Project ID: #2

The Simplistic and Inflatable Device that Converts Ocean Waves into Renewable Energy

By

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MEng Capstone Report

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Executive Summary

The demanding conditions of the marine environment have historically pushed wave energy solutions toward rigid, immobile, and material-heavy designs, ultimately making them economically unviable compared to other renewable energy sources. Our capstone project aims to evaluate whether the cost per kilowatt-hour can be reduced by developing an inflatable wave energy device capable of withstanding the ocean's dynamic and harsh conditions. At the same time, we aim to optimize the device's mechanical systems to lower both maintenance and production costs while maximizing power output.

To achieve this, we focus on maximizing the prototype's efficiency through the use of an inflatable structure and a streamlined system design, ultimately cutting down on fabrication, deployment, and upkeep expenses. Through extensive testing and analysis, we examined how inflatable materials respond to ocean waves and how this affects energy output. With its inflatable form and a straightforward, electricity-based power take-off system, the device presents a cost-effective and potentially scalable solution.

Our latest version of our prototype significantly outperformed our previous models, generating a peak power output of 9.7 Watts compared to its predecessor model which peaked around 2.4 Watts from the same wave height. As the project advances, the prototype is approaching readiness for real-world ocean testing, which is an essential step toward contributing to the nation's carbon neutrality goals.

1. Background

1.1 The Need for Renewable Energy & The Obstacles of Wave Energy

With the United States heading towards carbon neutrality by 2035, there is a growing need for renewable energy [1] (U.S. DOE, 2023)and wind are the leaders in the market now, but being weather-dependent makes them unreliable. Ocean wave energy is an unexplored opportunity with immense possibilities. Studies indicate that wave energy, theoretically, can supply up to 63% of the U.S. energy requirements [2] (IEA, 2023), yet only a fraction lower than 1% of this has been harnessed thus far due to limitations in technology and economy.

The main hindrance to wave energy adoption is its elevated unit cost in kilowatt-hours ($/kWh), significantly above solar and wind. It costs anywhere from $0.35 to $0.85 per kWh today, much more than solar and wind at less than $0.20/kWh [3] (REN21, 2023). The explanation is largely due to the harsh marine environment which, due to corrosion, and biofouling, makes maintenance more frequent, and the device lifespan shorter [4] (OES, 2023). Ocean water is saline and its salt content makes it very corrosive to almost everything. Most naval ships have a lifespan of just 25 years, even with corrosion and biofouling resistant coatings and materials. Biofouling is the accumulation of organisms on anything in an ocean environment.

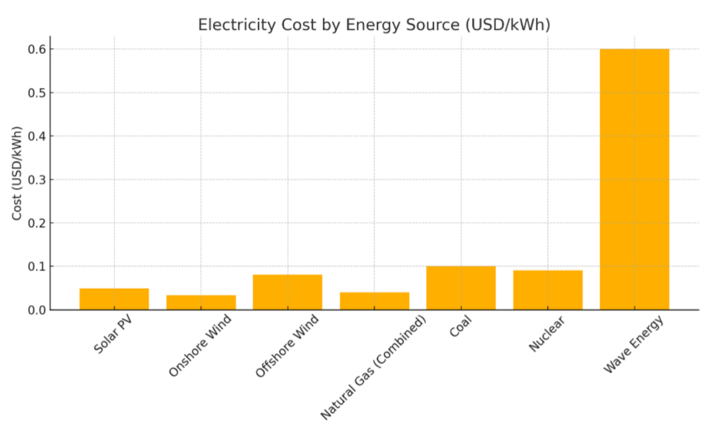


Figure 1: Electricity Cost by Energy Source (USD/kWh)

Despite all the above challenges, wave energy is a desirable source of renewable energy. Compared to solar and wind, which are weather-dependent, wave energy is relatively predictable and thus gives a steady energy supply [5] (IRENA, 2023). Such predictability renders it a desirable complement to other renewables as it is possible to balance supply and demand on the grid.

Moreover, severe droughts have extensively reduced available water resources, restricting the capacity to produce electricity and impact revenue for hydroelectric generators. At the same time, large-scale hydroelectric plants have also come in for increased criticism due to their environmental track record. Alternatively, manufacturers have more and more used tiny scale schemes, known as "small hydro" plants, which produce at the highest 30 megawatts and are considered more sustainable. This prolonged crisis for the hydroelectric sector has stimulated many investors in search of other alternative renewable energies with a conducive environment for innovative small projects like ours that pose smaller environmental footprints, rapid deployment, and scalable potential.

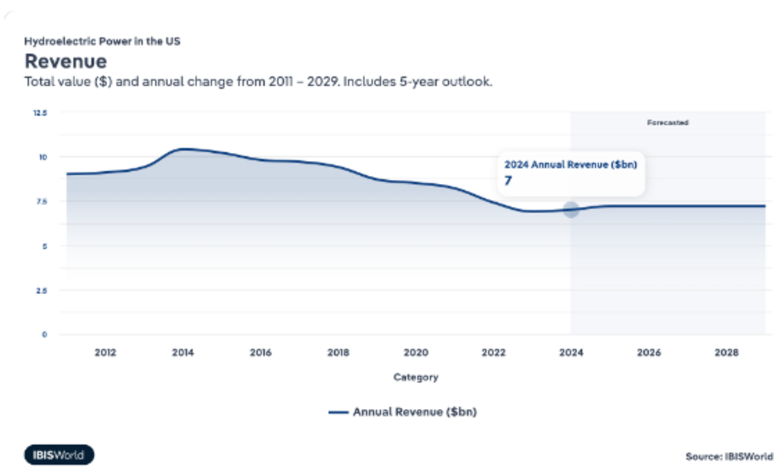


Figure 2: Hydroelectric Power in the US: Total value ($) and annual change from 2011-2029 [6] (IBIS World, 2024)

1.2 Market Analysis and Potential

The economic viability of wave energy remains a challenge, but growing government and private investments are an indication of change. In 2023, the U.S. Department of Energy invested $120 million in wave energy research [7] (U.S. DOE, 2023), and Oregon State University is constructing a wave energy test facility to be opened by 2024 [8] (Water.ca.gov, 2024). These projects indicate a greater effort toward making wave energy economically viable.

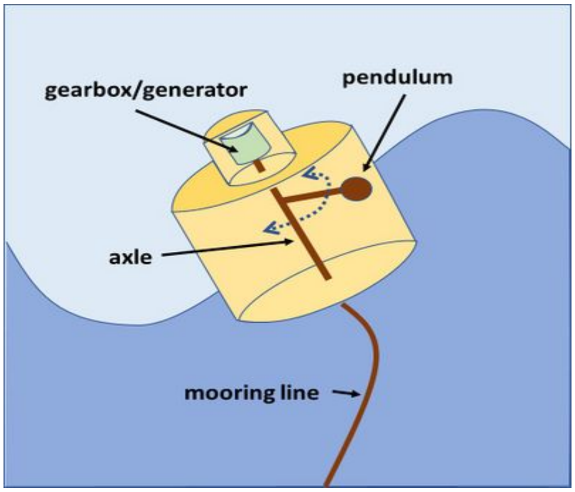
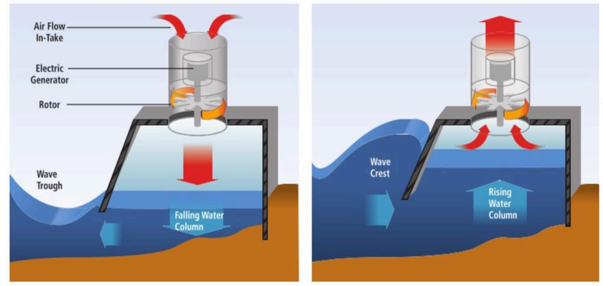
Technologies for Wave Energy Converters are also developing with scientists focusing on making it more efficient and less expensive. Under development are new promising technologies including point absorbers, oscillating water columns, attenuators, and overtopping devices [5] (IRENA, 2023). The newer technologies focus on enhancing durability, optimizing energy harvesting, and reducing maintenance costs.

In the coming years, the future of wave energy is promising. Lowering costs with new materials, streamlined designs, and scalable technology could turn wave energy into a major contributor to the renewable energy mix. Harnessing this vast energy resource successfully would be a giant step toward a healthy and diversified energy system [9] (Ocean Energy Europe, 2023).

1.2.1 Existing Technologies and Market Players

Wave Energy Converter (WEC) Technologies currently under development include:

- Point Absorbers: devices that float on the surface and convert vertical motion into energy.
- Oscillating Water Columns: systems that use air displacement from wave motion to drive turbines.
- Attenuators: long, hinged devices that flex with wave movement to generate power.
- Overtopping Devices: structures that fill with seawater and release it through turbines.

<table>
<tr><th>Point Absorbers</th><th>Oscillating Water Columns</th></tr>
<tr><td>
</td><td>
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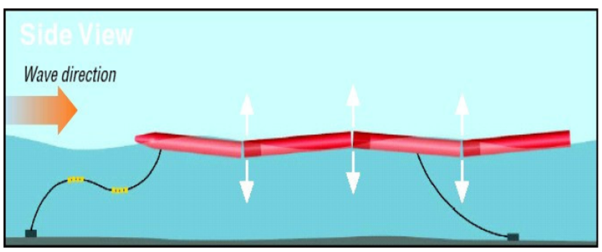
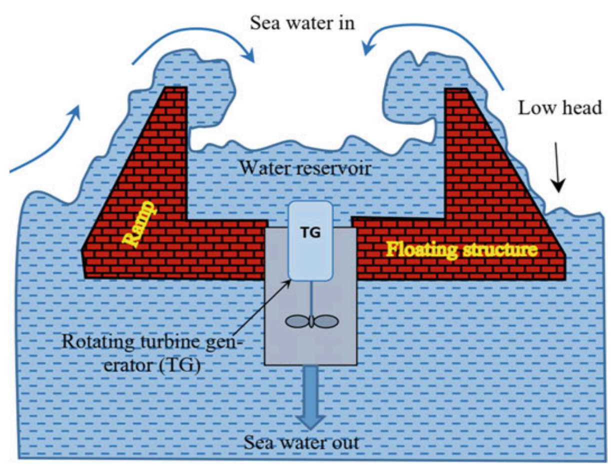
<tr><th>Attenuators</th><th>Overtopping Devices</th></tr>
<tr><td>
</td><td>
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Figure 3: Existing Technologies

1.2.2 Leading Companies in the Sector:

- CorPower Ocean (Sweden): Advanced point absorber technology; high efficiency and performance, but with complex control systems and high maintenance needs.

- Eco Wave Power (Israel): Shore-based floaters attached to existing structures; low maintenance and low-cost, but restricted to built environments.
- Ocean Power Technologies (USA): Buoy-based systems suited for offshore operations; proven in niche markets, but limited in power output.
- CalWave (USA): Submerged systems with low visual impact, still under demonstration.
- Wello Oy (Finland): Developed the Penguin WEC, floating systems with good energy output, but requiring strong marine infrastructure.

1.2.3 Competitive Analysis

Advantages of Existing Competitors:

- Field-proven technologies with deployment history
- Strong government support and funding
- Operational experience in real ocean conditions

Disadvantages:

- Heavy and rigid systems with high logistical and transport costs
- Often optimized for centralized grid-scale power—not suitable for remote/off-grid areas.
- Susceptibility to damage and wear in harsh marine environments.

1.2.4 Strategic Approach to Establishing a Competitive Edge

Our inflatable-based Wave Energy Converter (WEC) offers a distinctive value in the marine renewable sector through:

- **Low Costs** – Inflatables are cheap to assemble, and maintain versus rigid systems.
- **Lightweight & Modular** – No cranes or ships needed for transport or setup, enabling quick deployment.
- **Scalable for Off-Grid Use** – Ideal for remote areas, rural electrification, and humanitarian missions.
- **Rapid Deployment** – Suited for temporary setups and emergency response.
- **Eco-Friendly Design** – Minimizes impact on marine life and coastal environments.

1.2.5 Market Saturation and Opportunity

The global wave and tidal energy market is still in its early stages. The sector is projected to grow from $1.28 billion in 2024 to $19.75 billion by 2032, reflecting a CAGR of 40.75%, which is a clear indicator of strong momentum and ample room for innovation (Fortune Business Insights, 2025).

At the same time, prolonged droughts have undermined hydroelectric output and revenue, while large-scale hydro faces growing environmental scrutiny. As a result, investor interest is shifting toward “small hydro” (<30 MW) and alternative clean energy solutions.

This market transition creates a prime opening for compact, affordable, and modular technologies like our inflatable Wave Energy Converter.

1.2.6 Barriers to Entry and Exit

Entry Barriers:

- High capital requirements for prototyping and deployment

- Complex regulatory and permitting processes
- Technical challenges in unpredictable ocean environments

<u>Exit Barriers:</u>

- Low resale value of specialized marine equipment
- Long-term service or support commitments

Our inflatable, modular system lowers both entry and exit risks by reducing upfront costs, simplifying maintenance, and enabling flexible, small-scale deployments.

SWOT Matrix for *InflatErnergy*:

Strengths	**Weaknesses**
Low-cost, inflatable design Easy to transport and deploy Rapid deployment in emergency/off-grid settings Environmentally gentle footprint	Limited long-term real-sea data Perception challenges with non-traditional materials Validation in harsh ocean conditions still in progress
Opportunities	**Threats**
Decline of large hydro opens space for compact renewables Surge in demand for mobile, off-grid energy systems Increased government and NGO interest in disaster resilience	Competition from established players like CorPower Delays in permitting and policy uncertainties Fast-paced evolution of marine energy technologies

1.3 Stakeholder and field feedback with regards to Inflatable WEC

To better understand user needs, we distributed a structured questionnaire to organizations in disaster relief, infrastructure development, and energy access. The objective was to gather insights into their priorities, cost expectations, and operational constraints related to marine energy solutions.

While feedback collection is ongoing, early responses have been encouraging. Stakeholders expressed strong interest in affordable, compact, and rapidly deployable systems, especially for emergency scenarios needing reliable off-grid power. Key requirements included low maintenance, autonomous operation for over 24 hours, and transportability without heavy equipment. Several organizations also expressed willingness to participate in future field trials or demonstrations. This process is helping us refine our design goals around real-world use cases while building a pipeline of potential users and partners for future scaling.

1.4 Inflatable and Buoys for Ocean wave energy.

As per the previous breakthrough there is another potential wave energy technology that can be used in inflatable and buoys are becoming a trend. According to one of the article focuses on the shape and material aspects (mainly focuses on the GRP (glass reinforced plastic), polyurea, polyurethane and polystyrene) of the buoy which can improve the energy absorption and energy conversion can be efficient from waves (Deliginnia et al.,2023). Furthermore, design from NREL has used two body systems to harvest ocean wave energy in which one body is on the surface and other body is in the water connected with tether connection and there is oscillation movements in the system and that oscillation movements are in form kinetic energy and it is transferred to a conversion system and it converts mechanical energy to electrical energy (Tom et al., 2023). This paper also showcases that use of inflatables make it a more cost effective solution compared to traditional based WEC(Tom et al., 2023). Moreover there is an interesting

WEC using the electromagnetic system. Huang et.al article showcases the effective swing of the buoy system connected to dynamo can induce emf in the generator and this mechanism can be adapted in the buoy WEC (Li et al.,2019).

2. New paradigm design approach to ocean wave energy

2.1 The project approach

Ocean wave energy is not a new concept, but its technological development has been significantly limited by the harsh marine environment, leaving wave energy as an underutilized resource. The success of any wave energy converter (WEC) largely depends on minimizing operational costs (such as maintenance), using durable materials that can withstand marine conditions, and maximizing power generation efficiency (O'Connor et al., 2013). A major cost driver for WECs has historically been the rigidity of their structures, which are prone to damage in rough marine environments and expensive to maintain, making wave energy less competitive in the market (Hasn & Yang, 2023).

One potential solution explored in this project is the use of inflatable structures, which may reduce both capital and operational costs. Rigid WECs often rely on costly materials like steel and incur high maintenance expenses, whereas inflatable designs could present a more affordable and resilient alternative. This work builds on prior research into inflatable WECs, following a successful proof of concept that demonstrated power generation using a single-point absorber inflatable device.

The single-point absorber was selected for its simplicity, functioning as a mass-spring-damper system. In this setup, the damper extracts energy from the wave motion by resisting movement, while the spring stretches and recoils, restoring the device to its original position and releasing stored energy for additional power generation (Guo et al., 2022). An electric motor was chosen to serve as the damper, offering a cost-effective and durable power take-off solution compared to alternative systems (Tom, 2022).

With the proof of concept complete and the single-point absorber design selected, this project now focuses on advancing the design and prototyping of various inflatable configurations to determine the most effective geometry for power generation. The work also aims to improve the efficiency of the power take-off system and investigate marine-grade materials that can extend the device's lifespan. The overarching goal is to implement improvements to the initial inflatable prototype that will reduce the levelized cost of energy (LCOE) to below \$0.20/kWh, making wave energy competitive with other renewable sources such as solar and wind on a commercial scale (Wimalaratna, 2022). As part of this design and prototyping project for a single-point absorber WEC, the following key questions will be addressed:

1. Which inflatable geometry offers the most effective response to wave motion for optimal power extraction?
2. Which materials can improve the survivability of the wave energy converter (WEC), and by how much do they increase durability or lifespan?
3. What are the trade-offs between reducing moving parts to minimize maintenance and the potential impact on overall device efficiency?
4. What design strategies or system improvements can help reduce the device's levelized cost of energy (LCOE) to below \$0.20/kWh?

2.2 The Design (Floating One-Body Point Absorber)

This project uses a floating one-body point absorber wave energy converter (WEC), where a buoy moves with the waves, driving a power take-off (PTO) system anchored to the seabed (Guo et al., 2022). The design features an inflatable body that oscillates with wave motion, pulling a mooring line connected to a motor shaft. A spring retracts the line as the inflatable descends, generating power in both directions.

Studies suggest that buoy shape greatly impacts efficiency, with conical and hemispherical designs performing best (Pastor et al., 2014; Kalofotias, 2016). Accordingly, this project adopts a conical inflatable shape, testing multiple iterations, including multi-inflatable configurations, to optimize wave interaction.

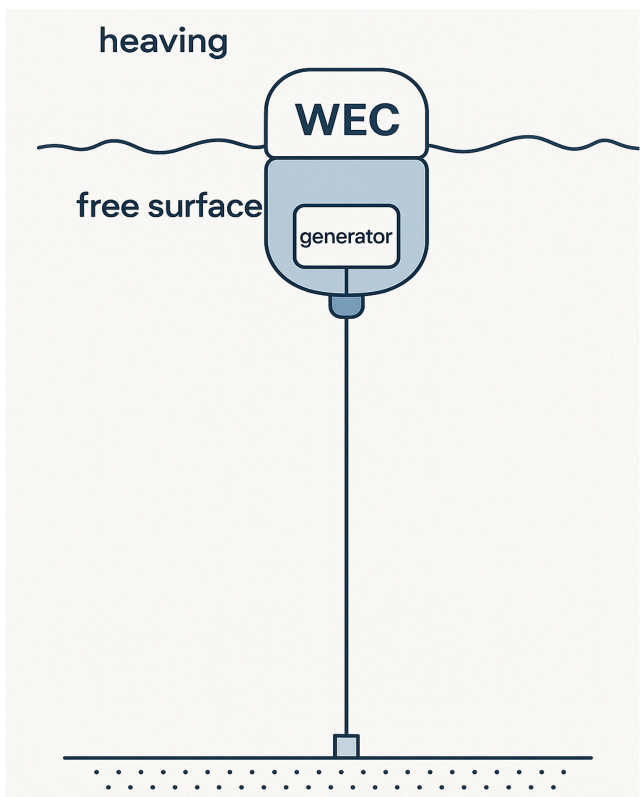

Figure 4: Sketch of the Inflatable Point-Absorber WEC

2.3 System components specifications

This wave energy converter relies on its power take-off (PTO) system, where an AC permanent magnet generator converts wave motion into electricity. As the floating buoy oscillates, it pulls a mooring line connected to the generator shaft, creating rotational torque that generates power.

Thanks to foundational research conducted by the initial team working on this project, a power electronics system was developed to condition the generator's variable power output. This system converts the fluctuating AC output from the generator into a stable DC signal that can reliably power a load, such as charging a cellphone. The conversion process begins with a full-bridge rectifier, which turns the AC signal into DC. A capacitor bank then smooths the signal to reduce voltage ripple and ensure a clean, usable output.

The power electronics are housed in a dedicated electrical enclosure, with cables running from the generator on the WEC to allow for easy monitoring and measurement. To protect the generator from water and physical impacts, it is encased in a custom 3D-printed housing. The key components are listed in the table and figures below:

Name	Specification
Power take off	100W, 600RPM, 85% max efficiency
Mooring line	Wire string / fishing line (inextensible)
Buoy	Inflatable structure
Power Electronics	Full bridge rectifiers, capacitor ban, voltage regulator, power outlet
Load	Light bulbs, cellphone

Table 1: Specification of components

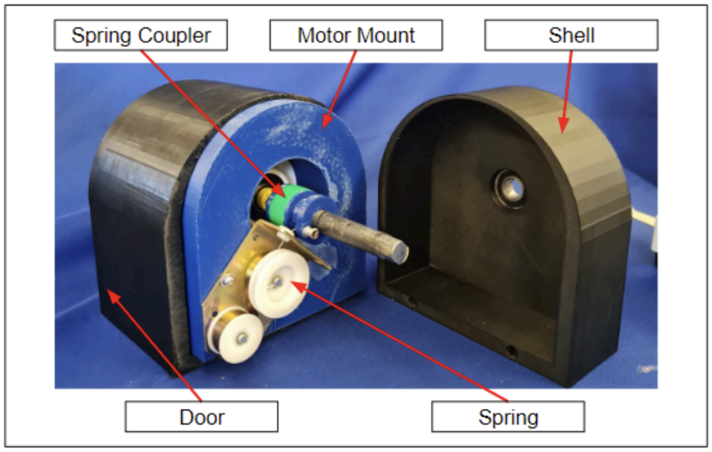

Figure 5: Power takeoff in the 3D housing.

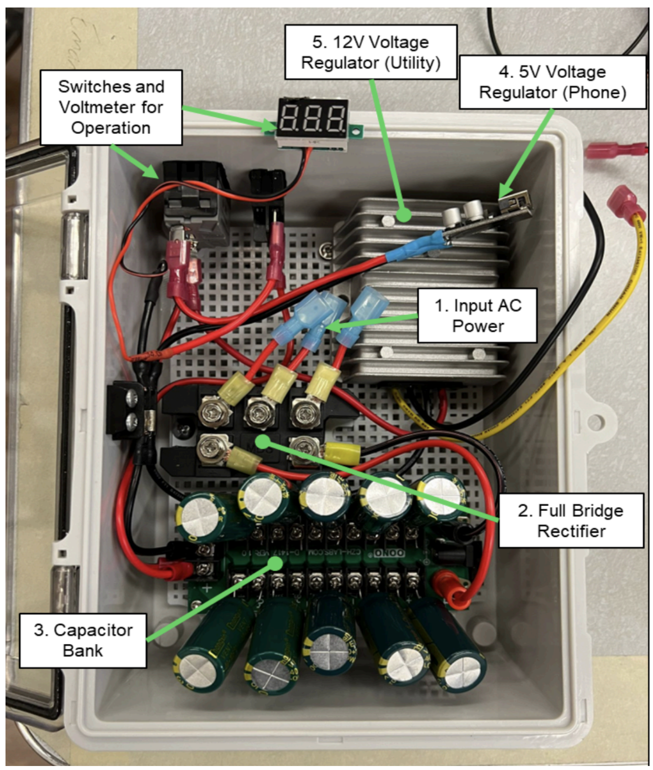

Figure 6: Power Electronics box

2.4 Materials research for prototype

Considering the harsh ocean environment, finding the correct materials for resistance against corrosion is essential. During our initial research there were a few several factors we had to take into consideration. First was the corrosion resistance which is the cause of most maintenance. Second is biofouling resistance, which without could stand a serious chance of destroying any inflatable. Third is UV protection. A lot of plastics can degrade or become brittle when exposed to UV light for long periods of time. Fourth is overall lifespan. Our device needs to last as long in the ocean water as possible before the device is replaced to make the device viable. Lastly is cost, which needs to be reduced as much as possible to allow for this method to be viable in the first place and compete with other green energy and fossil fuels.

The most common material for anything involving the ocean is steel and has been for over a century, and for good reason. Steel is incredibly strong and corrosion resistant while still being very workable and cheap. Steel also comes in a lot of forms for different uses. Mild steel is most often used for ship hulls due to its balance of strength and workability, high tensile steel is used for areas that need to resist extra stress and stainless steel which is used in areas that need additional corrosion resistance. Steel ships are also usually complemented with antibiofouling paints containing copper that stop sea life like algae and barnacles from sticking to it. Steel is most often used on larger ships that need the strength of steel to hold up its massive weight but it becomes to costly and heavy on smaller vessels like pleasure craft and even our device since the constant reapplication of antifouling paints adds a lot of maintenance cost and ways down the device making it less buoyant. For similar reasons a lot of other metals are not viable. An honorable mention goes to titanium since it is the only material that could potentially resist the ocean's corrosion entirely and even has good antifouling properties, however it is entirely impractical for our application due to the sheer complexity of manufacturing.

The other option is plastics. Plastics can provide a variety of benefits, from their corrosion resistance and antifouling properties to their cost and ease of use. The most common material for small craft these days is fiberglass reinforced plastic due to its good strength to weight ratio, durability and relatively low cost. Most fiberglass in ships is made from woven fiberglass which is binded with a thermoset plastic resin, which is most commonly polyester but other materials like epoxy and vinyl are also used. The fiberglass reinforces the plastic resin giving it strength and durability while the resin holds the fibers together and creates a hard surface. However the ultimate problem for fiberglass is that it is not impervious to biofouling and still needs to be coated with antifouling paints regularly and has its lifetime reduced by the continuous UV exposure. As the main issue with wave power is its cost and the main cause of said cost is maintenance, continual coating would only exemplify that issue. The best option for plastics is High Density Polyethylene or HDPE for short as it covers all angles. HDPE is both extremely corrosive resistant and one of the best antifouling materials out there. When researching the longevity of boats based on the material of their hulls, often you will read the line ‘with proper maintenance’. HDPE is one of few that is not referred to as such but instead held in high regard for its low maintenance due to its exceptional resilience against the elements making it an optimal choice for this product.

Material	Steel w/ coating	Fiberglass	HDPE
Corrosion resistance	Great	Great	Great
Biofouling resistance	Good	Good	Great
UV resistance	Great	Great	Good
Ease of manufacturing	Good	Good	Great
Maintenance cost	Poor	Average	Great
Overall cost	Average	Good	Great

Table 2: Materials and its properties

3. Prototyping and Testing

3.1 Prototyping Goals

With the core materials for prototyping and the power take-off (PTO) system readily available, the project progressed into the next phase: assembling the prototype for real-world testing. The main goal of this stage was to evaluate how the prototype would perform in practical conditions, beginning with a small-scale proof-of-concept model and eventually exploring how the design could be scaled for commercial wave energy generation.

The foundation of the prototyping effort was built around the guiding questions outlined in the *Project Approach* section. These included assessing the overall effectiveness of the system, estimating operational costs, identifying opportunities to minimize moving parts, evaluating scalability, and understanding the system's survivability in harsh marine environments.

To address these objectives, the prototyping process followed an iterative approach involving redesigning, reassembling, and testing the system repeatedly. This allowed us to isolate individual components or design features and evaluate how changes would affect performance relative to the key deliverables. In essence, this was a structured trial and error process aimed at refining both function and reliability.

To manage the workload efficiently and take advantage of each team member's strengths, responsibilities were divided across different focus areas such as hands-on prototyping and assembly, analyzing PTO performance during tests, and optimizing the materials and structural design of the prototype.

3.2 Prototype 1: Base Design

The first prototype was assembled with the aim of addressing the key prototyping goals, which included validating the proof of concept, evaluating system efficiency, identifying critical design considerations, and examining material performance. This initial prototype featured a donut-shaped inflatable structure, with the power take-off (PTO) system mounted on a flat circular platform fixed at the center of the inflatable. To ensure balance and prevent the system from tipping or sinking on one side, a counterweight was added opposite the PTO system.

The inflatable design was selected for several practical reasons. Its shape aligns with established research on buoy geometries that provide optimal motion response for point absorber wave energy devices. Additionally, it was a cost-effective and easily accessible option, which helped accelerate the early testing phase. To simulate a controlled aquatic environment, a small inflatable pool was also acquired. This allowed the team to test the prototype's stability in water and observe how efficiently the PTO system converted motion into electrical output. The fully assembled model was placed in the water-filled pool for initial testing, as shown in the figure below.

Figure 7 & 8. Base Design Prototype

3.2.1 Testing and Evaluation of Base Design

Two rounds of testing were conducted to evaluate the performance of the base prototype. The preliminary test, performed in the inflatable pool, confirmed that the device had good floating stability. However, it was quickly observed that the generator shaft was not rotating as expected. This issue was traced to the dry torque of the motor and limitations in the mooring line configuration, both of which were preventing smooth motion.

Further observations from this test also revealed that the inflatable pool was not an ideal environment for wave simulation. Its small size caused wave reflections that interfered with new wave formation, leading to chaotic, non-uniform waves. As a result, the inflatable body of the prototype was unable to oscillate vertically in a consistent manner. Instead, it tended to rock side to side, which significantly reduced the effectiveness of the power take-off system. The open-circuit voltage recorded during this test peaked at only 2.85V, indicating minimal energy generation.

To address the torque issue, modifications were made to the shaft by adding a ring with a larger outer diameter. This allowed for freer rotation by reducing the effect of dry torque on the motor. The ring was designed based on analytical calculations to determine the optimal dimensions needed to overcome static friction. It was 3D printed to fit tightly on the shaft and featured a groove to guide the mooring line and improve rotational control.

The second test was carried out in a larger swimming pool that offered better conditions for wave propagation without significant reflections. Using the same wave height (12 cm) as in the first test, the system showed marked improvement. The generator shaft rotated more freely, and the open-circuit voltage reached a peak of 7.20V; thus, a 2.5-fold increase compared to the first test. This demonstrated the effectiveness of both the design adjustment and the improved testing environment.

3.3 Prototype 2: Modular Model

After completing the tests on the base design, the team gained deeper insight into the behavior, functionality, and dynamics of the mooring line and overall system motion. Several performance issues were identified during the evaluation that informed the direction of the next prototype.

Key Issues Identified:

1. **High Center of Mass and Instability**

   The base design had a high center of mass, which made the structure unstable in water. During testing, the prototype exhibited a rocking motion, causing much of the wave energy to be lost to wobbling instead of being converted into useful rotational motion for power generation.

2. **Drifting and Spinning**

   The prototype also tended to drift or spin due to wave action. This unpredictable motion disrupted the orientation of the device, which reduced the efficiency of energy capture by the power take-off system.

3. **Poor Hydrodynamic Performance**

   The original design lacked a hydrodynamic profile, which caused the structure to respond to wave forces with random and uncontrolled movement. This further hindered consistent energy harvesting.

Design Response and Modular Platform Construction:

To address these challenges, the team developed a second prototype based on a triangular platform design. A triangle offers inherent geometric strength and improved stability, making it an ideal base for supporting the PTO system. For cost-effective fabrication, the platform was constructed using a combination of acrylic sheets and styrofoam. This material pairing provided the following advantages:

- **Acrylic sheets** added rigidity and structural support, preventing bending or warping under load.
- **Styrofoam** contributed lightweight buoyancy, helping to keep the platform afloat and maintain a lower center of mass.

Together, these materials created a modular structure that was more stable, durable, and buoyant. In contrast, earlier platforms made from simple plastic boards lacked sufficient buoyancy and were prone to bending or sinking, especially under uneven weight distribution. The new modular model was designed not only for improved performance but also for easier adjustments and component swapping during iterative testing.

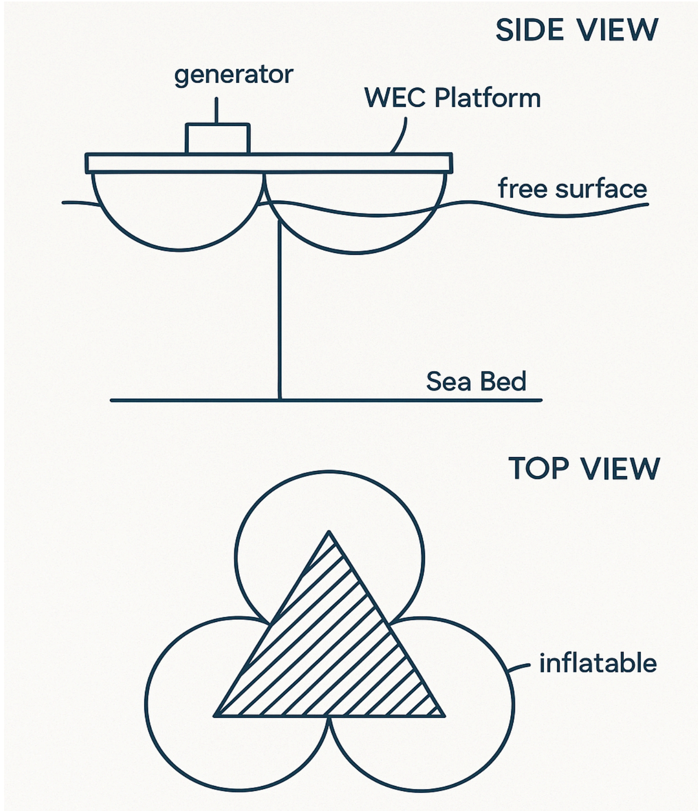

Figure 9: Modular Inflatable Sketch

In the new prototype, the team transitioned from using a donut-shaped inflatable to styrofoam hemispherical balls for the base structure. This modification introduced several key advantages that improved both the stability and functionality of the system.

Benefits of the hemispherical pontoon design:

- **Improved buoyant force distribution:** The hemispherical shape provides a more stable lift in the water.
- **Lower center of mass:** Enhances the system's balance and reduces the likelihood of tipping.

- **Hydrodynamic advantage:** The new shape reduced unwanted motion in the water, such as spinning, drifting, and wobbling, allowing for more consistent energy harvesting.
- **Ease of mounting components:** The hemispheres were arranged into a triangular pontoon configuration, creating a flat and rigid surface that made it easier to securely attach the power take-off system and other components.
- **Flexibility by design:** The modularity component of the inflatable means that they can be re-arranged depending on the type of generator used as well as the environment that they are in.

During testing, the team discovered that over time, the styrofoam began to absorb water due to its naturally porous microstructure, which gradually reduced buoyancy and structural integrity. To address this, each pontoon was carefully wrapped in polyethylene bags and thoroughly sealed, creating a protective barrier that effectively prevented water ingress and maintained the pontoons' performance during extended water exposure.

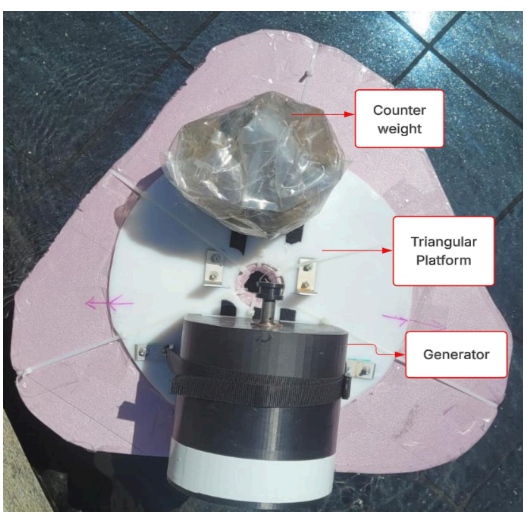

Figure 10 & 11: Modular Inflatable Prototype with Triangular platform

3.4 Prototype 3: Advanced Model

After testing the modular model, several areas for improvement became apparent. While the idea of using smaller inflatables seemed promising from an upscaling perspective, practical challenges arose. As the volume of the device increased, the number of modular inflatables required would grow exponentially, necessitating a larger platform to accommodate the added units. Additionally, the placement of the buoyant inflatables would shift the center of mass, which could alter how the system interacted with wave forces.

Despite these challenges, the advanced model offered several advantages over previous versions:

- **Improved buoyancy distribution:** The buoyant force was spread over a larger area relative to the center of mass, reducing the tendency for the device to bob and wobble excessively in the water.
- **Increased durability:** With a larger physical distance from the water, the device interacted less with the ocean, which could prolong its lifespan.
- **Symmetry and wave interaction:** The design required only a single symmetrical inflatable, which meant that the angle at which waves hit the device became less critical to performance.

As the project progressed, a potential area for further optimization was identified. By removing the counterweight, which currently doubled the weight of the prototype; the device would become more reactive to wave forces, improving its efficiency and power output. Additionally, by lowering the center of mass and further spreading out the buoyancy, we could enhance the stability of the generator, maximizing the conversion of wave motion into rotational energy and ultimately increasing energy production.

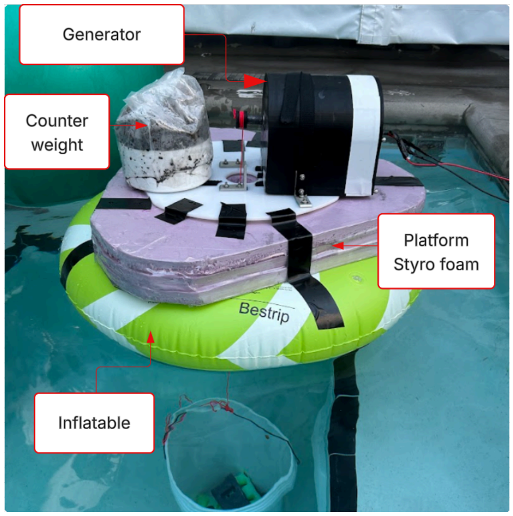

Figure 12: Prototype 3

3.5 Results and Discussion

After testing all three prototypes, the team observed some interesting results and gained valuable insights into the power output of each model. The findings not only helped us understand the effectiveness of each design but also provided a clearer direction for future improvements. To assess the performance of each prototype, the following methodology was employed during testing:

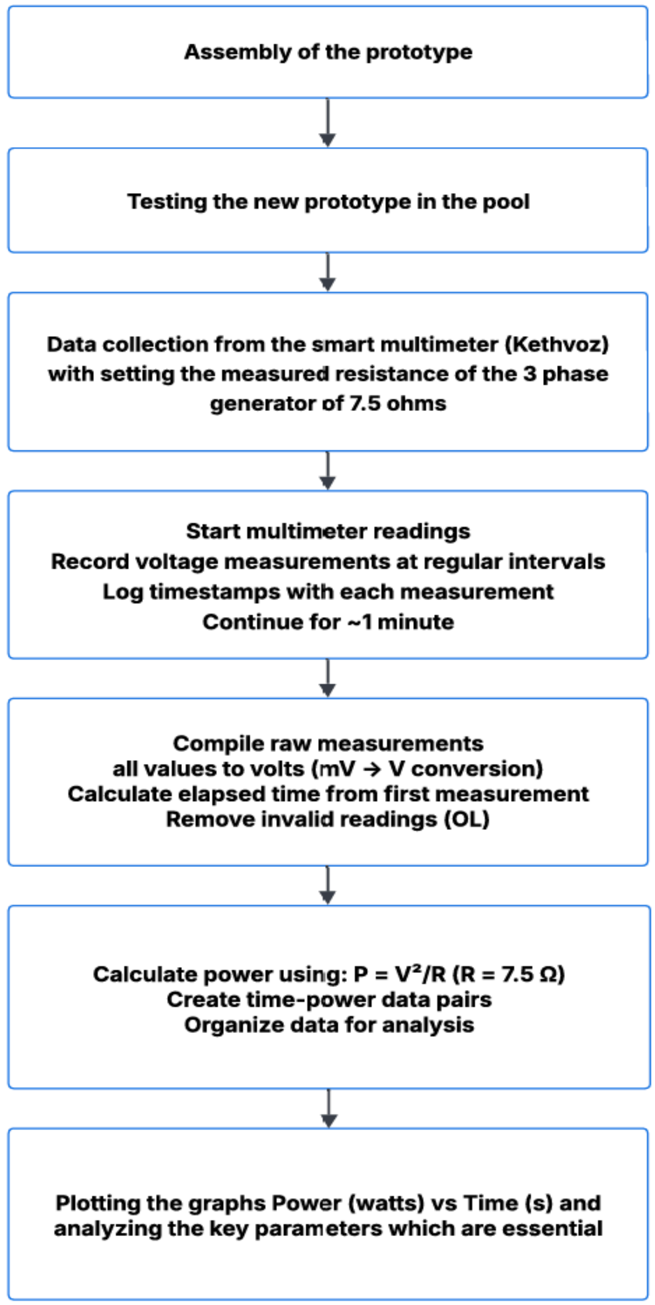

Figure 13: Flowchart for the result analysis

After testing all three prototypes, the team gathered significant insights into the power output and overall performance of each design. The data revealed distinct differences in how the prototypes responded to wave forces and their ability to convert this motion into usable energy.

Prototype 2: Prototype 2 exhibited a more modest range of power output, fluctuating between approximately 1.3W and 2.4W throughout its 60-second test duration. The power curve for this prototype started at around 1.5W, then dipped slightly to 1.4W in the initial seconds before rising sharply to approximately 2.0W at the 7-second mark. Following this initial rise, the power output followed a consistent and subtle increase, reaching a peak of around 2.4W at the 40-second point. After peaking, the power output gradually declined, falling to approximately 1.3W by the end of the 60-second test .

Prototype 3: In contrast, Prototype 3 displayed a much broader power output range, starting at approximately 0W and reaching a peak of up to 9.7W at around 90 seconds. Initially, the prototype showed little activity, with power levels staying near zero for the first 15-20 seconds. However, at the 20-second mark, there was a significant increase in power, with output climbing sharply from around 0.8W to nearly 6W by the 30-second point. This sharp rise in the initial phase marked a key distinction between Prototype 2 and Prototype 3 in terms of how quickly power output ramped up.

Comparison of Overall Performance: When comparing the two prototypes, Prototype 3 demonstrated a major improvement in power generation, with a peak output of 9.7W—over four times the peak power of Prototype 2, which reached 2.4W. However, this increase in power came at the cost of operational stability and the time required to reach peak performance. Prototype 2 exhibited a steeper power decline after reaching its peak, while Prototype 3 experienced a more gradual decrease in power over time, indicating a smoother transition in its performance.

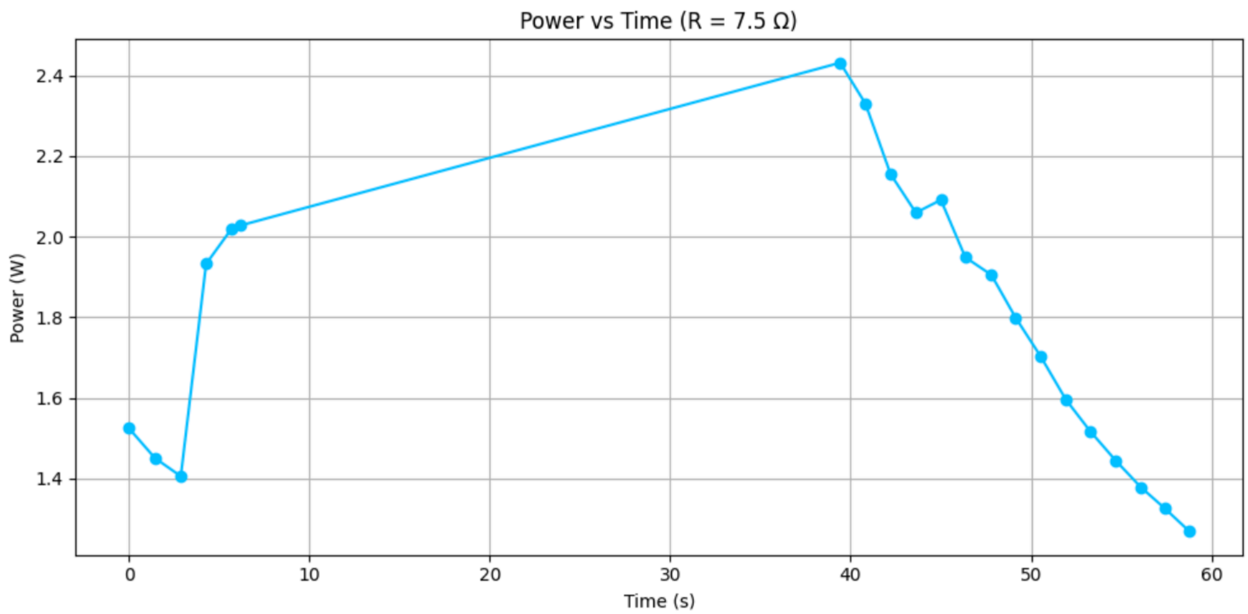

Figure 13: Power vs Time in prototype 2

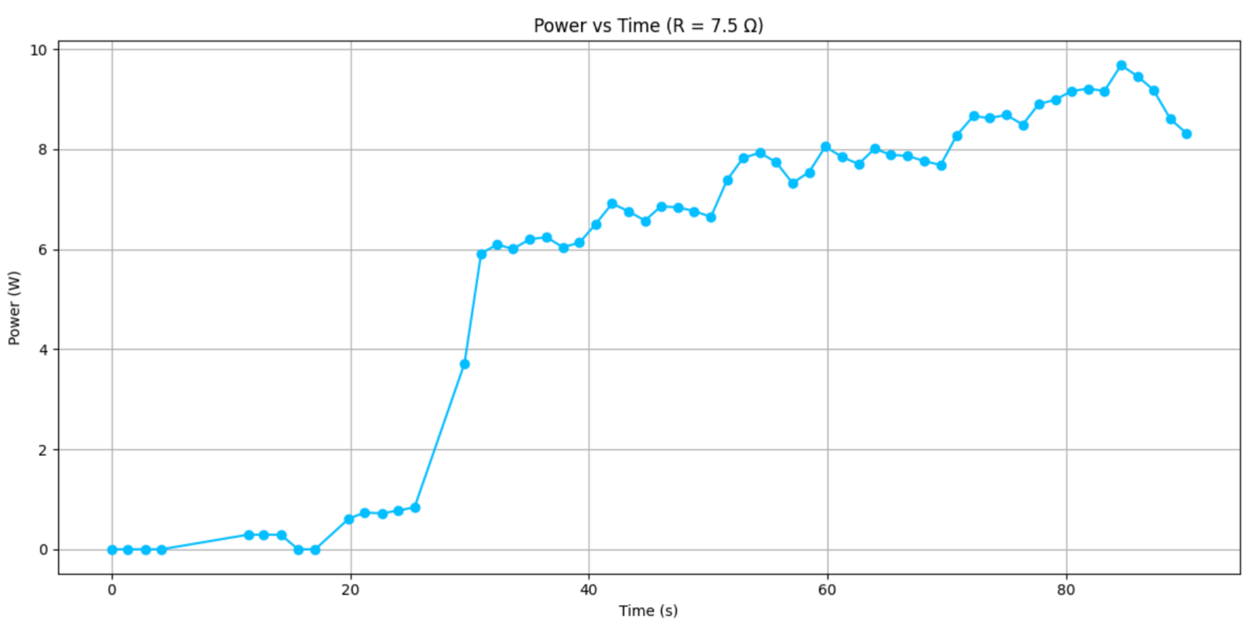

Figure 14: Power vs Time in prototype 3

Prototypes	CapEx ($)	Avg. Power (kWh)	Annual Output (kWh)	LCOE ($/kWh)
1	80	1.00	8.76	0.91
2	90	1.43	12.53	0.72
3	100	5.77	50.53	0.20

Table 3: LCOE calculations for each prototype

Table 3 compares the Levelized Cost of Energy (LCOE) for three models of inflatable point absorbers. Between Prototype 1 and Prototype 3, the development saw a substantial increase in both average power output and annual energy production, as well as a drastic decrease in LCOE—from $0.91/kWh for Prototype 1 to $0.20/kWh for Prototype 3. This observation implies that design optimization resulted in better efficiency and far cheaper energy, with Prototype 3 being the most economically effective and high-functioning one.

The calculation process explains how we calculated each prototype's average power output and efficiency for the LCOE (Levelized Cost of Energy) calculation in Table 3. We measured the peak power output of each prototype while testing: 1.68 W for Prototype 1, 2.4 W for Prototype 2, and 9.7 W for Prototype 3. Wave energy converters typically work below their maximum level. Therefore, the average power was 70% of the peak value. This gave average powers of 1.18 W, 1.68 W, and 6.79 W, respectively. Then, the efficiency of the generator (85%) was multiplied by those values to arrive at the final average power output of Prototypes 1, 2, and 3 at

1.00 W, 1.43 W, and 5.77 W. With these calculated average powers, the LCOE and annual energy output were determined, and it was shown that with enhancement in the prototypes, the energy output increased. At the same time, the cost per kilowatt-hour decreased significantly. This step-by-step calculation shows how the improvement in design and efficiency affects the overall cost-effectiveness of the wave energy converter.

3.6 Ethics & IP strategies

3.6.1 Ethics

During the project, we maintained engineering ethics despite encountering challenges with testing the prototype. As for the testing, the team was trying to use a dedicated wave generator but the tank had persistent leaks that consumed four months of our timeline as we attempted to fix it. We were inclined to use an impractical inflatable pool for testing but understood that this would compromise data integrity - primarily due to challenges with making consistent waves in the pool. Instead of just completing the tasks before the deadlines, the team followed professional engineering ethics by eventually getting in touch with the Legends Aquatic Center facility. It was in line with our commitment to experimental validity, open reporting of challenges, ethically obtained data, and scientific integrity. By refusing to present questionable data and insisting that all tests were conducted according to set protocols with the necessary approvals, we demonstrated that ethical engineering practice goes beyond compliance with rules; it involves adherence to standards that assure reliable and reproducible results—even when such adherence requires additional effort and creative problem-solving. This experience reinforced the idea that engineering ethics is not an abstract concept but a practical framework that guides decision-making within the context of real constraints and pressures.

3.6.2 IP strategies:

While the latest prototype is not yet finalized and requires further improvements before filing for a US patent, the team has outlined a strategic approach for future intellectual property (IP) protection. The initial step in the IP strategy for the inflatable Ocean Wave Energy Converter

(WEC) will be to submit a US provisional patent application within the next three months. This filing will establish priority rights and allow for international filing options to remain open.

The provisional patent application will cover key innovations, including the novel inflatable structure architecture, supported by a comprehensive prior art search of existing WEC technologies and inflatable marine concepts to substantiate our claims. Concurrently, we will implement robust confidentiality measures, such as non-disclosure agreements (NDAs) with all contractors and partners, and establish thorough documentation processes, including witnessed engineering notebooks. Additionally, we will devise a disclosure strategy to determine which innovations should be patented and which should be maintained as trade secrets.

As the 12-month provisional period nears its expiration, we will prepare a complete non-provisional patent application. Depending on market needs, we may file under the Patent Cooperation Treaty (PCT) to maintain international options, particularly in key markets with strong marine renewable energy incentives, such as the US, EU, UK, and Japan. This structured approach will protect our core technology while allowing room for future expansion. The strategy will include quarterly reviews to refine our approach based on technological advancements, changes in the competitive landscape, and potential partnership opportunities, ultimately enhancing UC Berkeley's position and creating strong barriers to competition.

4. Conclusion & Future Steps

4.1 Future Steps

Several critical metrics must still be measured to fully assess the inflatable prototype's performance. First, the true durability of the device in the ocean environment remains largely untested. While predictions can be made based on the materials used and their expected behavior in water, conducting a comprehensive durability and fatigue test is challenging given the project's time constraints. Durability is a key factor in determining the device's cost per kilowatt hour, so understanding the prototype's actual lifespan is essential for accurately gauging its cost, despite the ability to make rough estimates.

Another important area for further investigation is the generator's performance, particularly whether the constant force spring is the most efficient method for counter-rotating the shaft after each wave. While the focus of the project has primarily been on optimizing the inflatable component for ocean use, the efficiency of the generator is equally critical in determining the overall effectiveness of the device. Although it's possible to compare different inflatable designs, evaluating their feasibility in the ocean environment requires more research in these areas.

Regarding the testing environment, using a proper wave tank would significantly improve the consistency of wave generation. In this year's tests, waves were generated by displacing water with a yoga ball, combined with resonance effects. However, this method relied on manual labor and resulted in variability between waves. Installing a more robust wave tank would allow for larger and more consistent waves, leading to more reliable data for future tests.

If the aforementioned steps can be accomplished, the cost of energy production of our device can reach a competitive price point of $0.20 per kWh, and the appropriate coastal regions for which this device is used, then it can be concluded that this device can be used as a reliable and consistent source of renewable energy production. The long-term success of this project is to ultimately help shift energy production methods to a more sustainable method while the short-term goals remain on determining its viability and practicality in the real-world.

4.2 Conclusion

The use of inflatables in wave energy converters is an exciting development in the renewable energy field. Inflatables are cost-effective and easy to manufacture, with the potential to reduce the cost of ocean energy to competitive levels, alongside other renewable sources like wind and solar. Beyond the technical progress made with the inflatable, the team has also gained valuable insights into the target market and potential customers in this sector. The work completed so far represents a significant step towards the next steps – testing the prototype in real ocean conditions, where the true durability and power generation capabilities of the device can be fully evaluated.

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