WaveNet

Technical Summary Report *March 2003*

Overview of the work of the European Thematic Network on Wave Energy

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EXECUTIVE SUMMARY

The European Commission and 14 R&D actors from various European countries established the European Thematic Network on Wave Energy, or Wave Net, in 2000. Its task was to address important scientific, technical and economic aspects in wave energy conversion.

This report presents a brief overview of Wave Net's work. A full technical report, over 500 pages in length not including appendices, and containing detailed results of the work carried out, has also been published. This is available in downloadable form on the Wave Net web site www.wave-energy.net as a single document and a individual chapters.

The different workgroups in the network have carried out a series of tasks under the following headings:

- Network Co-ordination & Support
- Co-operation With Power Industry
- Social, Planning and Environmental Impact
- Financing & Economic Issues
- R & D on Wave Energy Devices
- Generic Technologies
- Promotion of Wave Energy

These tasks have produced a variety of outputs, which have been disseminated via conferences and a web-site developed in the course of the project, to relevant targets groups such as developers, operators, public bodies, financiers, planners, etc. The results of the activities are:

Co-operation with Power Industry

The objectives of this task were to promote co-operation with the electrical power industry and to build on the experience gained in electrical generation and transmission of other relevant industries (e.g. wind). Under this work package the following output has been produced:

- A standard for grid connection of wave power plants
- A standard for the safety of wave power conversion systems
- Procedures for power transmission for offshore and near-shore devices

Social & Environmental Impact, Planning Considerations

The aims of this task were to identify the barriers (planning, legal, structural and environmental) to the development of wave energy, together with the social and environmental benefits (e.g. employment issues, emissions reductions) arising from expected deployment of wave energy schemes, leading to the development of recommendations and guidelines for such deployment. The output of this task was:

- A number of case studies, principally of offshore wind developments, to enable wave power developers to learn lessons from past experiences

- A study of the employment and related socio-economic benefits that the development of a marine renewables manufacturing industry could bring to Scotland
- A summary of the environmental impacts of wave energy devices.

Financial & Economic Issues

This task has produced the following outputs:

- An evaluation of the generating costs of the leading devices to assist in establishing credibility of wave energy as a generation source.
- An evaluation of the rates of return that wave energy devices will have to produce in order to attract private-sector finance.
- An estimate of the environmental external costs of wave energy and compare them with those of conventional energy generation.

Research & development

This has collated, reviewed and evaluated material from current and past EU funded projects, national programmes and industrial projects. Key research priorities were identified and a strategy was developed.

Generic technologies

This task aimed to collate existing knowledge on areas of "generic technology" that is common to most ocean energy devices, for example control systems, power take off and so on. Under this task the following activities were carried out:

- Information exchange and studies on plant control methods and related energy quality and power output prediction;
- Development of monitoring methodologies for plant performance;
- Establishment of design criteria based on measured data at existing power plants, other coastal structures and the offshore oil and gas industries;
- Exchange of experience on: maintenance requirements; corrosion; wear of structure and components and failures in wave power plants, leading to recommendations for reliability improvements;
- Development of hydrodynamic and power take-off modelling tools.

Promotion of Wave Energy

This task aimed to promote wave energy as a renewable source of energy within the public and a range of institutions and organisations involved in wave energy developments, as electrical power companies, offshore industries, research institutions, financial bodies, governmental offices etc. Under this task, the following activities gave been carried out:

- Two Open Door Events (One in Lisbon in 2001, and one in Brighton in 2002)
- The establishment of a web site (www.wave-energy.net)
- The production of a glossy brochure
- Two published papers in international journals

Table E1 - Project Achievements

Work Package	Objectives	Achievements in Year 1	Achievements in Year 2	Achievements in Year 3
Network Co-ordination & Support	To provide the basic infrastructure to operate the network and co-ordinate its activities.	Network set up. Network-wide meeting held, as well as meetings of groups associated with each Task. First year report submitted.	Two steering group meetings were held. Work on planning Year 3 conference commenced.	One Steering group meeting two network-wide meetings held.
Co-operation With Power Industry	To induce a long-term co-operation with the power industry (e.g. electricity utilities, wind power industry) in order to involve the utilities and to learn from the experience of the wind power industry.	Considerable consultation with representatives of the Power Industry (manufacturers, utilities, etc.). Data and background information are being collected.	Draft reports on the development of standards for the quality of grid connections and for electrical safety were prepared and circulated for comments.	Final versions of standards produced and included in publishable report.
Social, Planning And Environmental Impact	To identify the planing, legal and commercial barriers and the social benefit, energy and environmental impact from the expected development of wave energy schemes. To create recommendation for their development.	A study of the economic benefits to Scotland of wave energy and questionnaires on technical barriers and planning procedures have been distributed. A report on environmental impacts of wave energy and a questionnaire on this topic have been distributed. A report transferring lessons on public acceptability of wind power to the wave energy is being prepared.	Based on the questionnaire on these topics a draft report has been produced and distributed for comment.	All reports finalised and included in publishable report.
Financing & Economic Issues	To evaluate the financing, economics and monetary issues for developing wave energy schemes.	Meetings with device developers and sources of funding. The capital and generating costs and life cycle emissions of representative devices evaluated. A report has been issued on all the above.	Draft reports on the financing of wave energy projects, the economics of wave energy and environmental economics were circulated for comment and discussed at the meeting in Lisbon.	All reports finalised and included in publishable report.

Work Package	Objectives	Achievements in Year 1	Achievements in Year 2	Achievements in Year 3
R & D on Wave Energy Devices	To identify the current status of wave and tidal energy device development. To determine the technical barriers to the commercial development of these devices at different time scales. To develop a standard for assessment of existing and new devices. To develop a Strategy for Development and an Action Plan.	Reports on a tidal stream device, OWCs and advanced concepts have been issued. A large amount of material in other areas has been collated is being assembled into a report.		An extensive overview of current R&D and an analysis of and rationale for future R&D requirements has been produced and is included in the publishable report.
Generic Technologies	To co-ordinate activities on generic technology issues concerning the utilisation of wave and tidal/current energies, so as to facilitate the exchange of experience and the transfer of knowledge. To promote the knowledge and technology transfer from the offshore industry and coastal engineering. To promote studies on these issues.	Reports on plant control, plant monitoring and device modelling have been prepared. Common data relevant to structural loading have been determined and questionnaire issued. Work on reliability and maintenance started.	Further work was done on studying and reporting on these issues	All reports have been finalised and are included in the publishable report.
Promotion of Wave Energy	To promote wave energy as a renewable source of energy, capable of significant contribution to electricity production in Europe in the near future. This promotion will use several media in order to reach different areas of industry and society.	One 'open door' conference organised, including papers and exhibits on wave energy. The first 'open publication' promoting wave energy was published and promoted significant interest. Numerous papers presented at a range of conferences. Network web site established.	A major academic paper was written and its final version agreed between the partners at the Lisbon meeting. A web site, www.eave-energy.net, has been established and planning was begun on a 50 page glossy brochure.	An open door conference was organised, the paper written in Year 2 was published and another paper was also published. A high-quality glossy brochure was prepared and printed.

The following Tables present the deliverables and milestones relevant to the work undertaken by the Thematic Network

Tabe E2 - Deliverables

No	Due Month	WP/ Task	Nature	Description	Status
D1	12	7.4	IT	Establishment of wave energy internet site	Complete
D2	18	2.1	Standard	Draft standard for electrical connection	Complete
D3	18	2.2	Standard	Draft standard for electrical safety	Complete
D4	18	7.1	Literature	Supporting material on wave energy for conferences etc	Complete
D5	20	1	Report	Progress report and financial statement following network meeting	Complete
D6	24	3.1	Report	Report on industrial benefits	Complete
D7	24	3.2	Report	Report on technical barriers	Complete
D8	24	3.3	Report	Report on environmental impacts	Complete
D9	24	4.3	Report	Report on integration of environmental benefits	Complete
D10	24	7.3	Material	Pamphlet on wave energy for the public, investors and industry	Complete

Table E3 - Milestones

No	Due date	Description	Decision Criteria	Status
M1	18	Task 1 - Network-wide meeting	Publication of a report on the meeting	Meeting held Nov 2001. Minutes & action list circulated
M2	18	Task 2 - Draft standard for electrical connection	Presentation & discussion at workshop	Draft standard prepared Nov 2001
M3	18	Task 2 - Draft standard for electrical safety	Presentation & discussion at workshop	Draft standard prepared Nov 2001
M4	18	Task 3 - Interim reports on social, planning and environmental aspects.	Presentation & discussion at workshop	Draft reports prepared Nov 2001
M5	18	Task 4 - Interim reports on financing & economics	Presentation & discussion at workshop	Draft report circulated for comment and discussed at Lisbon.
M6	18	Task 5 - Interim report on devices and their R&D requirements.	Presentation & discussion at workshop	This report was prepared and discussed at the Network meeting in Brussels in February 2003.
M7	18	Task 6 - Interim recommendations on monitoring methodology, design criteria & reliability.	Presentation & discussion at workshop	This report was prepared and discussed at the Network meeting in Brussels in February 2003.

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1 INTRODUCTION

The European Thematic Network on Wave Energy (Wave Net) was a major initiative by the European Commission to bring together the various organisations working on ocean energy around the EU. Despite its name, the project was intended to cover both wave and tidal energy. Its objective was to enable R&D actors from industry and research organisations to network together, to promote greater sharing of expertise and to create a structure for collaboration. The project began in April 2000 and finished at the end of March 2003. Fourteen organisations from nine EU countries were involved. They were:

- Future Energy Solutions from AEA Technology, UK
- University College Cork (UCC), Ireland
- Rambøll, Hanneman & Højlund A/S (Rambøll), Denmark
- EMU, Denmark
- Instituto Nacional de Engenharia a Technologica Industrial (INETI), Portugal
- Chalmers University of Technology, Sweden
- Teamwork Technology, The Netherlands
- Centre for Renewable Energy Studies (CRES), Greece
- Ponte di Archimede nello Stretto di Messina SpA (PdA), Italy
- University of Edinburgh, UK
- Instituto Superior Technico (IST), Portugal
- Ecole Centrale de Nantes (ECN), France
- Hammarlund Consulting, Sweden
- ESB International, Ireland

A steering group consisting of FES, Rambøll, CRES, UCC and the European Commission's Project Supervisor guided the project.

The work was divided into seven work packages. These were:

1. Network Co-ordination & Support
2. Co-operation with the Power Industry
3. Social, Planning & Environmental Impact
4. Financing & Economic Issues
5. R&D on Wave Energy Devices
6. Generic Technologies
7. Promotion of Wave Energy

The main output from the project is a large report that brings together the outputs of the work packages and should serve as a useful reference for those interested in the status and development of ocean energy technologies, the challenges faced and the potential for the industry. In addition to the report, the network has also established a web site (www.wave-energy.net) and organised two open conferences - one in Lisbon in 2000 and one in Brighton in 2002. The detailed results of the work can be found in the larger report, which is available to download from www.wave-energy.net. The full report is over 500 pages long not including appendices.

This technical summary report, on the other hand, summarises the results in a more concise form and draws the work to a conclusion. It is structured in order of the work packages and also discusses Work Package 7, the promotion of wave energy, which was not discussed in the main technical report. The large report was structured in an order designed to be logical to an interested reader with no knowledge of the project itself and omitted information about WP 7 for the same reason.

Table 2.1.1 below lists the objectives of the various work packages and Table 2.1.2 below lists the participants involved in each work package and identified the work package co-ordinator.

Table 2.1.1 - Main Work Packages in Thematic Network

Work Package	Title	Objectives
1	Network Co-ordination & Support	To provide the basic infrastructure to operate the network and co-ordinate its activities.
2	Co-operation With Power Industry	To induce a long-term co-operation with the power industry (eg electricity utilities, wind power industry) in order to involve the utilities and to learn from the experience of the wind power industry.
3	Social, Planing And Environmental Impact	To identify the planning, legal and commercial barriers and the social benefit, energy and environmental impact from the expected development of wave energy schemes. To create recommendation for their development.
4	Financing & Economic Issues	To evaluate the financing, economics and monetary issues for developing wave energy schemes.
5	R & D on Wave Energy Devices	To identify the current status of wave and tidal energy device development. To determine the technical barriers to the commercial development of these devices at different time scales. To develop a standard for assessment of existing and new devices. To develop a Strategy for Development and an Action Plan.
6	Generic Technologies	To co-ordinate activities on generic technology issues concerning the utilisation of wave and tidal/current energies, so as to facilitate the exchange of experience and the transfer of knowledge. To promote the knowledge and technology transfer from the offshore industry and coastal engineering. To promote studies on these issues.
7	Promotion of Wave Energy	To promote wave energy as a renewable source of energy, capable of significant contribution to electricity production in Europe in the near future. This promotion will use several media in order to reach different areas of industry and society.

Table 2.1.2 - Distribution of Work in Thematic Network

Work Package	Co-ordinator	Participants
1	FES	CRES, Rambøll, UCC
2	Rambøll	Chalmers, CRES, EMU, ESBI, INETI
3	EMU	CRES, FES, Hammarlund, Rambøll
4	FES	Chalmers, EMU, Rambøll, Teamwork
5	UCC	Edinburgh, IST, PdA
6	INETI	IST, Nantes, PdA
7	CRES	FES, UCC

2 SCIENTIFIC AND TECHNICAL PERFORMANCE

The project was carried out in 7 work packages. This section summarises the output of these packages. Work Package 1, Network Co-ordination & Support, is not covered, as it was merely an enabling activity that did not generate any results of its own.

2.1 Work Package 2 – Co-operation with the Power Industry

This work package was co-ordinated by Rambøll. Table 2.1.1 below lists the organisations involved and their roles.

Table 2.1.1 - Distribution of Work in Work Package 2

Task	Description	Task Leader	Task Contributors
1	Development of a standard for power quality of grid connected wave power plant.	EMU	ESBI, INETI
2	Development of a safety standard for wave power conversion systems	Chalmers	ESBI, INETI
3	Power transmission of wave power plants	CRES	ESBI, INETI

The Work Package has developed three standards to help wave energy device developers interface with the Power Industry. These are large documents and are reproduced in their entirety in the main results report. The standards developed here have not yet been granted official status but are rather starting points from which institutions such as CEN, ISO or the IEC can, if they wish, develop official standards at the appropriate time.

Grid and distribution networks themselves are subject to codes and standards that ultimately meet the requirements of regulatory authorities under broad headings of power quality, reliability, commercial fairness and safety, and these must form the starting point from which standards for ocean energy developers are derived.

The power quality standard specifies in detail how the power quality issues that face wave power development in relation to existing grid parameters can be overcome. The main implication of the work is that these systems must be geared to meeting established criteria for network connection. The criteria may be grouped under the broad headings of

- Planning
- Connection Conditions
- Operations
- Data Registration

The recommended approach to the issue of achieving adequate power quality for grid connection can be summarised as follows:

- At the present stage of development of wave conversion systems, it is likely that most connections will be made to the distribution network rather than at national transmission grid level.
- It is likely that this situation will prevail until converters are sufficiently proven at this level to warrant interest in larger-scale developments that would justify the substantially higher cost of connection at 110 kV level or above.

- Wave power should meet the same quality standards as would apply to other non fully-dispatchable renewable energy conversion systems when connected to the distribution network
- The attainment of a level of power quality should be viewed in the context of the mutual duties and obligations of the Distribution System Operator and wave power developer in addition to the particular technologies that will permit them to maintain power quality.
- The foundations of power quality should be set in the criteria established for connection to the distribution system in the first place, followed by a regime of monitoring, maintenance and testing as set out in this draft document.
- It should be accepted that the mechanisms by which developers utilise the characteristics of wave energy and the features of their particular converters to meet the obligations of the draft standard may of course vary in each case.
- Much of the information that will be required from the developer will relate to the characteristics of his electrical generator. It will originate with the generator supplier and to a lesser extent with the prime mover supplier. Integration of these systems to meet the requirements of the System Operator or utility (if different) and the Electricity Regulator will require the involvement of competent electrical engineering personnel on the developer's team.

The standard on safety covered the following areas:

- Design
- Construction/fabrication
- Installation
- Commissioning
- Operation
- Decommissioning

Like the power quality standard, this is intended to be a starting point from which eventual official standards can be developed. However, safety procedures are also of value in research as well as in any eventual commercial deployment. There may be value in developing a wave energy safety standard for use by research organisations carrying out research at sea.

Power transmission

This guideline report addresses the procedures and facilities that typically influence the transmission of electrical power from off and nearshore power plants. The report commences with a brief technical resume tracing the evolution of high voltage submarine cable installations over the past half-century. It also discusses some of the salient features to be borne in mind in relation to cable selection and emphasises that successful cable installations are necessarily relatively expensive and require careful attention to detail design. It is not simply a case of laying 'insulated wire' on the seabed! It is expected that before major wave power installations will be developed, much useful experience will have been gained from connections to offshore wind farms. The integrated nature of wave power development is emphasised by the breadth of the requirements alluded to in the section dealing with permissions and safety issues. Some of these topics are more fully dealt with under Sections F 1 and F 2.

2.2 Work Package 3: Social, Planning & Environmental Impact

This work package is co-ordinated by EMU. Table 2.2.1 below lists the organisations involved and their roles.

Table 2.2.1 - Distribution of Work in Work Package 3

Task	Description	Task Leader	Task Contributors
1	Industrial Benefit and Job Creation	FES	Rambøll, CRES
2	Technical Barriers	EMU	Hammarlund
3	Environmental Impact	EMU	
4	Public Acceptability	Hammarlund	Rambøll,
5	Planning Consideration	EMU	FES, Hammarlund, CRES

Ocean energy, and indeed renewable energy in general, is attractive mainly because of its much lower environmental impact compared with conventional energy, specifically its almost zero CO_2 emissions. However, no form of energy generation is completely without effect on the environment or society. This Work Package looked at the challenges that social, planning and environmental issues pose for the large-scale deployment of ocean energy technology.

As the wind energy industry has discovered, environmental benefits are no guarantee of public acceptability. Consequently, the Work Package examined these public acceptability issues with reference to relevant legal frameworks. An important conclusion was that public acceptability is enhanced by openness of information and public involvement from the start and that, conversely, secrecy and lack of public involvement can diminish public acceptability. Some approaches have been suggested that might help promote public acceptability of wave & tidal energy projects. These were based on case studies of several offshore wind projects in Denmark and involve ensuring that information is available in the public domain, that people are engaged in the project and that the project is judged fairly on its merits. Some examples of engaging the public on offshore wind farm developments are included and many lessons for ocean energy can be learned from these.

The socio-economic benefits of ocean energy have been investigated, the main plank of which is an analysis of the impact that the emergence of an ocean-energy industry could have of the economy and society in Scotland. This showed that the development of an ocean energy industry would bring jobs, help diversify other industries and re-deploy skills from declining industries such as shipbuilding.

Ocean energy devices will need to fit in and around other existing and potential sea uses. These can include ships, military training areas, existing sub-sea cables and pipelines, fishing, recreation and archaeology among others. Understanding the nature of these issues and their importance will be helpful to the widespread deployment of the technology. This Work Package investigated these issues and identified some ways in which they might be tackled. There is an interaction here with public acceptability as measures to reduce collision risk, such as flashing lights and marker buoys, can increase visual impact.

All EU countries have planning laws of one form or another and these are increasingly subject to the harmonising effect of EU directives. The Work Package examined the main types of planning requirements and the legal principles on which they operate. It then identified the issues associated with planning for ocean energy with particular reference to environmental impact assessment for individual schemes, the development of strategic environmental assessments for regions that may prove suitable for the deployment of the new technologies. Also covered were the international conventions and declarations for the protection of species and habitats.

It is to be expected that ocean energy devices will have some environmental impacts. In many cases these can be minimised and mitigated. The impacts include effects on mammals, the seabed and local benthos, hydrography and on the coastal processes that shape and characterise our shores. Other impacts include the airborne and underwater noise and visual amenity; and these have been investigated. There is also the potential for impacts due to accidents. Some discussion on how to ensure that accidents have minimal long-term effects is has also been studied.

Of course, the environment will have an impact on the devices too. The devices can become fouled by debris and encrusted with sea creatures. They will be sensitive to sea currents, wind and corrosion. These issues are of importance to the design and operation of ocean energy devices.

Ocean energy devices bring environmental benefits. These are mainly in terms of the avoidance of emissions of CO_2 and other greenhouse gasses generated by conventional power stations.

2.3 Work Package 4: Financing & Economic Issues

This work package is co-ordinated by FES. . Table 2.3.1 below lists the organisations involved and their roles.

Table 2.3.1 - Distribution of Work in Work Package 4

Task	Description	Task Leader	Task Contributors
1	Financing of wave energy projects	FES	Rambøll, EMU, Chalmers, Teamwork
2	Economics of wave energy	FES	Rambøll
3	Environmental economics	FES	

The capital asset pricing model (CAPM) was used to derive a “required rate of return” (RRR) for ocean energy projects. This was in the region of 10%. This shows the minimum return on their investment that will tempt investors to invest in this technology. It is clear that there are economic benefits to using ocean energy providing it can deliver the rates of return required by investors whilst being competitive with other forms of energy generation.

To compete with other forms of power generation ocean energy devices must be produced at the right cost. This Work Package investigated the cost of producing energy for some existing devices. These show that some significant developments in wave energy have taken place in recent years leading to potential reductions in generation costs when, after all R&D is complete, the devices eventually reach commercialisation. This assumes that when this happens, the devices will achieve their currently predicted capital costs, operating costs and power outputs.

There is therefore a clear potential for wave energy to compete with other forms of generation providing that the R&D can be successful and that there is a sufficiently strong market pull for the technology.

One of the main drivers for the uptake of renewable energy is its low environmental external costs compared with those of conventional energy. This project investigated the environmental economics of ocean energy using the ExternE methodology. This methodology was developed by a large EU project in the late 1990s. The results show that the external costs of conventional energy generation, excluding the effect of global warming, which is likely to at least double the quoted figures, is in the range 0.29 to 1.6 US¢/kWh, whereas the external costs of wave energy are likely to be around 10^{-3} €¢/kWh including global warming.

2.4 Work Package 5: R&D on Wave Energy Devices

This work package is co-ordinated by UCC Table 2.4.1 below lists the organisations involved and their roles.

Table 2.4.1 - Distribution of Work in Work Package 5

Task	Description	Task Leader	Task Contributors
1	Review current & wave energy device development status	UCC	
2	R&D requirements for first generation devices	UCC	IST, Edinburgh
3	R&D requirements for second generation devices	UCC	
4	R&D requirements for third generation devices	UCC	Edinburgh
5	Tidal current device development status and research requirements	UCC	PdA
6	Develop strategy & action plan for R&D for current and wave energy devices	UCC	

This work package sought to identify what R&D is needed to help bring ocean energy technology from its current position to one where it is capable of generating commercial electricity. Its specific objectives were:

- To identify the current status of wave energy device development.
- To identify technical barriers to development.
- To develop a Strategy for Development and an Action Plan.

Ocean energy systems are currently at an early stage of development. Most are still undergoing significant R&D work. The project focussed mainly on wave energy but did also look at tidal stream R&D issues.

For the purposes of this analysis, wave energy devices were classified into "generations". The first-generation devices fixed shoreline systems, several of which have been installed already. The second-generation devices will be the floating or offshore devices. Fourth-generation research looks at how new materials, manufacturing systems and technologies can be applied to the problems of ocean energy. The term "fourth generation" was used by analogy with the software industry, which uses this term to refer to developments that rely on new materials and processes not yet already available. There is, consequently, no third generation.

The first-generation R&D includes improving the efficiency and control of wave-to-air systems, refining the design of the main structures for survivability, energy capture enhancement and lower material cost. The main research needs for 1st generation technology were identified to be:

- Shoreline / Nearshore Wave Climate
- Hydrodynamics
  (Mathematical and Physical Modelling)
- Air Turbines
- Generator and Electrical Equipment
- Ancillary Mechanical Equipment
- Design and Construction Methods
- Probabilistic Modelling
- Analysis of Results from Pilot Plants

There are still many knowledge gaps for floating devices, these include knowledge of the ways waves behave and how the resource is characterised as well as on the magnitude of the loads caused by the marine environment. The engineering challenges for floating devices include gaining a better understanding of different types of power take-off systems and how these can be tailored to wave energy, moorings and flexible electrical connections. To be successful these new device types require skills from many different fields and so good multidisciplinary teams are required to bring the development of these ideas forward. The main research requirements for floating devices were identified as:

- Hydrodynamics
  (Mathematical and Physical Modelling, Arrays)
- Air Turbines
- Hydraulic Systems
- Short Term Wave Behaviour / Wave Weather
- Performance and Survival
- Monitoring Systems
- Flexible Cables and Connections
- Low Cost Mooring Systems –Device Dependant
- Low Cost Construction
- Deployment and Recovery Methods

Looking further into the future there are many issues that could be progressed further with the use of new materials, novel manufacturing techniques and so on. These are considered to be fourth generation research areas. They include:

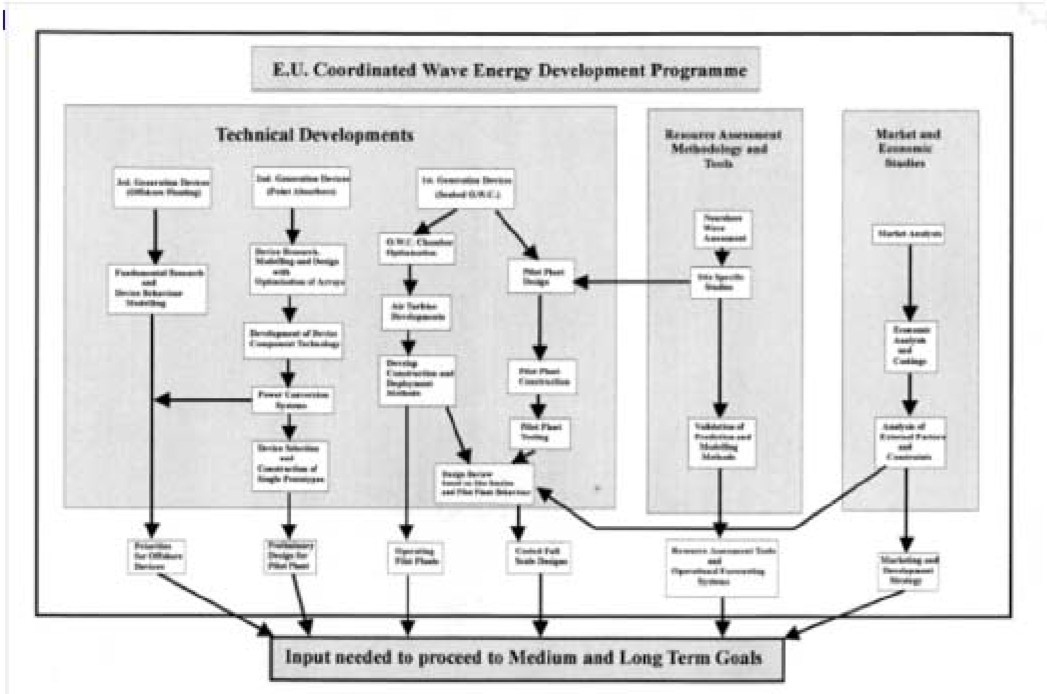
- Hydrodynamic Modelling
  (especially non-linear and real fluid effects)
- Large Scale Component Testing at Sea
- Control Systems and Methods

- System Configuration Options Selection
- Power Take Off Systems / Smoothing
- Large Size Bearings / Seals
- Materials Selection and Coatings
- Construction Methods
- Improved tank-testing facilities

The main research requirements for Tidal Stream were considered to be:

- Tidal Flow Modelling with Details
- Rotor Design for Vortices and Cavitation
- Installation / Recovery Methods
- Power Take-Off Systems
- Materials, Corrosion, Protection
- Bio Fouling
- Variable Pitch Rotors
- Anchoring / Foundations
- Maintenance Systems
- Grid Connections

A road map for ocean energy R&D has been developed under this work package. This is summarised in the following diagram:



2.5 Work Package 6: Generic Technologies

This work package was co-ordinated by INETI . Table 2.5.1 below lists the organisations involved and their roles. An overview of progress in this area was not available by this report's deadline. An update will be provided in due course.

Table 2.5.1 - Distribution of Work in Work Package 6

Task	Description	Task Leader	Task Contributors
1	Plant control & power output prediction	INETI	
2	Plant monitoring & assessment of performance	INETI	
3	Loads and survivability	INETI	
4	Maintenance & reliability	INETI	
5	Modelling & standard design methods	INETI	ECN, PdA, IST

Ocean energy devices are still mainly at the research and development stage. They face a number of different challenges. Many of these are common to all, or at least most, device types. They include:

- Control Systems
- Power Output Prediction
- Monitoring and Reporting On Prototype Systems
- Wave Loads and Survivability Criteria
- Reliability & maintenance
- Standard modelling and design methods

Most wave energy devices will benefit from good control systems. Control systems that use resonance or phase control were investigated along with their potential benefits and challenges. Producing good quality electricity to the grid is of prime importance. The implications that this has for plant design were investigated.

It is particularly challenging to predict the output of wave energy devices in given situations. The available techniques and the current state of the art were reviewed and commented upon. Whilst more work needs to be done to understand these issues the work carried here comprises some important foundations.

The issues of monitoring and reporting on prototype systems were investigated in some detail. The positioning and choice of sensors, the good monitoring and data collation are all important issues and some clear guidance on sensible approaches was developed.

The environment in which these devices will be deployed is a difficult one. This study developed some methodologies for estimating wave loads and survivability criteria and derived some guidelines for the design of marine structures.

Ocean energy devices are capital-intensive. In order to be economic they must operate reliably and with low operating cost for long periods of time. The issues associated with maintaining plant were investigated with particular reference to the operation of some prototype plants such as the Pico OWC plant in the Azores, the Japanese Mighty Whale floating offshore device and the Dutch-designed Archimedes Wave Swing soon to be deployed in Portugal.

To enable ocean energy systems to be designed and built in large numbers some standardisation of the modelling and design methods may be required. This report discusses some modelling approaches for estimating performance from the 'wave to the wire', i.e. from the input energy source to the output electricity demand. Each of the steps in the wave-to-wire model can be separated and dealt with in different ways.

Methods for modelling device-wave interactions at both large and small sizes were investigated. Means for performing tank tests of different device shapes and operational conditions were also studied along with appropriate methods of scaling the results to full device sizes. It is recognised that the implications of real sea conditions with irregular and random waves on modelling results are important and these effects were also covered.

2.6 Work Package 7: Promotion of Wave Energy

This work package is co-ordinated by CRES.

Table 2.6.1 below lists the organisations involved and their roles.

Table 2.6.1 - Distribution of Work in Work Package 7

Task	Description	Task Leader	Task Contributors
1	Support for wave energy events	FES	All
2	publications in international journals	CRES	All
3	Dissemination of printed material	CRES	All
4	Development of a wave energy internet site	UCC	All

2.6.1 Objectives

The objective of this work package was to raise awareness of ocean energy systems amongst a diverse range of target audiences.

- Open Door Events
- Web site
- Brochure
- Published Papers in international journals

Open Door Events

Two open door events have been held. One in Lisbon in 2001, and one in Brighton in 2002.

The programme for the Brighton conference was structured according to the work packages. The presentations have been put, in pdf form, on the Wave Net web site. Ninety-three delegates registered to attend the Brighton conference and 82 turned up. Table 2.2 below lists the countries represented at the conference.

Table 2.2 - Delegates countries of origin

Country	No of Delegates
UK	48
Denmark	6
Ireland	6
Netherlands	4
Portugal	4
Sweden	3
Canada	2
France	2
Germany	2
Japan	2
Russia	1

Of those delegates who attended, 31 filled in feedback questionnaires. Of the delegates who filled in feedback questionnaires, 23 said that their objectives were met and 4 said they were not.

Web site

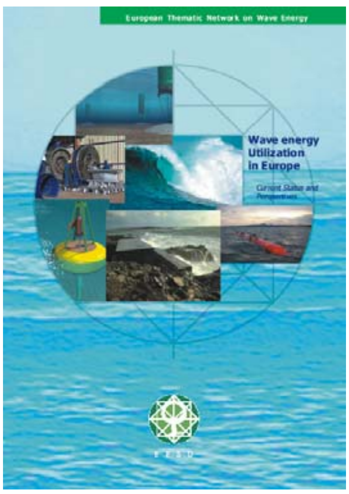
The address of this web site is http://www.wave-energy.net. Traffic on the site has been quite high - around 15 to 20 thousand hits per month from all over the world. The site is about to be re-vamped to make it look more dynamic. The site includes sections on the following topics:

- RTD
- Industry
- Wave Energy
- News
- Links
- Home
- Library
- Discussion Forum NEW
- Network Overview
- For Schools

The library section includes papers and other publications on wave energy as well as the presentations from the recent Brighton conference. The "News" section includes information about relevant conferences.

Brochure

A high quality glossy brochure has been produced that is intended to give a general overview of the current status of wave energy utilisation in Europe. Initially 500 of these were printed but following requests made at the Meeting in Brussels on 21 February 2003, and extra 2000 are in the course of being printed. The brochure will be distributed among the Network Participants for their own use in publicising the benefits of wave energy.



The brochure includes information about the Wave Energy Resource around the world, a general introduction to wave energy utilisation, an overview of the Current Status of Wave Energy Technologies, including its Economic Status, and some information about the Network and its work programme. It also includes a list of references and links to further information.

Published Papers

Two papers have been published in international journals. These are:

"**Wave energy in Europe: current status and perspectives**"; Alain Clément, Pat McCullen, António Falcão, Antonio Fiorentino, Fred Gardner, Karin Hammarlund, George Lemonis, Tony Lewis, Kim Nielsen, Simona Petrocini, M.-Teresa Pontes, Philippe Schild, Bengt-Olov Sjöström, Hans Christian Sørensen, Tom Thorpe; Renewable and Sustainable Energy Reviews, 6(2002) 405–431.

and

"**Stochastic modelling of OWC wave power plant performance**", A.F. de O. Falcão & R.J.A. Rodrigues, Applied Ocean Research 24 (2002) 59–71

3 DELIVERABLES & MILESTONES

3.1 Deliverables

Table 3.1.1 below lists the deliverables completed.

Table 3.1.1 - Deliverables completed

No	Due Month	WP/ Task	Nature	Description	Status
D1	12	7.4	IT	Establishment of wave energy internet site	Complete
D2	18	2.1	Standard	Draft standard for electrical connection	Complete
D3	18	2.2	Standard	Draft standard for electrical safety	Complete
D4	18	7.1	Literature	Supporting material on wave energy for conferences etc	Complete
D5	20	1	Report	Progress report and financial statement following network meeting	Complete
D6	24	3.1	Report	Report on industrial benefits	Complete
D7	24	3.2	Report	Report on technical barriers	Complete
D8	24	3.3	Report	Report on environmental impacts	Complete
D9	24	4.3	Report	Report on integration of environmental benefits	Complete
D10	24	7.3	Material	Pamphlet on wave energy for the public, investors and industry	Complete

3.2 Milestones

Table 3.2.1 below lists the deliverables completed.

Table 3.2.1 - Milestones

No	Due date	Description	Decision Criteria	Status
M1	18	Task 1 - Network-wide meeting	Publication of a report on the meeting	Meeting held Nov 2001. Minutes & action list circulated
M2	18	Task 2 - Draft standard for electrical connection	Presentation & discussion at workshop	Draft standard prepared Nov 2001
M3	18	Task 2 - Draft standard for electrical safety	Presentation & discussion at workshop	Draft standard prepared Nov 2001
M4	18	Task 3 - Interim reports on social, planning and environmental aspects.	Presentation & discussion at workshop	Draft reports prepared Nov 2001
M5	18	Task 4 - Interim reports on financing & economics	Presentation & discussion at workshop	Draft report circulated for comment and discussed at Lisbon.
M6	18	Task 5 - Interim report on devices and their R&D requirements.	Presentation & discussion at workshop	This report was prepared and discussed at the Network meeting in Brussels in February 2003.
M7	18	Task 6 - Interim recommendations on monitoring methodology, design criteria & reliability.	Presentation & discussion at workshop	This report was prepared and discussed at the Network meeting in Brussels in February 2003.

3.3 Contact Details

Table 3.3.1 lists the contact detains of current Members of the Network.

Table 3.3.1 - Up-to-date contact details for current network members.

Organisation	Contact	Telephone	Fax	E-mail
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