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Euro – CASE Conference 3 Nov. 2008

How can Europe meet its 2020 Renewables Targets?

Future of Wave Power in Europe

P. McCullen

ESB International

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Contents

"It takes years to develop a design, We apply Edisonian thinking to our engineering process, small step-by-step changes to see what works and what doesn't. It means that we develop every aspect of the design until each one is right". – James Dyson

Abbreviations Used:

ART	AR Thomson
BERR	Dept. of Business Enterprise and Regulatory Reform (UK)
CT	Carbon Trust
DEFRA	Dept. of Environment, Food and Rural Affairs (UK)
DNV	Det. Norske Veritas
DTI	Dept. of Trade and Industry (Reorganised as BERR) (UK)
EMEC	European Marine Energy Test Centre
EPRI	Electric Power Research Institute (US)
EU	European Union
IEA	International Energy Agency
LR	Learning Rate
MEC	Marine Energy Challenge
MRDF	Marine Renewables Deployment Fund
OWC	Oscillating Water Column
RE	Renewable Energy
RD+D	Research, Development and Demonstration
RO	Renewables Obligation
ROC	Renewable Obligation Certificate
SEA	Strategic Environmental Assessment
SEI	Sustainable Energy Ireland

Euro – CASE Conference 3 Nov. 2008

How can Europe meet its 2020 Renewables Targets?

Future of Wave Power in Europe

"After thirty years of research, the world is no closer to a large scale grid-connected wave power plant. Is the technology available that offers the potential for future commercial electricity generation? If not, what new innovations are needed?

1. Introduction

The simple (rather trite) answer to the above challenge is that the world is thirty years closer to grid-connected wave power!

This presentation will examine the intensity of research effort over the period, compare the position thirty years ago with that which exists today and attempt a forward projection. It is contended that the technology is becoming available and that necessary support systems have been identified and are being put in place that will allow that technology to reach the commercial stage.

2. Position Thirty Years Ago

2.1 Resource

Much work had been done to convert a database reflecting over one hundred years of visual observations made by ship's officers into probability estimates of world-wide wave distribution (2). Hindcast models based on meteorological data and spaced on a 'fine' grid of 50km, resolution had become available (3). These were referenced against measurements made on ocean weather ships located hundreds of kilometres from projected sites of interest. Relatively few sets of measurements using wave rider or other buoys were available.

2.2 International Collaboration

Under the auspices of the IEA this had manifested itself in the international trials utilising the 'Kaimei' in the Sea of Japan (4). The osciallating water column (OWC) coupled to either a rectifying or conventional air turbine had evolved as a means of converting slow wave motions into the higher speed rotation necessary for electricity generation, primarily at shoreline locations, although an alternative view favoured the use of hydraulic conversion systems.

Having digested the somewhat sobering result of the 'Kaimei' trials, the brightest hopes of the wave energy community were probably the Kvaemer Brug multi-resonant OWC (500kW) and Tapchan (350kW) coastal installations in Norway. (Unfortunately the Kvaerner Brug converter suffered severe storm damage some time later and was not recommissioned (5)).

2.3 Research Expenditure

The great surge in preliminary research expenditure had already taken place, the U.K. and others wound down their research programmes (see Fig. 1). Cheap oil was back again and except for limited work principally in UK, Portugal, Japan and Denmark with some EU support, wave energy research found itself reduced to a 'care and maintenance' level where it languished for over a further decade.

2.4 Reasons for Wind Down

- Lack of confidence at policy maker/government level in what was now being seen as a high risk technology that had not delivered large scale generation despite earlier claims and substantial expenditure.
- Rapid development of a world coal trade that helped moderate other fossil fuel prices.
- Confusion as to which wave conversion system would become dominant and recognition that the price of weeding out unsuccessful technologies would be high.
- Promise shown by other potentially more predictable and rewarding renewable technologies having either greater accessible resources or being located closer to customers (e.g. wind).

3. Intervening Period

3.1 Introduction

Referring to Figs. (1, 2) showing reported government RD+D budgets for IEA members over the period 1974 – 2004, it may be noted (6) that the vast bulk of this occurred in the early years 1976 – 83 and that expenditure dropped to a small fraction of this thereafter. In fact, total expenditure on wave energy amounting to $837m (2004 value) represented only 3.5% of the total renewable energy RD+D budgets over that period.

3.2 Shoreline Converters

During this period lessons were being learned in Europe the hard way. Following the above mentioned Norwegian projects, the pioneering ART Osprey failed during installation on the northern coast of Scotland. This was followed by the initial Islay Gulley owc and the Portuguese Pico project, both of which encountered difficulties either during construction or operation. They were followed by the Islay Limpet which, with Pico, still functions in an R+D role. In the late 1990s Ireland had a invited proposals for the installation of a coastal converter but the project failed to materialise due to funding difficulties. There is now renewed interest in a number of shoreline converters of later design.

3.3 Research

Although the low funding level could not support a high level of research effort, the above projects and a measure of government and EU support did facilitate ongoing work particularly in the UK, Portugal and Denmark with some dissemination of results. A feature of EU supported work was the requirement for funded projects to incorporate participants from different member states.

4. Renaissance in Wave Power Research and Development

4.1 Introduction

Something of a new dawn occurred in the years leading up to the turn of the century and it is worth noting the milestones that followed. Much of the work being carried out over this period has begun to lay foundations for a more commercial approach to ocean energy development. An indication of the increasing level of activity on the field is provided by Fig. 4 which shows a (non exhaustive) cumulative trend in technical papers and reports published on wave energy issues since 2000.

4.2 EU Wavenet

The EU Wavenet report 2003 (7) included detailed reference to projected wave power economics and typical standards that might be required for power quality of grid connections, safety and power transmission from wave power plants.

4.3 Carbon Trust

The establishment of the U.K. Carbon Trust led to some very positive developments, summarised later, where wave energy exploitation is concerned.

4.4 Development of Design Guidance

While research related issues and developments are reported in the regular ocean energy and other conferences and in learned journals, A series of reports has issued that provide an appreciation of the issues governing the technical, legal and commercial application of the technology in the real world.

4.5 Test Sites

A further milestone was the establishment of European Marine Energy Centre (EMEC) in Orkney, partly funded by the Carbon Trust.

Test/Demonstration sites have important multiple roles in developing the credibility of wave energy resources, converters, systems and techniques with:

- Developers, utilities, financiers and investors
- Politicians, government agencies, regulators, coastal and offshore planning authorities and general public.
- Shipping, fishing, recreational sea users and rescue services
- Environmentalists.
- Equipment, material suppliers, standard agencies, researchers.

EMEC has demonstrated a proactive role in the development of a range of draft standards, see Fig. 7. These are both necessary to establish the pedigree of converters being presented for test, to allow the issue of test certification and to seek measurable and certifiable improvements in performance over time. In addition to EMEC several marine test sites are available or in prospect to assist at different stages of converter development including:

- Nissum Bredning (Denmark), Galway Bay (Ireland): Both circa 1 : 4 scale
- Belmullet (Ireland) : Projected for 2010 Full Scale (Atlantic) 5-7MW
- Wave Hub (Devon UK) : Full scale multiple small arays. 5-20MW
- Portugal : permitted cable corridor and multi-unit mooring area (ultimate potential 330MW)

5. Impact of Wind Energy Experience

5.1 Introduction

While we noted the initial high peak and subsequent tailing off of investment in wave energy research in the period 1980 – 2000, something else of significance was taking place during that period. That was of course the development of onshore and subsequently offshore wind power technology.

5.2 Wind Technology Transfer

Many of the developments that have taken place in relation to resource quantification, machine design (particularly generator, power conditioning and control systems, grid connection, permitting and venturing offshore) have provided valuable inputs to the nascent wave power industry. Although it must be admitted that one of the most robust challenges facing commercial wave power development is the availability of individual wind turbines whose output now equates to that projected for small wave farms of several converters.

5.3 Offshore Wind Limits

There are, however, many areas where offshore wind farms cannot readily be built for a variety of reasons but which will be suitable for wave farm installation e.g. exposed deep water locations along Europe's Atlantic coastline.

5.4 Wind/Wave in Combination

It has been shown (8) that wind and wave are in fact complementary and that whether, in a totally integrated UK scenario comprising wind wave and tidal power or in a wind only system or in a more limited 2020 scenario supplying 20% of UK demand the result was:

- Increased capacity credit of the renewable energy portfolio of circa 20-30%
- Reduced variability in the renewable electricity supply, circa 6-38%
- Reduced additional balancing costs, circa 5-37%

While subject to a number of caveats (e.g. transmission system implications) the prospect of complementary benefits when used in combination with wind power provides a 'pull' for wave power provided that costs and reliability reach acceptable levels.

5.5 Areas of Common Interest

It has been evident the ocean industry should participate jointly with wind industry to attempt resolution of grid connection, charging, permitting, environmental and other generic issues.

6. Reviews by External Agencies

6.1 Introduction

A number of reviews of the technology have been made at arms length by external players and the results published.

6.2 E21 EPRI Review

The benchmark E21 EPRI report (9) of 2004 provided an assessment of how eight different converters were projected to perform in the waters off particular North American states. Performance was calculated using a methodology developed for the project based on a conceptual 1500MWh/yr pilot plant and a 300,000MWh/yr commercial plant (100MW @ 40% capacity factor). Ocean Power Delivery's Pelamis emerged as the then acceptable converter for pilot plant application (having its development near completion and full scale long term testing in the ocean underway) as other converters had still some way to go in resolving key R+D issues and initiating full scale or finalising sub-scale tests.

At their then stages of development (2004) the several converter concepts evaluated (using type adjusted capacity factors) were projected to deliver the following range of outputs:

Table 6.1

Results of E21 EPRI Assessment

State	Wave Power Density kW/m	Converter Annual Energy Production							
		Pelamis	Orecon	Wave Swing	Wavebob	Wave Dragon	Seadog	Energetech	Aqua Buoy
Maine	12.4	1076	2782	1209	523	7038	117	1631	81/124
Oregon	21.2	1337	4661	3078	1147	10998	139	2275	105/186
Washington	26.5	1587	4915	2653	1271	12302	167	2844	110/196
Hawaii	15.2	1143	4488	1564	726	7240	125	1631	103/168
Rating kW		750	1000	4000	1000	4000	-	500/2000	250
Ascribed Cap Factor %		40	50	20	40	34	40	33	40
Origen		EU	EU	EU	EU	EU	USA	Aus.	USA

In fairness all of these converters were still subject to ongoing development and improvement. At that point the only full scale prototypes available were Pelamis and Wave Swing. The analysis provided useful performance information for locations where the wave power density ranges 12-26kW/m i.e. toward the lower end of the scale.

6.3 Carbon Trust Review

With the insight provided by completion of the Marine Energy Challenge (Summer 2005) its £3.0m engineering support programme for selected ocean energy conversion systems, this report (10) for Carbon Trust examined:

- Factors that influenced costs and performance of marine renewables and the costs at which electricity could be generated.

- Whether future costs of wave energy could be reduced to become cost competitive with other forms of generation
- Whether wave farms could be developed to supply material quantities of electricity to the UK grid and the influence this would have on carbon emissions

In summary the report confirmed that:

- The potential energy resource was indeed significant and could meet 15-20% of current UK electricity demand
- Cost of energy from initial wave farms was estimated to range between 12-44p/kWh with estimates for offshore farms converging to 22-24p/kWh.
- It foresaw considerable potential to reduce future costs via
    - Converter concept development
    - Detailed design optimisation
    - Economy of scale
    - Learning experience in all phases of production, installation, O&M partly based on inference from other industries
- It concluded that wave energy had the potential to become competitive with other generation forms in the future but to achieve this would need the installation of hundreds of MW of capacity and that **fast learning or a step change in cost reduction was needed to make wave energy converters cost competitive for reasonable amounts of investment.** This is illustrated by Figs. 5 + 6.

6.4 International Energy Agency Review

This Report (6) identified 53 ocean wave technologies currently being developed showing a significant growth in prospective devices being pursued since as recently as 2003. Some earlier research projects had dropped out of contention due to poor prospects for commercial viability.

Although development had been hampered by the somewhat slow learning and feedback process, uncertainties in respect of network connection of early demonstration projects, environmental impacts, sensitivity about sharing intellectual property there was an expectation that vital Government expenditure would increase provided that RD+D objectives were systematically achieved.

This implied that guidelines and standards to support measurable project development, evaluation, testing and comparison would become available so that policy makers, utilities and investors could identify project characteristics and discriminate between the successful and less promising projects.

The fundamental barrier preventing deployment was seen to be lack of full scale public demonstration of working prototype installations that confirmed technical performance, availability, reliability and survivability while meeting acceptable generation costs.

- The majority of technologies currently in development started in the 1990s thus whatever could be learned from earlier work had been taken on board (often by new players) and the process moved forward.
- The distribution of identified ocean wave projects (2006) was:

Table 6.2

World-Wide Ocean Wave Projects

Australia	3	Netherlands	1
Belgium	1	Norway	3
Canada	4	Portugal	3
Denmark	3	Spain	2
France	2	Sweden	2
Greece	1	UK	17
Ireland	3	USA	10
Japan	1	Finland	1
Korea	1		

This showed an increase in total projects from 30 to 53 relative to the 2003 figure.

- While many projects started as a concept developed by an individual or small team, the multi-disciplinary nature of project demands made it essential to involve external expertise from various quarters to accelerate the technological rate of development. External agencies (CT + EU) have assisted in this process through targeted funding.
- The location of RD+D was seen to be influenced by
  - Availability of the human resource and skills required
  - Location of appropriate R+D support facilities
  - Availability of financial support within particular country
- A review of known ocean energy projects * in 2006 showed them to have reached the following stages of development:

Table 6.3

Development of World Wide Ocean Energy

Conceptual Design	22
Detailed Design	10
Small scale model tank testing	12
Fractional scale model sea testing	24
Prototype sea testing	12
Multiple full scale converter at sea	1

* (including tidal technology)

While undoubtedly a number of these projects will fail to emerge successfully from the above process for a variety of reasons the number being evaluated is a heartening one, although the number of prototypes quoted as undergoing sea testing appears large.

7. Issues Emerging from In-depth Reviews

7.1 Introduction

Concerns arise at the slow rate of progress being made in bringing ocean wave on stream at a time when all renewables are being promoted in an effort to reduce CO_2 emissions and reduce dependence on imports, particularly those that may be liable to disruption possibly without notice.

7.2 Potential of Wave Industry

- UK has 35% of Europe's wave resource. One deployment scenario suggested a possible 3000MW installed by 2020 if they can be successfully developed on a commercial scale.
- UK has "world leading" base of marine renewables technology
  - Increasing private sector interest in industry
  - Research showing potential for cost reduction in technology
  - Strong existing offshore skills
- One cost reduction scenario projected (10) showed that onshore wind power capacity increased from virtually nothing in 1980 to 50GW in 2004 and unit costs fell from 20€c/kWh to 5€c/kWh, implying a learning rate (LR) of 18%.

7.3 Need for Cost Reduction

Lack of operating devices hinders development of confidence in the commercial future of the industry and in its ability to reduce costs by refinement in design.

Figs. 5 and 6 illustrate a critical issue for the future of wave energy development. The key factor centres on the areas beneath the curves as these represent the total expenditure necessary to achieve cost reduction via economy of scale, by analogy with growth in offshore wind power capacity at different learning rates (LR). As the horizontal axis scale is logarithmic it can be seen that about 5GW of capacity needs to be installed for the unit cost/kWh to fall from 25p/kWh to 8.5p/kWh (Curve A, LR = 10%).

By contrast Curve B starting at a lower value of 22p/kWh and with LR = 15% can achieve 8.5p/kWh with installation of only 250MW. (8.5p/kWh is taken as a future fossil fuel rate)

The respective areas between the curves and the 8.5p/kWh line are £18.5 Billion and £770 Million showing the critical importance of a high (fast) learning rate.

In Fig. 6 the impact of a technological 'breakthrough is shown. Here the Curve B scenario was followed until a conceptual breakthrough occurred when about 50MW had been installed and unit cost dropped from about 17p/kWh to 10p/kWh leaving only a further 50MW to be installed to reach 8.5p/kWh.

These figures underline the importance of both high learning rates and the search for technological breakthroughs in driving costs toward more competitive levels. This topic is discussed further in (22).

7.4 Rising Fossil Fuel Cost Base

While there are and have been legitimate expectations that the present lack of cost competitiveness of wave power relative to fossil power and other renewables will reduce with experience and development of scale, it is probably true that a more significant reduction in the gap will occur due to rising fuel costs and mechanisms such as Carbon taxes, Climate Change levies, Emissions Trading etc. all of which bring the fossil base upward.

8. Support and Commercial Development Measures

8.1 Introduction

By 2006 a series of reports (8, 10, 14, 15, 16) had identified and brought together the various strands of support required to ensure maximisation of available economic and environmental opportunities and made key recommendations. While these focussed on conditions in UK they have parallels elsewhere in EU.

8.2 Existing RE Policy Support Framework

Four stages of technology evolution have been recognised:

(1) Early Research + Development

(2) Early Demonstration

(3) Large scale

(4) Near Commercial

Fig. 3 shows the limited support that has been available in IEA member countries for wave energy relative to other renewables and may be taken as being indicative of its low profile among policy makers until very recently.

8.3 Bridging Funding Gaps

In the UK it was urged that there should be

- A single DTI (now BERR) Ocean Energy Strategy document bringing many strands together to provide a clear signal to industry and investors.
- It was found that there was urgent need of a support mechanism to enable deployment of large scale arrays and significant projects that would bridge the gap between available support at demonstration stage and that available to more mature technologies (wind) from Renewable Obligation Certificates (ROCs) and Climate Change Levy. Without this UK installations would remain stuck at demonstration stage.
- The level should be such as to create "market pull" and to recognise that UK grid constraints would mean suboptimal location in energy terms for a number of years.

8.4 Multiple ROCs and Technology Banding

The use of this option (to reduce the bias toward onshore wind by placing ocean wave energy in a more advantageous position for a period within the existing Renewables Obligation (RO)) secured little support within the wider industry, particularly from utilities. However it is now the one proposed for implementation by the UK authorities (27) and wave energy will be eligible for 2 ROCs/MWh. This doubled the earlier allowance, with potential for further review at intervals of a few years.

8.5 Feed-in Tariff

This was a preferred option for industry stakeholders for whom it provides investment security but it was recognised that it could take longer to introduce than amendments to RO in UK

Key issues for any scheme are:

- Speed of implementation

- Certainty of its cash flows
- Stability over long term
- Level Set
- Efficiency in administrative simplicity and cost to consumers/tax payers.

Portugal introduced a feed in tariff of €0.23/kWh capped at 50MW capacity. Ireland has also introduced a similar tariff. (€0.22/kWh + negotiated market rate)

On an EU wide basis it should be noted that the countries where wind energy was most successfully introduced employed a feed in tariff almost without exception.

8.6 The Near Term to 2020 (UK)

Three scenarios have been evaluated (11), to quantify the projected emerging gap between UK forcast capacity requirement and available supply based on expected coal/nuclear retirements. The best case suggests a 14GW gap in conventional capacity by 2015.

In reviewing the inefficiencies of the then current renewable policy framework it was pointed out that onshore wind was the only economically viable renewable technology under the Renewables Obligation that could contribute to future generation at scale. Before the next technology can be pulled through there is a timing delay as Renewable Obligation Certificate (ROC) prices have to rise to a high enough level for that technology to provide economic returns to an investor in the next technology (Offshore Wind).

Installation of onshore capacity is restricted by grid and planning issues and although high ROC prices provide comfort to onshore developers they do not provide sufficient subsidy to close the funding gap for offshore wind which could provide significant cost effective capacity in the near term. This is an inherent characteristic of “technology blind” policies. There is also a leakage in the RO system away from developers to both PPA providers and financiers who demand a percentage of the RO to cover risk in long term contracts or who discount the ROC value respectively.

Analysis of the RO policy framework applied over the period to 2015 showed that, allied with planning and grid constraints it would not deliver the desired offshore wind capacity and five other options were analysed to replace ROCs:

(1) Renewable Development Premium

(2) R.O. Top up Subsidy

(3) Fixed price ROC per MWh for offshore wind capacity, capped at 2GW (power)

(4) Capping of ROC recycle value, with surplus going to offshore capital grants

(5) Multiple/Fractional ROCs to match respective technologies

It was found that the Renewable Development Premium was the most efficient in terms of cost of delivered renewable energy by 2020.

This is in essence a Renewable Feeder Tariff such as has been adopted by the European countries with the most successful levels of onshore wind energy penetration.

In the same report Planning, Network and Supply chain constraints, all of which militate against onshore and consequently offshore wind development, were analysed. In conclusion it suggests that three key objectives need to be accepted by onshore and offshore developers and consumers/tax payers:

- Wind to make meaningful contribution by 2015
- Offshore wind to be cost competitive by 2020
- Subsidy efficiency measured by lowest subsidy/MWh produced.

It is important to note that this 2006 study produced for Carbon Trust, which had a detailed insight into promising wave power technologies during the Marine Energy Challenge, did not recognise wave power as making a significant contribution in the period to 2020.

Thereafter it was seen as one of a diverse number of “low carbon opportunities for the future” that should be “preserved” in view of the many uncertainties in the energy market. It is seen as an area where UK expertise could bring major economic benefits in export of systems and services. It is suggested that UK (or any country) should play an active role where

- It has significant resources
- The technology can make a significant electrical contribution
- The country has a significant comparative advantage
- Economic (export) development benefits can be derived

UK wave energy meets all of those criteria.

It was perceived that mast wave converters were currently in Stage 1 (R+D) or Stage 2 (Early Development) and that the research grant process (although burdensome) was working for Stage 1 but that feedback from later stages of development into the R+D programme was limited.

The Marine Renewables Deployment Fund (MRDF) was then seen as being an appropriate mix of capital and revenue support in principle but it was considered insufficient to support projects of adequate size (> 5MW) to start substantial movement down the learning curve. The RO alone could not provide a support mechanism at the demonstration stage beyond the MRDF before the Stage 3 policies were reached. The private sector was being held back by this absence of a visible longer term market.

To counter this a step-wise reducing Revenue Development Premium subsidy was suggested (in addition to ROCs) as a controlled ‘pull through’ mechanism. It was suggested that entry to the MRDF should be more stringently filtered and that a feed back loop should be incorporated to feed back generic information to the R+D stage.

This funding would be terminated when it was evident that the industry had converted toward a single technology or indeed if the technology failed to deliver capacity or move down the cost curve.

It is understood that in fact take up of the MRDF was minimal and that this could be attributed to developers being unable to meet the conditions or being unready to deploy within its timeframe, neither of which looks well for the industry at large.

9. New Guidelines and Standards

9.1 Introduction

Why standards?

- Head-off repetition of recognised and proven shortcomings
- Provide a reference base for investors, regulators, customers, utilities
- Allow comparison against common base
- Provide a measured mechanism for increased performance, reliability, safety, response to extreme conditions

9.2 Technical Guidelines and Standards

Recognising, in the context of its Marine Energy Challenge, that much of the technology or application of existing technology in wave energy converters was considered to be relatively new and unproven, the Carbon Trust commissioned Det Norske Veritas (DNV) to develop guidelines (12) providing interpretation and guidance on the application of various existing standards and guides, many from the offshore industry, to wave converter projects. It was not a standard in itself but rather a starting point for further standards development. The guide contained 28 sections and cites 44 primary standards based on application of over 600 more specialised secondary standards guides and references.

The multiplicity of cited standards is due in part to the number of different converter types being researched and inevitably a degree of refinement will take place as more experience is gained and the relevance of some cited standards diminishes. Over time it is to be expected that the level of detail in standards developed specifically for wave energy purposes will increase in a more focussed way but that the number of cited secondary standards will decrease.

As a UK-sponsored document the guidelines focus to some degree on UK applications but this is no way takes from its more general value.

There is some danger that the small developer will feel daunted by this mass of codes and standards and equally that administrators, insurers, investors, regulators etc. will hide behind them and demand their wholesale application where it is quite unjustified and could represent overkill for a fledgling industry.

However the numerous challenges do not have to be faced all at once. The document provides guidance on concept development, design, construction and life cycle processes and does recognise the difference in design philosophies reflected in the offshore industry codes and those applicable to wave converter design where material fatigue may be a dominating criterion. In general as a converter evolves from a concept to a successful component in a wave farm, adherence to a pathway through the guidelines becomes increasingly relevant and they should point towards a selection of ways of designing specific risks out of particular converter concepts.

9.3 EMEC Standards

The development of a more directly applicable set of standards has been put in hand by EMEC (13) and, at the time of writing, indications were that virtually all of the titles listed on Fig. 7 would be completed by year end 2008, slightly later than planned. It is evident therefore that the necessary relevant standards are being put in place for the industry.

10.Ocean Energy Research Priorities

10.1Introduction

The European Commission having supported a number of wave energy RD+D projects articulated the following list of priorities for those involved in the industry (12) and in receipt of EU support:

10.2 EC Priorities in respect of Ocean Energy Research

To:

- Define medium/long term research and development needs including research facilities (with their human and technical resource requirements), standards and terminology
- Improve converter efficiency
- Validate capital and operating costs (including decommissioning)
- Clarify environmental and ecological implications
- Involve larger industries to minimise technical and financial risks and provide political support
- Include end users/utilities
- Encourage networking to promote, disseminate and apply best practices
- Seek a dedicated wave energy association involving all stakeholders to address common issues

10.3Implementation

Application of the above general objectives has been found in the following programmes even where they were not necessarily in receipt of EU funds.

- European Thematic Network on Wave Energy : Wavenet (1999-2003)
- Supergen Marine Energy Research Program (Phase 1 + Phase 2) (2003-2011)
- Concerted Action Programme
- Establishment of European Wave Energy Association
- Biannual European Wave + Tidal Energy Conferences
- Work Programmes of individual converter developers
- A new willingness of utilities to become involved

In general the thrust of these initiatives has been to focus on generic but real problems in the implementation of wave energy research and by resolving them in a step by step fashion to realistically strengthen the basis for commercial wave power application.

11.Utility Perspective

11.1Introduction

National electricity utilities were active in supporting R+D studies during the early years of wave energy research. Thereafter interest waned, and with the onset of privatisation and emphasis on the 'bottom line', support for technological R&D all but vanished apart from that needed to fit wind energy into the system. Interest in wave energy has been reignited more recently on the following basis. (30)

11.2Developing Wave Energy : Utility Perspective (2008)

- **Opportunity: Marine Energy Resource is recognised and quantifiable**
- Potential for Environmental and Economic Benefits
- High oil/gas prices offer further incentive
- Reduce dependency on imported fossil fuels
- Current support at political level

Challenge: Managing Significant Financial & Technical Risks

- Commercialising the Technology
- Consenting and Environmental Issues
- Deployment and Survivability in Marine Environment
- Grid Issues
- Adequacy of Funding

Utility Requirements: Reliable Utility Scale Technology

- Commercially viable technology
- Clarity of costs
- Cost reduction potential via economy of scale/technical refinement
- Developers with Capacity to manage risk, deliver technology and projects

Credible Technology Companies: Sound Technology with IP protection

- Clear strategic development path
- Technical, Financial, Business and Marine skills
- Recognition of skills gaps
- Appropriate timing, level and type of funding with right partners and investors
- Capacity to commercialise technology

Utility Role: Assist in creation of right policy framework

- Support for sector
- Provide technical support in key areas
- Support commercialisation of well founded technologies
- Potential Investment on sound commercial principles

12. Visible Hurdles to Development

12.1 Introduction

Evidence from numerous quarters suggests that key hurdles to wave energy development are Financing, (which implies cash for ongoing technological development and production) Grid Access, Planning and Permitting (10, 11, 14, 15, 16, 17)

12.2 Approach to Technology Development

Having assessed a range of technologies during the Marine Energy Challenge (MEC) the view is reached (10) that there are no fundamental engineering barriers to the technical proving of wave energy. Considerable further engineering effort will be necessary for success. To maximise the likelihood of success it is very necessary to:

(1) Accelerate development of well advanced promising technologies

(2) Continue investigation of less advanced but promising concepts that may have potential for step change in costs

(3) Stop development of unpromising technologies which are unlikely ever to be cost competitive and which simply dissipate resources.

12.3 Technical Barriers to Project Development

- Proven methodologies of energy resource assessment and energy yield prediction for financial models
- Standards of certification of converter structural integrity, reliability, moorings
- Evidence of longterm availability linked to robust maintenance schemes.

12.4 Planning and Permitting

Licencing processes for offshore wind energy development projects are reasonably well established. However the introduction of the EU Strategic Environmental Assessment process (SEA) (22) has added a new hurdle to Ocean energy development.

The EU requirement to carry out Strategic Environmental Assessments before formalising a large scale licencing process has led (in some countries) to a number of information gathering initiatives that will enable a central Government fulfil its obligations under this Directive.

Lack of a prepared SEA to facilitate siting, planning and permitting including EIA for commercial deployment might be expected to delay such development by at least two years.

In theory SEA should clarify the principle of permitting commercial developments in particular areas and restrict the scope necessary for the subsequent EIA process applicable to particular projects. In practice there is some chance that special interest groups may view this as a double opportunity for opposing projects or calling for yet more studies. The EU Water Framework Directive insofar as it applies to coastal waters within one nautical mile of coastal baselines brings another layer of influence into marine licencing the effect of which is at this stage unclear. (Cables at least will have to pass through this zone).

In the UK the introduction of Marine Spatial Planning (MSP) (21) currently represents another hurdle. It is envisaged that SEA will be incorporated into MSP.

Consultation on the Marine Bill closed in 2008 and the MSP element could take three years to incorporate. As SEA requires scoping, generic research, gap analysis, monitoring regimes for demonstration projects, and stakeholder consultation process it was considered essential that SEA should have started in 2006. At that stage only Scotland had taken the initiative for permitting beyond the 'demonstration' stage and completed its pioneering marine renewables SEA in 2007, against a projected back drop of 1300MW of ocean energy.

- The scope of monitoring to be carried out on initial demonstration prototype and small arrays for maximum benefit in scaling upwards is seen to be critical. The excuse is sometimes used that this is difficult to specify because it is converter specific and because of the multiplicity of converter types under development. Clearly many marine 'stakeholders' have a lack of understanding of the actual impacts likely to arise from developments and seek to reserve their positions in varying degrees.
- The suggestion has been made that for the Portuguese designated/commercial wave energy site aspects of the Strategic Environmental Assessment might be conducted and shared internationally on a generic basis to reduce cost.
- In Ireland a relatively straightforward common procedure was introduced in 2001 for the permitting of commercial offshore wind, wave and tidal systems. This now falls within the ambit of SEA and will result in further delay to commercial permitting.

It is unclear at this stage what will be the impact of the new Marine Strategy Directive and the proposed EU Integrated Maritime Policy on ocean energy developments.

12.5Development Costs & Timescales

Experience of the Marine Energy Challenge (Carbon Trust) MEC showed that

- Evaluation of wave concepts to the point that costs of energy are reasonably firm can cost up to several hundred thousand pounds.
- Development of engineering designs to the point of finalisation for initial large scale projects can cost up to several million pounds
- Manufacture, installation, testing a full scale prototype is also likely to cost several million pounds
- Capital cost of initial wave arrays is also likely to range upwards to £5m/project.

In terms of time, likely durations are:

Concept to Prototype:	5 years
Initial Project Development/Finance	1-3 years
Breakeven Operation	5-10 years

Hence substantial public and private finance will be needed for circa 10 years and additional public support in operation for 15+ years.

Public funding is essential while technology risks are high and a visible long term policy commitment must exist so that private investors can see a clear route to market that meets their entry and exit criteria. The present global slowdown and financial uncertainty may put further pressure on investment flow.

12.6 Resource/Grid Mismatch

UK faces mismatch (16) between resource availability (Scotland) and grid availability although the situation is better around Bristol Channel area.

- Mismatch between location of resource and grid strength and high wind farm location in some areas (Scotland). Distribution level connections vary 5-30MW but these suffer broadly from the same problems.
- Cost of connection and user charges are high for these areas of good resource.

It is abundantly clear that prototype and small array installations will have to ‘cut their teeth’ via connections at Distribution rather than Transmission level. In UK the transmission constraints for large scale developments have already been well researched. The position in Ireland is rather similar at present but Portugal is more promising in this respect.

13.Transnational Approach

13.1Introduction

International Cooperation in the wave energy field within Europe has been driven significantly by the influence of EU contractual support mechanisms. However most would-be converter developers have seen profitable overseas market penetration as a critical goal for the success of their products. Some of the issues that arise are discussed below.

13.2Internationalisation within the Ocean Energy Industry

The predominant interest at national level in supporting ocean energy development is usually focussed on socio-economic benefits, reduction of pollutant emission, increased security of supply and reduced imports. (20)

Converter developers however focus on

- Rapid development of technology to yield a saleable product
- Rapid development toward commercialisation/survival
- Growth in the sector

While a majority of ocean energy firms see the early technical development phases (to prototype stage) being largely conducted within their own countries, the balance shifts during later development and full scale phases.

It is well known that the bulk of firms founded in a capital intensive business fail within a few years and unfortunately the wave energy industry is capital intensive. There is little surprise that the needs identified by most players were for (1) access to capital and (2) need for political action (which probably translates to provision of more capital!).

The two types of firms likely to survive are the slow moving niche firm (mostly funded by owner equity) and the more promising innovative and growth oriented business whose demand for capital has forced it to seek/accept foreign investment, but which has managed to maintain a balance between the necessarily rapid rate of technological growth and the availability of cash.

In terms of demonstration in a country, other than their country of origin, developers cite three key factors:

- Presence of a proactive Government there
- Availability of Government funding
- Ease of access to a permitted site/network connection

Thus firms will tend to migrate toward locations where these conditions are most likely to be encountered.

UK (Scotland) aspires to create the world's leading marine energy industry by 2020 with an installed capacity of 1300MW, growing at 100MW/yr and employing 7000 people. A series of reviews have taken place to identify shortcomings in support and a series of remedial measures have been introduced in recent years. However the issue of "licensing barriers" has not yet been cracked – witness the delays (15) experienced by 'Wave Dragon' in 'educating' the numerous bodies with involvement in the environmental and permitting processes associated with the Pembroke Project. 'Wave Hub' has had a rather similar experience (16).

Portugal on the other hand took the view that its objectives could best be met by import of foreign developed technology with maximum participation by Portuguese based expertise. Thus it focussed on creating an attractive REFIT Scheme in a predesignated area. It is targeting (2007) a possible 330MW capacity in a pilot zone designed to bridge the gap from demonstration to commercial projects.

Ireland falls somewhere between the two. It aspires to develop a home based technological capacity if this can be done cost effectively but it is recognised that meeting a stated target of 500MW capacity by 2020 would most probably involve the use of imported technology and even that would be challenged by the familiar problems of network access and permitting.

The downside of early involvement in international markets is the resource demand but a classic example is the effect of the Danish wind industries involvement in California and the feedback of revenue and knowledge that occurred and was put to good use.

(By way of encouragement, it is worth noting that the early wind turbines in California were only of 60-100kW capacity, achieved capacity factors below 0.2 and frequently failed, yet formed the basis of a subsequent thriving industry.)

New markets will be important, not only for revenue generation, but due to the rather limited opportunities and energy absorbtion capacity that exist on the coastal margins of any one country or indeed Europe as a whole. A diverse number of markets should produce a more stable development environment.

Although, lessons can be learned from the development of the wind industry it is premature to say how the dual interests of the state (clean energy, security of supply, wealth and employment creation) and the entrepreneur (deployment, testing, supportive siting and regulatory environment, commercial basis) can best be met to the benefit of both.

Marine energy development is a capital intensive industry and its development depends largely on political actions. If a national society wants the benefits it must pay the club membership fee!

14. Forward Projections

14.1 Introduction

In a report (11) prepared to review the case for renewable electricity production in light of the Energy Review commissioned by the UK Govt. (2006), factors affecting future wave power prospects were identified as:

- Cost of energy in general
- Strategic and security of supply issues
- Availability of finance and public support
- Readiness of technology for commercial application and management of development risks
- Availability of network connection and electrical compatibility of generated energy with system requirements
- Environmental and regulatory factors and responsiveness

14.2 Wave Power Possibilities

A further report (10) concluded that, by analogy with windpower, several gigawatts of installed capacity of wave power was possible across Europe by 2020 with a required investment of several billion pounds and potential CO_2 abatements of 2-7Mt/yr. A large part of this could be in UK.

Looking toward the future the report specifically noted that

- UK industrial base and experience left it well placed to accelerate progress in the sector, capture economic value, and maintain marine renewables option looking ahead to the time when the technologies become cost competitive.
- Further investment was required to allow industry accelerate the pace of development beyond current levels.
- Great emphasis needed to be placed on cost reduction to ensure commercial viability.
- Early development of wave farms was essential to accelerate learning effects.
- The public sector should consider:
    - Increased support, in particular for RD + D, with a focus on cost reduction
    - Supporting technically viable project development into medium term, again with a focus on cost reduction
    - Need to develop a clear long term policy framework of support to provide investor certainty

14.3 Future Growth

In broad terms future growth of wave power was felt to depend on:

- Strategic and security of supply factors: High or uncertain imported fuel prices raise base price of electricity bringing forward breakeven point for wavepower and focussing on its indigenous nature as part of a strategic energy mix.
- Financial Factors: Financing for both technology and project development through several stages, each with different investment criteria will be essential.

- Current small farm demonstration support schemes in Portugal, UK, Ireland have caps in terms time and capacity. Apart from regulatory caution some of of these may paradoxically have arisen from over optimistic claims by developers.
- Fast continuous technological development is necessary to maximise learning, bring about cost reductions and present a fundable project in the shortest possible time. This is difficult for small developers working in isolation to achieve due to the multidisciplinary nature of the technology. Striking a balance between rapid development and management of risk usually results in a cautious stepwise approach toward deployment.

14.4Strategic Development Objectives

Noting that there is potential for strong domestic export markets and the Danish wind experience, a two pronged approach (10) is suggested for UK.

(1) Acclerate progress of technology development with focus on cost reduction

(2) Encourage early development of wave farms to accelerate learning effects

The key barriers noted were:

- High and uncertain costs
- Diversity and unproven nature of the technologies

And thus key objectives are:

- Maximising cost reductions by four identified routes including fast learning and creating likelihood of step change cost reductions
- Increase certainty of costs and performance
- Develop track records of serviceability and reliability
- Encourage early convergence to optimal technologies
- Site Indentification & Learning
- Strategy for site allocation necessary for large scale projects.

14.5Key Actions for Path to Growth

Table 14.1

Projected Key Actions for Ocean Energy Growth

Sector	Actions
Developers	• Maintain strong focus on cost reduction • Accelerate engineering testing and prototype testing to produce track records of survivability, reliability, performance
Public Sector Funders	• Provide increased support particularly for RD+D to help deliver cost reductions • Support project development into medium term, for viable technologies slowing evidence of cost reduction • Improve investment certainty by development of a clear long term policy framework of support
Academic Funders +	• Place greater emphasis on cost reduction topics

Researchers	
Regulator/Network Operators	• Consider future wave capacity when planning grid modifications/upgrades
Govt./Industry Env. Stakeholders	• Take pragmatic prioritised approach to overcoming Environmental Uncertainties • Take proportionate approach to local env. Impacts of small developments balanced against global benefits of low carbon output from future larger projects.

14.6Current Status of Prototype Scale Converters

Ocean Power Delivery delivered 3 Pelamis converters to Portugal (now scheduled for operation for Winter 2008-9) with a letter of intent for 28 further machines (23.25MW in total). (It is understood that these machines have supplied satisfactory power to the local network and that all three will be left on station during the winter of 2008-9. The delay in activation over the past year has been attributed to problems of umbilical cable buoyancy in the deeper Portuguese waters rather than any inherent problems with the converters themselves). In addition:

- Ocean Power Technology proposes Power Buoy demonstration arrays at Santona (Spain 1 + 10 x 0.15MW converters) and off the French coast.
- Pelamis, Power Buoy and SEEWEC converter arrays are proposed for installation at Wavehub off North Cornwall (20MW)
- A single 4MW WaveDragon prototype is proposed for installation off the coast of South Wales.
- Two converters of circa 1MW capacity are proposed for a test site in Ireland.

14.7Assessment of Growth Scenarios and Implications for Ocean Energy Industries in Europe

Parallels are made with the growth of offshore wind since installation of first farm in 1991. The Carbon Trust projected 2500MW wave in Europe by 2020. This paper however predicts that realistic growth for wave at 500-1000MW for Europe to 2020.

An analysis of effect of discount rates and farm cost shows that ocean energy would still require support mechanisms to become viable. It also projects reductions on turnkey costs, generating costs and increases in direct and indirect employment by analogy with offshore wind rate of installation constant discount rate of 10% and learning rates of 10 and 15%.

Based on a stated set of assumptions applicable over the periods 2005-10 and 2010-50 an assessment of potential growth on a Europe wide scale was made (8). These suggested that by 2020 the position might be as follows.

Table 14.2

Projected Europe Wide Growth Potential (22)

	2020
Installed Capacity MW	1000/2500
Capital Deployed (£m)	1000/2500

NPV of cost of support above base £m	700/2200
Annual CO_2 abatement Mt/yr	1-3.3

Based on the rather slow early growth of the offshore wind industry, the inertia in the SEA, planning and permitting process, uncertainty in world financial markets and rate of convergence toward an optimum converter design the writer's assessment of installed capacity for 2020 (12 years time) is less buoyant than some of those made in earlier reports and amounts to 750MW, comprising a variety of different converters (which also militates against rapid cost reduction).

UK	Portugal	Ireland	France	Spain	Denmark	Total
250	150	100	100	100	50	750MW

15.Conclusions

- The development of wave conversion technology for successful commercial application in the marine environment will take time. There should be no apology for this given Mr. Dyson's comments (1) on his company's approach to a domestic appliance like the vacuum cleaner!
- We have seen that over much of the 30 year period during which active wave energy research was in progress, actual funding levels were miniscule compared to the funds and supports being made available to other renewables.
- There has been a sea change during the present decade and the wave energy industry is engaged in measures to bring in a new professionalism via the introduction of standards that provide a point of reference for designers, investors, regulators and their advisors.
- The fact that new conversion concepts are still coming forward has positive and negative aspects. On the one hand it increases the possibility of the development of a unique design that achieves the 'breakthrough' desired in the cost reduction process; on the other hand it leads to further requirements for development, finance and further delay in achieving an identifiable 'optimum' system.
- Fortunately the availability of new recognised screening and developmental test protocols (29) should eliminate less promising concepts at least cost to all concerned and serve to stimulate further development of the more promising concepts.
- The critical importance of rapid development of optimal systems in sufficient numbers to bring down cost has been highlighted. Society would pay an unacceptably high price if slow development, spread over a multiplicity of converter types, delayed achievement of economy of scale.
- This ties in with the critical need at the present time to get confidence building prototypes operating on station throughout the year. Their absence currently forms a significant hurdle to development and, anecdotally at least, has impacted on fund raising.
- A variety of institutional and administrative hurdles have also been identified. These include Strategic Environmental Assessment, Foreshore Leasing process, Environmental Impact Assessment and interfacing with various quasi autonomous Government organisations, permitting authorities and special interest groups. Numerous difficulties and delays continue to be in prospect until sufficient experience has been up to convince doubters that wave power converters can be sited in arrays without causing any significant environmental degradation.
- Considerable improvements in our understanding of the nature of the wave energy resource and its categorisation using satellite and in situ measurements coupled with hindcast meteorological modelling on more refined grids have taken place over the past 30 years. Good forecasting of likely resource levels up to several days ahead is now possible.
- More needs to be done to map seabed conditions conducive to cable laying on the rocky Atlantic margin of western Europe. The presence of a rocky bed need not itself be a "show stopper" to development but adds considerably to cost.

- From a utility perspective it is difficult to see how “small and beautiful” can succeed in terms of converter design and installation. Clearly there is a link between appropriate size of converters and the wave climate in which they are located but the impact of a multiplicity of moorings and cables on service vessel access must also be considered.
- Considering the delays inherent in the SEA/EIA/Permitting process, slow down in achieving demonstration by converters of scale over the past two years and the general uncertainty in world financial markets, the writers perception is that the installed wave power capacity for EU could reach 750MW (±250MW) by 2020 rather than earlier higher estimates.

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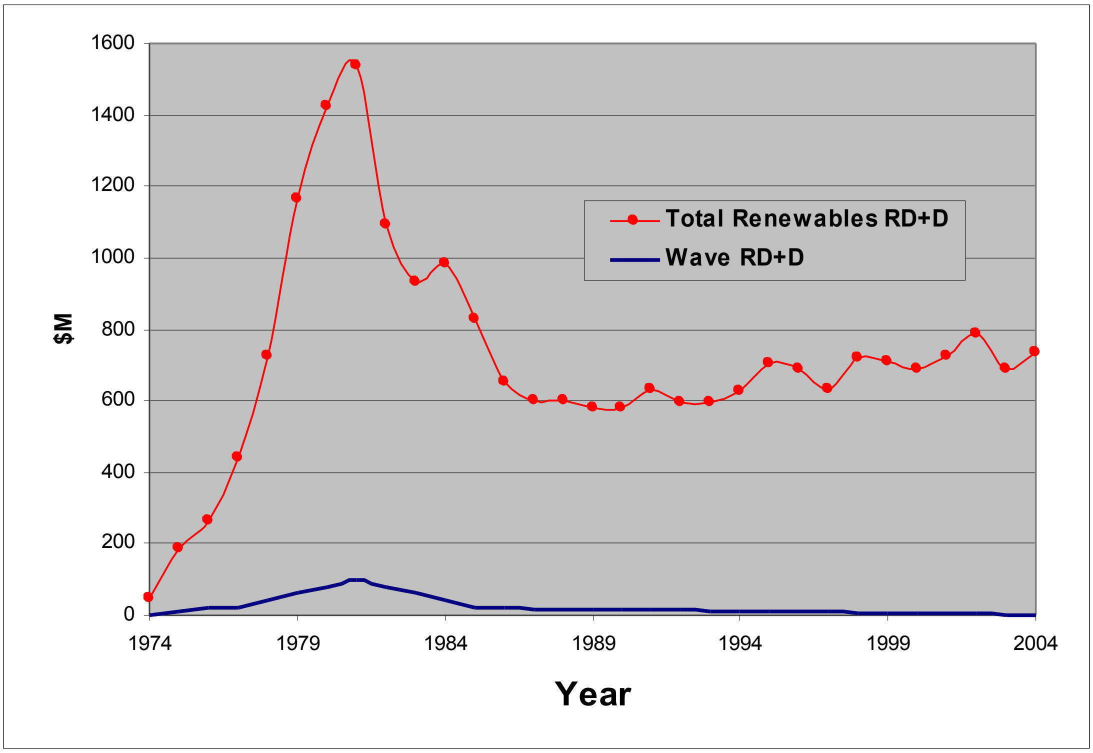

Fig 1. Profile of Total Renewables RD+D Expenditure - IEA Countries (1974-2004) (6)

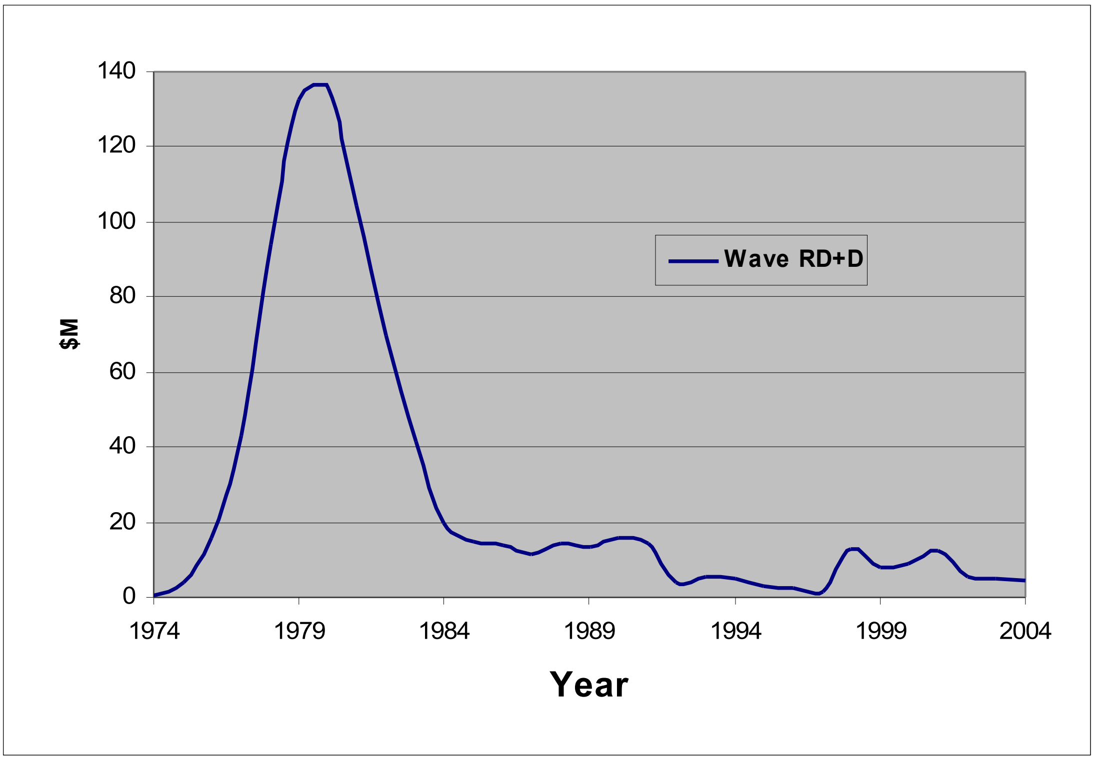

Fig 2. Profile of wave power RD+D Expenditure - IEA Countries (1974-2004) (6)

		Australia	Belgium	Canada	Denmark	France	Germany	Greece	Ireland	Italy	Japan	Korea	Netherland	New Zealand	Norway	Portugal	Spain	Sweden	UK	USA	Brazil	China	India	Mexico	South Africa	Finland
W	Capital Grants															●			●							
A	3rd Party Finance																									
V	Inv/Prod.Tax Credits						●													●						
E	Obligations																		●						●	
	Tradable Certificates																		●							
	Guaranteed Price/Tariffs						●									●			●							
	Prog.+ Admin Rules															●			●							
O	Capital Grants	●	●	●	●	●	●	●	●	●	●	●	●		●	●		●	●	●		●				●
T	3rd Party Finance		●	●		●	●					●	●				●			●	●					●
H	Inv/Prod.Tax Credits		●	●		●	●		●			●	●			●	●	●		●				●		●
E	Obligations	●	●	●	●	●	●		●	●	●	●	●	●	●		●		●	●	●	●			●	●
R	Tradable Certificates	●	●							●		●	●		●			●	●		●					
S	Guaranteed Price/Tariffs			●	●	●	●	●	●		●	●				●	●	●		●	●	●				
	Prog.+ Admin Rules	●	●		●	●	●	●	●	●		●		●	●	●	●	●				●				

Fig 3 Relative RD+D Support Availability - Wave Versus Other Renewables (2004) (6)

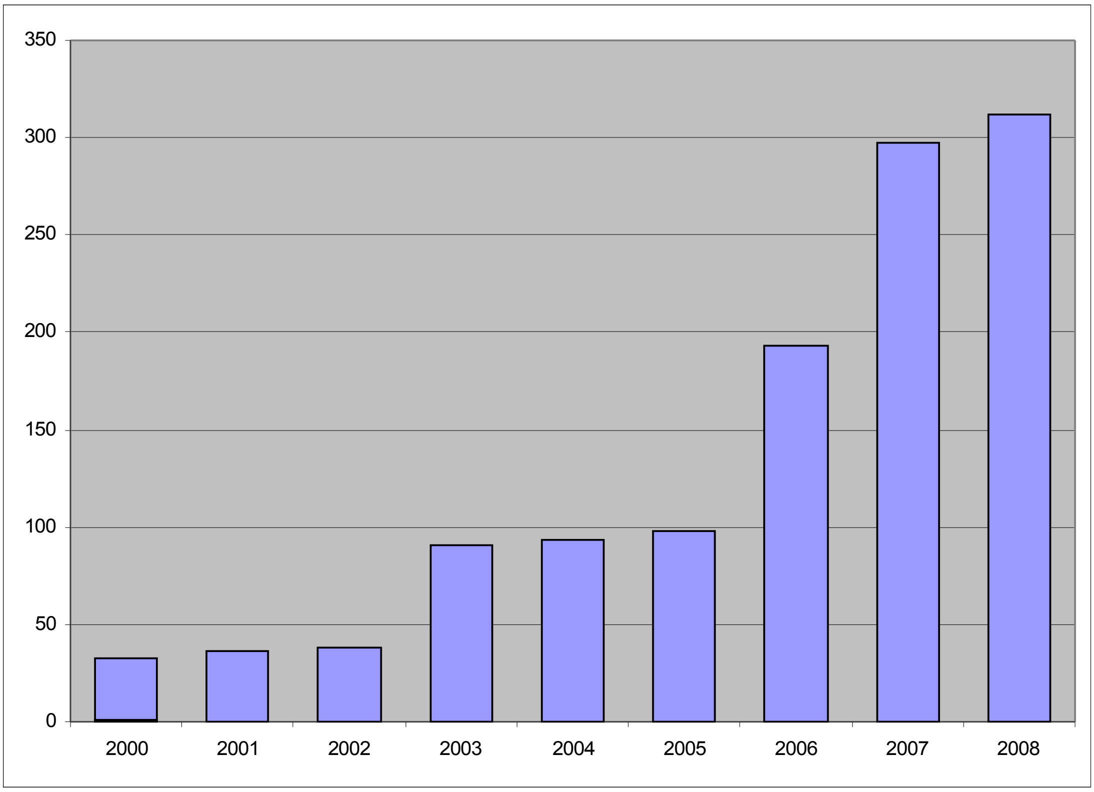

Fig 4. Indicative Cumulative Trend in No. of Wave Energy Technical Reports/Papers (2000-8)

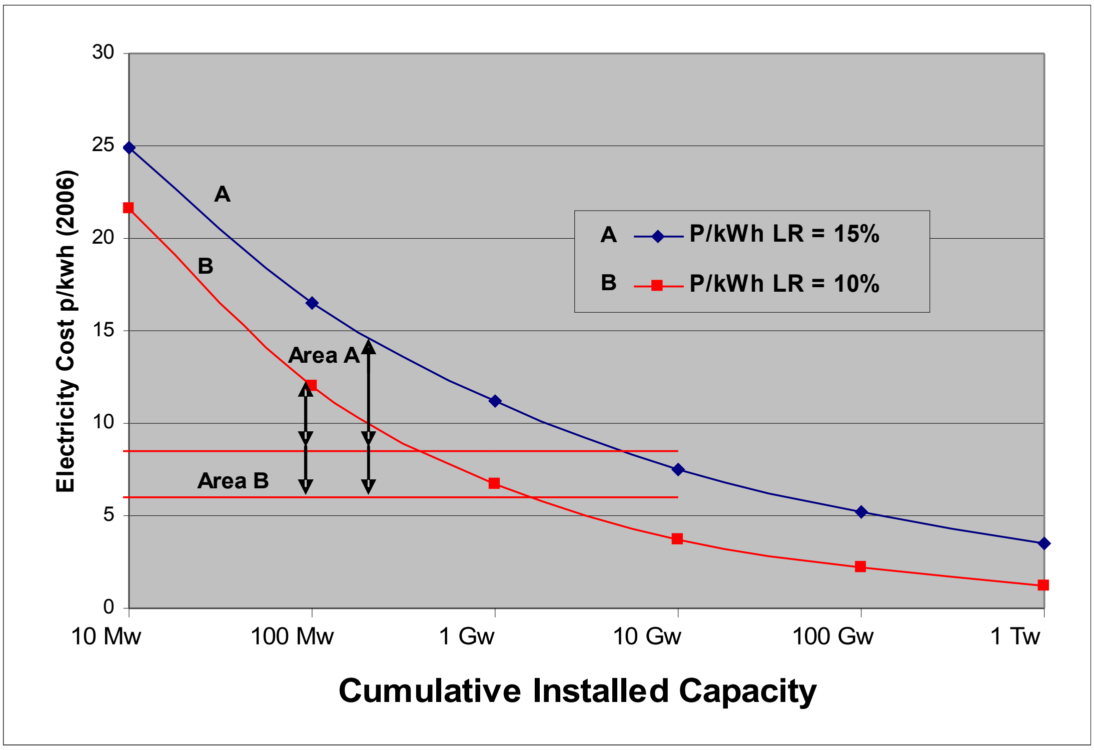

Fig 5. Production/Learning/Cost Reduction Curve (10)

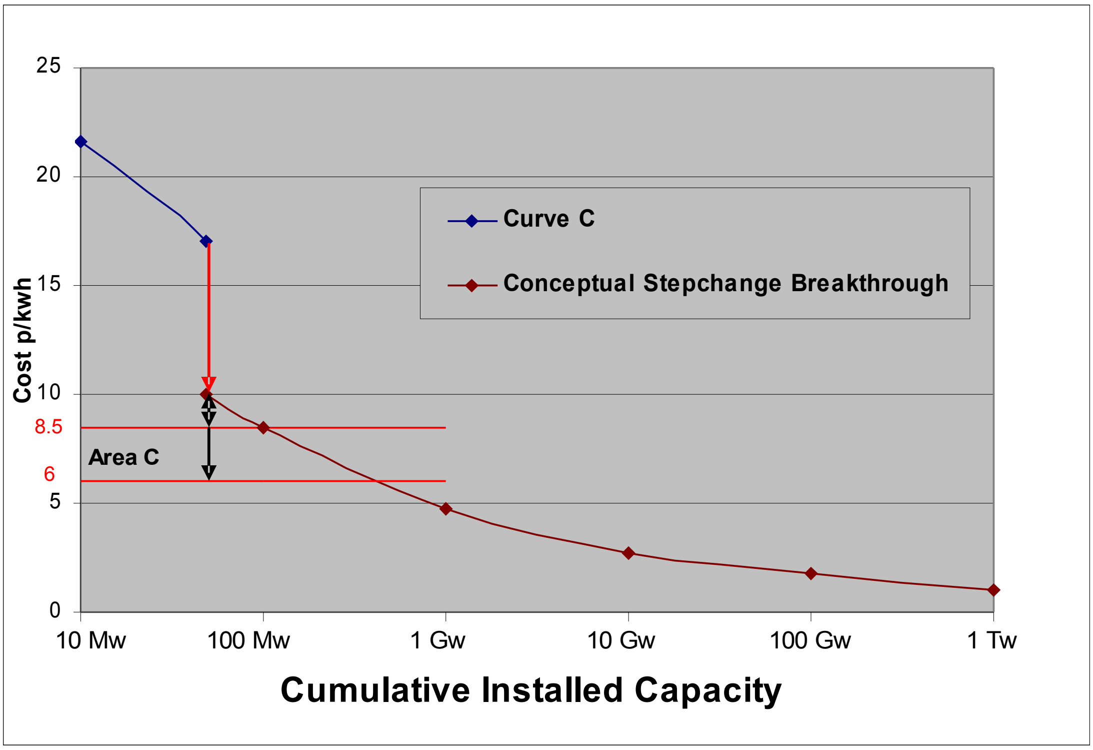

Fig 6. Impact of Step Change in Technology on Succeeding Costs (10)

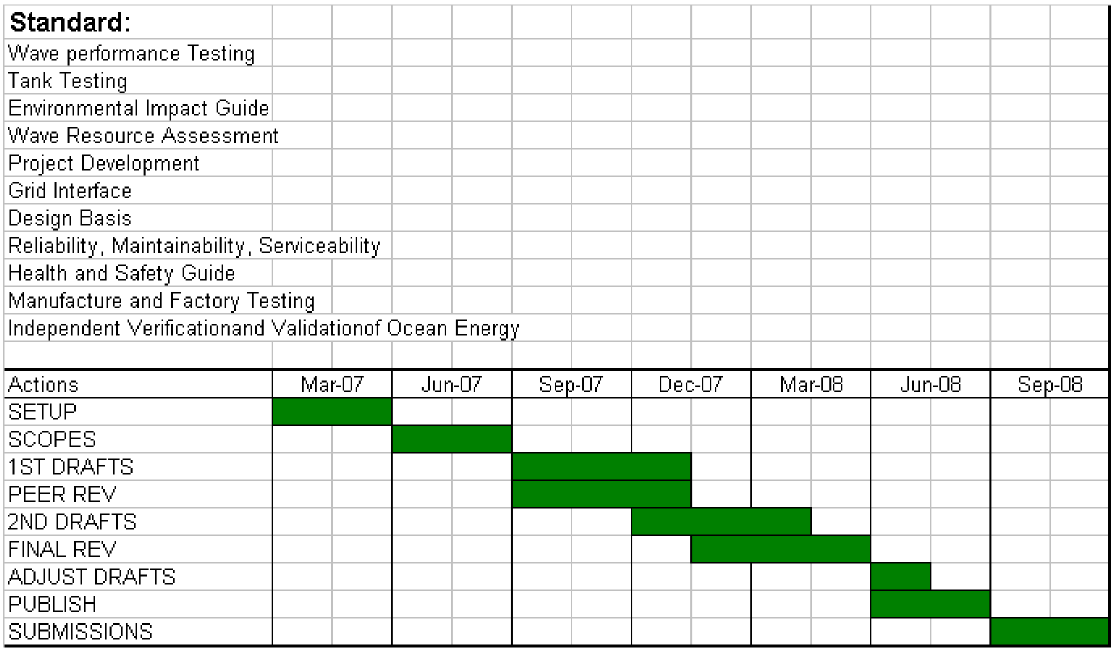

Figure 7 EMEC Standards Development Programme (Wave)