Performance Evaluation of the Wavestar Prototype

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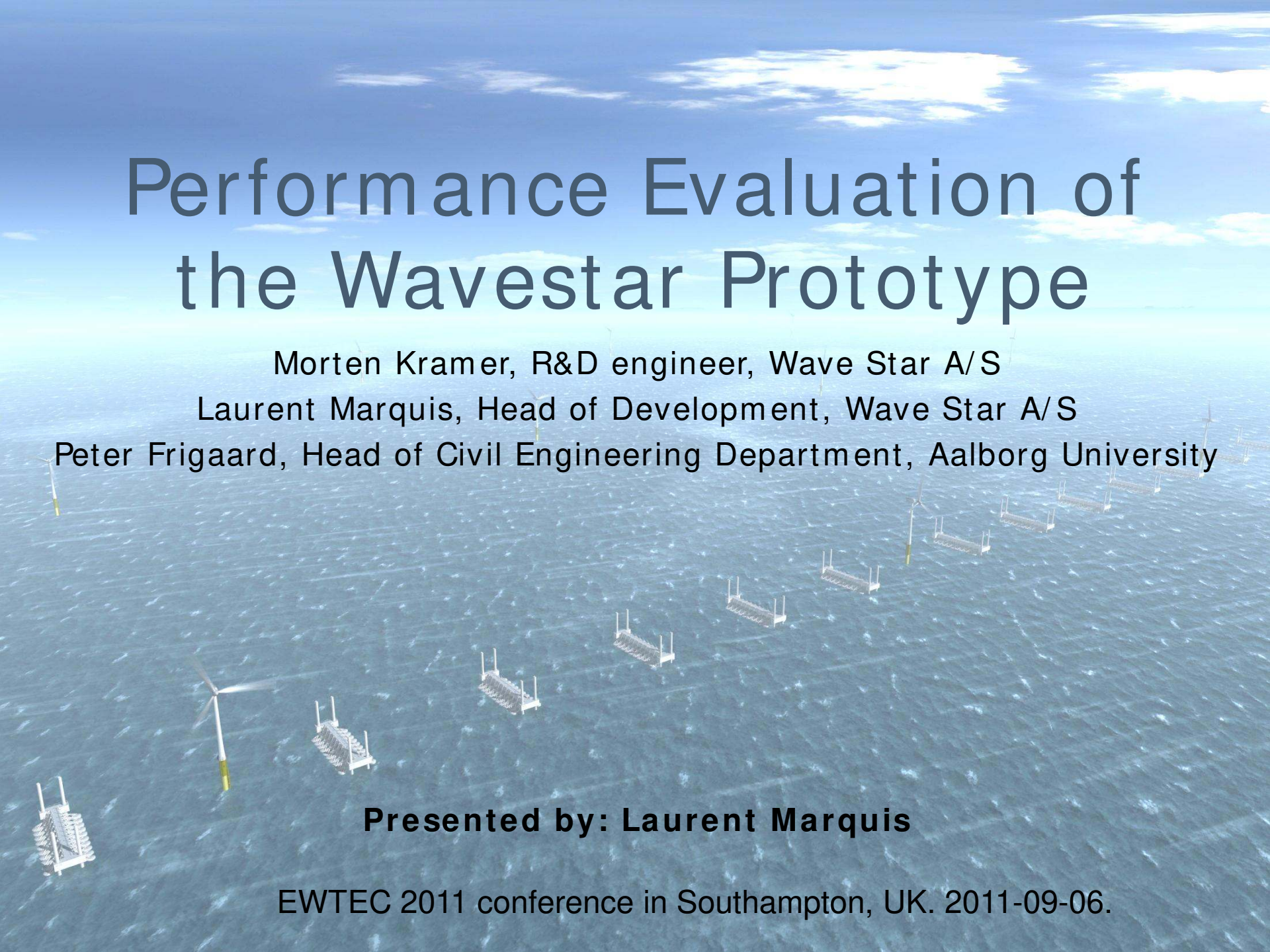
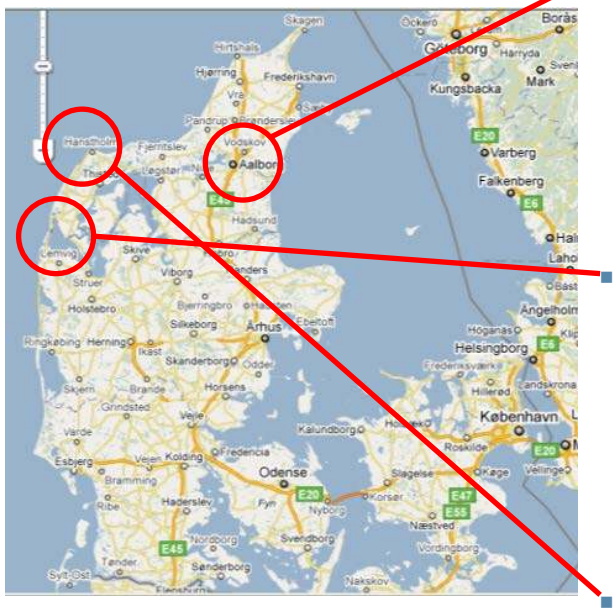


Presented by: Laurent Marquis

EWTEC 2011 conference in Southampton, UK. 2011-09-06.

Wavestar test machines



- Test machine at Aalborg University
  - Deployment: 2004-2005
  - Scale: 1/40
  - Float diameter: 0.25 m

- Test machine at Nissum Bredning
  - Deployment: 2006-2010
  - Scale: 1/10
  - Float diameter: 1.0 m

- Prototype test section at Hanstholm
  - Deployment: 2009->
  - Scale: 1/2
  - Float diameter: 5.0 m

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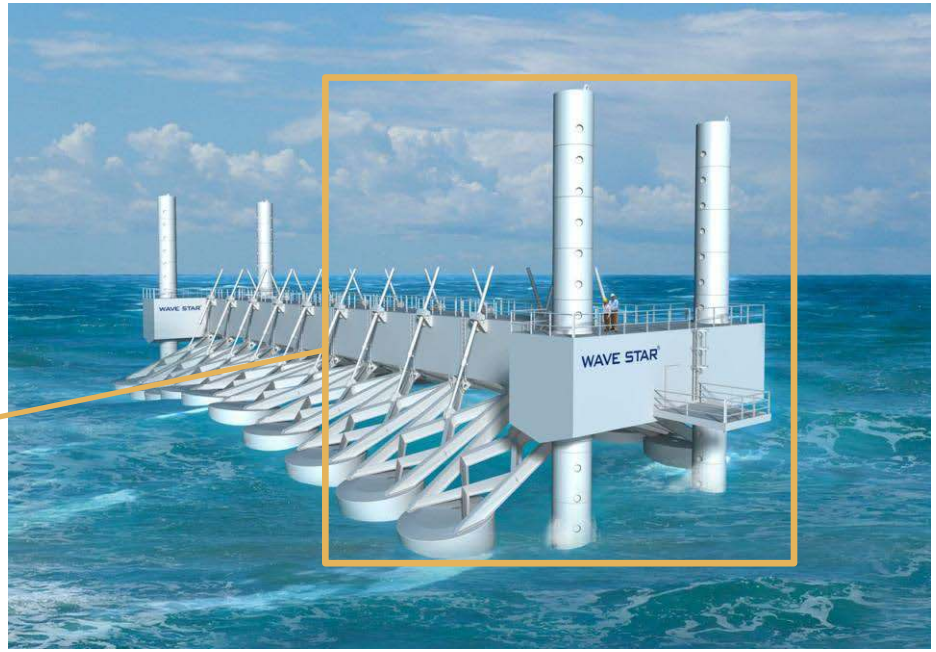
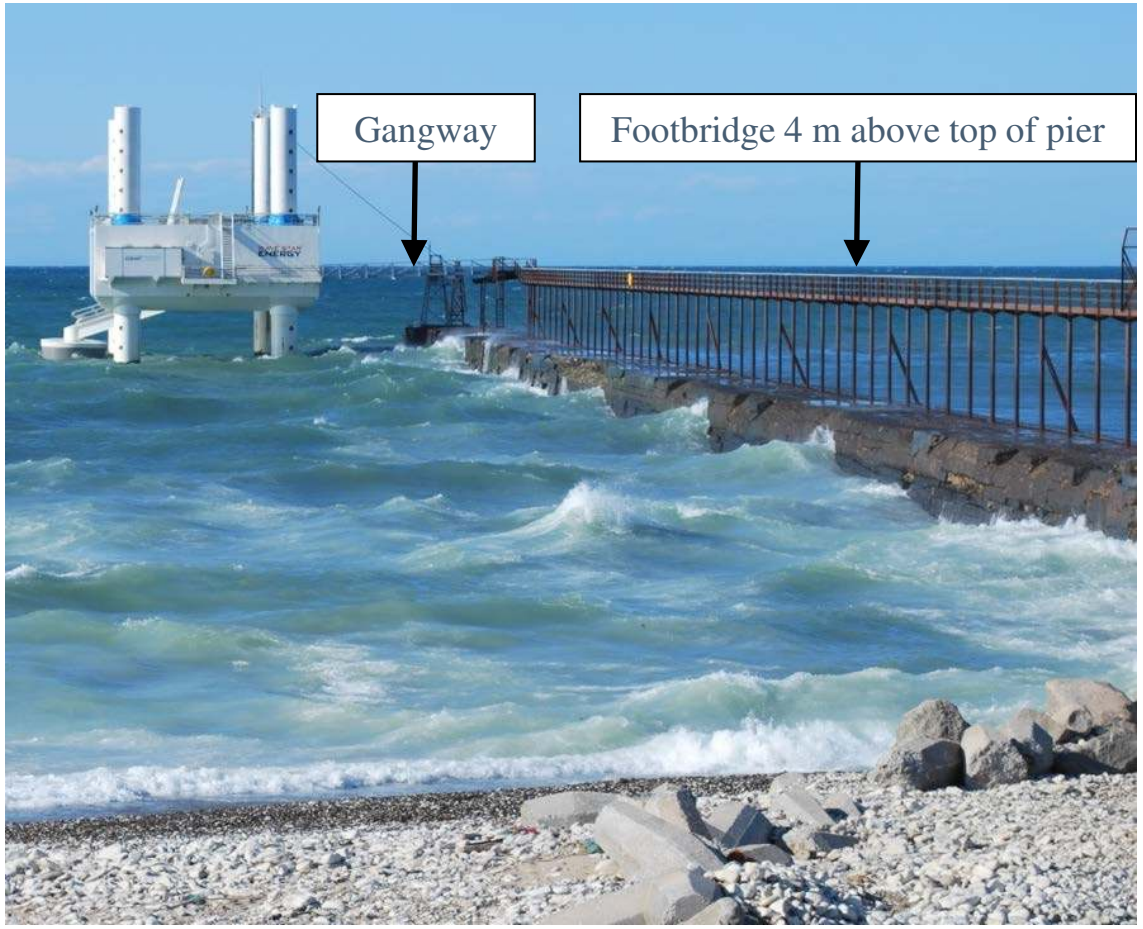
The Wavestar prototype is a 2-float section of the full 20-float machine

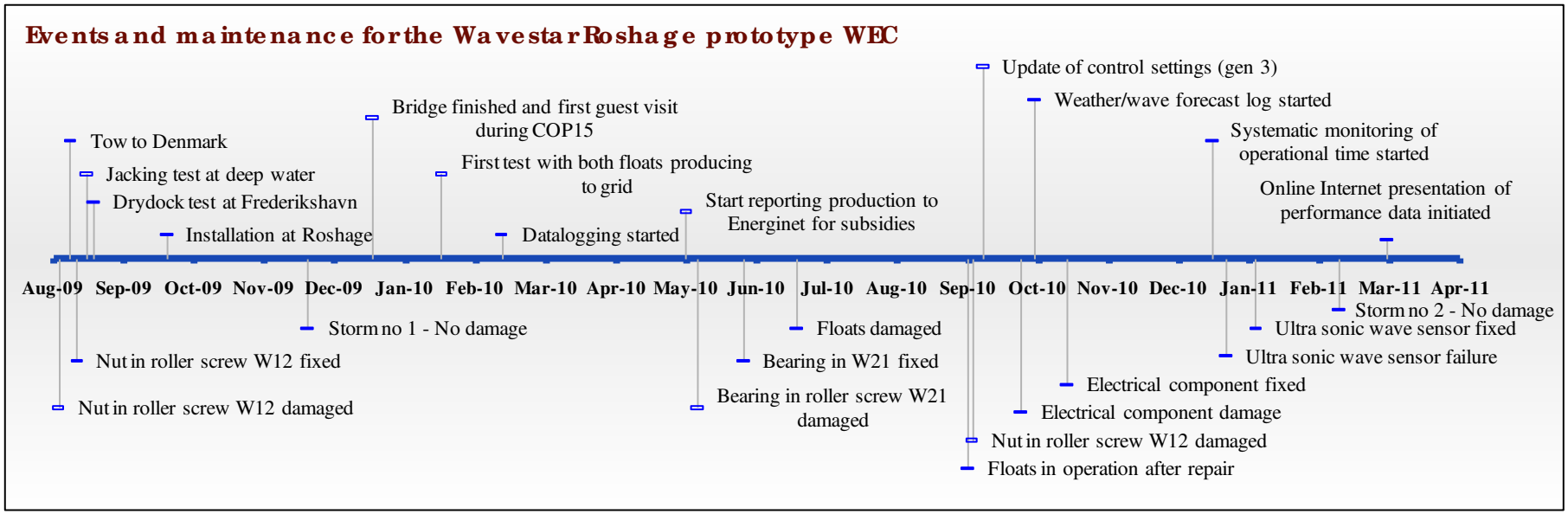


Parameter	Hanstholm prototype	Commercial Wavestar 0.6 MW
Number of floats	2	20
Float diameter	Ø5 m	Ø5 m
Arm length	10 m	10 m
Weight	1000 ton	1600 ton
Nominal electrical power	110 kW	600 kW

The Wavestar prototype was installed from a barge in September 2009 and it is accessible in any weather via a 300 m long access bridge



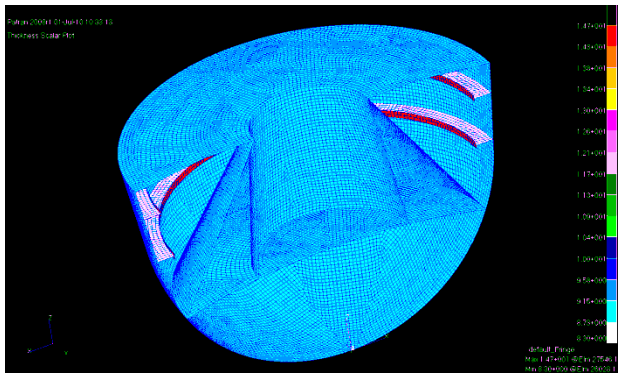
Two years of experience at real sea

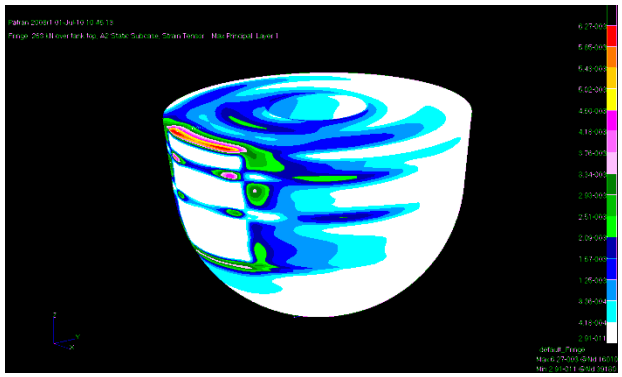


In general there have been no major problems with the design of the prototype. All structural and mechanical components in the WEC have proven functionality as intended. The WEC has survived two large storms with no damages and no service afterwards. Only minor design faults with the float design, the jacking-system, and some electrical problems have been identified and corrected.

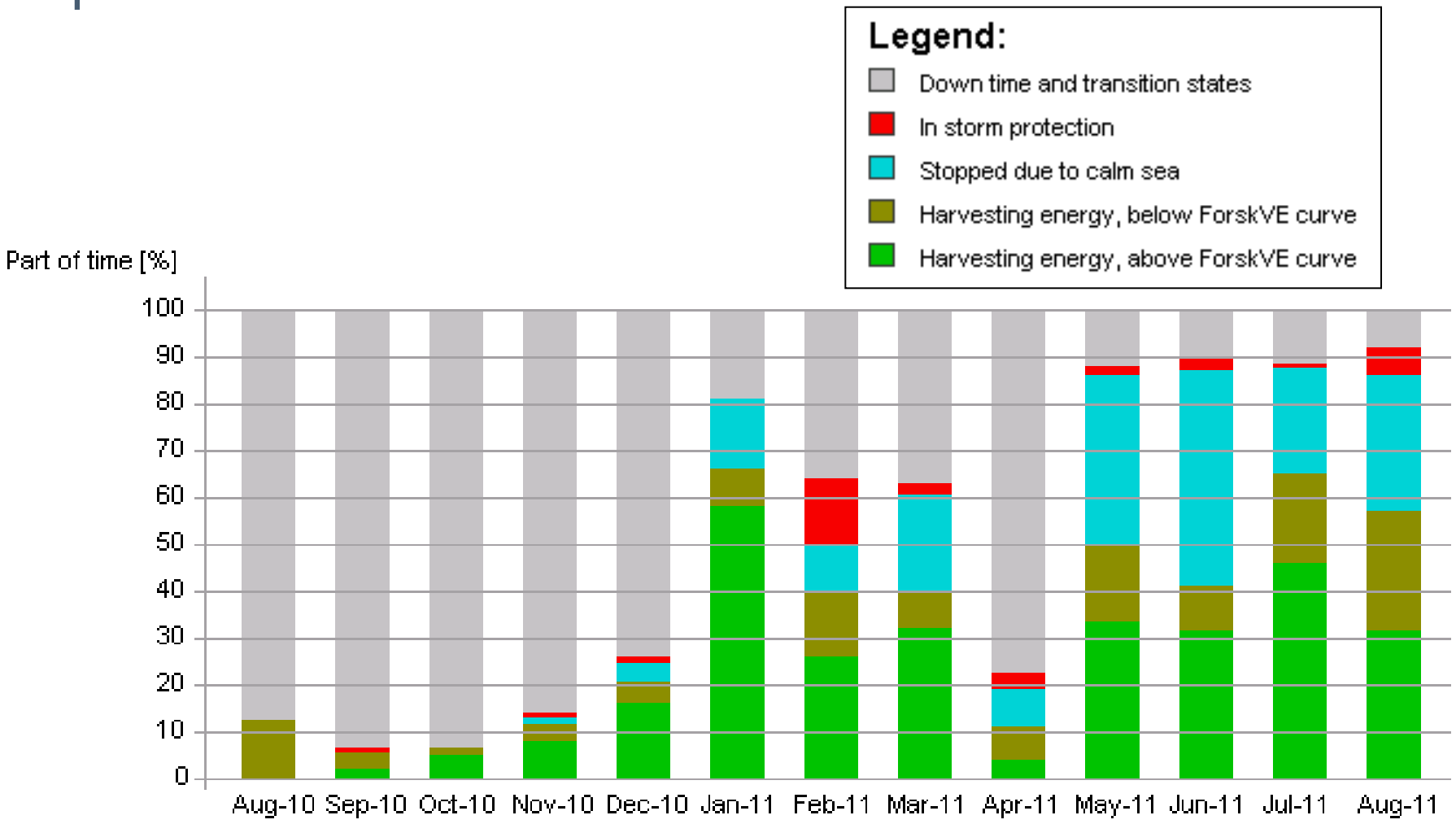
Jacking system adjustments

Float damage

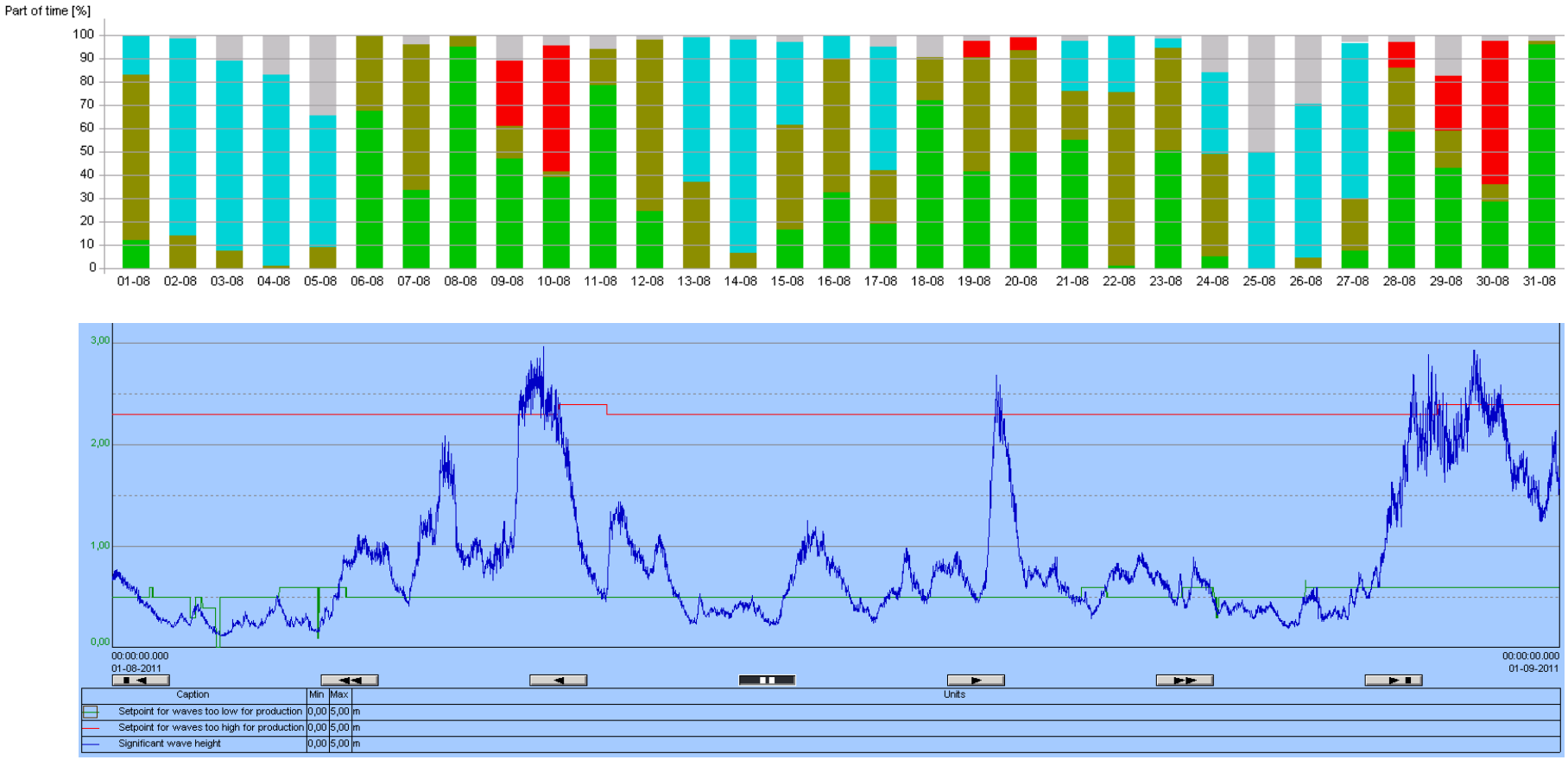




Operational time 2010-2011



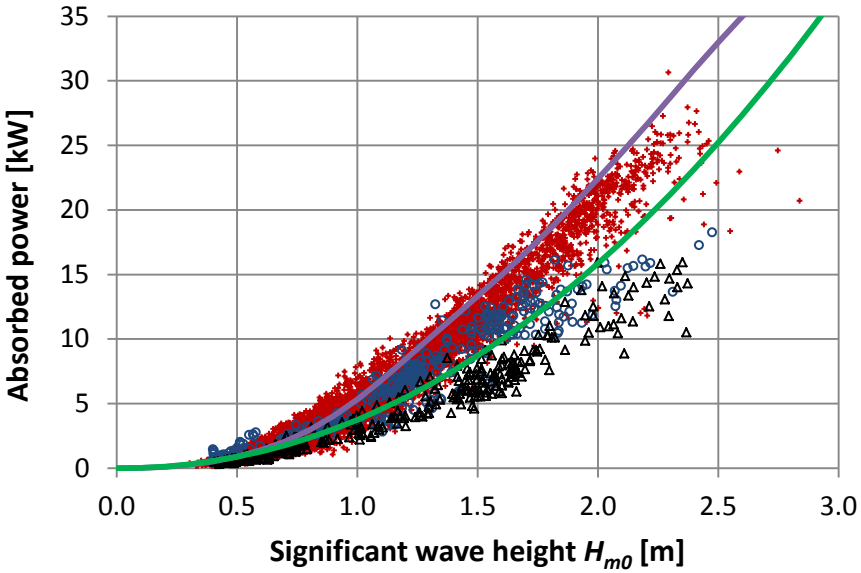
Operational time and waves in August 2011

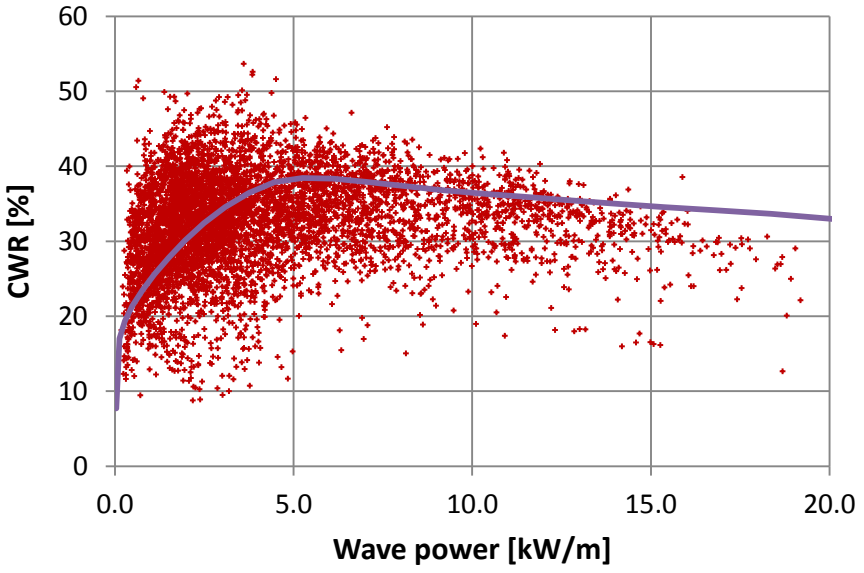


Power measurements from the Hanstholm test unit

- Measured Sept 2010 to Sept 2011 (control generation 3)
- Measured June 2010 (control generation 2)
- Measured May 2010 (control generation 1)
- Simulation (control generation 3)
- ForskVE limit for subsidies

$$CWR\ [\%] = \frac{Power\ [\mathrm{kW}]/Wave\ power\ [\mathrm{kW/m}]}{Float\ diameter\ [\mathrm{m}]} \cdot 100$$





- Red data points are 30 minute average values of harvested power from one float (hydraulic power leaving one cylinder)
- 5740 red data points are shown corresponding to 120 days of full operation
- A typical wave period for the Hanstholm location is used for the simulated curve

Power matrix for a C5 Wavestar with 20 floats (Ø5 m, 10 m long arms)

Values are average electrical power to grid in kW.

Wave height H_{m0} (m)	Wave period $T_{0,2}$ (s)										
	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0
0.5 - 1.0	0	49	73	85	86	83	78	72	67	63	59
1.0 - 1.5	54	136	193	205	196	182	167	153	142	132	123
1.5 - 2.0	106	265	347	347	322	294	265	244	224	207	193
2.0 - 2.5	175	429	522	499	457	412	372	337	312	288	267
2.5 - 3.0	262	600	600	600	600	540	484	442	399	367	340
3.0 -	Storm protection										

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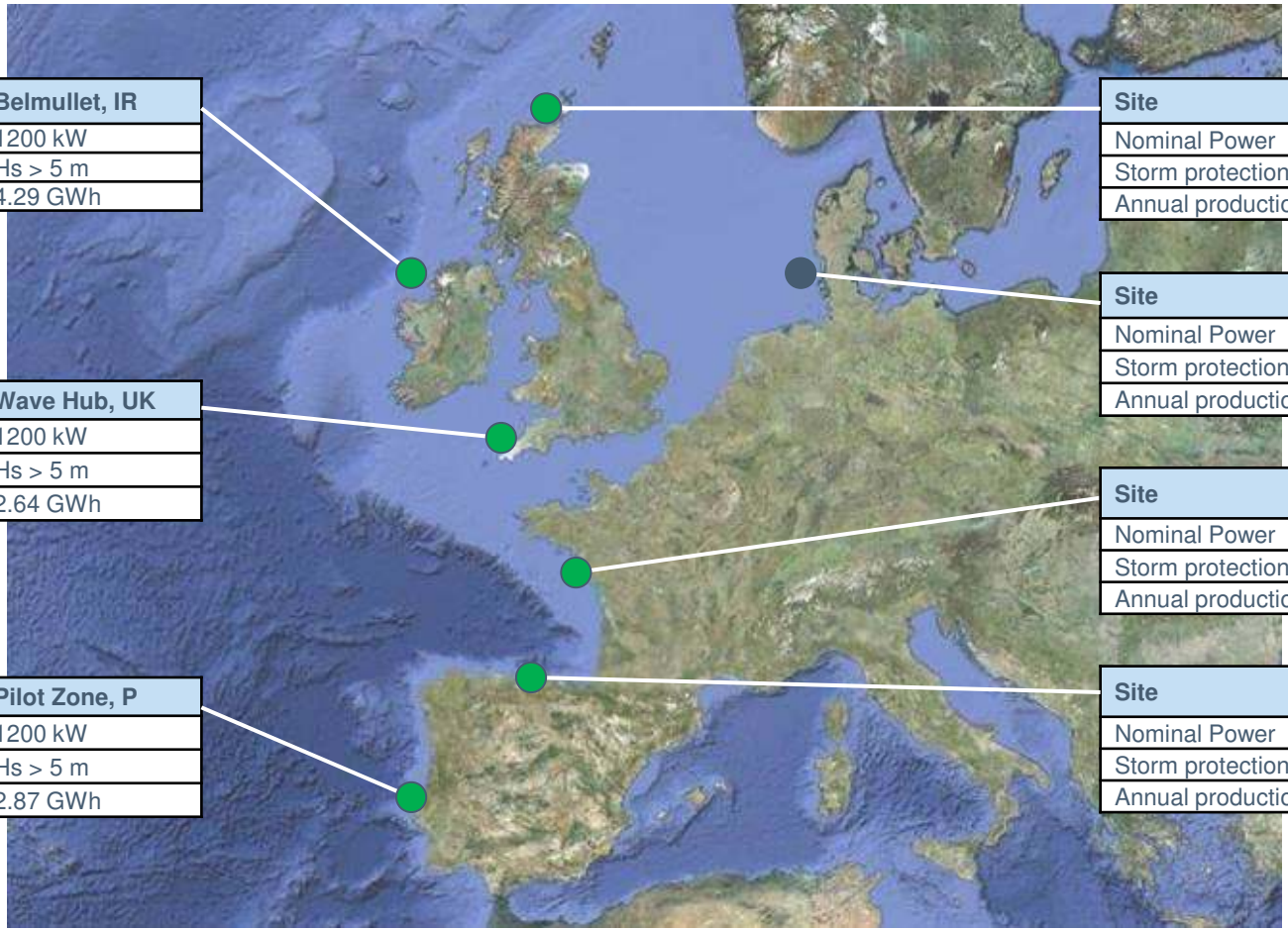
Perspective:
Wavestar performance in Europe



Site	Belmullet, IR
Nominal Power	1200 kW
Storm protection	Hs > 5 m
Annual production	4.29 GWh

Site	EMEC, UK
Nominal Power	1200 kW
Storm protection	Hs > 5 m
Annual production	2.88 GWh

Site	Horns Rev 2, DK
Nominal Power	600 kW
Storm protection	Hs > 3 m
Annual production	1.41 GWh

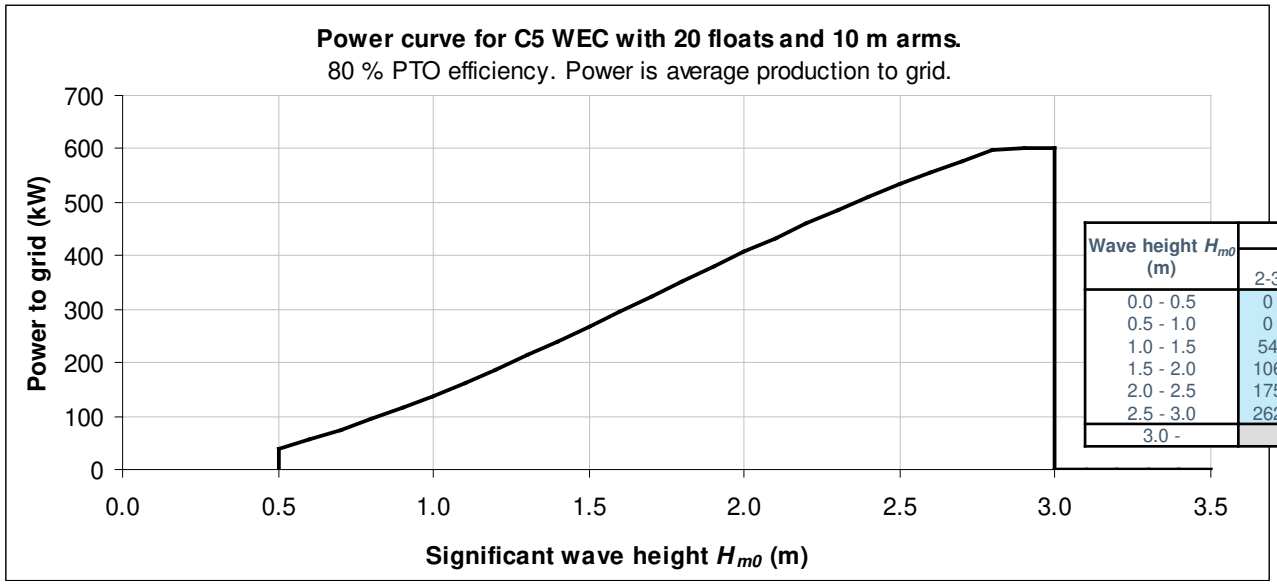
Site	Wave Hub, UK
Nominal Power	1200 kW
Storm protection	Hs > 5 m
Annual production	2.64 GWh

Site	SEM-REV, F
Nominal Power	1200 kW
Storm protection	Hs > 5 m
Annual production	2.37 GWh

Site	Pilot Zone, P
Nominal Power	1200 kW
Storm protection	Hs > 5 m
Annual production	2.87 GWh

Site	BIMEP, ES
Nominal Power	1200 kW
Storm protection	Hs > 5 m
Annual production	2.21 GWh

● C5-10 (10 m arm) ● C5-16 (16.7 m arm)



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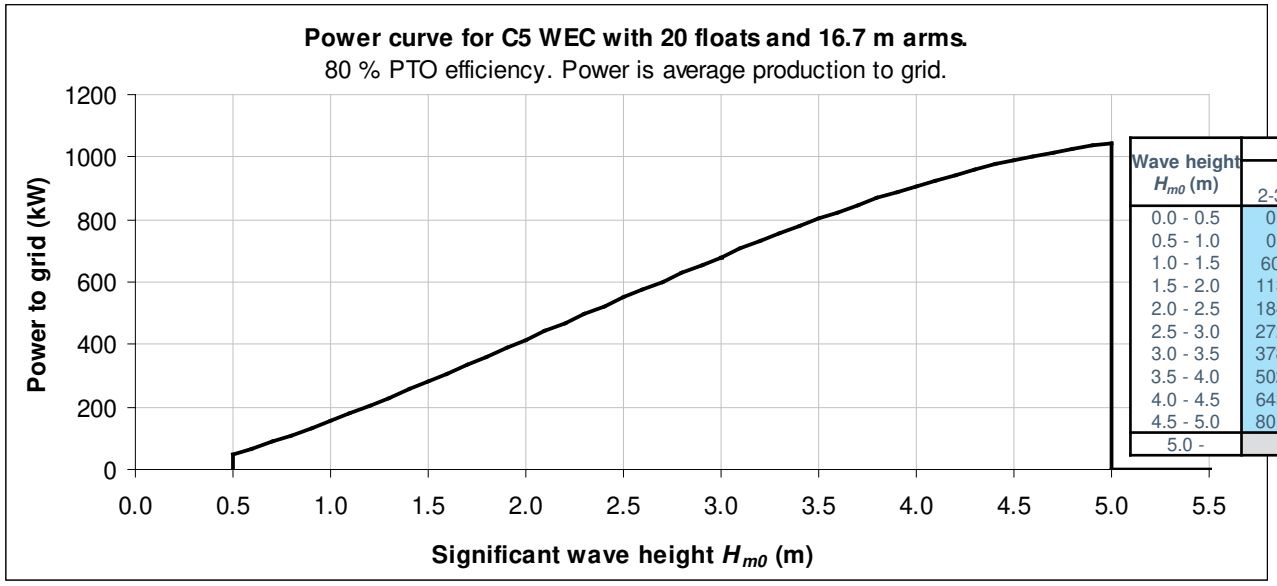

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0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0
0.5 - 1.0	0	51	74	87	90	87	83	77	73	68	64
1.0 - 1.5	60	136	194	211	206	193	179	166	155	144	135
1.5 - 2.0	113	263	350	358	339	314	288	265	246	228	213
2.0 - 2.5	184	424	527	521	484	443	405	371	343	318	297
2.5 - 3.0	272	612	721	695	638	580	527	483	444	411	383
3.0 - 3.5	378	821	928	879	799	722	655	597	549	508	472
3.5 - 4.0	502	1049	1146	1071	967	870	786	716	656	606	564
4.0 - 4.5	643	1200	1200	1200	1141	1021	921	836	766	707	657
4.5 - 5.0	801	1200	1200	1200	1200	1177	1058	959	877	809	751
5.0 -	Storm protection										

From 600 kW to 6 MW

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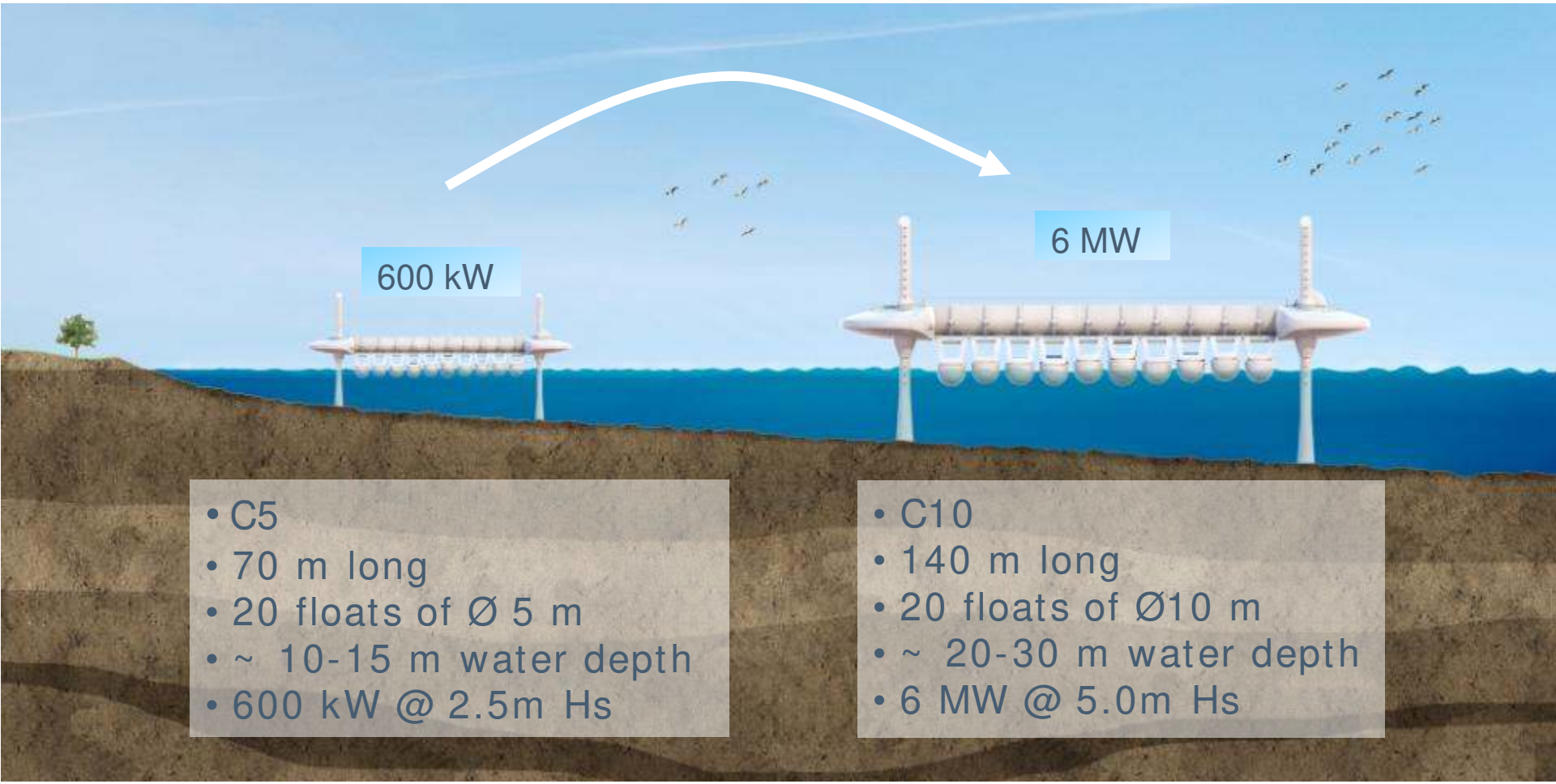

Double size = 11 times more power

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Wavestar machines in synergy with wind turbines