Wave Energy Converter Archetypes and Power Performance Representation

Prepared by:

Nicholas May-Varas, Oregon State University

Bryson Robertson, Oregon State University*

*bryson.robertson@oregonstate.edu

TABLE OF CONTENTS

OVERVIEW

There is a continuing and increasing need to develop renewable energy technologies that are efficient, cost-effective and produce usable forms of energy. Wave energy converters (WECs) have an opportunity to play a key and significant role in the integration of renewable energy technologies on a commercial scale.

It is estimated that waves off the United States coast could provide ~64% of U.S electricity generation in 2018 [1]. A priority requirement to assist marine energy development is a better understanding what types of WECs are currently being developed and their current associated power production performance estimates.

This report explains the key differences between different WECs and the various power take-off (PTO) systems within then. Overviews of how the WEC operates, basic dimensions of the WEC, and a performance matrix are provided for each WEC archetype. The performance matrices illustrate the amount of power generated based on the significant wave height and the wave energy period, as per the International Electrotechnical Commission TC-114 Technical Specifications.

POWER TAKE-OFF (PTO) SYSTEMS

All information retrieved from R. Ahamed et al. [2].

Direct Electrical Drive System

Direct Electrical Drive Systems generally consist of a stator, wire coils, permanent magnets, and a translator. As waves come into contact with the WEC, the translator moves the permanent magnets through the stator, which leads to the flow of current through the wire coils.

Direct Mechanical Drive System

Direct Mechanical Drive Systems generally consist of a mechanical transmission system, a gearbox, and an electric generator. As waves come into contact with the WEC, the motion of the WEC causes the electric generator to directly convert the movement into electricity.

Hydraulic Motor System

Hydraulic Motor Systems generally consist of a hydraulic cylinder or ram, a hydraulic motor, an accumulator, and a generator. Waves drive the hydraulic cylinder within WECs, which increases the pressure of a hydraulic fluid. The pressurized hydraulic fluid is the driving force that will run the hydraulic motor, which in turn, will run a generator.

Hydro Turbine Transfer System

Hydro Turbine Transfer Systems use water pressure from waves coming into contact with the WEC to produce electricity. The waves spin a hydro turbine, which directly drives a generator to produce electricity.

Pneumatic Air Turbine Transfer System

Pneumatic Air Turbine Transfer Systems use the changing air pressure as waves come into contact with the WEC. The changing air pressure causes a turbine to spin, which is generally directly attached to a generator, which produces electricity.

Triboelectric Nanogenerators

Triboelectric Nanogenerators produce electricity due to the process of electrostatic induction. The motion of waves displaces one of the materials within the triboelectric nanogenerator, which is attached to the WEC. That displacement helps to transfer charge between electrodes and a polymer.

POINT ABSORBER WECS

Point Absorber WECS generally consist of two main components, which are the surface float and the spar buoy. Power is generated due to the relative motion between the two components.

Accumulated Ocean Energy (AOE)

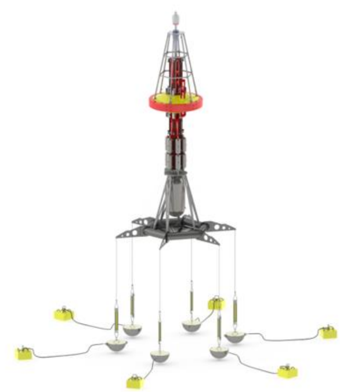
All information and specifications retrieved from E. Thacher [3].

Specific Functionality

AOE uses a Pneumatic Air Turbine Transfer PTO system. For AOE, air is compressed and sent onshore where it can be stored for later use or used immediately by driving an electric generator.

Table 1: Accumulated Ocean Energy Dimensions

Property	Value	Unit
Length (Diameter of the buoy)	10.97	m
Height (of the column)	8.43	m
Width (Diameter of the buoy)	10.97	m
Total Mass	217.29	Mg



Performance Matrix

P [W]		Wave Energy Period [s]												
		5.50	6.50	7.50	8.50	9.50	10.50	11.50	12.50	13.50	14.50	15.50	16.50	17.50
Significant Wave Height [m]	0.25	696	1090	1330	1220	958	737	599	476	340	328	261	208	172
	0.75	6480	10000	11400	11800	9550	6550	5780	4290	2760	2990	2480	1970	1490
	1.25	17000	25600	31100	29400	24900	20900	16300	13800	8920	9940	6000	5110	3630
	1.75	33200	52700	53000	58200	45300	32200	29000	22400	19600	18100	12200	11700	8330
	2.25		84600	82800	99600	79700	58000	46900	40900	36000	26600	20100	14900	14600
	2.75		116000	104000	128000	122000	97900	58400	52500	46300	38200	34200	24200	19700
	3.25		156000	137000	168000	163000	128000	86800	76100	61500	56800	47200	40400	29600
	3.75		214000	196000	190000	192000	167000	142000	111000	72400	71800	71600	53100	37200
	4.25			229000	235000	255000	216000	179000	147000	128000	98800	71800	50700	49100
	4.75				309000	254000	241000	219000	143000	146000	109000	94200	92600	66700
	5.25					368000	322000	272000	212000	170000	151000	104000	93100	78900
	5.75						336000	247000	251000	180000	143000	150000	105000	84800
	6.25						394000	321000	283000	260000	203000	149000	99800	106000
	6.75						350000	357000	300000	254000	229000	163000	121000	145000
	7.25						476000	466000	287000	260000	236000	180000	153000	133000
	7.75						464000	379000	418000	292000	285000	231000	171000	143000

CETO (BREF-SHB)

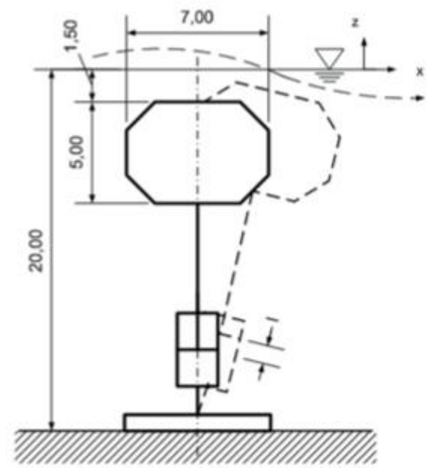
All information and specifications retrieved from A. Babarit et al. [4].

Specific Functionality

BREF-SHB uses a Hydraulic Motor PTO system. For this WEC, the buoy is submerged and attached to a wire that is fixed to the seabed.

Table 2: BREF-SHB Dimensions

Property	Value	Unit
Length (Diameter of the buoy)	7.0	m
Height	18.5	m
Width (Diameter of the buoy)	7.0	m
Total Mass (of the buoy)	35.0	Mg



Performance Matrix

P [W]		Wave Energy Period [s]												
		3.43	4.29	5.14	6.00	6.86	7.71	8.57	9.43	10.28	11.14	12.00	12.86	13.71
Significant Wave Height [m]	1.00	5000	9000	9000	10000	7000	6000	5000	4000	3000	3000	2000	2000	1000
	1.50	12000	19000	22000	20000	15000	13000	10000	8000	6000	6000	4000	3000	3000
	2.00	13000	32000	38000	32000	25000	23000	17000	13000	11000	9000	7000	7000	5000
	2.50		48000	54000	47000	41000	33000	26000	20000	17000	14000	10000	9000	8000
	3.00		65000	75000	68000	56000	46000	36000	26000	23000	18000	15000	10000	10000
	3.50			97000	86000	71000	62000	46000	33000	29000	23000	20000	15000	13000
	4.00			119000	121000	97000	69000	58000	47000	38000	31000	27000	21000	16000
	4.50			147000	146000	107000	93000	74000	61000	48000	37000	33000	26000	21000
	5.00			156000	174000	139000	116000	83000	63000	59000	45000	38000	25000	22000
	5.50				201000	164000	133000	89000	79000	66000	54000	41000	35000	28000
	6.00				216000	197000	153000	127000	88000	79000	65000	46000	40000	33000
	6.50				244000	209000	175000	151000	113000	95000	76000	55000	44000	39000
	7.00				260000	209000	183000	157000	114000	103000	82000	62000	51000	42000

Pontoon Power Converter (F-HBA)

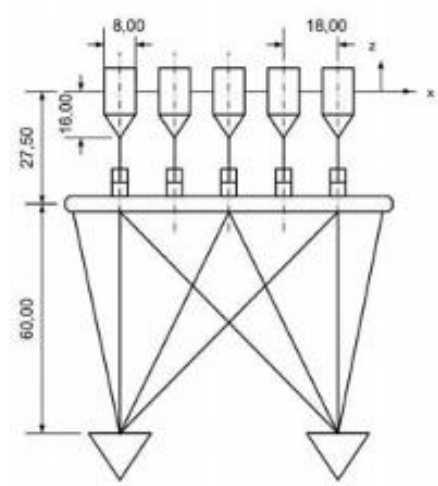
All information and specifications retrieved from A. Babarit et al. [4].

Specific Functionality

F-HBA uses a Hydraulic Motor PTO system to convert wave energy into electricity. F-HBA consists of many floats that are connected to a single submerged structure.

Table 3: F-HBA Dimensions

Property	Value	Unit
Length (Diameter of the float)	8.0	m
Height	87.5	m
Width (Diameter of the float)	8.0	m
Total Mass (of the float)	364.0	Mg



Performance Matrix

P [W]		Wave Energy Period [s]												
		3.43	4.29	5.14	6.00	6.86	7.71	8.57	9.43	10.28	11.14	12.00	12.86	13.71
Significant Wave Height [m]	1.00	180000	166000	153000	171000	125000	87000	72000	65000	85000	85000	37000	29000	16000
	1.50	223000	195000	157000	148000	261000	192000	223000	139000	155000	155000	74000	67000	46000
	2.00			214000	227000	396000	335000	237000	235000	172000	138000	115000	104000	70000
	2.50				440000	598000	514000	379000	342000	204000	169000	142000	128000	95000
	3.00				681000	801000	735000	594000	486000	199000	174000	151000	134000	121000
	3.50				904000	1035000	949000	788000	617000	239000	209000	183000	164000	146000
	4.00				1131000	1269000	1163000	982000	743000	285000	248000	216000	195000	175000
	4.50				1358000	1488000	1374000	1187000	869000	330000	287000	250000	225000	201000
	5.00				1585000	1712000	1585000	1392000	988000	380000	334000	285000	263000	226000
	5.50				1812000	1937000	1798000	2138000	1107000	429000	381000	323000	301000	261000
	6.00				2040000	2162000	2010000	2884000	1234000	439000	416000	361000	336000	295000
	6.50				2267000	2386000	2221000	3143000	1360000	449000	450000	406000	372000	329000
	7.00				2494000	2611000	2433000	3619000	1483000	506000	464000	451000	408000	363000

Seabased (BREF-HB)

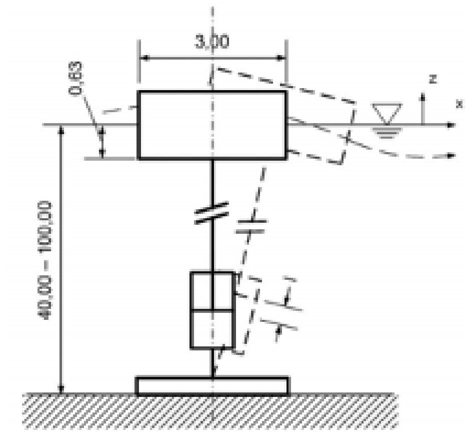
All information and specifications retrieved from A. Babarit et al. [4].

Specific Functionality

BREF-HB uses a Hydraulic Motor PTO system. For this WEC, the buoy is floating on the ocean surface and moving under a surge and heave motion, which drives the linear generator attached to the seabed.

Table 4: BREF-HB Dimensions

Property	Value	Unit
Length (Diameter of the buoy)	3.0	m
Height	40.63-100.63	m
Width (Diameter of the buoy)	3.0	m
Total Mass (of the buoy)	1.0	Mg



Performance Matrix

P [W]	Wave Energy Period [s]												
Significant Wave Height [m]	3.43	4.29	5.14	6.00	6.86	7.71	8.57	9.43	10.28	11.14	12.00	12.86	13.71
1.00	1200	1300	1200	1200	1100	1000	900	800	700	700	700	600	700
1.50	2600	2500	2300	2200	2300	2000	1900	1700	1400	1500	1200	1200	1200
2.00	4400	4000	3700	3600	3500	3100	2800	2500	2300	2200	2000	1800	1700
2.50		6000	5200	4500	4600	4300	3900	3600	3000	2800	2500	2700	2600
3.00		7400	6700	6200	5700	5400	4700	4100	4100	3700	3300	3300	3200
3.50			8400	7300	6900	5800	5400	4900	4400	4200	3700	3400	3600
4.00			8900	8600	7600	6800	6200	5600	5000	4600	4500	4300	3600
4.50			10600	9500	8700	7600	7000	6100	5900	5400	5100	5000	4700
5.00			12200	10800	9200	8600	7300	7200	6300	5900	5700	5400	5000
5.50				11100	10100	8900	8100	7500	6800	6400	6100	5500	5800
6.00				13100	11300	10100	9100	8300	7500	6700	6900	6400	5800
6.50				13500	11600	10400	9800	9000	7600	7300	7500	6200	6400
7.00				15000	12900	10900	10000	8800	8600	8200	7600	7300	6800

Wavebob (F-2HB)

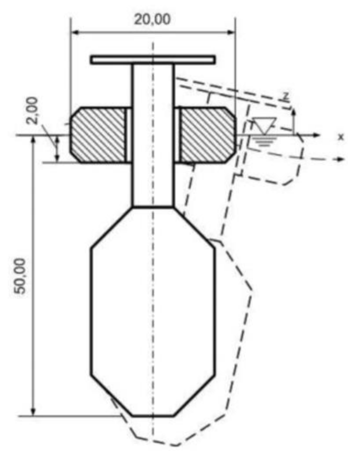
All information and specifications retrieved from A. Babarit et al. [4].

Specific Functionality

Wavebob is an axisymmetric WEC that uses a Hydraulic Motor PTO system. Wavebob also uses a mooring system, which is attached to the seabed and provides stability to the entire structure.

Table 5: Wavebob Dimensions

Property	Value	Unit
Length (Diameter of the float)	20.0	m
Height	52.0	m
Width (Diameter of the float)	20.0	m
Total Mass (of the buoy)	4960.0	Mg



Performance Matrix

P [W]		Wave Energy Period [s]												
		3.43	4.29	5.14	6.00	6.86	7.71	8.57	9.43	10.28	11.14	12.00	12.86	13.71
Significant Wave Height [m]	1.00	6000	11000	19000	25000	30000	44000	50000	53000	44000	34000	22000	20000	17000
	1.50	13000	25000	43000	55000	68000	90000	102000	92000	91000	66000	65000	45000	37000
	2.00	24000	45000	65000	100000	121000	153000	175000	151000	122000	126000	87000	61000	58000
	2.50		35000	104000	141000	191000	179000	243000	255000	190000	181000	135000	99000	83000
	3.00		96000	137000	205000	244000	357000	293000	353000	260000	248000	184000	137000	120000
	3.50			192000	254000	291000	431000	385000	424000	314000	285000	239000	222000	172000
	4.00			256000	366000	403000	551000	536000	531000	473000	420000	289000	268000	179000
	4.50			327000	418000	574000	678000	708000	665000	509000	415000	386000	244000	249000
	5.00			358000	514000	658000	824000	828000	618000	638000	512000	452000	384000	333000
	5.50				610000	774000	880000	936000	905000	805000	603000	456000	397000	311000
	6.00				711000	952000	974000	1000000	838000	886000	648000	501000	503000	396000
	6.50				788000	1000000	1000000	1000000	979000	1000000	727000	577000	435000	424000
	7.00				781000	1000000	1000000	1000000	1000000	1000000	959000	748000	574000	472000

Wavestar (B-HBA)

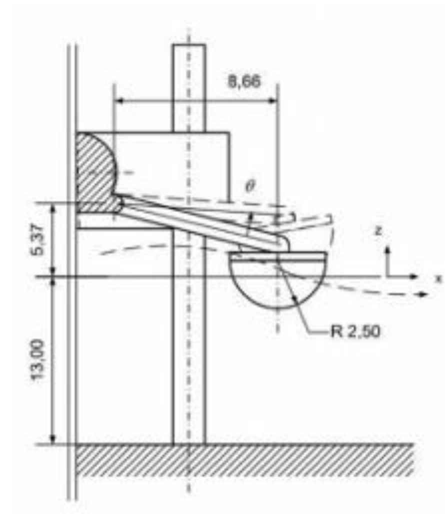
All information and specifications retrieved from A. Babarit et al. [4].

Specific Functionality

B-HBA uses a Hydraulic Motor PTO system. The device consists of many floats that are connected to a single structure standing on the seabed. The single structure provides the fixed reference for the B-HBA.

Table 6: B-HBA Dimensions

Property	Value	Unit
Length (Diameter of the float)	5.0	m
Height (of the float)	2.5	m
Width (Diameter of the float)	5.0	m
Total Mass (of the float)	35.0	Mg



Performance Matrix

P [W]		Wave Energy Period [s]												
		3.43	4.29	5.14	6.00	6.86	7.71	8.57	9.43	10.28	11.14	12.00	12.86	13.71
Significant Wave Height [m]	1.00	63000	92000	85000	73000	63000	60000	60000	53000	47000	48000	46000	42000	37000
	1.50	134000	174000	181000	160000	141000	124000	118000	115000	100000	89000	77000	94000	80000
	2.00	207000	313000	296000	275000	250000	223000	229000	229000	200000	161000	148000	180000	153000
	2.50		463000	462000	396000	393000	379000	320000	370000	306000	294000	225000	236000	228000
	3.00		653000	641000	602000	557000	555000	460000	471000	431000	393000	437000	381000	325000
	3.50			900000	848000	785000	717000	662000	656000	557000	551000	571000	580000	478000
	4.00			1123000	1098000	1030000	984000	799000	857000	821000	830000	637000	592000	652000
	4.50			1339000	1339000	1202000	1181000	1050000	1140000	1012000	848000	863000	672000	828000
	5.00			1689000	1518000	1403000	1318000	1248000	1348000	1115000	1176000	825000	890000	982000
	5.50				1943000	1749000	1517000	1477000	1374000	1395000	1376000	1089000	1212000	1117000
	6.00				2192000	2144000	1618000	1789000	1586000	1634000	1783000	1585000	1346000	1313000
	6.50				2335000	2162000	1975000	1962000	1857000	1660000	1492000	1619000	1336000	1668000
	7.00				2709000	2437000	2449000	2262000	2205000	1900000	2292000	1785000	1443000	1750000

OSCILLATING WATER COLUMN WECS

Oscillating Water Column WECs generally consist of a large hollow structure that contains an air chamber. Power is generated due to waves changing the pressure within the air chamber, which results in air to flow across a turbine.

Ocean Energy (BBDB_OWC)

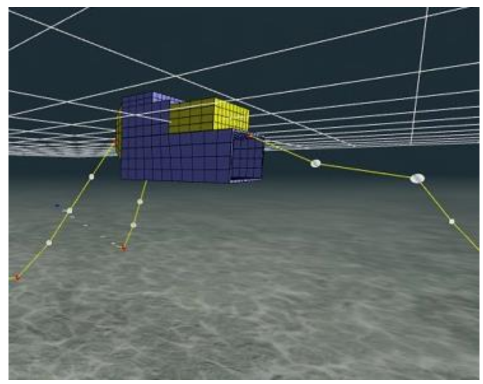
All information and specifications retrieved from H. Bailey et al. [5].

Specific Functionality

BBDB_OWC uses a Pneumatic Air Turbine Transfer PTO system. A Variable Radius Turbine is used as part of the PTO system of the WEC. BBDB_OWC has a three-point mooring system attached to the seabed.

Table 7: BBDB-OWC Dimensions

Property	Value	Unit
Length	35.0	m
Height	27.5	m
Width	27.0	m
Total Mass	2027.0	Mg



Performance Matrix

P [W]		Wave Energy Period [s]									
		5.50	6.50	7.50	8.50	9.50	10.50	11.50	12.50	13.50	14.50
Significant Wave Height [m]	0.25										
	0.75		838	3590	5700	8050	7390	7430	5680		
	1.25		3760	13800	19900	27300	28000	24600	20700		
	1.75		11000	31400	52500	57000	52700	51300	40400	34700	
	2.25		22700	57800	88200	94600	88200	85100	70000	64700	
	2.75		34200	83100	120000	128000	123000	117000	106000	84100	
	3.25			115000	158000	177000	165000	162000	129000	119000	
	3.75			152000	204000	203000	209000	182000	169000	147000	143000
	4.25				234000	253000	229000	232000	201000	181000	156000
	4.75					277000	272000	261000	227000	197000	180000
	5.25						303000	240000	252000	252000	
	5.75						296000	296000	279000		
	6.25										
	6.75										
	7.25										
	7.75										

SURGING FLAP WECS

Surging Flap WECs generally consist of a hinged rectangular flap that is attached to a pivot at its base. Power is generated due to waves applying forces on the flap that, when oscillating, compresses and expands a working fluid.

Langlee (F-3OF)

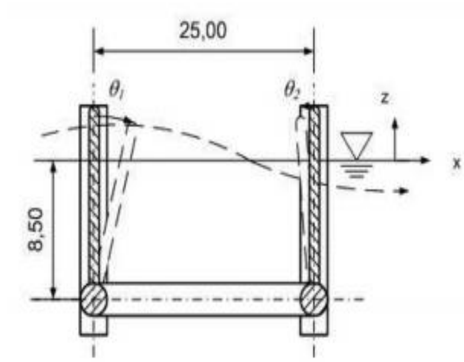
All information and specifications retrieved from A. Babarit et al. [4].

Specific Functionality

F-3OF uses a Hydraulic Motor PTO system. F-3OF uses four hinged flaps which are connected to one structure, which is attached to the seabed via mooring lines.

Table 8: F-3OF Dimensions

Property	Value	Unit
Length	25.0	m
Height	8.5	m
Width (of the flap)	9.5	m
Total Mass	1451.5	Mg



Performance Matrix

P [W]		Wave Energy Period [s]												
		3.43	4.29	5.14	6.00	6.86	7.71	8.57	9.43	10.28	11.14	12.00	12.86	13.71
Significant Wave Height [m]	1.00	19000	29000	47000	57000	52000	37000	29000	20000	17000	13000	9000	7000	7000
	1.50	42000	63000	92000	111000	109000	65000	56000	38000	29000	22000	19000	13000	11000
	2.00	66000	99000	151000	201000	165000	105000	85000	59000	52000	41000	29000	24000	19000
	2.50		160000	242000	262000	226000	166000	118000	83000	70000	57000	39000	29000	26000
	3.00		213000	319000	372000	327000	211000	152000	116000	94000	75000	66000	45000	42000
	3.50			436000	503000	408000	293000	203000	148000	115000	93000	75000	58000	44000
	4.00			554000	540000	521000	355000	261000	192000	144000	123000	84000	81000	56000
	4.50			645000	746000	587000	379000	302000	236000	190000	154000	106000	90000	74000
	5.00			796000	926000	695000	586000	341000	287000	211000	168000	136000	111000	94000
	5.50				955000	808000	603000	430000	343000	231000	201000	150000	120000	97000
	6.00				1161000	957000	642000	481000	329000	289000	212000	172000	146000	111000
	6.50				1476000	1039000	702000	488000	397000	312000	237000	204000	153000	120000
	7.00				1665000	1197000	821000	612000	466000	385000	252000	223000	181000	146000

Oyster2 (B-OF)

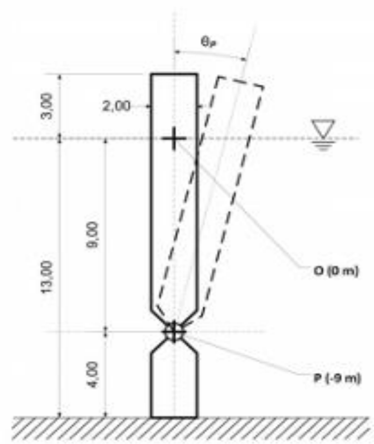
All information and specifications retrieved from A. Babarit et al. [4].

Specific Functionality

B-OF uses a Hydraulic Motor PTO system, which is placed at the base of the entire structure. The particular PTO system used for the B-OF pumps the hydraulic fluid onshore, which drives an onshore generator.

Table 9: B-OF Dimensions

Property	Value	Unit
Length	2.0	m
Height	16.0	m
Width (Diameter of the float)	2.0	m
Total Mass (of the float)	150.0	Mg



Performance Matrix

P [W]		Wave Energy Period [s]												
		3.43	4.29	5.14	6.00	6.86	7.71	8.57	9.43	10.28	11.14	12.00	12.86	13.71
Significant Wave Height [m]	1.00	27000	39000	27000	76000	87000	104000	109000	100000	101000	98000	94000	94000	87000
	1.50	63000	92000	126000	168000	201000	213000	201000	239000	207000	198000	183000	150000	154000
	2.00	75000	160000	233000	301000	380000	408000	383000	399000	329000	365000	319000	265000	259000
	2.50		254000	378000	467000	568000	623000	616000	601000	519000	523000	481000	390000	428000
	3.00		368000	503000	693000	799000	824000	876000	792000	759000	704000	546000	579000	554000
	3.50			655000	934000	1032000	1085000	1241000	1075000	973000	925000	862000	747000	688000
	4.00			843000	1093000	1352000	1427000	1430000	1390000	1158000	1224000	1139000	1138000	863000
	4.50			1219000	1408000	1644000	1677000	1807000	1641000	1662000	1562000	1404000	1370000	1191000
	5.00			1247000	1670000	1965000	1962000	2097000	2002000	1833000	1798000	1814000	1459000	1442000
	5.50				1979000	2339000	2308000	2115000	2389000	2120000	2012000	1940000	1518000	1587000
	6.00				2406000	2713000	2776000	2344000	2705000	2451000	2396000	2182000	2414000	2133000
	6.50				2778000	3044000	3001000	2989000	3211000	2986000	2896000	2716000	2455000	2309000
	7.00				2871000	3119000	3131000	3127000	3176000	3332000	2877000	2925000	2676000	2658000

Resolute Marine Energy's (RME) Flap

All information and specifications retrieved from H. Bailey et al. [6].

Specific Functionality

RME's Flap uses a Hydraulic Motor PTO system, which is placed at the base of the entire structure. RME's Flap operates well in nearshore locations, which allows for a reduction in expenses.

Table 10: RME Flap Dimensions

Property	Value	Unit
Length	8.0	m
Height	7.5	m
Width	3.0	m
Total Mass (of the flap)	4.5	Mg

Performance Matrix

P [W]		Wave Energy Period [s]										
		7.50	8.50	9.50	10.50	11.50	12.50	13.50	14.50	15.50	16.50	17.50
Significant Wave Height [m]	0.25			1796	1601	1296						
	0.75	11178	10423	11700	9243	9290	7376	5626	4749	3683		
	1.25	25665	31119	22365	23939	18402	17549	15564	13440	10134	8779	
	1.75		44390	38580	38826	30984	33022	31393	22614	18271	15853	
	2.25		70567	59863	49201	48077	44461	40116	36770	29886	28194	21128
	2.75		85178	78792	77256	72900	62942	52322	47422			
	3.25			116675	89885	83898	83825	59415	56691			
	3.75						112635	111077	88295			
	4.25							117412	111213			
	4.75								129960			

RM5 OSWEC

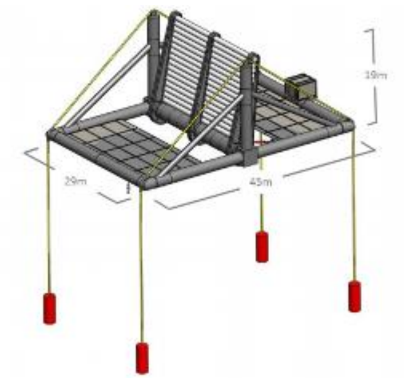
All information and specifications retrieved from Y. Y.-H et al. [7].

Specific Functionality

RM5 OSWEC uses a Hydraulic Motor PTO system. RM5 OSWEC was designed to perform optimally in deep waters ranging from 50 meters to about 100 meters while being attached to the seabed via cables.

Table 11: RM5 OSWEC Dimensions

Property	Value	Unit
Length	45.0	m
Height	19.0	m
Width	29.0	m
Total Mass	725.7	Mg



Performance Matrix

P [W]		Wave Energy Period [s]													
		4.50	5.50	6.50	7.50	8.50	9.50	10.50	11.50	12.50	13.50	14.50	15.50	16.50	17.50
Significant Wave Height [m]	0.75	12000	17000	19000	21000	23000	22000	21000	19000	19000	17000	16000	14000	13000	12000
	1.25	32000	41000	45000	48000	52000	49000	45000	42000	40000	36000	35000	32000	29000	27000
	1.75	58000	72000	77000	82000	87000	81000	74000	70000	67000	60000	58000	53000	49000	45000
	2.25	91000	110000	116000	119000	127000	117000	108000	102000	97000	86000	83000	76000	71000	65000
	2.75	131000	155000	160000	163000	172000	159000	145000	138000	130000	116000	110000	101000	95000	87000
	3.25	175000	204000	209000	210000	221000	203000	186000	176000	166000	148000	140000	130000	121000	110000
	3.75	224000	259000	262000	262000	272000	250000	228000	215000	205000	183000	173000	160000	148000	135000
	4.25	277000	317000	319000	316000	327000	299000	272000	257000	246000	220000	207000	192000	177000	162000
	4.75	335000	360000	360000	360000	360000	349000	317000	302000	228000	259000	243000	225000	209000	190000
	5.25	360000	360000	360000	360000	360000	360000	360000	349000	333000	299000	380000	261000	242000	220000
	5.75	360000	360000	360000	360000	360000	360000	360000	360000	360000	340000	319000	299000	276000	251000

BUOYANT RAFT WECS

Buoyant Raft WECS generally consist of a large floating platform that is attached to a hydraulic cylinder. Power is generated due to waves applying forces on the Raft that, when rotating about the fixed point, compresses and expands a hydraulic cylinder.

SURFPOWER RAFT (1B-PA)

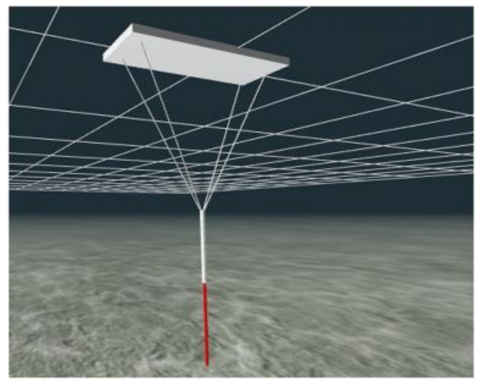
All information and specifications retrieved from H. Bailey et al. [6].

Specific Functionality

1B-PA uses a Hydraulic Motor PTO system. 1B-PA is attached to the seabed via a hydraulic cylinder and is able to rotate and move in 5 Degrees of Freedom.

Table 12: 1B-PA Dimensions

Property	Value	Unit
Length (of the raft)	24.0	m
Height (of the raft)	1.0	m
Width (of the raft)	7.0	m
Total Mass	--	Mg



Performance Matrix

P [W]		Wave Energy Period [s]												
Significant Wave Height [m]		5.50	6.50	7.50	8.50	9.50	10.50	11.50	12.50	13.50	14.50	15.50	16.50	17.50
	0.25													
	0.75			19400	11000	10900	12100	7990						
	1.25		58600	85200	83000	94000	85500	69300						
	1.75		147000	164000	167000	174000	156000	141000	139000					
	2.25		209000	209000	235000	233000	213000	205000	196000	179000				
	2.75		298000	310000	313000	308000	271000	236000	233000	216000	218000			
	3.25			379000	364000	359000	335000	315000	295000	265000	265000			
	3.75			435000	431000	420000	401000	368000	366000	317000	313000			
	4.25				507000	473000	445000	435000	388000	376000	356000			
	4.75				583000	564000	492000	482000	445000	414000	380000			
	5.25					596000	553000	527000	479000	447000	410000			
	5.75					625000	588000	545000	526000	479000	457000	417000		
	6.25						626000	555000	558000	504000	461000	443000		
	6.75						664000	601000	585000	529000	501000			
	7.25													
	7.75													

ATTENUATOR WECS

Attenuator WECS generally consist of large cylindrical sections that are connected together via joints. They are also generally aligned parallel to the wave direction, with a PTO in each section producing electricity.

Pelamis

All information and specifications retrieved from R. Yemm et al. [8].

Specific Functionality

Pelamis uses a Hydraulic Motor PTO system. Pelamis consists of multiple cylindrical sections, which are connected by hinged joints. Pelamis was designed for survivability, which is shown in its streamlined form. Due to its structure, Pelamis is able to be protected against the extreme amounts of hydrodynamic loading present in the ocean.

Table 13: Pelamis Dimensions

Property	Value	Unit
Length (of the float)	180.0	m
Height (Diameter of the float)	4.0	m
Width (Diameter of the float)	4.0	m
Total Mass	1300.0	Mg

Performance Matrix

P [W]		Wave Energy Period [s]									
		4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00
Significant Wave Height [m]	1.00			29000	37000	38000	35000	29000	23000		
	1.50		32000	65000	83000	86000	78000	65000	53000	42000	33000
	2.00		57000	115000	148000	152000	138000	116000	93000	74000	59000
	2.50		89000	180000	231000	238000	216000	181000	146000	116000	92000
	3.00		129000	260000	332000	332000	292000	240000	210000	167000	132000
	3.50			354000	438000	424000	377000	326000	260000	215000	180000
	4.00			462000	540000	530000	475000	384000	339000	267000	213000
	4.50			544000	642000	628000	562000	473000	382000	338000	266000
	5.00				726000	707000	570000	557000	472000	369000	328000
	5.50				750000	750000	737000	658000	530000	446000	355000
	6.00				750000	750000	750000	711000	619000	512000	415000
	6.50				750000	750000	750000	750000	658000	579000	481000
	7.00					750000	750000	750000	750000	613000	525000
	7.50					750000	750000	750000	750000	686000	593000
	8.00						750000	750000	750000	750000	625000
	8.50						750000	750000	750000	750000	750000

REFERENCES

[1] "Wave power - U.S. Energy Information Administration (EIA)." https://www.eia.gov/energyexplained/hydropower/wave-power.php (accessed May 14, 2020).

[2] R. Ahamed, K. McKee, and I. Howard, "Advancements of wave energy converters based on power take off (PTO) systems: A review," *Ocean Engineering*, vol. 204. Elsevier Ltd, p. 107248, May 15, 2020, doi: 10.1016/j.oceaneng.2020.107248.

[3] E. Thacher, "Simulation Based Design and Performance Assessment of a Controlled Cascaded Pneumatic Wave Energy Converter," 2015.

[4] A. Babarit, J. Hals, M. J. Muliawan, A. Kurniawan, T. Moan, and J. Krokstad, "Numerical benchmarking study of a selection of wave energy converters," *Renew. Energy*, vol. 41, pp. 44–63, 2012, doi: 10.1016/j.renene.2011.10.002.

[5] H. Bailey, B. R. D. Robertson, and B. J. Buckham, "Wave-to-wire simulation of a floating oscillating water column wave energy converter," *Ocean Eng.*, vol. 125, pp. 248–260, Oct. 2016, doi: 10.1016/j.oceaneng.2016.08.017.

[6] H. Bailey, B. Robertson, and B. Buckham, "Variability and stochastic simulation of power from wave energy converter arrays," *Renew. Energy*, vol. 115, pp. 721–733, Jan. 2018, doi: 10.1016/j.renene.2017.08.052.

[7] Y.-H. Yu, D. S. Jenne, R. Thresher, A. Copping, S. Geerlofs, and L. A. Hanna, "Reference Model 5 (RM5): Oscillating Surge Wave Energy Converter," 2013. Accessed: Jun. 11, 2020. [Online]. Available: www.nrel.gov/publications.

[8] "Pelamis: experience from concept to connection | Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences." https://royalsocietypublishing.org/doi/full/10.1098/rsta.2011.0312 (accessed Jun. 10, 2020).