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Programme Area: Marine

Project: Technology Scoping and New Demonstrators

Title: Executive Summary

Abstract:

The ETI's Marine Energy Programme was launched in December 2007. The first Call under the Marine Programme yielded three major projects (ReDAPT, PerAWaT and Wetmate Connector). In order to inform the future development of the ETI's Marine Energy Programme, the ETI also commissioned a detailed benchmarking study of the marine energy technology landscape.The key purpose of the study was to analyse and map key marine energy (wave and tidal stream) component and system technologies in order to identify the major industry technology challenges and high-additionality technology opportunities that could be of interest to ETI. The study was commissioned as a Flexible Research Programme (FRP) project by Black & Veatch with DNV and Entec as sub-contractors, over 6 months and at a cost of £116k.

Context:

The key purpose of the study was to analyse and map key marine energy component and system technologies in order to identify the major industry technology challenges and high-additionality technology opportunities that could be of interest to ETI.

ETI Executive Summary

Programme: Marine

Project Name: Technology Scoping & New Demonstrators

Introduction

The ETI's Marine Energy Programme was launched in December 2007. The first Call under the Marine Programme yielded three major projects (ReDAPT, PerAWaT and Wet-mate Connector). In order to inform the future development of the ETI's Marine Energy Programme, the ETI also commissioned a detailed benchmarking study of the marine energy technology landscape.

The key purpose of the study was to analyse and map key marine energy (wave and tidal stream) component and system technologies in order to identify the major industry technology challenges and high-additionality technology opportunities that could be of interest to ETI. The study was commissioned as a Flexible Research Programme (FRP) project by Black & Veatch with DNV and Entec as sub-contractors, over 6 months and at a cost of £116k.

The project was divided into four Phases:

Phase	Scope
Phase 1 - Categorisation of Marine Technologies	Details of the science and engineering principles behind these classification matrices as well as the advantages, disadvantage and innovation potential of each class.
Phase 2 - Review of Component Technologies	1. An understanding of the component makeup of generic wave and tidal stream technologies and what contributes to overall cost of energy (COE) 2. The identification of the specific components used within the tidal and wave energy devices and their respective TRLs 3. Identification of which components offer most innovation and technology development potential
Phase 3 - Component Analysis & Prioritisation	Analysis of the identified components, introducing new metrics including development time, development cost and potential IP challenges. A prioritised list of components was identified for further ETI consideration.
Phase 4 - Additionality, Project Recommendations & Optimal Technology Configuration	Recommendations for potential ETI projects based on the component analysis of Phase 1-3, the integration of these components at the system level, likely project duration and cost, and considerations of the likely skill sets required to deliver projects and ETI additionality.

The key deliverables for the project were Tidal and Wave Technology Landscape Maps and a Tidal & Wave Energy Technology Benchmarking Report. These are available to ETI members.

In this work there was close interaction with the ETI Marine Strategy Advisory Group (SAG), including presentations at each stage and a workshop to incorporate SAG input.

Results summary

Phase 1 (Categorisation of Marine Technologies)

The high-level classification matrices for tidal stream and wave technologies developed in Phase 1, along with some high-level descriptions, are reproduced in Appendix A. These classifications were developed by Black & Veatch to enable a specific wave or tidal stream device's key features and operating principles to be defined and compared.

The project deliverables provide details of the science and engineering principles behind these classification matrices as well as the advantages, disadvantage and innovation potential of each class (see Appendix A).

Phase 2 (Review of Component Technologies)

Phase 2 findings can be grouped into 3 areas:

1. ***An understanding of the component makeup of generic wave and tidal stream technologies and what contributes to current overall cost of energy (COE)***

Key findings:

- For tidal energy systems, the fixation (mooring) systems and operations and maintenance (O&M) costs are on average the most significant contributors to cost of energy (20% and 18% of COE respectively); other major contributors to COE include site installation (13%) and power take-off systems (13%). It was also concluded (see Figure 1) that horizontal axis free-stream tidal technologies, such as the TGL, MCT or Hammerfest Strom types, are potential industry leaders in terms of COE.
- For wave energy systems, O&M costs, hydrodynamic absorbers and the power take-off system are on average the most significant contributors to COE (25%, 21% and 17% respectively); Installation (6%) and fixation (5%) also provide significant contributions to COE. It has also concluded (see Figure 2) that attenuator technologies, such as Pelamis or Anaconda, are potential industry leaders in terms of COE.

These findings provide focus to ETI towards the types of component and system technologies that are most likely to have a significant impact on cost reduction.

For reference, and as example, the COE breakdown for generic wave energy types provided by Black & Veatch is reproduced in Figure 3.

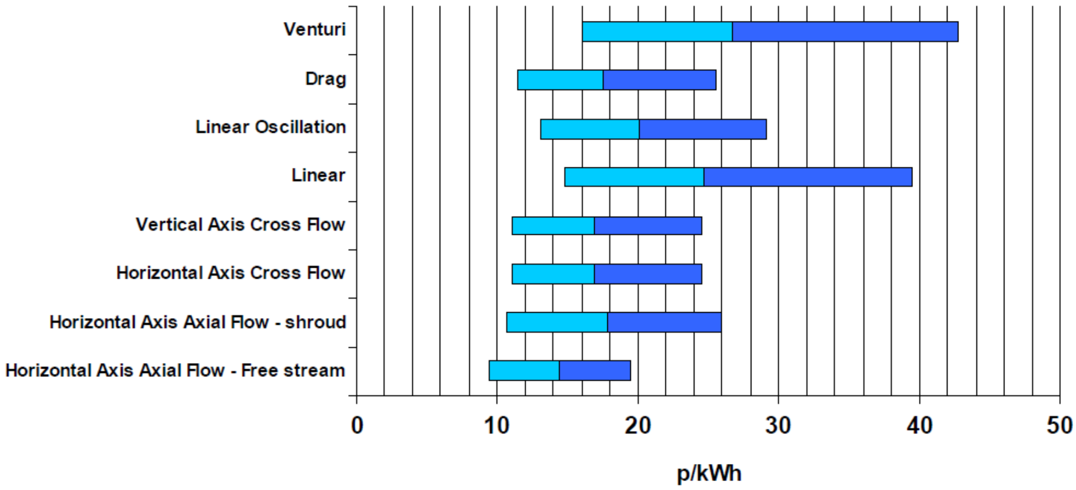


Figure 1 – Relative COE of different tidal stream classifications

Light Blue = 'claimed' current CoE range

Dark Blue = B&V's view of the uncertainties around these estimates based on design and performance

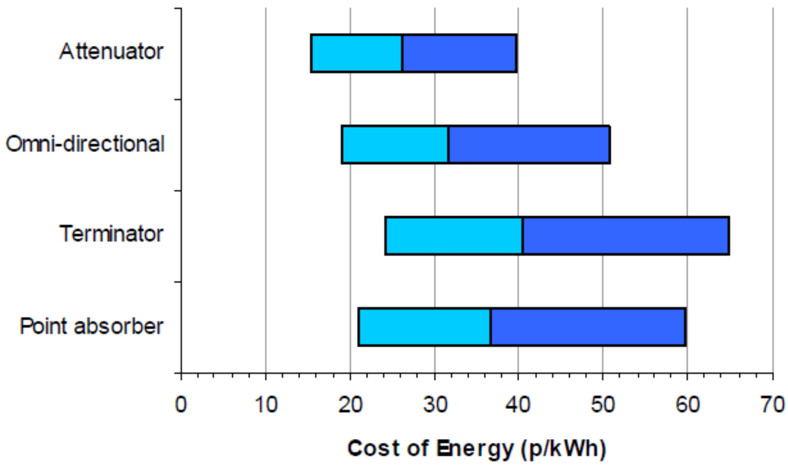


Figure 2 – Relative COE of different wave energy classifications

2. *The identification of the specific components used within the tidal and wave energy devices and their respective TRLs*

A total of 37 tidal technology developers and 47 wave energy technology developers with concepts at TRL3 or greater were identified during the study and reviewed in detail to identify and categorise the components that make up these devices. A total of 68 components were identified and categorised into four groupings; hydrodynamic, power take-off, control and fixation/reaction. The full list is reproduced in Appendix B. This list was then analysed in more detail to identify priority component opportunities.

3. *Identification of which components offer most innovation and technology development potential*

This analysis comprised as assessment of the component's innovation potential, its average cost of energy, its industry cross-over (i.e. the degree to which it is used in other industries), and its commonality (i.e. how many different devices use the component).

Innovation potential was classified using four categories, as a measure of the degree of technical challenge in applying a component that will deliver a performance improvement in marine renewable energy applications. The four categories are:

1 = no new technical uncertainties

2 = new technical uncertainties

3 = new technical challenges

4 = demanding new technical challenges

As examples – A seal is a TRL 9, well established component; however, placing it in the offshore environment and requiring it to operate for 3 years between maintenance routines introduces new technical uncertainties (level 2). A blade is a TRL 9, well established component, but for different tidal stream developers the blade could be a level 2 or 3 (or even in some cases 4) depending on how different loadings, blade materials, development and testing has been achieved compared to that required to place it at level 1.

Furthermore Black & Veatch also introduced an additional parameter, the "effective TRL", which takes into account the fact that although some components may be available in other industries their application to the marine energy sector may require additional (and possibly significant) development work before being deployed. An example of the analysis for the hydrodynamic components is shown in Appendix C.

Of the 68 components identified by Black & Veatch, 22 of these were identified as having high innovation potential and also a significant impact on COE. All 68 components were taken forward for more in-depth analysis in Phase 3.

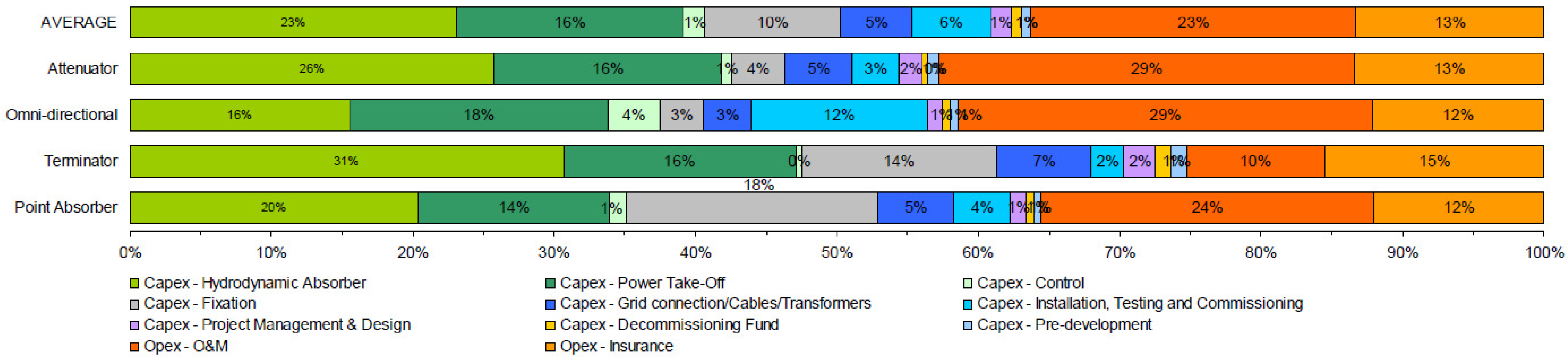


Figure 3 - COE components of leading wave energy converter types

Phase 3 (Component Analysis & Prioritisation)

Phase 3 further developed the analysis of the identified components, introducing new metrics including development time, development cost and potential IP challenges. By analysing and assessing each component against a common ranking methodology, including weightings based on ETI priorities, a prioritised list of components was identified for further ETI consideration. This list is shown in Figure 4 below.

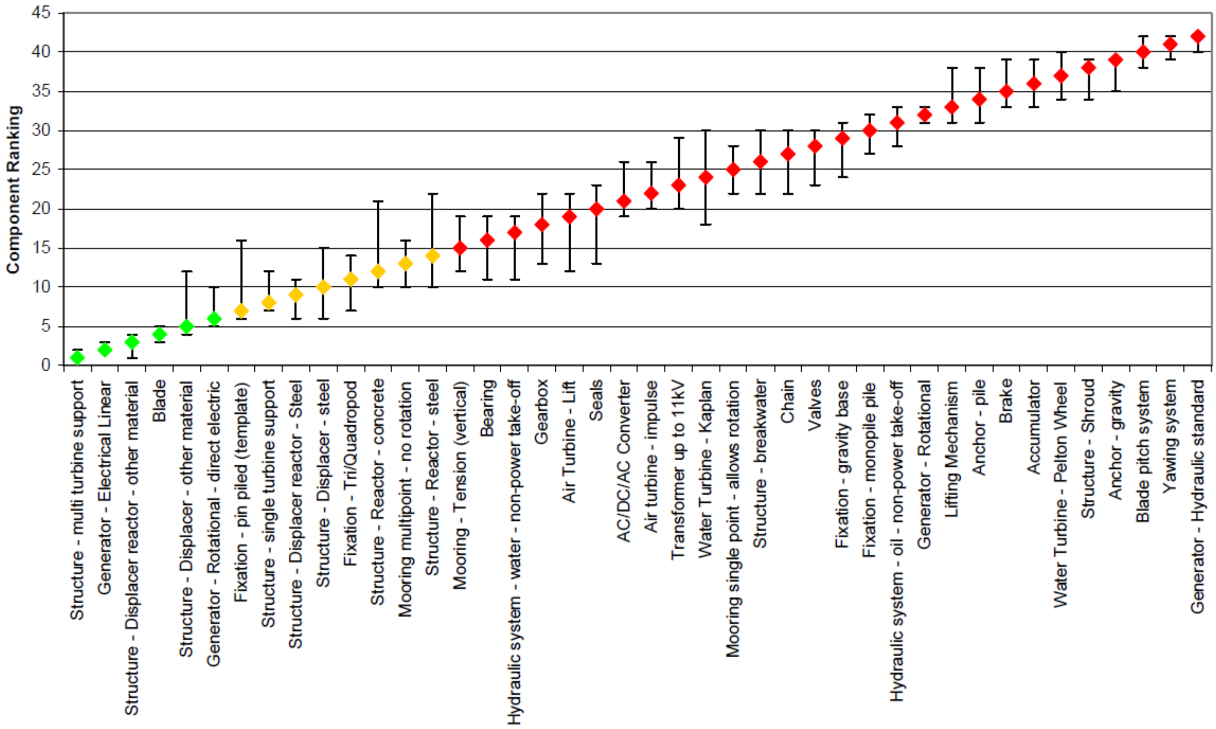


Figure 4 – Prioritised component list for ETI consideration

The components are shown in order of priority from left to right (highest on the left); also shown are sensitivity ranges based on varying the weightings of the various ranking categories. The components shown in green are those that could be in the top 5 based on their variance; those in orange are those that could fall within the top 10; all others are shown in red.

From the analysis Black & Veatch selected the top 14 ranked components and identified these as primary components for ETI intervention. These are shown in Figure 5. In addition, two other technology areas were identified as being worthy of further ETI consideration:

- Novel (more intelligent) sensors – primarily as a means of wave characteristics in order to inform the control system and thereby increase yield;
- Novel hydraulic generating equipment – these are not used currently in the marine energy sector but may offer cost savings

The final versions of technology landscape maps for both the wave and tidal stream sectors were also completed at the end of Phase 3. These are included in Appendix D.

Figure 5 – Top 14 ranked components for ETI consideration

Rank	*Subsystem*	*Component*	*WEC or TEC*
1	Reaction	Structure – multi turbine support	TEC
2	Power take-off	Generator – electrical linear	Mainly WEC
3	Hydrodynamic	Structure – displacer reactor – other material	WEC
4	Hydrodynamic	Blade	TEC
5	Hydrodynamic	Structure – displacer – other material	WEC
6	Power take-off	Generator – rotational – direct electric	TEC
7	Reaction	Fixation – pin piled (template)	Mainly TEC
8	Reaction	Structure – single turbine support	TEC
9	Hydrodynamic	Structure – displacer reactor – steel	WEC
10	Hydrodynamic	Structure – displacer – steel	WEC
11	Reaction	Fixation – tri/quadropod	Mainly TEC
12	Hydrodynamic	Structure – reactor – concrete	WEC
13	Reaction	Mooring multipoint – no rotation	Mainly WEC
14	Hydrodynamic	Structure – reactor - steel	WEC

For definitions of the terms in this table – please refer to Appendix E

Phase 4 (Additionality, Project Recommendations & Optimal Technology Configuration)

Phase 4 provided 2 key outputs:

1. Recommendations for potential ETI projects based on the component analysis of Phase 1-3, the integration of these components at the system level, likely project duration and cost, and considerations of the likely skill sets required to deliver projects and ETI additionality. Five project areas (in priority order) have been identified by Black & Veatch as shown in Figure 6. These will be considered further by ETI in conjunction with the Marine SAG as part of the ongoing Marine Programme process.

Project No.	Project Name	Applic ability	Aims	CoE potential reduction	Risk	Potential ETI Accelerat ion	Project Cost (ex demo)
1	TEC Foundations	TEC	This project seeks to review the challenges presented by foundations as a whole, and identify new ways of providing reaction to TECs at a reduced cost and in deeper water.	2-6%	Medium	Up to 3 years	c.£4.5M
2	Low Cost WEC Structures	WEC	This project would focus on identifying, testing and demonstrating new materials that could replace steel, and thus improve the economics of WEC (and potentially TEC) devices.	1-17%	High (novel material)	5 years + (novel material)	c.£4.5M
3	TEC Blade Optimisation	TEC	This project would seek to identify, trial and qualify new materials (with high long-term strength to cost ratio) and manufacturing techniques (appropriate mass production), with the aim of optimising the blade design for TECs in terms of CoE.	1-4%	Medium	5 years + (new material)	c.£2.5M
4	Optimised PTO Solutions	WEC & TEC	This project would match leading novel PTO companies with leading TEC and WEC technology developers to accelerate the development and testing of full scale systems that would be suitable for industry-wide deployment.	1-6%	Medium	Up to 3 years	c.£2.5M
5	WEC Sensors	WEC	The aim of this project is to develop and prove sensors to detect the location, speed, length and height of waves approaching WECs.	1-15%	Medium	Up to 3 years	c.£2.5M

Figure 6 – Potential ETI projects proposed by Black & Veatch

2. Suggestions from Black & Veatch on the classifications of marine energy concept that appear most likely to have the best chances of long-term commercial viability. These are:

   For tidal stream: the optimal configuration is likely to be horizontal axis, free-stream system; the landscape mapping provided by Black & Veatch indicates that there are 13 devices currently in development that fall within this classification. These include TGL, MCT, Hammerfest Strom, Atlantis and Verdant Power.

   For wave energy: the optimal configuration is likely to be attenuator systems with a rigid or flexible working surface; the landscape mapping provided by Black & Veatch indicates that there are 3 devices that fall within this classification, with only Pelamis and Anaconda appearing to be making significant ongoing development.

   These findings have been taken forward into the 2010 Marine Programme Review.

Key findings

This section presents a summary of the key findings of the project. The project has delivered the following headline outputs:

- A wave and tidal stream device technology classification methodology in order to provide a consistent method for mapping and comparing the merits of known marine energy technologies;
- Descriptions and details of the key engineering features of these classifications and comparisons of their advantages and disadvantages, thereby providing a steer towards those high-level concepts and sub-component technologies most likely to offer technical and economic advantages, and informing opportunities for technology innovation;
- Detailed technology landscape maps, populated with all known wave and tidal stream devices, showing where each sits within the technology classifications developed above and what sub-components they comprise. This is used to show graphically how different technologies compare from the technical perspective, their respective TRLs, their key sub-components and how widely these sub-components are deployed across the marine energy sector;
- Detailed analysis of how the different technology components of the wave and tidal stream classifications contribute to the overall cost of energy (COE), how common these components are across the marine energy sector, their innovation and performance/cost improvement potential, their reliability, likely development times and development intervention costs. These components have also been ranked in terms of their attractiveness for ETI intervention; this helps identify those components that are likely to offer the greatest technology improvement opportunities and COE reduction potential for ETI. Sixteen components were identified as primary components (those of highest priority;
- Recommendations for possible ETI projects in a second ETI call, (both component and system level) that are likely to provide the greatest impact based on the earlier component analysis and ETI's strategic objectives, including indicative development costs and timescales. These cover both wave, tidal stream and generic technology projects covering both areas, i.e.:
    1. tidal stream foundations
    2. low-cost wave energy structures
    3. optimised tidal stream blade technologies
    4. optimised power take-off systems (wave & tidal)
    5. wave energy sensors for control system optimisation and yield improvement.

- The consortium's views on the features of "optimal" wave and tidal stream devices; this provides guidance towards the technologies that Black & Veatch believes are most likely to be commercially viable in the long term (i.e. for wave – rigid or flexible attenuators; for tidal stream – horizontal axis axial-flow and horizontal axis cross-flow types).

Further work

The detailed outputs from the project are a key input to the ETI's Marine Programme Review that will report to Technical Committee in August 2010.

Appendix A: Classification Matrices

For tidal systems, the five main features that define any given tidal energy converter have been categorised as:

- Hydrodynamics – defines the principle method of converting energy from the incoming tidal stream flow into another useful form (e.g. lift, drag, etc);
- Primary motion – defines how the energy is actually converted into a useful format for the power take-off system (e.g. rotating horizontal axis turbine);
- Augmentation – describes whether and how the incoming flow is augmented prior to energy extraction (e.g. does the flow pass through a nozzle?);
- Foundation – defines how the technology reacts against the seabed;
- Location in water column – e.g. is the device adjacent to the surface, in mid-water or adjacent to the seabed?

Tidal Classification Matrix

Hydrodynamics	Primary Motion	Augmentation	Fixation	Location in water column
Lift (L)	Rotation: Horizontal Axial Flow (H)	Free Stream (F)	Moored (M)	Adjacent to surface (A)
Drag (D)	Rotation: Horizontal Cross Flow (C)	Shroud (D)	Tensioned (G)	Mid-water (I)
Venturi (T)	Rotation: Vertical Cross Flow (V)		Seabed fixed (B)	Adjacent to seabed (E)
Vortex Shedding (X)	Linear Oscillating: Vertical (E)			
Other (O)	Linear Oscillating: Horizontal (Z)			
	Linear: Linear (N)			

Red = low innovation potential
Orange = moderate innovation potential
Green = high innovation potential
(See page 6 for definition of innovation potential)

For wave systems the five main features that define any given wave energy converter have been categorised as:

- Configuration – provides a high-level description of how the wave energy converter interacts with the waves (e.g. attenuator like Pelamis, point absorber like OPT);
- Working surface – describes the physical component of the device that interacts with the waves (e.g. is it a rigid structure, flexible structure?);
- Reaction – describes the type of reaction mechanism that all wave energy converters need to resist the force of the waves and thereby extract power;
- Mode – describes the movement of the wave energy device (e.g. heave, where the device moves up and down);
- Energy transfer – describes the primary mechanism by which power from the wave energy device is transferred prior to conversion to electricity (e.g. pneumatic, hydraulic, etc)

Wave Classification Matrix

Configuration	Working Surface	Reaction	Mode	Energy Transfer
Attenuator (A)	Fluid (F)	Dynamic External Mass (D)	Heave (H)	Pneumatic (C)
Terminator (T)	Rigid (G)	Non-dynamic Mass (N)	Surge (S)	Oil-hydraulic (O)
Point Absorber (P)	Flexible (L)	Internal Mass (I)	Hybrid (Y)	Water Hydraulic (W)
Omni-directional Absorber (M)		Balancing (B)		Direct Electrical (E)
				Mechanical Linkage (K)

Red = low innovation potential
Orange = moderate innovation potential
Green = high innovation potential
(See page 6 for definition of innovation potential)

Appendix B - Component Technologies and Groupings

Hydrodynamic		Power take-off		Control		Fixation/Reaction	
H1	Bearing	P1	AC/DC/AC Converter	C1	Blade pitch system	F1	Anchor - drag embedment
H2	Blade	P2	Accumulator	C2	Control system high complexity	F2	Anchor - gravity
H3	Chain	P3	Air turbine - impulse	C3	Control system low complexity	F3	Anchor - pile
H4	Hub	P4	Brake	C5	Yawing system	F4	Anchor - torpedo
H5	Hydrofoil	P5	Cable			F5	Fixation - gravity base
H6	Seals	P6	Counterweight			F6	Fixation - monopile pile
H7	Structure - Displacer - Other material	P7	Gearbox			F7	Fixation - pin piled template
H8	Structure - Displacer - steel	P8	Generator - Electrical Linear			F13	Fixation – Tri/Quadropod
H9	Structure - Displacer reactor - other material	P9	Generator - Hydraulic - standard			F8	Jacket
H10	Structure - Displacer reactor - Steel	P10	Generator - Rotational			F9	Lifting Mechanism
H11	Structure - Reactor - concrete	P11	Generator - Rotational - direct electric			F10	Mooring - Tension (vertical)
H12	Structure - Reactor - steel	P12	Hydraulic system – oil – non power take-off			F11	Mooring multipoint - no rotation
H13	Structure - Shroud	P13	Hydraulic system - water			F12	Mooring single point - allow rotation
H14	Yoke & yaw	P14	Pinion gear			F14	Structure - ballast chambers
		P15	Pulley			F15	Structure - breakwater
		P16	Pump - Hose Pump			F16	Structure - multi turbine support
		P17	Rack & Pinion			F17	Structure - pontoon
		P18	Shaft			F18	Structure - shore mounted
		P19	Spring			F19	Structure - single turbine support
		P20	Structure - Reservoir			F20	Structure - blockage
		P21	Transformer up to 11kV				
		P22	Turbine - Francis				
		P23	Turbine - Kaplan				
		P24	Turbine - Pelton Wheel				
		P25	Turbine - water new design				
		P26	Turbine - Lift				
		P27	Valves				
		P28	Air turbine – unidirectional fan				
		P29	Hydraulic generator - novel				
		P30	Cooling system				

Appendix C - Component Assessment Matrix (Hydrodynamic Components)

Ref	Component name	TRL	Innovation potential	Effective TRL	Commonality	Lifecycle influence on CoE
H1	**Bearing**	**9**	**2.6**	**6-7**	**85**	**10-20%**
H2	**Blade**	**9**	**2.7**	**6-7**	**39**	**1-2%**
H3	Chain	9	2.5	6-7	2	<1% CoE
H4	Hub	9	1.8	7-8	23	2-5%
H5	Hydrofoil	9	2.0	6-7	2	1-2%
H6	**Seals**	**9**	**2.9**	**6-7**	**76**	**10-20%**
H7	***Structure - Displacer - other material***	***9***	***2.0***	**5-6**	***1***	***10-20%***
H8	***Structure - Displacer - steel***	***9***	***1.9***	**7-8**	***25***	***10-20%***
H9	***Structure - Displacer reactor - other material***	***9***	***2.7***	**5-6**	***3***	***<1% CoE***
H10	**Structure - Displacer reactor - Steel**	**9**	**2.2**	**6-7**	**10**	**10-20%**
H11	***Structure - Reactor - concrete***	***4***	***2.3***	**6-7**	***8***	***10-20%***
H12	***Structure - Reactor - steel***	***4***	***2.1***	**6-7**	***17***	***1-2%***
H13	Structure - Shroud	9	2.0	7-8	6	1-2%
H14	Yoke & yaw	9	2.0	5-6	1	2-5%

Red text = particularly important components due to combination of high innovation potential and significant influence on COE.

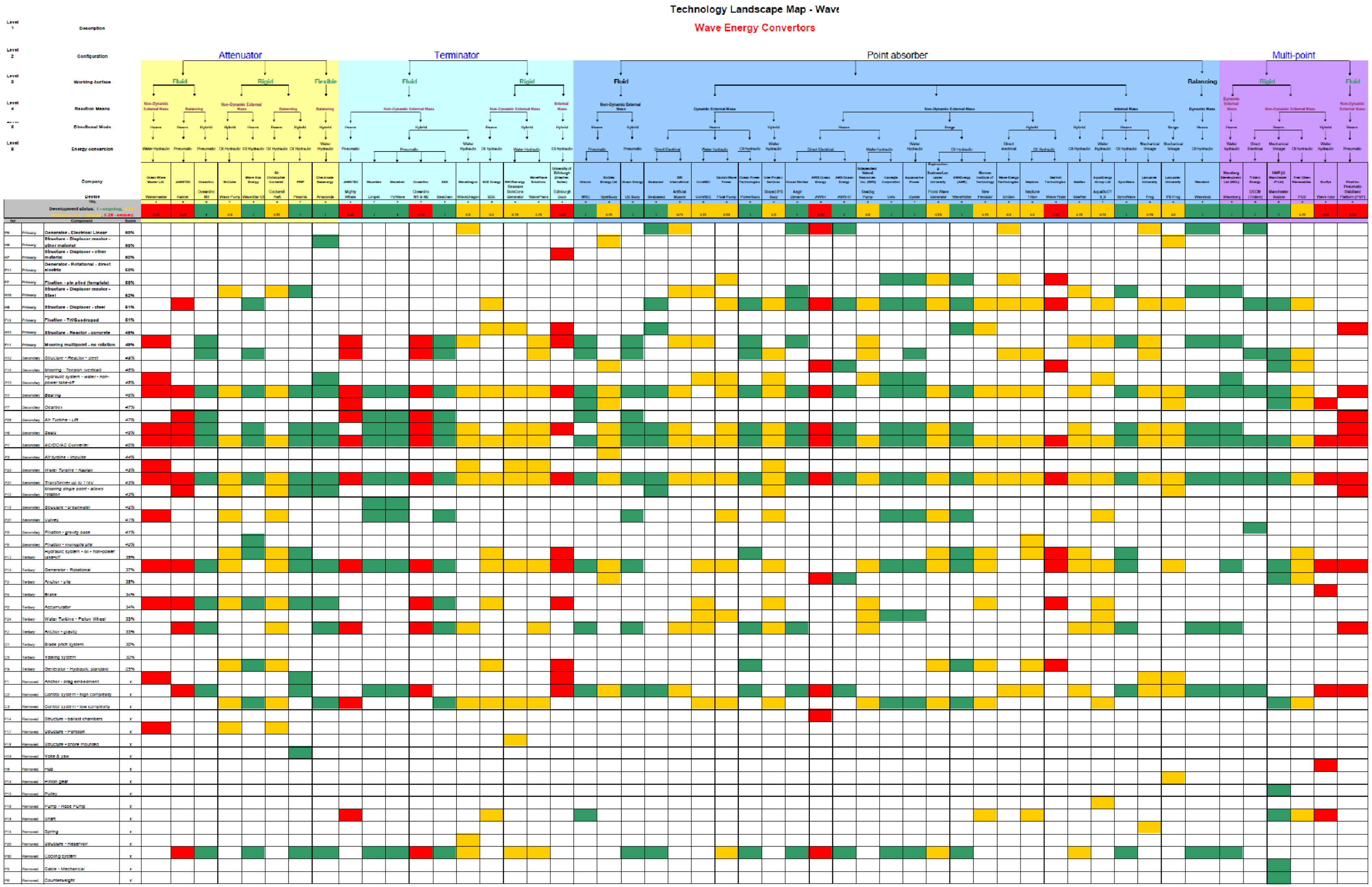
Blue text = important components with high innovation potential and influence on COE

Black text = rest

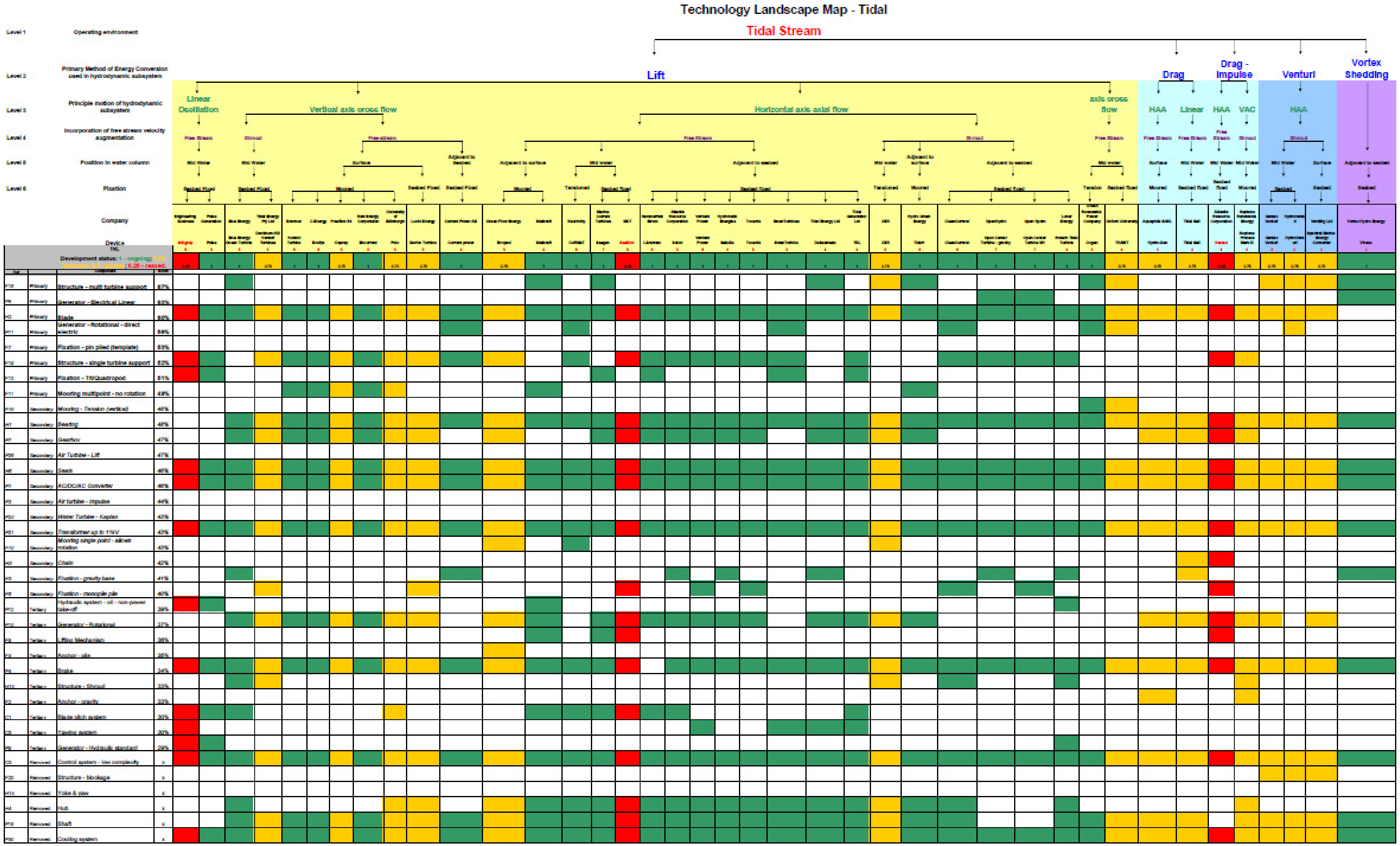
Innovation Potential = a measure of the degree of technical challenge in applying a component that will deliver a performance improvement in marine renewable energy applications. Scale 1 to 4, with 1 being no new technical uncertainties, and 4 being demanding new technical challenges.

Commonality = number of devices using this component

Appendix Da - Wave Technology Landscape Map



Appendix Db - Tidal Technology Landscape Map



Appendix 5 - Definition of terms in Figure 5

Subsystems:

Reaction	The means by which a wave device resists the wave force and extracts power (e.g. external mass)
Power take-off	The system that converts wave motion into electrical power (includes, for example, electrical generator, power electronics, gearbox, etc)
Hydrodynamic	The method of converting tidal flow into energy of a useful form (e.g. lift force such as tidal blades)

Components:

Structure – multi turbine support	Single support structure containing two or more tidal turbines (e.g. Tidal Stream and Partners, MCT next generation system)
Generator – electrical linear	Conventional generator used in many wave power concepts. Directly converts oscillating linear motion to electrical power.
Structure – displacer reactor	In some designs the reactor is inside the displacer; this component type relates to such systems - These have been categorised either as “steel” or “other” (i.e. non-steel)
Blade	
Structure – displacer	The displacer in a wave energy device is the section that moves in response to the waves
Generator – rotational – direct electric	“Direct drive generator” – converts low speed (usually <100 rpm) rotational power to electrical power directly (i.e. without an intermediate power converter)
Fixation – pin piled (template)	A tidal turbine base fixed to the seabed via a number of pins (e.g. a monopile structure where the monopile itself isn’t driven into the seabed, but where pins (attached to the monopile) are instead driven into the seabed
Structure – single turbine support	Usually refers to a monopile structure (e.g. MCT)
Fixation – tri/quadropod	Three or four legged support structure for a tidal turbine (e.g. TGL tripod)
Structure - reactor	The reactor is the section of the device against which the displacer reacts. Usually (but not necessarily) the foundation.
Mooring multipoint	Mooring system whereby a wave device is fixed to the seabed by a number of mooring lines (e.g. Pelamis)