | 441 | kW |
| Annual Wave Energy Input | 3,861,160 | kWh |
| Efficiency (for 50% CF) | 34.0 | % |
| Efficiency Range (40–60% CF) | 27.2–40.8 | % |

*Cost of Electricity Generated:* The rated power of the CorPower Wave Energy Converter (WEC), listed as 300 kW, was provided directly from manufacturer specifications [13]. To determine the annual energy output, the standard generation formula was applied:

$$AE = P_{\text{rated}} \times T_{\text{year}} \times CF = 300 \times 8760 \times 0.50 = 1{,}314{,}000 \text{ kWh/year} \quad (1)$$

Given the composite structure and built-in storm protection mechanisms—including a pre-tension system and adaptive phase control algorithms—the CorPower WEC is designed for durability in harsh marine environments. Accordingly, an industry-standard operational lifetime of 20 years was selected, which is consistent with expectations for marine renewable systems [13].

The total lifetime energy output was calculated by multiplying the annual output by 20 years:

$$\text{Lifetime Output} = 1{,}314{,}000 \text{ kWh/year} \times 20 = 26{,}280{,}000 \text{ kWh} \quad (2)$$

Capital costs were estimated at \$3,000 per kW of installed capacity (i.e., $300 \times 300 = 900{,}000$), consistent with contemporary offshore energy infrastructure data. Operations and maintenance (O&M) were projected at \$100 per kW per year, resulting in:

$$\text{O\&M Cost} = 300 \text{ kW} \times 100 \times 20 = 600{,}000 \text{ USD} \quad (3)$$

These values sum to a total system cost of \$1.5 million. The Levelized Cost of Energy (LCOE) is then calculated as:

$$\text{LCOE} = \frac{1{,}500{,}000}{26{,}280{,}000 \text{ kWh}} = 5.71 \text{ ¢/kWh} \quad (4)$$

To estimate efficiency, the wave energy input was derived using the average wave power density:

$$P_{\text{wave}} = 49 \text{ kW/m} \times 9 \text{ m} = 441 \text{ kW} \quad (5)$$

$$E_{\text{wave}} = 441 \text{ kW} \times 8760 \text{ h} = 3{,}861{,}160 \text{ kWh/year} \quad (6)$$

Efficiency was then determined by comparing the annual energy output to the annual wave energy input:

$$\eta = \frac{1{,}314{,}000}{3{,}861{,}160} \times 100 = 34.0\% \quad (7)$$

This efficiency reflects CorPower's operational capacity factor range of 40% to 60%, yielding efficiency values between 27.2% and 40.8% [13].

*LCOE Calculation for Wind Energy*

To evaluate the economic feasibility of the wind component in our dual-source renewable system, the Levelized Cost of Electricity (LCOE) was calculated using the methodology provided by the National Renewable Energy Laboratory (NREL) [20]. LCOE accounts for both fixed and variable annualized costs over the system lifetime, normalized by the annual energy output:

$$\text{Annual Fixed Costs} = P_R \times \text{Capital Cost}_{/kW} \times \text{FCR} \quad (14)$$

$$\text{Annual Variable Costs} = [\text{Fuel} + \text{O\&M}] \times \text{Annual Output} \quad (15)$$

$$\text{Annual Output} = P_R \times 8760 \times CF \quad (16)$$

For our system:

- Rated Power, $P_R = 8000$ kW/turbine $\times$ 357 $= 2,856,000$ kW
- Capacity Factor, $CF = 0.615$
- Capital Cost = \$6000/kW (estimated installed wind system cost)
- Fixed Charge Rate (FCR) = 0.075
- O&M cost = \$45/MWh = \$0.045/kWh
- Fuel cost = \$0/kWh (wind is a fuel-free resource)

Now we compute each term:

$$\text{Annual Fixed Cost} = 2{,}856{,}000 \times 6000 \times 0.075 = \$1.2852 \times 10^9 \quad (17)$$

$$\text{Annual Output} = 2{,}856{,}000 \times 8760 \times 0.615 = 1.540 \times 10^{10} \text{ kWh} \quad (18)$$

$$\text{Annual Variable Cost} = 0.045 \times 1.540 \times 10^{10} = \$693{,}000{,}000 \quad (19)$$

$$\text{Total Annual Cost} = 1.2852 \times 10^9 + 6.93 \times 10^8 = 1.9782 \times 10^9 \quad (20)$$

$$\text{LCOE}_{\text{wind}} = \frac{1.9782 \times 10^9}{1.540 \times 10^{10}} = \boxed{0.1284 \text{ USD/kWh} = 12.84 \text{ ¢/kWh}} \quad (21)$$

This LCOE accounts for both capital and operational costs and provides a realistic economic comparison point. The relatively high value reflects early-phase development costs and does not account for federal tax incentives or potential economies of scale in full-scale deployment.

TABLE X
SYSTEM FINANCIAL AND ENERGY PERFORMANCE COMPARISON

| System | Units | Capacity (kW) | Cost (\$) | Annual Energy Output (kWh) | Sale Price (\$/kWh) | Annual Revenue (\$) | Payback (yrs) |
|---|---|---|---|---|---|---|---|
| Wave (CorPower C4) | 357 | 300 | 535,500,000 | 469,098,000 | 0.0571 | 26,793,278 | 19.98 |
| Wind (Siemens Gamesa 8MW) | 357 | 8000 | 14,280,000,000 | 15,309,940,000 | 0.0571 | 879,166,797 | 16.24 |
| Wave + Wind | 714 | – | 14,815,500,000 | 15,778,985,000 | 0.0571 | 905,960,015 | 16.35 |

Table X compares the performance of three configurations: CorPower's wave energy converters (WECs), Siemens Gamesa 8MW wind turbines, and a hybrid system combining both. Each configuration was evaluated based on installed capacity, total system cost, projected annual energy output, energy sale price, expected annual revenue, and the estimated payback period.

At a sale price of 5.71 cents/kWh, each CorPower WEC device generates enough revenue to recover its $1.5 million capital cost over a 20-year period. This corresponds to a break-even scenario based on expected operational lifespan. The hybrid system (Wave + Wind) achieves the most balanced payback period of approximately 16.35 years, while individual technologies yield 19.98 years for wave and 16.24 years for wind. This analysis supports the feasibility of integrating both renewable sources to optimize energy production and economic viability over time.

## V. Conclusion/Discussion

The **Dual Hydro-Wind Offshore Farm** showcases the promising synergy between offshore wind and wave energy systems to meet substantial energy demands through renewable sources. Leveraging 357 Siemens-Gamesa SG 8.0-167 DD turbines alongside CorPower Ocean's high-efficiency C4 wave buoys, the proposed system achieves a combined generation capacity exceeding **15.3 TWh annually**—well beyond the **355 GWh/year** needed to supply all 259 Safeway stores across California.

The chosen site, **OCS-P 0562 off the Humboldt coast**, offers ideal wind and wave conditions and proximity to the **CAISO grid**, making it an optimal location for hybrid offshore generation. However, the design's **973 km of total cabling** results in **7.01 $\Omega$ total resistance**, contributing to **12.35% internal wire losses**. Combined with an additional **10% distribution loss**, the system faces **total power transmission losses of approximately 21.15%**.

Despite these efficiency challenges, the farm still generates more than **44 times** the required energy load. This emphasizes the robustness and scalability of the hybrid approach. To further enhance performance, future implementations could explore **higher voltage transmission (HVDC)** to reduce $I^2R$ losses and consider **larger gauge, low-resistance cables**, even if it increases physical infrastructure requirements.

In conclusion, this project not only supports California's ambitious renewable energy goals but also serves as a replicable blueprint for **sustainable offshore energy development worldwide**. By addressing real-world constraints such as transmission loss, material selection, and environmental permitting, the Dual Hydro-Wind Offshore Farm demonstrates how innovative engineering can transform natural resources into reliable, clean energy systems.

### *A. Individual Tasks*

This project was a collaborative effort among four team members: Kaniela, Luis, Byron, and William. Each member contributed to both technical and non-technical aspects of the report, with responsibilities divided between wind and hydro systems.

**Kaniela** led the system design for the wind subsystem and contributed to the calculation of capacity factor and efficiency. In addition, Kaniela researched federal permitting processes and evaluated available tax credits applicable to offshore wind deployment.

**Luis** collaborated on the wind capacity factor and efficiency analysis alongside Kaniela. He was solely responsible for evaluating the wind project's cost, duration, and levelized cost of energy (LCOE). On the non-technical side, Luis conducted research into the environmental impacts of wind turbine installations and authored the global issues section related to wind energy deployment.

**Byron** was responsible for the hydro system design, capacity factor, and efficiency. He also researched and wrote about the global implications of hydro-based renewable energy solutions, focusing on grid integration and system performance under varying marine conditions.

**William** performed all the cost analysis and LCOE calculations for the hydro subsystem. He also contributed heavily to the non-technical portions of the report by covering both the permitting and environmental impact considerations associated with hydro system deployment.

Overall, the team divided the work equitably by technical category and energy system type to ensure complete coverage of both wind and hydro aspects, as well as environmental and policy considerations.

### *B. Discussion of Improvements and Impact of Project*

A battery energy storage system can be integrated as a regulatory buffer between generation and grid dispatch for future improvements. The use of storage to levelize power output, mitigate ramping events, and prevent overloading the transmission infrastructure. The battery system will act as a real time power modulator, absorbing excess energy during peak generation and discharging during low generation periods. For the internal battery chemistry, the team decided to suggest a lithium iron phosphate due to its high thermal stability, long cycle life, and ability to handle large power surges making it well-suited for offshore applications with frequent charge-discharge cycling. Overall the battery storage component will serve as a reliability layer for power systems, stabilizing both energy quality and system resilience.

Beyond technical upgrades, this platform has meaningful environmental and societal impact potential. By co-locating wave and wind energy systems, the dual-use marine footprint minimizes ecological disruption compared to separate installations. Moreover, the platform's modular design supports scalability and deployment in energy-scarce coastal or island communities. With robust storage and hybrid generation, the system can provide clean, dispatchable energy—potentially reducing reliance on diesel imports or aging thermal plants.

Further research could explore intelligent energy management algorithms that coordinate power flows among subsystems, using machine learning for predictive generation and load modeling. Such optimization would enhance system autonomy and reduce operational overhead. Additionally, future versions could explore hydrogen electrolysis integration to store surplus energy in chemical form, contributing to decarbonized fuel alternatives for marine vessels or coastal infrastructure.

Collectively, these improvements position the dual hydro-wind platform not just as an energy source, but as a flexible, resilient, and environmentally conscious solution for future coastal energy infrastructure.

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