Brief Introduction of Marine Power

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***Abstract*—Marine energy, throughout the world, is currently undergoing a period of growth in terms of development and implementation. This report is a brief introduction of Marine power technology. History, basic theory, and state of the art designs are introduced. Then, the paper discusses impacts and challenges with relevant stories and industry accounts. In the end, several successful application and related papers are investigated to highlight the considerable potential of marine power technology.**

***Index Terms*— Marine power, tidal power generator, wave energy, renewable energy**

I. History and Basic Theory

Harnessing the power of the ocean has always interested mankind. Marine power, specifically tidal and wave power, involves taking the kinetic energy from the tides, or waves, and converting that energy into electricity. The first tidal mills date back to the middle ages [1]. These tide mills took advantage of the potential energy difference between high and low tides. At high tide, water would be allowed to flow in and fill a large pool or pond. Once this pool was filled, it would be closed off. Then, once the tide had receded, the water would be allowed to flow out and, upon exiting, would spin a water wheel, creating mechanical energy. This energy was typically used to grind grains. Wave power has not been around quite as long as tidal power. However, the first patent to harness the power of the waves was filled in 1799 in France. In 1910, Bochaux Praceique developed the first working wave powered device that he used to power and light his house.

Today there are four methods to generate power using ocean tides [2]-[3]. The first method, Tidal Stream, uses underwater turbines similar to wind turbines to make use of the kinetic energy of moving water. The next method, Tidal Barrage, is the oldest method of generating tidal power, and it works using a specialized dam that allows water to enter at high tide and releases water through turbines at low tides. This works similarly to the earliest tidal mills and takes advantage of the potential energy difference between high and low tides. The third method, Dynamic Tidal Power, is a new, untested method that involves 'T' shape dam like structures. The final generating method, Tidal Lagoon, is also a relatively new generating method that works similar to tidal barrage. However, it is built on an artificial site rather than a pre-existing ecosystem. Although mankind has been attempting to harness marine power for centuries, it was not until 1966 that the first Commercial Tidal Power Plant was opened and not until 2008 that the world's first wave farm was opened.

Marine Power is a rapidly developing field for renewable energy, with new state of the art designs and products being developed all the time.

II. State of the Art designs/products

Despite the fact that marine power is currently in an early stage in terms of its worldwide commercial acceptance and implementation, there are actually a number of technologies that have successfully transcended the research phase and have experienced industry deployment, two of which have been successfully integrated into commercial grids. Many examples of these cutting-edge technologies can be found in both wave and tidal energy [4]. Overall, while a traditional tidal barrage power plant application is still the most realizable and proven method for harnessing energy from the ocean tides, it is no secret that a large percentage of these state-of-the-art products are attempting to deviate from the tidal barrage system.

A. *Wave Energy Converters*

Tidal barrage power plants, since the construction of the Rance Tidal Power Plant in 1966, have proven that the naturally occurring ocean tides can be successfully utilized for electric energy generation purposes on a commercial scale. However, a scheme for converting ocean wave energy into electricity generation with equal success has yet to exist, much less a wave energy conversion technology that has undergone any significant level of commercial grid integration. That being said, the research push for wave energy converters (WEC) is highly active and has been since the beginning of the twenty-first century. WEC's are typically implemented at the ocean surface and extract energy using the surge, heave, or sway motion of wind-induced ocean waves [5]-[6].

B. *Pelamis Wave Energy Converter*

Having established that there are a wide variety of wave energy converter designs that exist in the research pipelines of the marine power industry, it would be unfair to not focus, in detail, on at least one of these state-of-the-art designs [7]. Being classified as an attenuator WEC, the Pelamis Wave

Energy Converter is one such design. Table I is the selection of WEC Categories and device developers.

TABLE I. SELECTION OF WEC CATEGORIES AND DEVICE DEVELOPERS

Device Type	Device Developers
Attenuator	Pelamis, Dexa-Wave, AlbaTERN
Point Absorber	Ocean Power Technologies Wavestar, Seatricity, CETO Wave Energy Technology, SeaRaser
Oscillating Wave Surge Converter	Aquamarine Power, Wave roller, Langlee Wave Power
Oscillating Water Column	Voith Hydro WaveGen, WavEC Pico Plant, Oceanlinx, Ocean Energy
Overtopping/Terminator	Wave Dragon, Waveplane
Pressure Differential	AWS Ocean Energy
Rotating Mass	Wello Oy
Bulge Wave	Checkmate Sea energy

Developed by Pelamis Wave Power in the early 2000'S, THe Pelamis Wave Energy Converter (PWEC) is, structurally, a snake-like apparatus with several tubular subsections linked end-to-end by universal joints. The PWEC floats semi-submerged at the surface of the water and maintains a fixed location and bearing by being moored, or tethered, to the ocean floor. This mooring typically occurs at sea depths exceeding 50m, exceeding the range of near-shore WEC's and qualifying the PWEC as an intermediate off-shore device. Mechanically speaking, the energy conversion is initiated as waves pass under the PWEC, which instigates a complementary bending motion in each of the linked subsections. Hydraulic rams are located at each linking point, and they act to resist the bending motion which pumps hydraulic fluid through pressure smoothing accumulators to drive a hydraulic motor. This hydraulic motor, in turn, rotates an electric generator in the tail of the converter. Figure 1 shows Pelamis Wave Energy Converter.

Figure 1. Pelamis Wave Energy Converter

To date, the PWEC is the first WEC to have been successfully integrated into a commercial electric grid. This grid connection was established in the United Kingdom in 2004. Since then, 5 additional PWEC's have been developed and are undergoing grid-integrated testing at the EMEC in the Orkney Islands and the Aguçadoura Wave Farm off the coast of Portugal. According to an official 2012 report released by the Strategic Initiative for Ocean Energy, the current model of the PWEC, the P2, is capable of a 750 kW daily electric output. Ideally, the successful integration of the PWEC will serve as a means to inspire other WEC designs to ascend past the throes of R&D, and into the prosperity of commercial grid integration and industry acceptance.

C. Tidal Energy Converters

In an effort to push tidal power ever closer to commercial viability, a considerable amount of time and resources has been invested into research and development of Tidal Energy Converters (TEC). These TEC's function as alternatives to tidal barrage plants, the most prominent existing tidal energy technology, and they are hydraulic mechanisms for converting the kinetic energy produced by tidal currents into electric energy. Certain new tidal generation methods look promising, with dynamic tidal power and tidal lagoon on the horizon. However, these methods are still being properly theorized, and, as a result, the staggering majority of state-of-the art TEC designs are in line with the generation method of tidal stream generation.

Much like the WEC's, a large enough accumulation of R&D has occurred over the past decade such that the marine power industry has established several categories of TEC. Table II is the selection of TEC Categories and device developers.

TABLE II. SELECTION OF TEC CATEGORIES AND DEVICE DEVELOPERS

Device Type	Device Developers
Horizontal Axis	Siemens MCT, Anditz Hydro Hammerfest, TGL, Atlantis, Voith Hydro, Verdant Power, Scotrenewables, Tocardo, Straum Hydra Tidal, Oceanflow Energy
Vertical Axis	Neptune Renewable Energy, Ponte de Archimede
Oscillating Hydrofoil	Pulse Tidal
Endlosed Tips (Ducted)	Open Hydro, Clean Current
Helical Screw	Flumill
Tidal Kite	Minesto

D. SeaGen Tidal Stream Generator

When addressing the topic of tidal stream generation, the most prominent stat-of-the-art product that comes to mind would certainly be the SeaGen Tidal Stream Generator. Falling into the TEC category of Horizontal Axis, SeaGen was first developed and deployed by Siemens Marine Current Turbines (MCT) in April 2008.

From a structural standpoint, SeaGen is composed of two rotor branches with turbines at the outer end each of each one. These rotor branches are joined to a central spar unit that can be vertically elevated and lowered on a central mast. The foundation of this mast is embedded into the sea floor, while the top of the mast rises up to a height 15-20 meters above the surface of the water. Turbines assume operation mode whilst the spar and rotor branches are underwater, but by raising he spar above the water and deactivating the turbines, O&M becomes streamlined. Figure 2 shows SeaGen Tidal Stream Generator.

Figure 2. SeaGen Tidal Stream Generator

Mechanically, the turbines rely on the kinetic energy provided by directional tidal currents to induce spinning. Additionally, the turbine blades have a pitch-shifting capability (much like wind turbines) with a rotation range of 180° to correct for reversals in tidal current direction. The aptly named rotor branches house individual rotors that rely on the turbines to achieve rotation. On the inner side, the rotors both feed into a gearbox that itself ties to the generator housed in the mast. The gearbox steps up the speed of rotation represented by the rotor in order to maximize generator output capability.

To date, SeaGen is the first tidal stream generator to have been successfully integrated into a commercial electric grid. This grid connection occurred in July 2008 when a 1.2 MW SeaGen converter was installed in the Strangord Lough, a loch located in Northern Ireland, United Kingdom. In 2012, this SeaGen TEC managed to output 5 GWh of electricity into the Northern Ireland electric grid.

III. Impacts

Wave and Tidal power have the ability to cause major impacts in the world should they evolve into a more popular power source. The impacts from tidal power have both advantages and disadvantages. Tidal power is able to cause impacts in both the environment and the economy. As tidal power grows as a source of energy, so will its impact in the world [8].

Tidal power is capable of making a global impact on the environment via its lack of greenhouse gas emissions [9]. By using tidal power, one is able to cut down on the carbonization of the world. However, while tidal power is environmentally friendlier than other sources on the global scale, it does have several negative environmental impacts on the local level. The invasive structures could cause strike damage to local marine life via rotor blades and other moving parts. The tidal power source could also interfere with animal movements and migrations through the plants ability to alter the current and waves. The plant also has the ability to interfere with animal migration through the emission of electromagnetic fields. Those emissions have the ability to obstruct some marine animals' ability to navigate. There is also the potential hazard from operation due to the toxicity of the paints, lubricants, and antifouling coatings used in the plants. There is also significant worry should anything break, because the resulting leaking hydraulic fluid would also cause damage.

The economic impact from tidal power could be very beneficial to anyone seeking to invest in the research of this field. Should tidal power get further out of the research stage, it has the ability to develop a market for developers and suppliers of the necessary equipment for a plant. One example of the economic impact is how China is installing a dynamic tidal power plant instead of constructing two nuclear plants. China is spending $160 million on this project. The project is also improving international relations since it is a Dutch and Chinese project. However, it can be costly when errors are made. A small error in the coding of one SeaGen plant causes the rotor system to be destroyed. Since the blades are pitch shifting, the error caused the pitch to be incorrect, and the forces of the tides were able to break the rotors.

IV. Research and Development

A. Challenges

There are many challenges to perfecting Marine energy. One of the main problems tends to occur after the development stage of a prototype; the prototype is destroyed due to the extreme forces of the tidal waves. This is unfortunate because of the financial expense of these prototypes. Since they are prototypes, a variety of diverse, expensive materials will be used until the process is perfected. The research and development programs for this renewable energy are always under-budgeted due to unknown expenses. When these programs go over budget, they are rushed to make a final product which has not been properly tested. This is what leads to so many failed prototypes. There is also a lack of interest in this field because companies are more interested in finding oil in the ocean rather than producing electricity. Investors are also not interested in losing money if a prototype breaks when tested.

B. Funding

The research and development for converting kinetic marine energy into electrical energy is growing very slowly. Europe has been funding this research since the 1980's and still continues to do so.

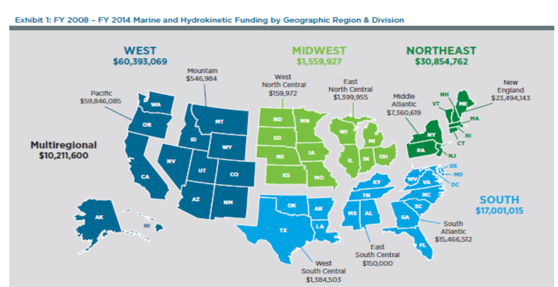

Figure 3. Map of U.S. funding

Other marine energy funding is coming from the U.S., Scotland, and China. Recently, China has been the largest funder because of a project that is projected to be the largest dynamic tidal plant in the world. They've spent 160 million dollars on this project so far. A map of U.S. funding is shown in Figure 3.

C. Potential

There is a lot of potential for marine energy if it can be properly developed. This is a map of the potential energy that could be harnessed along the U.S. coastlines. This would be enough energy to power many homes in the U.S. In just the southern Alaskan region, this energy could power over 100,000 homes.

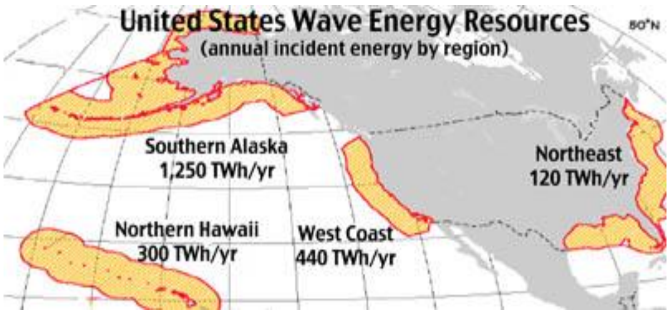

Figure 4. Map of the potential energy

D. Commercialization

To commercialize any product, it must go through many development steps, a procedure known as the technology journey. Marine energy is no different. The first step of the technology journey is basic research. This is to prove that the principle is possible and can be useful. Applied research goes more in depth to prove that the concept is true. Once the research is finished, early demonstrations can be performed. These demos show whether or not the product will be viable. If the early demos succeed, full scale demonstrations will be made to show that the product has scalability. After this step occurs, marine energy research would build its first farms to ensure durability. These farms are also known as arrays in marine energy. Once all of these steps are achieved, marketability can be simulated.

V. SUCESSFUL APPLICATION

Since tidal stream generators are an immature technology, there are less than 20 power stations that are in operation. Many tidal power stations are only at a proposal stage.

A. Four Biggest Tidal Power Station

Since tidal stream generators are an immature technology, there are less than 20 power stations that are in operation. Many tidal power stations are only at a proposal stage. The four biggest operating tidal power stations are introduced.

1) Sihwa Lake Tidal Power Station

Sihwa Lake Tidal Power Station (Figure 5) is the world's largest tidal power installation, with a total power output capacity of 254 MW; surpassing the 240 MW Rance Tidal Power Station which was the world's largest for 45 years prior to 2011. It is operated by the Korean Water Resource Corporation.

The tidal barrage makes use of a seawall constructed in 1994 for flood mitigation and agricultural purposes. Ten 25.4 MW submerged bulb turbines are driven in an un-pumped flood generation scheme; power is generated on tidal inflows only and the outflow is sluiced away. This slightly unconventional and relatively inefficient approach has been chosen to balance a complex mix of existing land use, water use, and conservation, environmental and power generation considerations.

Figure 5. Sihwa Lake Tidal Power Station

The tidal power station provides indirect environmental benefits as well as renewable energy generation. After the seawall was built, pollution built up in the newly created Sihwa Lake reservoir, making its water useless for agriculture. In 2004, seawater was reintroduced in the hope of flushing out contamination; inflows from the tidal barrage are envisaged as a complementary permanent solution.

2) Rance Tidal Power Station

Rance Tidal Power Station (Figure 6) is the world's first tidal power station. The facility is located on the estuary of the Rance River, in Brittany, France. Opened on the 26th November 1966, it is currently operated by Électricité de France (EDF).

Its 24 turbines reach peak output at 240 megawatts and average 62 megawatts, a capacity factor of approximately 26%. At an annual output of approximately 540 GWh, it supplies 0.012% of the power demand of France. Besides, the barrage is 750 m long, from Brebis point in the west to Briantais point in the east. The power plant portion of the dam is 332.5 m long and the tidal basin measures 22.5 km^2.

Figure 6. Rance Tidal Power Station

The La Rance tidal plant produces a source of energy that is clean, renewable and sustainable. It has no impact on climate because it does not omit any greenhouse gases. The pattern of the tides is preserved so that the impact on species living in the estuary is minimal. The operator, EDF, monitors the tides and weather forecasts to program the barrage operations on a weekly basis.

3) *Annapolis Royal Generating Station*

The Annapolis Royal Generating Station (Figure 7) is a 20 MW tidal power station located on the Annapolis River immediately upstream from the town of Annapolis Royal, Nova Scotia, Canada. It is the only tidal generating station in North America. The generating station harnesses the tidal difference created by the large tides in the Annapolis Basin, a sub-basin of the Bay of Fundy. Opened in 1984, the Annapolis Royal Generating Station was constructed by Nova Scotia Power Corporation, which was, at the time, a provincial government Crown corporation that was frequently used to socially benefit various areas in the province.

Annapolis Royal Generating Station has had mixed results. While effectively generating electricity, the blocking of water flow by the dam has resulted in increased river bank erosion on both the upstream and downstream ends. The dam is also known as a trap for marine life. In August 2004, when a mature Humpback whale swam through the open sluice gate at slack tide, ending up trapped for several days in the upper part of the river before eventually finding its way out to the Annapolis Basin.

Figure 7. Annapolis Royal Generating Station

4) *Jiangxia Tidal Power Station*

The Jiangxia Tidal Power Station (Figure 8) is the fourth largest tidal power station in the world, located in Wuyantou, Wenling City, Zhejiang Province, China. Although the proposed design for the facility was 3,000 kW, the current installed capacity is 3,900 kW, generated from one unit of 500 kW, one unit of 600 kW, and four units of 700 kW.

Figure 8. Jiangxia Tidal Power Station

This facility also hosts a 40 kW solar PV power installation with an estimated 45,000 kWh annual production capacity. This system is composed of 216 pieces of 185 W monocrystalline solar modules manufactured by Perlight Solar. The power station feeds the energy demand of small villages at a 20 km distance, through a 35-kV transmission line.

Table III is the comparison of these four biggest tidal power stations.

TABLE III. FOUR BIGGEST TIDAL POWER STATIONS

Name	Sihwa Lake	Rance	Annapolis	Jiangxia
Year	2011	1966	1984	1980
Cost(million dollars)	293	120	Unknown	1.9
Turbine	10	24	1	6
Tidal Range(m)	5.6	8	6.5	8.4
Capacity(MW)	254	240	20	3.9
Annual-Generation(GWh)	552.7	540	50	7.32

B. *Plans for world's biggest wave farm*

The UK government approved a plan for building the world’s biggest wave farm in Scotland. Full consent has been given for a 40MW farm off the north-west coast of Lewis - enough to power nearly 30,000 homes.

Figure 9. Oyster

Oyster, shown in Figure 9, is the wave generators. It will play an important role in the plan. Scotland needs both wave and tidal stream technologies to help decarbonize the electricity system, increase energy security and reduce dependence on imported fossil fuels.

C. *Interesting Invention*

Someone in Lebanon invent the ‘Iris’ sculptures to get the electricity for daily use. It looks like an eye and can provide shelters as well as generate power. The conceptual structures are designed as a way of reclaiming Beirut’s shoreline for locals who could use them to harvest electricity and as look outs.

Designed to look like an eye, the ‘Iris’ sculptures would open and shut like an eye to provide shelter and would be connected to a buoy in the sea to harvest electricity. An offshore buoy with an electric generator attached via an ‘extended antenna’ would play a role in allowing the sculptures to harvest tidal power, but it is not known how much electricity the structures could generate.

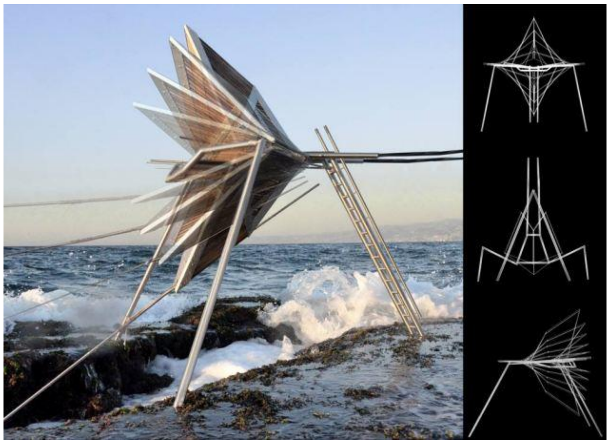

Figure 10. Iris Sculptures

VI. RELATED PAPER—TIDAL ENERGY MACHINES: A COMPARATIVE LIFE CYCLE ASSESSMENT STUDY

A. Introduction

This investigative study is done by the University of Leeds, Sheffield and York compares four different types of marine energy harvesting devices that capitalize on tidal forces from the ocean’s depths [10]. At this point in time anthropogenic climate change is inevitable and its effects are visible in the world’s climate. Temperature rise, glacial retreat, rising sea levels, shrinking sea ice, warming of the oceans, and extreme weather occurrences are all evidence of this climate change. In order to slow these degenerative effects on our planet we must limit the amount of greenhouse gases that are consistently bombarding our atmosphere. One of the main culprits being CO^2 gas, or carbon dioxide. 184 Megatons of CO^2 were emitted in the course of energy generation and supply in the UK during 2011, which is 40% of total emissions for the UK. This being in the UK alone raises concern for many individuals and they plan to decarbonize their national grid by utilizing Marine power. The Carbon Trust estimates that a contribution of up to 20% of total UK energy generation could be provided by marine energy by 2050. Due to marine energy being at its infancy, a wide spectrum of device types currently exists, and a market leader has yet to emerge. By observing the multiple devices being compared in this study, there will be one or two clear-cut choices for the future of marine energy cultivation.

B. Ideal Site

A fictional site was chosen instead of a specific site that could skew the results in favor of a particular device. The use of a fictional site would also avoid potential problems gathering data for existing sites. The hypothetical site was located in the UK, in a 5km wide channel between the mainland and an island. The sea bed area available for tidal energy extraction was assumed to be about 1km by 1km.The conditions included a 50 meter water depth, a maximum tidal range of 2.6m; mean tidal velocity of 2.5m/s, 5 ° angle between tidal ebb and flow, and a bedrock seabed. The site was also to be connected to the shore by cables and then linked to local and national grid with an 11kv substation located on the coast. The site was assumed to be located just north of the British Isles, and to experience a cool climate. Average summer and winter temperatures were assumed to be 12 and 4 °C respectively, with frequently strong winds.

Figure 11. Location of Ideal Site

C. Devices

1) The Tidal Generation Ltd(TGL)

DeepGen device (Figure 12) is a tri-blade single turbine design, with a support structure mounted by piles to the seabed. A 500 kW prototype has been undergoing testing at EMEC since 2009. The body and foundations of the device are constructed largely from steel, with the blades being of composite construction. The company’s commercial device is rated at 1MW and has a 25 year design life.

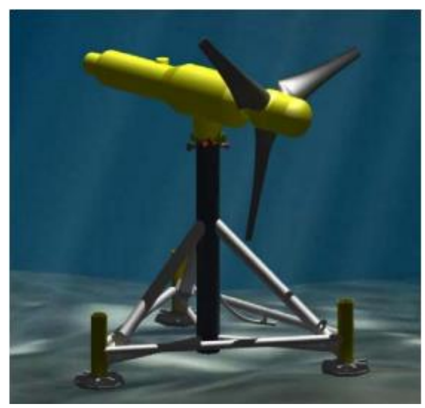

Figure 12. TGL DeepGen Device

2) The OpenHydro device

The OpenHydro device (Figure 13) is an open-center horizontal axis multi-blade turbine with a ducted housing, known simply as the Open Centre Turbine. Four commercial-scale devices are currently being installed in an array off the Brittany coast. The device is constructed primarily from steel, with glass reinforced plastic blades. Commercial scale devices are rated at 2MW and as having a 20 year design life. The company has developed an installation method using their own specific installation barge.

3) The ScotRenewables

The ScotRenewables SR2000 device (Figure 14) is a floating twin horizontal axis turbine design, with cable moorings, constructed of steel with composite blades.A 250kW demonstration device has undergone a 12 month testing period at EMEC in the Orkney Islands. The commercial scale device will be rated at 2MW, and is designed for installation in arrays of 10MW, with a 20 year design life.

Figure 13. OpenHydro Device

Figure 14. ScotRenewables Device

4) Flumill

Flumill (Figure 15) is a unique twin Archimedes' screw design of tidal device, mounted to the seabed by a monopole foundation. A test device has been installed at EMEC for 3 months. The commercial scale device will be constructed from PVC Foam with a composite shell, and is rated at 2MW for a 20 year design life.

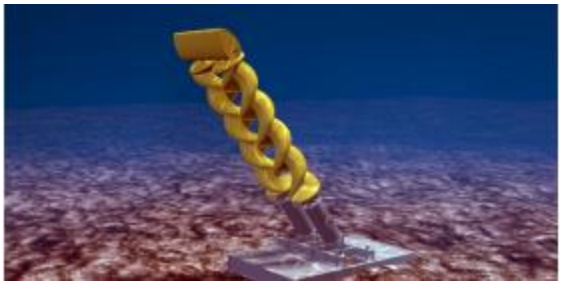

Figure 15. Flumill Device

D. Life Cycle Assessment

Each of the devices are put through a 100 year hypothetical test in this study that determine which of the four devices has the lowest impact on the environment and the highest energy output. This test includes the energy costs and CO^2 output of producing the materials, manufacturing, transportation, installation, maintenance, and the recycling of each device in the 10MW array required.

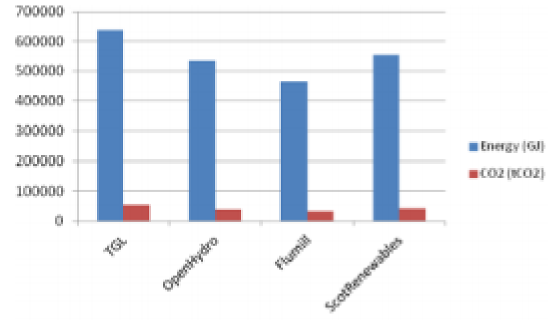

Figure 16. Embodied Energy & CO^2

Figure 16 shows the total embodied energy and CO^2 output created from each individual device over a 100 year period. Noticing that the TGL has the highest in each category, this is mainly due to the fact that it's a 1MW design vs. a 2 MW design like the other devices. This in the end causes much more maintenance costs and CO^2 emitted due to the TGL array needing 10 devices instead of 5 for each of the other devices.

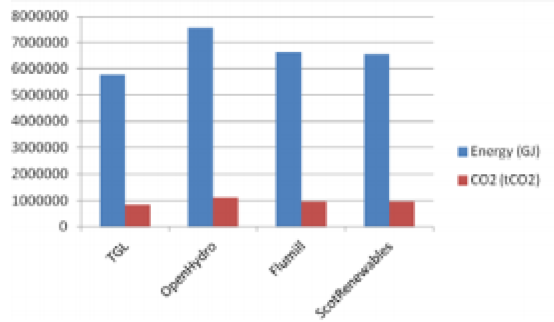

Figure 17. Lifetime energy generation and CO^2 savings per array

Figure 17 displays the surplus values of energy generated and amount of CO^2 saved after taking the manufacturing of each array into account. Each device flirts with about a million tons of CO^2 saved, which has the ability to make great headwinds if coal plants slowly become decommissioned at the same time further decarbonizing the UK's power grid and easing up on the environmental impact humans create with their insatiable energy demands.

E. Device Comparison

One of the most efficient ways to make an accurate assessment on which device is superior to the next is to see which device has the quickest payback periods for embodied energy and CO^2. This enables investors to get a quick view of what could be the most lucrative option money wise and what will give the quickest return on investment environmentally speaking in order to tackle the energy crisis taking place.

1) TGL

Table IV compares each device's payback periods with the TGL DeepGen being dead last at 11.2 years. As mentioned earlier, it is at a disadvantage due to each individual device being a 1MW design compared to the others being 2MW.

However, the TGL device power curve means it performs well in high tidal velocity areas compared to the other devices.

TABLE IV. PAYBACK PERIODS FOR ENERGY AND CO^2

Payback	TGL	OpenHydro	ScotRenewables	Flumill
Energy(yrs)	11.2	7.3	8.7	7.2
CO^2	5.9	3.6	4.5	3.5

2) The OpenHydro device

The results of the study indicate that the OpenHydro device produces the largest amount of energy over the functional unit. The OpenHydro device achieves energy payback quicker than the others, but has high materials energy requirements.

3) The ScotRenewables

The ScotRenewables device has the lowest energy requirement for installation, maintenance and decommissioning. These low values are due primarily to the mooring system, which allows the device to be easily towed to the installation site and installed more easily than the other three devices, which all require piled foundations to the seabed.

4) Flumill

The Flumill device has the lowest in both categories due to its low weight design, low maintenance costs, and relative simplicity of the device design. By looking at Figure 17, it is shown to be tied in second with energy production at 6.5 million GJ produced.

F. Conclusion

TABLE V. RANKINGS

Devices	Payback Period (Energy)	Payback Period ($C0^2$)	$C0^2$ Intensity ($gC0^2$/kwh)	Devices & Lifetimes	Energy Produced (100yr period in GJ)
TGL	11.2	5.9	34.2	10,4	5800000
OpenHydro	7.3	3.6	19.6	5,5	7500000
Flumill	7.2	3.5	18.5	5,5	6500000
ScotRenewables	8.7	4.5	23.8	5,5	6500000

By observing the results of Table V, it's easy to see that the Flumill array has the greenest cells, which means it's ideally the best device for this study. However, the OpenHydro array produces the most energy and is relatively close in the other categories to the Flumill. If materials cost and an energy requirement wasn't a concern this would be most ideal. The TGL array gets poor results again due to the need for 10 individual devices needed compared to 5 with the rest. This device would outperform the others in areas with high tidal velocities, so this design type could actually be more effective if the company producing these devices could reduce their initial costs to make it a more competitive option. In terms of simplicity of installation, maintenance, and recycling, the ScotRenewables array is superior.

The purpose of this study was to compare devices that are superior in their own way if certain variables are given more weight than the others. Marine energy is very close to be implemented heavily on a global scale due to the great potential in many areas of the globe. Each potential site around the world has different conditions and this study is based on a fictional site in order to reduce bias. Just like with other types of renewable energy, there isn't a clear-cut solution that will solve all of our energy needs. Each region of the earth favors different types of energy production and this is the point the authors of this study were trying to get across.

VII. CONCLUSION

Marine power has great potential. As more and more money is being invested into this technology by various countries and individuals, the time is near for marine energy to become integrated into lives and to reduce the amount of damage people have already done to the planet.

References:

[1] Minchinton, Walter Edward. "Early tide mills: some problems." Technology and Culture, pp.777-786, October 1979

[2] Evans, Robert. *Fueling Our Future: An Introduction to Sustainable Energy*. New York: Cambridge University Press, 2007.

[3] Chang, Jen. "Hydrodynamic modeling and feasibility study of harnessing tidal power at the Bay of Fundy." ProQuest, 2008.

[4] Yorozu, T., et al. "Electron spectroscopy studies on magneto-optical media and plastic substrate interface." *IEEE Trans. Magnetics*, vol.2, pp. 740-741, 1987.

[5] Miller, E. H. "A note on reflector arrays (Periodical style—Accepted for publication)." *IEEE Trans. Antennas Propagate*, 1990.

[6] Alqueres, J. L., and J. C. Praca. "The Brazilian power system and the challenge of the Amazon transmission." Transmission and Distribution Conference, Proceedings of the 1991 IEEE Power Engineering Society. IEEE, 1991.

[7] Hwang, Sunghwan. "Frequency domain system identification of helicopter rotor dynamics incorporating models with time periodic coefficients." 1997.

[8] Schmitt, Russell J., and Craig W. Osenberg, et al. *Detecting ecological impacts: concepts and applications in coastal habitats*. Academic Press, 1996.

[9] Attrill, Martin J., and Michael Power. "Climatic influence on a marine fish assemblage." Nature 417.6886, pp.275-278, 2002.

[10] Walker, Stuart RJ, et al. "Tidal energy machines: A comparative life cycle assessment study." Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 2003.