Overview and Summary of WP3.1 Information Request

Identification of Limitations of the Current Practices Adopted for Early Stage Tidal Device Assessment

Authors: IFREMER, University of Southampton and University of Strathclyde

1 Introduction

Tidal stream technology is in its infancy with a broad range of devices either at the conceptual, model or full-scale demonstrator stage. Meaningful power generation (defined as input to the electrical grid) may well be achieved in the medium term thus it is critical that methods and criteria are set in place imminently to assess the tidal devices that will receive public funding and that eventually may see full-scale production and deployment. A robust assessment criteria is required to identify the strengths, weaknesses and potential risks associated with any device and to ensure due diligence is exercised at each development stage. These assessment criteria will involve both experts in the subject area to conduct the assessment and also a set of tools (methodologies, numerical simulation etc.) to be used to complete the assessment tasks. If this is achieved the following benefits would be realised:

- Better allocation of public funding
- A more robust tidal energy sector
- A clear pathway for developers to follow to market

The following report attempts to identify the limitations of the current practices adopted to undertake **initial conceptual appraisal of tidal devices**, specifically with regard to: power capture; conversion and power take off; and station keeping.

It is hoped that once present limitations are clearly defined, enhanced assessment criteria can be set in place to benefit the industry. This document summarises the results arising from information provided by tidal energy device developers with regard to current appraisal and assessment processes.

2 Methodology

Information was gathered from a very wide range of tidal developers (see 6.2). The limitations of current practice identified will later be used to produce a set of guidelines that will in future allow developers or assessors to more efficiently progress tidal technologies to market. All information submitted was treated as strictly confidential and therefore all responses are summarised and made anonymous in this report.

Initial concept appraisal would seem to be very broad and highly dependent on the developer's needs with regard to satisfying their own demand for concept viability. To gain the maximum expertise and experience from those who have developed tidal devices each known developer was asked a series of questions related to initial tidal device assessment. This was undertaken by means of a personal email invitation, an online information request (see 6.1), and follow up telephone calls were necessary.

The information request was based around the commonly used assessment subsets of: power capture, power take-off and power conversion, station keeping, computational methods, and general topics such as risk and economic viability. However some questions were left open-ended to allow for any variation from the assumed norm.

3 Outcomes

3.1 Summary of Responses

The status of all the developers approached (refer to 6.2) was not entirely known, and indeed it is thought that a small number may not presently be operational. Feedback was very quickly received from 12 of the 36 listed developers including a number who would be widely recognised as the market leaders in this emerging industry.

Those who responded are developing a very wide range of technologies including single and multi-rotor horizontal turbines, vertical axis turbines, vertically oscillating foils and horizontally moving hydrofoils. Additionally the devices are both devices fixed (piled or other structure) to the seabed and those floating (moored) within the water column or at the sea surface. The information submitted and the comments made are therefore representative of a very wide proportion of tidal experience and innovation.

3.2 Responses Concerning Novelty and Facets Assessed at Concept Appraisal

Every respondent had made a search to determine novelty before any early appraisal was made. Novelty was almost always determined by means of a patent search, and otherwise by analysis of any existing devices. The specific areas of early concept appraisal and evaluation are summarised in *Figure 1* as a percentage of all those replying to the information request. All developers who responded were extremely aware that commercial viability was the bottom line of any appraisal, although the early assessment of the technical merits was normally the basis on which this would be judged – as reflected by the figures in *Figure 1*.

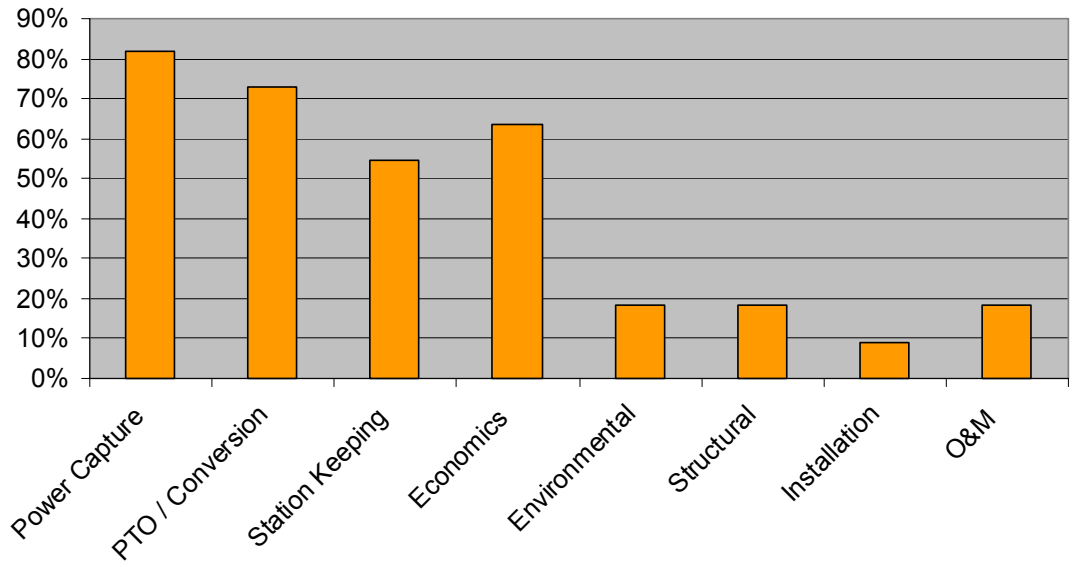

Figure 1: Factors Assessed during Early Stage Device Appraisal

Interestingly, 91% of respondents had undertaken informal model testing as a part of their initial concept assessment. The reasons given for this were linked to basic confirmation of operation, risk reduction, and basic physical proving which was seen to be more easily (reliably?) undertaken than computational modelling.

3.3 Responses Concerning Power Capture, Take-off and Conversion

The very early conceptual stage assessment of power capture, power take-off and conversion was generally undertaken for the following reasons (all eventually related to commercial viability – see *Figure 2*):

- To produce an approximation of a likely tidal stream to estimate and optimise system performance.
- To evaluate the prime mover full operational envelope power output characteristics and so identify the most suitable power-take off system
- To calculate the full water-to-wire efficiency of the system
- To identify the primary design drivers

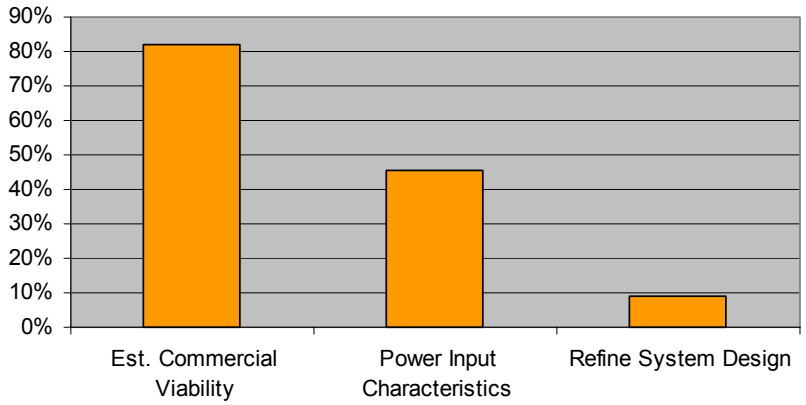

Figure 2: Reasons for Power Capture Assessment

With respect to power take-off and conversion, commercial viability continues as the main reason for assessment, however *Figure 3* also shows that these evaluations begin to influence the basic design decisions, for example, type of power take-off and conversion system best suited for grid connection, reliability, O&M etc.

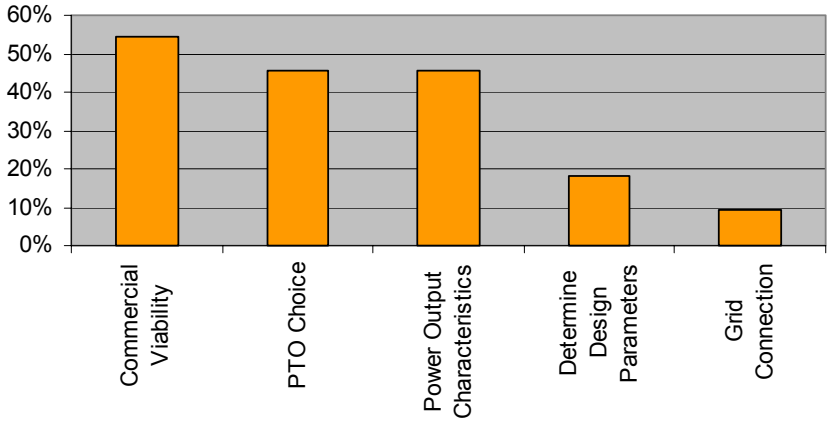

Figure 3: Reasons for Power Take-off and Conversion Assessment

A number of interesting points were made with respect to the level of detail, accuracy and limitations of the power capture, take off and conversion parameters evaluated:

- Conservative design assumptions should be used to avoid overly optimistic technology evaluation.
- Sensitivities in flow velocity make for large differences in performance evaluations.
- Effects of surface waves and turbulence are noted as being difficult to quantify both in real terms and in terms of power output.
- Complexities in scaling accurately (subsequently noted with scaled models).
- That the entire system should be optimised as a whole to determine all primary design sensitivities.
- To aid accurate evaluation and costing even at the earliest stages, advice and data from expert equipment manufacturers should be used where possible.

3.4 Responses Concerning Station Keeping

Station keeping refers to the method by which the tidal device retains its position (or limited movement) with respect to the tidal stream. Those responding that this was an important part of their assessment (10/12) had a very wide range of methods proposed, however this study finds a number of agreed areas of importance for early stage assessment as outlined in *Figure 4*. The level of assessment undertaken was generally conceptual (quasi static force calculations) at the early stages of device development, and was later refined during tank and sea tests.

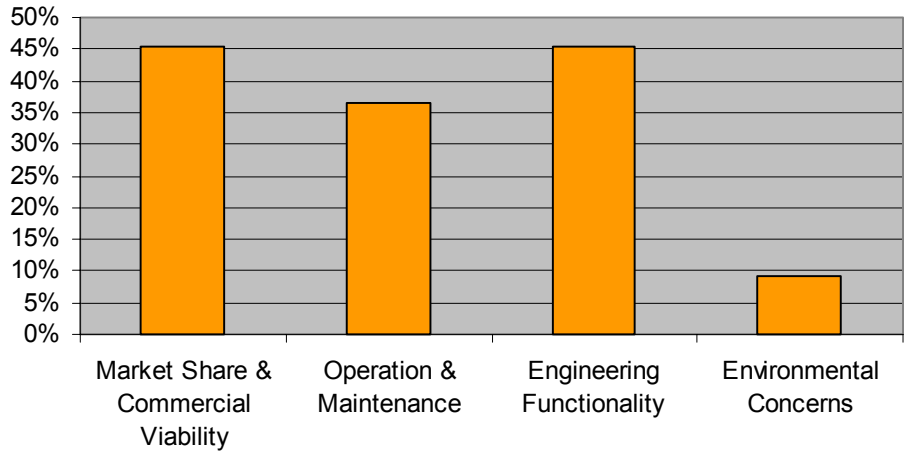

Figure 4: Reasons for Station Keeping Assessment

3.5 Responses Concerning Computational Methods

All tidal device developers responded that they had undertaken computational modelling, although only 60% had developed their own mathematical models or codes. It should be noted that due to the constantly evolving nature of each device's development it was difficult to determine the level to which this had been undertaken for early stage device evaluation. The later stages of device development use very complex and complete models, of which very little information is publicly available due to commercial sensitivity.

Responses however suggest that spreadsheet based models are commonly used as initial assessment tools to determine the sensitivity of basic design parameters, although these tend to be focused on each device developers own preferentially chosen factors and assumptions as alluded to in the previous sections on power capture, take-off and conversion.

Efficiency of power capture (and hence assessment of commercial viability) is the primary reason for additional modelling (CFD, BEM, Vortex Theory, Streamtube Models) at the early concept evaluation. The majority of such modelling (often undertaken in partnership with R&D partners) used either commonly available commercial packages or packages previously developed for other sectors, for example, wind turbines. Such modelling is most often used to inform the design of future small scale demonstrators and to provide the early scaled predictions for the commercial viability of full-size devices.

A secondary reason for computational methods is structural integrity, although this tends to be focussed on the later stages of technology development/design and will therefore not be further discussed here.

Verification of the early stage conceptual modelling is rarely undertaken at this stage, with the vast majority of respondents only being able to quantitatively verify any outputs during or post the scaled test programme and particularly once sea testing had been undertaken at a reasonable scale.

The early concept appraisal limitations of the current state-of-the-art modelling (outside of very device specific issues) from respondents are generally:

- The issue of relevant and accurate scaling factors.
- Modelling techniques are not adapted or specifically defined for underwater (hydro-dynamic) systems.
- The lack of widely available tidal data sets or a generally accepted proxy to use in the modelling of a device.
- Research organisations are often very cynical of new innovative ideas that do not lend themselves to established modelling techniques.
- A major concern is the lack of relevant publicly available research and literature - which leads to each developer producing their own state-of-the-art models.
- A lack of defined and accepted terms, for example with regard to turbulence, blockage, solidity etc.

Further additional concept development limitations of the current state-of-the-art modelling identified include:

- Evaluation of wake effects and their impacts for tidal arrays.
- Dynamic loads and stability issues.
- Lack of vigorous and defined environmental procedures and factors.
- Modelling of materials in the sea – particularly composite materials.

3.6 Responses With Regard to External Advice and Mitigating Risk

73% of respondents indicated that they undertook a risk assessment of the initial assessment methodology and technology. A small number of developers (36%) claimed to use formal methods such as FMEA, HAZOPS at a very early stage; however risk assessment was usually informally undertaken on a conceptual level at a very early stage of the development in order to identify possible "showstoppers" as well as to focus and correctly sequence the R&D effort.

Much uncertainty and hence risk was noted as being associated with possible and rarely defined environmental objections - despite having what was thought to be a technically competent device. This was underlined as of great concern even at the conceptual appraisal stage.

3.7 Responses Concerning Other Issues

It should be noted that all developers contacted could be noted as serious contenders and visible in the field by their experience and state of development. Thus the experience of the academic and test facilities becomes important at the very early appraisal stage as this is often where initial ideas are first sent for a basic concept appraisal. It is our experience that Government and development agencies often pass on many such early stage technology appraisals to such entities as they have some experience in the field without the obvious commercial self-interest of other developers.

Advice or guidance on how to proceed with device appraisal was externally sought by half of all developers surveyed. Of those receiving advice, all except one had turned to the academic sector for help. The actual feedback concerning academic advice was that very often the academics had a limited understanding or willingness to tackle innovative concepts.

This may explain why so many developers attempt to build basic conceptual devices before any computational or formal modelling takes place. Issues that cannot be modelled tend to be tackled by empirical methods during testing. With this are used "*sound engineering experience, analysis, judgement and innovative problem solving*".

As a foil to the novelty argument the words of a very experienced tidal developer would also seem important: *"novelty is not a virtue, it just increases the risk of failures. Therefore novelty needs first and foremost to be justifiable in terms of possible benefits (i.e. lower cost, better performance, etc) to outweigh the increased risks. It is a business; engineering and financial judgement based on whatever analysis can reasonably be carried out."*

4 Limitations Identified for Early Concept Appraisal

With regard to guidelines or standards for early stage concept assessment, a theme ran through many of the developer responses which could perhaps be summarised as scepticism because:

1. there are not enough experts /expertise to set or evaluate these,
2. tidal devices tend to be highly varied or unconventional at the conceptual stage and may not fit into a set of guidelines.

However a couple of respondents noted that the "hype produced by some developers" with regard to technical and commercial status will lead to a breakdown of trust between investors and the tidal industry. This presumably adds to the argument that it is necessary to deliver a suite of protocols for the equitable evaluation of marine energy converters, however it is noted that a wide inclusive expertise and approach to innovative technology must be retained.

This work package of EquiMar therefore seeks to identify the current limitations with respect to initial tidal concept appraisal and notes the following general limitations with respect to current equitable technology evaluations.

Limitation 1 – Lack of standardised experts to provide full initial concept appraisal

The scientific community active on the subject is very narrowly populated and unconvincing (in the experience of some developers) particularly with regard to unconventional concepts and innovation. It would be best assessed by people with genuine relevant experience of real tidal device technology. By its nature marine energy technology requires expertise in many disparate areas which are unlikely to be accessible to any single person or institution.

Suggested measure - a list of neutral experts using some of the appraisal schemes suggested below might begin to enhance the expertise base.

Limitation 2 – Incomplete or partial system concept submissions

In the words of a developer: “rigorous evaluation before moving through stages should be mandatory if any public money is involved”.

Suggested measure – a ‘gated’ checklist of general assessments completed by recognised neutral experts requiring some basic evidence for all system components (and system integration) to ensure that the developer has a complete and viable concept or system.

Limitation 3 – Lack of a general tidal dataset for early concept appraisal

Various developers were critical of those who utilise the best possible tidal sites to make their devices look more attractive than is either realistic or honest.

Suggested measure - perhaps an initial generalised standard set of trustworthy tidal site data against which all early stage concepts may be appraised. This would not provide a definitive energy output or cost-benefit answer, but would allow an early filter for technologies that are not realistically appraised.

Limitation 4 – A lack of standardised modelling know-how and published information

There is a perceived lack of published fundamental marine turbine research and few publicly available agreed definitions of fundamental properties.

Suggested measure – further fundamental research should be undertaken and published. An accessible general explanation of, and published methodology for various fundamental properties and common modelling issues, e.g. solidity, blockage factors, the scaling of tidal devices, generalised wake modelling, etc., etc.

Limitation 5 – Incomplete appraisal of non-technical factors

Technologies are noted by developers as often not taking into account the physical, environmental, commercial and regulatory realities in their assessment.

Suggested measure – standard and accepted general guidelines / checklist for initial concept appraisal before public money is granted. Could be an additional part of the general technical early concept assessment?

Limitation 6 – Lack of resource to complete a robust early concept appraisal

The aforementioned proposed measures should help to improve and bring forward serious well thought through technology innovation, however cost will be incurred. Although it can be argued that the private sector should be entirely responsible, the best ideas will not necessarily reside with those who have early financial access. Therefore to bring forward the greatest economical benefit to all concerned it may be appropriate for some (matched) state aid to incentivise innovation and prevent unnecessary monetary wastage at a later stage.

Suggested measure - a small ‘hands-off’ ‘inspiration’ fund (€2000 maximum) for each conceptual appraisal (particularly expert engagement) provided once an interview and online form /spreadsheet checking the very basic physical and economic parameters have been completed. The requirement would be to adhere to the general appraisal guidelines therefore providing an excellent lead-in to gaining informed follow-up investment from the public and private sectors.

5 Further Work and Conclusions

The six major limitations of equitable evaluation identified by developers during early concept assessments are outlined in the previous section but may be summarised as:

1. Lack of standardised experts to provide full initial concept appraisal.
2. Incomplete or partial system concept submissions.
3. Lack of a general tidal dataset for initial concept appraisal.
4. A lack of standardised modelling know-how and published information.
5. Incomplete appraisal of non-technical factors.
6. Lack of resource to complete a robust early concept appraisal.

General suggestions are made as to how to reduce these inequalities for fair concept appraisal and informed investment. These would make use of a two-way flow of information to the benefit of all, specifically: better published research and technical definitions of common comparators; checklists of necessary evaluations (technical, regulatory, economic, environmental) to prove general system integrity; the training of and access to neutral experts for sound evaluation and advice; and a small resource to incentivise innovation along these lines.

The next stage of this EquiMar work package will attempt to add detail to these suggestions in full consultation with the tidal community. The over-riding principle being to incentivise the widest possible innovation while providing equitable evaluation of all types of tidal technologies in a non burdensome manner.

6 Appendices

6.1 Information Request

EQUIMAR Information Request to Identify Limitations of the Current Practices Adopted for Early Stage Tidal Device Assessment

Introduction
The following Information Request attempts to identify the limitations of the current practices adopted to undertake **initial conceptual appraisal of tidal devices**, specifically with regard to: power capture; conversion and power take off; and station keeping.

The information you kindly submit will be used to identify the limitations of current practice so as to produce a set of guidelines that will in future allow developers or assessors to more efficiently evaluate and progress tidal technologies to market.

All information submitted will be treated as strictly confidential. A summary of the feedback will be produced to all those completing this information request. No specifically attributable information will however be published or shared outside of the core work-package partners (*University of Strathclyde, IFREMER and University of Southampton).*

Please use this document for your organisation's response. To minimise time spent, please simply delete the answers that do not apply and type your text to the open ended questions in the boxes provided […]. Other or extra comments are also most welcome.

A) GENERAL QUESTIONS

1) What is the name of your organisation and which type or class of device(s) does your organisation have experience with? […]

2) Was a search made to determine concept novelty before concept appraisal? Yes/No

1) Was the device proposed:
    a. A new concept.
    b. A variation of an existing or historical device.
2) How was the novel aspects of your device determined? **[…]**

3) Which concept elements does your organisation consider in its early stage appraisal?

a. Power capture
b. Power take-off and conversion
c. Station keeping
d. Economic
e. Other **[…]**

4) Was a very basic physical model/part-model informally tested to appraise the concept? ***(Please note that this does not refer to formal and rigorous tank/ flume testing.)*** **Yes/No**

1) Why was this undertaken? **[…]**

B) POWER CAPTURE ASSESSMENT

1) What were your **objectives** for the power capture assessment?
    a. Estimation of concept commercial viability.
    b. Investigation of power input characteristics.
    c. Other **[…]**
2) What **level of detail** was required, and which **parameters** were considered? **[…]**
3) What do you perceive to be the **limitations** and **accuracy** of the appraisal? For example, assumptions made. **[…]**

C) CONVERSION AND POWER TAKE-OFF ASSESSMENT

1) What were the **objectives** of the power capture assessment?
    a. Estimation of concept commercial viability.
    b. Investigation of power output characteristics.
    c. Choice of power take-off methodology.
    d. Other **[…]**
2) What **level of detail** was required, and which **parameters** were considered? **[…]**
3) What do you perceive to be the **limitations** and **accuracy** of the appraisal? **[…]**

D) STATION KEEPING ASSESSMENT

1) What were the **objectives** of the station keeping assessment?
    a. Estimation of concept commercial viability and market share.
    b. Evaluation of applicability/functionality to support power conversion technology.
    c. Evaluation of operation and maintenance requirements.
    d. Other **[…]**
2) What **level of detail** was required, and which **parameters** were considered? **[…]**
3) What do you perceive to be the **limitations** and **accuracy** of the appraisal? **[…]**

E) COMPUTATIONAL METHODS

1) In undertaking the initial appraisal, has your organisation experience in mathematical or computational modelling of power capture, conversion or station keeping? **Yes/No**

If YES

    a. Has your organisation developed mathematical models or codes? **Yes/No**
        i. If so, please briefly describe them, and how they have been applied. **[…]**
    b. What commercial or open-source codes have you used, and in what applications? How have simulations been conducted: e.g. size of domain, models used, kind of systematic analyses performed, and for what parameters? **[…]**
    c. What performance metrics have the models been used to establish? **[…]**
    d. What verification process has been undertaken to establish agreement/ accuracy with actual performance? **[…]**
    e. How has data from the modelling process subsequently been used? **[…]**
    f. Please comment on the present "state of the art" as you see it:
        i. the limitations of the modelling methods presently available; **[…]**
        ii. present lack of clarity over definitions and other terminology; **[…]**
        iii. the scope for inconsistencies and potential confusion. **[…]**

If NO

    a. Has your organisation supplied detailed calculations of loads, outputs etc.? **[…]**
    b. How are novel design aspects assessed (for which no numerical simulation package exists)? **[…]**

F) GENERAL ASSESSMENT AND OTHER COMMENTS

1) Has a risk assessment of the initial assessment methodology and technology been undertaken? **Yes/No**
    a. How was this undertaken, for example, have components/sub-systems been ranked in order of risk (least understood)? **[…]**
2) Was advice or guidance sought as how to proceed with concept appraisal? **Yes/No**
    a. Which specific agencies, groups, facilities and entities did you find most useful? **[…]**
    b. Were there any specific facilities that you feel are lacking and would be particularly useful in early concept appraisal? **[…]**
3) If concept appraisal has not been undertaken by the developer, was there communication and feedback between the developer and assessor to allow re-supply of data, calculations, justification etc.? **Yes/No**
    a. What caveats and details did the assessors require? **[…]**
4) Does your organisation have any other comments with regard to the gaps or limitations of the current practices adopted for early stage tidal device assessment? **[…]**

Thank you very much for your efforts in providing this information

6.2 Tidal Developers and Appraisal Organisations Approached

Technology Developers

Reference	Company	Country
TD1	Aquamarine Power (SSE)	UK
TD2	Atlantis Resources Corporation (Nereus and Solon)	Singapore
TD3	BioPower Systems Pty	Australia
TD4	Blue Energy Canada	Canada
TD5	Clean Current	Canada
TD6	CoRMaT	UK
TD7	Electricite de France	France
TD8	Edinburgh Designs (Polo?)	UK
TD9	GCK (Gorlov)	USA
TD10	Hydro Gen	France
TD11	Hydroventuri	UK
TD12	Inha University	Korea
TD13	Lunar Energy	UK
TD14	Marine Current Turbines	UK
TD15	Neptune Renewable Energy Company	UK
TD16	New Energy Corporation	Canada
TD17	Ocean Renewable Power Company	USA
TD18	Oceanflow Energy (Evopod)	UK
TD19	OpenHydro	Ireland
TD20	Ponte di Archimede S.p.A	Italy
TD21	Pulse Gen	UK
TD22	Sabella SAS	France
TD23	Scotrenewables	UK
TD24	Scottish Power / Hammerfest	UK
TD25	SMD Hydrovision (Tidel)	UK
TD26	Swann Turbines	UK
TD27	Teamwork Technology (Tocardo)	Netherlands
TD28	Tidal Generation Limited (Rolls Royce)	UK
TD29	Tidal Sails	Norway
TD30	Underwater Electric Kite	USA
TD31	Uppsala University	Sweden
TD32	Verdant	USA
TD33	Voith Siemens	Germany
TD34	Tidal Energy Limited	UK
TD35	VIVACE	USA
TD36	Tidal Stream	UK

Research and Development

Reference	Company	Country
RDD1	DNV	Netherlands
RDD2	Edinburgh University	UK
RDD4	EMEC	UK
RDD5	HMRC University College Cork	Ireland
RDD6	IFREMER	France
RDD7	Lancaster University	UK
RDD8	Maine Maritime University	USA
RDD9	NaREC	UK
RDD10	Robert Gordon University	UK
RDD11	Southampton University	UK
RDD12	Strathclyde University	UK