Robertson. Ocean Wave Energy Generation on the West Coast of Vancouver Island and the Queen Charlotte Islands, Guelph Engineering Journal, (3), 9-18. ISSN: 1916-1107. ©2010.

Ocean Wave Energy Generation on the West Coast of Vancouver Island and the Queen Charlotte Islands

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The west coast of Canada is one of the most active ocean wave zones on earth and, with many remote communities living on the offshore islands, extracting clean renewable energy from these waves is highly desirable. The Wave Dragon Over-Topping Device and the Pelamis are analyzed for usage on the west coasts of Vancouver Island and the Queen Charlotte Islands. The wave environment requirements, grid penetration ability, and capacity factors for these two devices on both coastlines show excellent potential for power creation in the future. On Vancouver Island, the Pelamis System and Wave Dragon achieved capacity factors of 51% and 21% respectively, while on the Queen Charlotte Islands, 59% and 30% values were reached. The Queen Charlottes present an excellent opportunity for renewable wave energy due to their isolation from the main electrical grid.

Nomenclature

ρ = density
g = gravity
H = wave height
$H_{1/3}$ = significant wave height
T = wave period
$T_{1/3}$ = significant wave period
a = wave amplitude
λ = wave length
u = wave celerity

I. Introduction

The west coast of Canada is one of the most active ocean wave zones on earth and, with many remote communities living on the offshore islands, extracting power from the waves that break along their shores is an attractive proposition. Extracting power from ocean waves has historically been extremely difficult due to the lack of knowledge in wave theory and the adverse working environment of the ocean. However, as new composite materials and equipment design for marine environments advance, the ability to extract power from ocean waves has become more feasible.

The number of methods and devices that extract power from waves increases every day, yet a few have risen above the rest and realized commercial scale products. The Wave Dragon Over-Topping Device and the Pelamis are two devices that both have reached commercial scale (no longer using scale-models) and operate efficiently within their targeted wave spectrums. This report studies the theory behind extracting power from ocean waves, assesses of possible locations on the west coast of Canada, and gives a detailed non-economic feasibility study for both the Pelamis and Wave Dragon devices.

II. Wave Energy Theory

Waves are created by any force that causes water particles to move out of their natural equilibrium position. In the oceans and all large water bodies, waves are created by wind blowing across the water surface. These winds are the result of differential heating of the earth's surface by solar energy. The waves generated are dependent on the length of time the wind blows, the strength at which the wind blows, and the undisturbed water surface (fetch) over which the wind blows. During this phase of wave creation, the resultant surface disturbances are called wind waves; however, once the wind/wave relationship has reached equilibrium and the wave propagates out of the area of wind influence and the resultant wave trains are known as swells.

Gravity waves (as wind created waves are known) can be characterized by several defining characteristics. Wave Height, *H*, is the distance between the wave trough and the wave crest while wave amplitude, *a*, is ½ the wave height. Wave period, *T*, is the time required for two successive wave crests/troughs to pass a fixed point, and wave speed, *u*, or celerity is the speed at which a wave disturbance passes a fixed point. Wavelength, λ, describes the horizontal distance between successive wave crests/troughs (Komar, 1998).

While these are the classical wave characteristics, $H_{1/3}$ and $T_{1/3}$ are generally more widely used in wave energy calculations. $H_{1/3}$ and $T_{1/3}$ represent the average value of the highest 1/3 of reported wave heights and wave periods. These values are what a casual observer would report if asked to report on the wave conditions at any point in time. This is relevant since most historical wave data is based on observations by ships' crew, lighthouse keepers and beach goers, rather than direct measurement by scientific equipment.

Further wave classification is separated into shallow, intermediate and deep water waves. This grouping is important due to the amount of energy present in a deep water wave, which is approximately 10% greater than in a shallow water wave. Waves are classified as deep water waves if their wavelength is at least double the depth of water through which the waves are travelling. If water depth is shallower, then the wave "feels" the ocean floor, looses potential energy to frictional effects and becomes increasingly difficult to model.

The amount of power P in single a deep water wave (per unit crest length – W/m) can be calculated by (Komar, 1998):

$$P = \frac{\rho g^2 H^2 T}{32\pi} \tag{1}$$

In general the wave conditions off the west coast of Canada range from 1 m to 8 m in height and vary from 5 second to 20 second periods. Large wave periods indicate that the area of wave generation was far from the coastline on which those waves are breaking. Large wave heights are more indicative of the wind speed in the area of generation rather than the distance travelled.

III. Wave Energy Conversion Devices

Wave energy conversion (WEC) devices are generally categorized as shallow or deep water wave power extraction devices. Shallow water devices have historically had better penetration into the renewable energy market due to their relative ease of installation and maintenance. The predominant shallow water system relies on an oscillating water column (OWC) driving a reversible air turbine. However, as each wave moves into shallow water (prior to power extraction via the OWC), they lose substantial amounts of extractable power. For this reason, many of the newer designs are working on off-shore concepts.

In contrast, deep water devices are able to access the full potential of the energy within each wave, but given their offshore location are expensive to install and difficult to maintain. The required grid-connect armoured cable drastically increases the cost of the installation and has often made these installations economically infeasible. Generally, deep water WEC devices are either point absorption or attenuator type devices. Point absorption devices feature a single buoy or point device that acts as a float and "bobs" with each passing wave. Many variations of point absorbers are currently available but they all extract power from the "bobbing" motion of the float. Attenuator type devices vary greatly in their method of extraction.

This report will focus on the Wave Dragon Device by Wave Dragon Aps of Denmark, and a variation of an attenuation type device, the Pelamis by Pelamis Wave Power Ltd of the United Kingdom. These two devices have both gone through the initial process of research and development (R&D), 1/7 device scale wave tank prototyping and have now reached a commercial scale product. These two products have also undergone destructive testing since, in the event of extreme swell and weather events, the unit must survive and not require replacement. Contrary to general perception and media releases, very few WEC devices have reached this stage of development and most are still in the R&D stage.

A. Wave Dragon Over-Topping Device

The Wave Dragon device can theoretically be mounted at any depth, but are generally located closer to shore to reduce seafloor mounting costs and electrical losses from distant installations. The Wave Dragon System features a large water reservoir, an over-topping ramp, an outlet turbine, and two large reflector arms. As a wave passes the Wave Dragon, each wave washes up the ramp and fills the water reservoir. The main water reservoir is located above sea level and thereby creates pressure head, which the turbine then turns into electrical energy. See Figures 1 and 2 for diagrams detailing the water path and orientation of turbine.

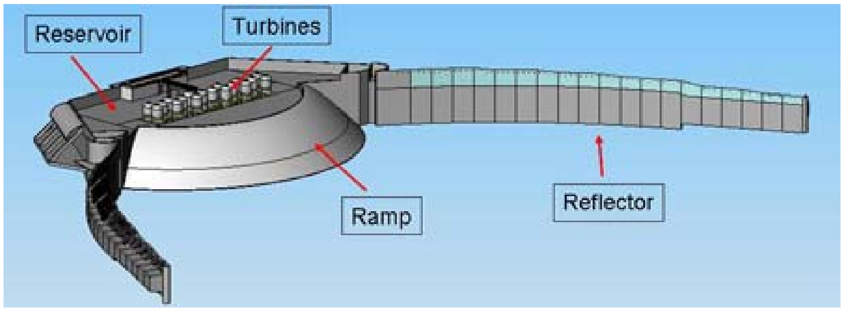

Figure 1: Wave Dragon Overview (Wave Dragon, 2010)

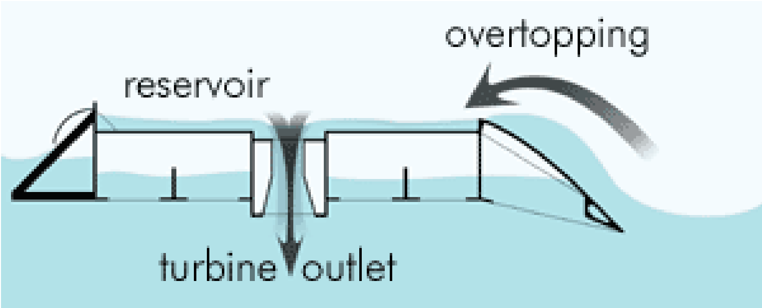

Figure 2: Wave Dragon System (Wave Dragon, 2010)

The design of a Wave Dragon system incorporates two large elliptical shaped wave reflector arms, which act to increase the incoming wave characteristics prior to the over-topping ramp. As a result, an incoming 1m wave can be amplified to create a much larger and energy dense wave flowing over the ramp and into the reservoir. These devices are semi-slack mounted and mounted into the direction of the most favorable swell. However, as the seasons change on the British Columbia coast, the dominant direction switches between northerly dominated and southerly dominated swells. The semi-slack mounting system allows the Wave Dragon to rotate a limited amount to take advantage of the seasonal swells, yet not enough to be able to extract the total available energy from the incoming wave spectra.

One major advantage of the Wave Dragon system is its' large size. Having such a large stable platform on-site allows much to the repairs, service and maintenance to be done on site, rather than towing units back and forth to ship yards. This is a huge reduction in cost and allowed for constant maintenance.

In this report a 7000kW Wave Dragon system will be analyzed for applicability on the west coasts of Vancouver Island and the Queen Charlotte Islands. A similar system was planned for installation in the Irish Sea, close to Milford Haven, before the global economic crisis.

In Table 1 (Dunnett et al, 2009) describes the rated power extraction from incoming wave spectra, depending on wave height H_s and period T_p. This performance curve helps describe the response of the system in differing wave climates and allows planners to maximize performance based on the wave train characteristics.

Table 1: Wave Dragon Power Output (kW)

	T_p (secs)												
H_s (m)	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1.0	160	250	360	360	360	360	360	360	320	280	250	220	180
2.0	640	700	840	900	1190	1190	1190	1190	1070	950	830	710	590
3.0	0	1450	1610	1750	2000	2620	2620	2620	2360	2100	1840	1570	1310
4.0	0	0	2840	3220	3710	4200	5320	5320	4430	3930	3440	2950	2460
5.0	0	0	0	4610	5320	6020	7000	7000	6790	6090	5250	3950	3300
6.0	0	0	0	0	6720	7000	7000	7000	7000	7000	6860	5110	4200
7.0	0	0	0	0	0	7000	7000	7000	7000	7000	7000	6650	5740

B. Pelamis Wave Energy Conversion Device

The Pelamis System is a deep water, attenuator-type device that is composed of numerous long cylindrical floating sections, joined by hydraulic energy extracting hinges. Each device is approximately 130m in length by 3.5m in diameter (Yemm et al, 2008). Figure 2 (Pelamis Power Ltd) shows how the Pelamis system extracts energy via both the heave and pitch motion of incoming wave trains. The slack moored system allows the Pelamis to orient itself perpendicular to wave crests, the most effective orientation for power extraction. Each hinge joint features four hydraulic rams, a reservoir, high pressure accumulators and a motor/generator set. As each hydraulic ram is compressed or extended, high pressure fluid is transferred to an accumulator which drives a hydraulic motor, which in turn drives the electrical generator. As the cylindrical floats are moved via ocean waves, one side of the hinged joint will extract power from the heave motions, while the opposite side will extract pitch energy.

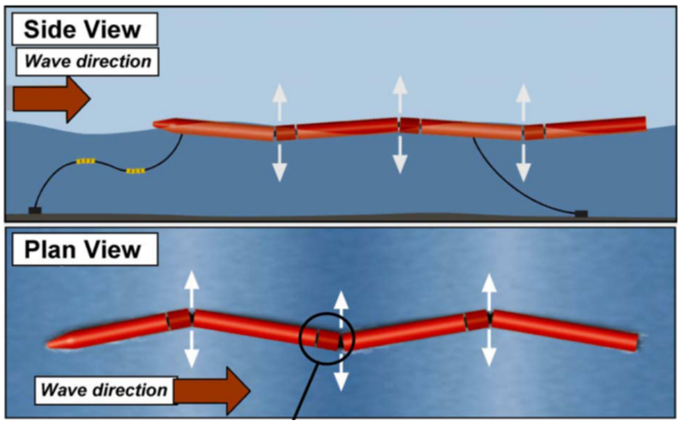

Figure 2: Pelamis Extraction System (Pelamis, 2010)

Given the small footprint and energy extraction possible for a single unit, Pelamis' are generally deployed in a farm style arrangement (Henderson, 2005). This allows the electrical output from each Pelamis to be joined at a single hub and sent to shore via a single seedbed cable. Each Pelamis system is rated at approximately 750kW and the mechanical to electrical conversion efficiency is quoted to be 70 – 80% (St Germain, 2005). One of the major advantages to the Pelamis system is low cost associated with maintenance as each device can individually be removed from the farm and towed back to a suitable location for maintenance (St Germain, 2005).

Table 2 (Boronowski, 2009) shows the amount of power extracted is dependant on the wave height and period. Given the extraction method, the length and volume of each floating tube can be optimized for expected wave energy resource height and period distribution. While this optimization is beyond the scope of this report, Pelamis Wave Power Ltd is reportedly developing a new configuration better suited for the west coast of North America than the current UK version (Dunnett et al, 2009). The west coast version would be optimized to extract more energy in continual long period / small wave height situations, which are experienced year round off the west coast of Canada.

Table 2: Pelamis Power Output (kW)

	T_p (secs)																
H_s (m)	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13
1.0	0	22	29	34	37	38	38	37	35	32	29	26	23	21	0	0	0
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
2.0	57	88	115	136	148	453	152	147	138	127	116	104	93	83	74	66	59
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
3.5	0	270	354	415	438	440	424	44	377	362	326	292	260	230	215	202	180
4.0	0	0	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
4.5	0	0	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
5.0	0	0	0	739	726	731	707	687	670	607	557	521	472	417	369	348	328
5.5	0	0	0	750	750	750	750	750	737	667	658	586	530	496	446	395	355
6.0	0	0	0	0	750	750	750	750	750	750	711	633	619	558	512	470	415
6.5	0	0	0	0	750	750	750	750	750	750	750	743	658	621	579	512	481
7.0	0	0	0	0	0	750	750	750	750	750	750	750	750	676	613	584	525
7.5	0	0	0	0	0	0	750	750	750	750	750	750	750	750	686	622	593
8.	0	0	0	0	0	0	0	750	750	750	750	750	750	750	750	690	625

IV. Location and Resource Assessment

A. Location Assessments

BC Hydro is mandated to provide affordable power for all residents of BC, while slowly beginning to introduce a more diversified portfolio of renewable energy sources. British Columbia is still largely powered by large and small scale hydro electric power plants. Global models estimate the wave power potential off the west coast of Canada to be approximately 40,000 MW (Campbell, OREG, Buigues et al, 2008). Vancouver Island is connected to the mainland power grid via an aged underwater transmission line, while the Queen Charlotte Islands run a completely spate electrical grid. For these reasons, both are interested in creating enough power generation on island to ensure they are not dependant on outside sources of power for their power requirements. As a result, these two locations are excellent for renewable wave energy deployments.

Vancouver Island currently has a load requirement of approximately 2000 MW (Robertson, 2010), and generally “imports” power from the mainland via three high voltage undersea cables, which are constantly requiring repairs and upgrades.

The Queen Charlotte Islands feature two smaller electrical grids, a north grid and a south grid. The north grid is rated at 11.4 MW and is powered solely via the Masset Diesel Generation Station, while the southern grid, rated at 14.85 MW, features both a hydropower scheme and a back-up diesel generation system (Boronowski,. 2009). For the purposes of this paper, it is assumed that the two power grids will be grid tied together and wave power generation will be utilized by all residents.

B. WEC Locations

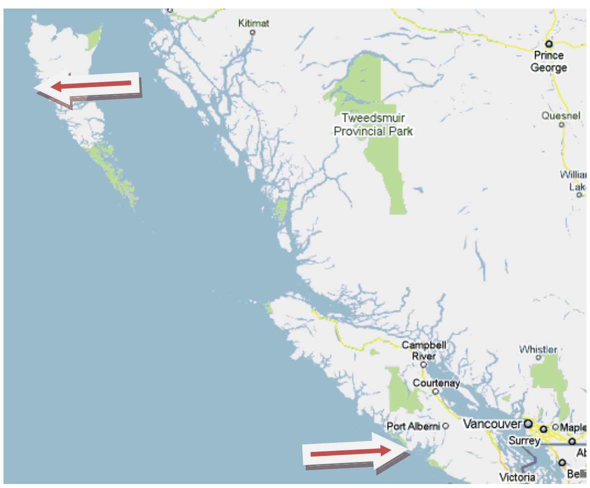

Figure 3: WEC Locations

For each island group, a close to shore site has been chosen for the Wave Dragon and an offshore site to the Pelamis System. The Wave Dragon system has been placed further inshore to take advantage of refractional bending of waves around land masses to minimize the directional spread of the wave spectra and maximize the power output per wave (without undue stresses being placed on the system). These locations have been chosen due to proximity to major grid ties or major urban centers, and suitable bathymetrical conditions. BC Hydro has long identified Amphitrite Point (Latitude: 48°55.16’N, Longitude: 125°32.55’N) near Ucluelet, as the most suitable location for an Wave Dragon (Power Supply Engineering, 2001), while a suitable offshore location for a Pelamis System is found at 48°55.42’N, 125°33.31W. Both of these systems are within 20 – 24 km of the Long Beach 30 MW substation.

In the Queen Charlotte Islands, reliable information on the location of electrical substation could not be found; therefore locations have been chosen to maximize their bathymetric suitability and wave power potential, while ensuring close proximity to urban centers. The Wave Dragon system could be installed at the 53°26.02N, 132°40.219W, while 53°24.766 N, 132°46.58 W would be a suitable location for a Pelamis farm. These two locations are within 20 km of Rennel Harbour and the electrical grid (The Sheltair Group, 2008). See Figure 3 for a graphical view of locations.

C. Power Grid Penetration

The addition of any variable energy output source to the electrical grid can create system loading issues and disturbances to the greater system. As a result, electrical governing bodies set maximum percentages for the penetration of such sources into the electrical grid. Grid Power Penetration is calculated according to equation (2) (Robertson, 2010).

$$\text{Grid Penetration} = \frac{\text{Maximum Renewable Power Output}}{\text{Total Grid Power}} \tag{2}$$

British Columbia Transmissions Corporation (BCTC), predicted that a 10% penetration would be possible on Vancouver Island, while the Queen Charlotte Island system would allow 20%, due to the smaller size and quick reaction times of both the diesel and hydroelectric systems on the islands (Robertson, 2010). This results in 200 MW of renewable generating potential on Vancouver Island and 5240 KW for the Queens Charlotte Islands.

V. Storage Options

As with all renewable energy systems, variability in the power output can create transmission problems when attempting to grid-tie systems. Creating storage systems as a "buffer" to the main electrical grid can increase the penetration allowances. The 10% and 20% allowances used in the report both take into account the use of pumped water storage to act as a buffer system. On Vancouver Island, the Jordan River Hydroelectric system supplies 32% (170 MW) of Vancouver Islands generating potential and is an excellent storage option for any renewable energy systems implemented on Vancouver Island (Times-Colonist, 2001).

VI. Vancouver Island Suitability Analysis

The ambient wave environment off the west coast of Vancouver Island has been characterized by the wave spectra data at the La Perouse Bank buoy (Number 46206 - 48.834 N, 126.00 W) downloaded from the National Oceanic and Atmospheric Administrations' (NOAA) website (NOAA, 2010). Figure 5: Queen Charlotte Wave Climateillustrates the variation in wave heights over a single year in 1996. A comparison of wave heights to residential power usage over the year reveal that the two curves follow the same trends with lower wave heights and power usage in the July/August time frame, while wave heights and power usage peak in December every year. This trend allows for the most efficient combination of power creation and usage over the year, allowing for greater grid penetration (St Germain, 2005). Using equation (1) and the average values for height and period calculated from the downloaded data, the calculated average wave power is 51.505kW/m. The blue line in the graphs indicates the recorded wave heights over the year, while the black line indicates the averaged wave height trend over the year.

It should be noted that the location of the Vancouver Island deployment is just beyond the boundary of Long Beach National Park. Large scale operations with significant geographic footprints would undoubtedly run into major local opposition, therefore small footprint technologies would be preferred.

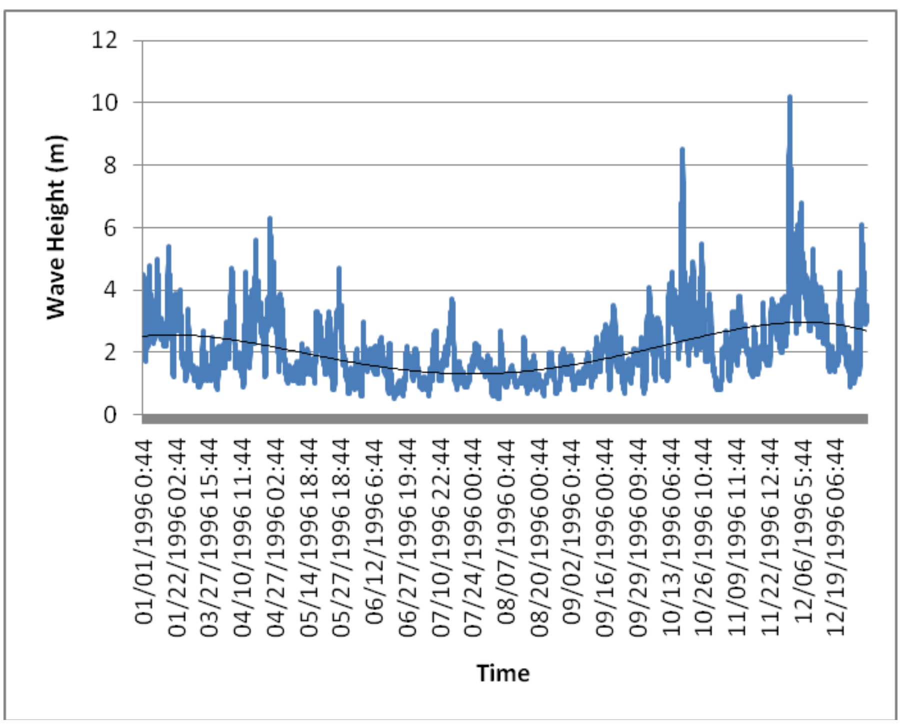

Figure 4: Vancouver Island Wave Climate

A. Wave Dragon Device

The Wave Dragon system analyzed in this report has a maximum power output of 7000kW, however as illustrated above, the system does not always run at full power output and it is therefore important to analyze the capacity factor of the system, i.e. what percentage power output that should be expected given the ambient wave climate. In order to calculate this value, the data downloaded from the NOAA website was characterized and extrapolated into the categories shown in Table 1. Each wave height and period value was given a fractional value of the overall wave environment; i.e. if the percentage values for all instances of wave height and period were summed, they would total 100. The fractional value in each instance was then multiplied by the claimed power output given in Figure 2, and the total summed. This total expected output, based on the wave environment, was then divided by the total value from the sum of all values given in Table 1. For the Wave Dragon system, the expected capacity factor was calculated to be 76.2%.

However, the Wave Dragon system is semi-slack mounted and unable to rotate fully, therefore it cannot take advantage all incoming wave trains - due to directional spreading. At the proposed locations, geographic effects will force refraction of incoming waves to a more suitable angle for generation but the shallow water will result in incoming wave power losses. Assuming that all wave directions received the same wave height and period spread, Table 3 describes the expected performance of the Wave Dragon System (Robertson, 2010, NOAA, 2010). For example, 39% of the incoming swell comes from the SW, and therefore the Wave Dragon system is oriented to extract all of this power, hence the 0% ”Energy Loss”, while just 4% of incoming swell comes from the NW and 90% of this power is lost due to the orientation of the Wave Dragon system. The “Shallow Water Retention” category accounts for the assumed 10% loss in incoming wave power due to the Wave Dragons’ shallow water location.

Table 3: Directional Spreading of Incoming Wave Data for Wave Dragon (Vancouver Island)

		Energy Loss	Shallow Water Retention	Energy
NW	4%	90%	90%	683
W	26%	30%	90%	31073
SW	39%	0%	90%	66585
S	24%	30%	90%	28683
SE	7%	90%	90%	1195
	100%	**Total estimated Power**		**128219**
		Directional Corrected Capacity factor		**0.515**

Taking into account the directional and shallow water aspects of the Wave Dragon system, a capacity factor of 51.5% should be expected, not the 76.2% previously reported. In order to supply 200MW, or 10% grid penetration of the Vancouver Island electrical grid, approximately 56 Wave Dragon systems would be required. A more detailed analysis would be required if this option was being considered as geographical footprint required to install 56 Wave Dragon systems would be extremely large. It should be noted that the 200 MW quoted is the maximum penetration BC Hydro recommends and, in order to maximize renewable use, the capacity factor is used to calculate the number of units required. However, if all units were working at maximum output, this figure would be greatly exceeded and this excess generation would be diverted to pumped storage at Jordan River.

B. Pelamis Attenuator System

The Pelamis system analyzed in this report has a maximum reported output of 750 kW (Pelamis Power, 2010), which is small when compared with the Wave Dragon system, but the required geographical footprint (130m x 3.5m) and required infrastructure is also considerably smaller. The possible extracted power for the Pelamis system off the west coast of Vancouver Island, based on performance characteristics, was calculated to be 18018 kW. Comparing this to the total possible energy extraction of 86198 kW, results in a capacity factor of just 20.9 %. The Pelamis system is slack moored in deep water and therefore will naturally rotate into a position for maximum wave energy extraction. As a result, the capacity factor need not be corrected for the directional variation of the incoming wave spectra and shallow water losses. However, with just 20.9% capacity approximately 1276 Pelamis systems would be required to meet the 10% grid penetration of Vancouver Island.

VII. Queen Charlotte Islands Suitability Analysis

The ambient wave environment off the west coast of the Queen Charlotte Islands has been characterized by the wave spectra data at the West Moresby buoy (Number 46208 – 52.52N 132.68W) (NOAA,2010). Figure 5: Queen Charlotte Wave Climate5 shows the comparatively more active ambient wave conditions off the Queen Charlotte Islands. This results in higher expected power extraction from WEC systems, yet increases the chance of extreme wave and weather events damaging the equipment and resulting in higher operational costs. Using equation (1) and the average values for height and period calculated from the downloaded data, the calculated wave power is 77.76 kW/m.

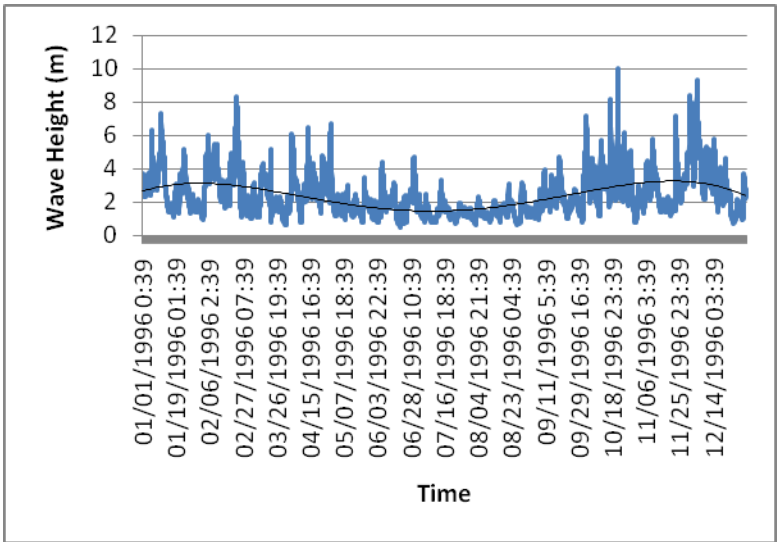

Figure 5: Queen Charlotte Wave Climate

A. Wave Dragon Device

Following the procedure outlined in the previous section, and the values in Table 4 the total non-directionally corrected capacity factor for the Wave Dragon calculates to be 87.98%, yet only 59.46 % when recalculated for directional spreading. It was assumed that the incoming wave spectra is equal to those experienced off the coast of Vancouver Island and that all directions received equal distributions of wave heights and periods. While the authors' experience would show errors in this assumption, no reliable data for the chosen installation position could be found

Only 1.3 Wave Dragon systems would be required to achieve 20% grid penetration to the Queen Charlotte energy grid (5240 kW). Combined with the close proximity and currently operating hydroelectric system in place on Moresby Lake, it may be possible to install 2 Wave Dragon systems and utilize the Moresby Lake reservoir as a pumped storage location during periods of high generation but low usage. In addition, the added cost of transporting diesel fuel for power generation in the Queen Charlottes results in a higher per kW economic cost and would increase the economic feasibility of an Wave Dragon system.

Table 4: Directional Spreading of Incoming Wave Data (Queen Charlotte Islands)

		Energy Loss	Shallow Water Retention	Energy (kW)
NW	4%	90%	90%	789
W	26%	30%	90%	35899
SW	39%	0%	90%	76926
S	24%	30%	90%	33137
SE	7%	90%	90%	1381
	100%	**Total estimated Power**		**148131**
		Directional Corrected Capacity factor		**0.595**

B. Pelamis Attenuator System

The Pelamis system analyzed for the Queen Charlotte Islands achieved a capacity factor of 29.5% which is considerably better than 20.9% achieved off Vancouver Island. Again, given the lower energy requirement in the Queen Charlotte Islands, the use of Pelamis systems as a source of renewable supplementary power deserves further detailed study. Only 23 systems would be required to meet a 20% grid penetration.

However, both the Pelamis examples show that further research and development by Pelamis Power Ltd in optimizing the Pelamis system for the ambient wave conditions on the west coast of Canada would greatly increase the capacity factor and economic feasibility. For example if the cylinder lengths were increased to allow for more power extraction from high period, low height swell would greatly increase the capacity factor.

VIII. Conclusion

The power extraction feasibility of wave energy conversion devices on the west coast of Vancouver Island and the Queen Charlotte Islands has been critically analyzed and shows substantial potential for usage in certain situations. In isolated coastal locations with low energy consumption expectations, this analysis shows considerable potential for these WEC technologies. The Queen Charlotte Islands would require just two Wave Dragon systems or 24 Pelamis systems would be required to maximize the allowable 20% grid penetration. However, incomplete data sets present only a partial picture of the situation. Detailed studies on the directional spreading of incoming wave trains would be beneficial get a more accurate idea of the true capacity factors for the Wave Dragon system. The usage of WEC's for centralized large scale power production on Vancouver Islands would require huge geographic footprints and infringe on Natural Park boundaries in the locations presented. This may cause environmental degradation and a full environmental analysis is recommended. In addition, an intensive economic feasibility study is suggested to analyze the costs of power take-offs, undersea cables, installations costs, electrical grid upgrade costs, etc. Despite these additional recommended studies, initial research shows huge potential of wave energy conversion devices in isolated locations on the west coast of Canada.

References

Boronowski, S, "Integration of Wave and Tidal Power into the Haida Gwaii Electrical Grid", Masters Dissertation, Department of Mechanical Engineering, University of Victoria, British Columbia, Canada, 2009.

Buigues, G, Zamora, I, Mazon, A, Valverde V and Perez, F,. "Sea Energy Conversion: Problems and Possibilities", Electrical Engineering Department, University of Basque Country, Spain, 2008.

Campbell, C,. "Renewable Wave and Tidal Energy – An Opportunity Communities Are (still) Waiting For", Proceedings of the BC Energy Summit, www.oreg.ca.

Dalton, G J, Alcom, R, and Lewis, T,. "Case Study Feasiblity Analysis of the Pelamis Wave Energy Converter in Ireland, Portugal and North America", Renewable Energy, Vol 35, 2010, pp. 443 – 445.

Dunnett, D., and Wallace, J., "Electricity Generation from Wave Power in Canada," Renewable Energy, Vol 34, 2009, pp. 179 – 195.

Falcao, F.O.A., "Wave Energy Utilization: A Review of Technologies," Renewable and Sustainable Energy Reviews, Vol 14, 2010, pp 899 – 918.

Henderson, R,. " Design, Simulation and Testing of a Novel Hydraulic Take-Off System for the Pelamis Wave Energy Converter:, Renewable Energy, Vol 31, 2006, pp. 271 – 283.

Komar, PD,"Beach Processes and Sedimentation – Second Edition", Prentice-Hall, Upper Saddle River, New Jersey, 07458.

National Data Buoy Center, National Oceanic and Atmospheric Administration, http://www.ndbc.noaa.gov/station_page.php ?station=46206, March, 2010.

Wave Dragon, Wave Dragon website, www.Wave Dragon.net, Date Accessed: September 5^{th}, 2010.

Pelamis Wave Power Ltd, website, www.pelamiswave.com, Date Accessed: April 2^{nd},2010.

Power Supply Engineering, BC Hydro,. "Executive Report on the Green Energy Study for British Columbia", BC Hydro Website, www.bchydro.com, July 2001.

Robertson, R., British Columbia Transmission Corporation, Formerly of BC Hydro Green Energy Group, Personal Communication, March 2010.

St. Germain, L,. " A Case Study of Wave Power Intergration into the Ucluelet Area Electrical Grid", Masters Dissertation, Department of Mechanical Engineering, University of Victoria, British Columbia, Canada, 2005.

The Sheltair Group, "Haida Gwaii Community Electricity Plan", Council of the Haida Nation, February 2008.

The Times-Colonist,"The Source of (Victoria's) Power", http://www.geog.uvic.ca/dept2/faculty/newcomb/JordanRiver Power.PDF, 18 March, 2001.

Yemm, RW, Henderson, R, and Taylor, CAE,."The OPD Pelamis WEC: Current Status and Onward Programme", Ocean Power Delivery Ltd, Edinburgh, UK, www.pelamiswave.com, 2008.