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Analysis of the Potential Economic Benefits of Developing Ocean Energy In Ireland

Final Report

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Table of Contents

Executive Summary

1. This report examines the potential of harnessing Ireland's ocean energy (OE) resources to produce electricity and the associated opportunity to develop an OE industry in Ireland. Existing work, both in Ireland and internationally, suggests that there are opportunities to develop a competitive industrial sector around ocean energy in Ireland. The technology is at an advanced experimental stage and there are prospects of commercial production being possible in the near future. However, a key question is whether the potential is sufficient to warrant Ireland engaging in a long-term programme of development. A Consultation Process undertaken by *Sustainable Energy Ireland* and the *Marine Institute* indicates the potential. It also indicates that there are considerable risks. The aims of the study are to identify the potential economic contribution of ocean energy to Ireland and to devise a rational, viable, and economically feasible strategy to promote the development of the sector.

2. Ireland's ability to develop an ocean energy industry can be summarised in a SWOT analysis, which provides an assessment of the overall capability of the Irish economy. This indicates the following:

Strengths

- The Irish wave resource is extremely rich relative to the energy needs of the country.
- The technology to build functional wave converters is developing rapidly but the opportunity to gain a lead remains.
- Ireland is, academically, well represented at the cutting edge of wave and tidal technology due to the technical competence of several universities and their participation in projects with other international participants.
- There is a manufacturing and construction industry available capable of the manufacture of components, systems and converters and their later installation.
- A unified embryonic licencing system exists that can facilitate development.
- Installation skills broadly similar to those needed for the growing offshore wind industry will be required for O&M.

Weaknesses

- There is, as yet, no proven 'winning' wave converter design available.
- There is little commercial investor confidence because the technology is at an early stage and the economic and performance risks associated with technologies at pre-commercial stage are very large.
- There is currently no power purchase regime in place for early stage projects, unlike that which is available in some other markets, such as Portugal.
- There is a lack of publicly available data on the characteristics and extent of the Irish resources, due to incomplete measurement and lack of dissemination.
- Research funding has been sparse and intermittent. This has slowed the rate of progress that could otherwise have been possible.
- There is an unrealistic demand for industry to provide counterpart funding for research projects.
- There is a lack of integrated understanding at utility level as to the merits of wave and tidal relative to wind energy.
- The tidal barrage option appears to face very severe economic and environmental obstacles and is ultimately excluded from consideration in the development strategy.

Opportunities

- The fact that there is, as yet, no proven 'winning' wave converter design available provides a significant opportunity to place Ireland in a frontline position in the sector.

- There is a very significant resource globally and a potentially large market in a number of key countries, in addition to niche markets elsewhere.
- Ireland has still the prospect of establishing commercially viable designs and exploiting these locally, or in collaboration with overseas players, in terms of supply and services, although this opportunity will not last for much longer.
- Direct synergies exist with offshore wind, which should accelerate the development of wave and tidal service capabilities.
- Wave and tidal resources provide sustainable demand in the medium to long term.

Threats

- Designs developed elsewhere will become the norm and 'capture' the market.
- Better pre-commercial support, e.g. capital grants, power-purchase terms, being provided elsewhere, may delay of stultify Ireland's development in the field.
- Greater market size and the development of standard designs abroad, coupled with economies of scale in production and rising costs in Ireland, may lead to manufacturing being carried out elsewhere.
- The research resource could easily disappear as it is primarily led by a small number of key individuals who face uncertainty in securing regular funding.

3. The analysis, including examination of the situation in other countries and the strategies that have been used to develop successful renewable energy sectors, leads to the conclusion that Ireland has an important opportunity to develop an industry, based on ocean energy. This would have the potential to lead in a creation of valuable intellectual capital, economic wealth and employment opportunities. Furthermore, it would have a desirable regional spread, in the sense that development would take place in areas of the country that are lagging economically.

4. In advance of implementing a development program, there is a need to develop a vision of ocean energy and of its place in the renewables portfolio available in Ireland. Within that vision wave and tidal energy conversion should be seen as distinct concepts having different potentials and characteristics.

5. In the case of wave energy, the analysis indicates that Ireland has a significant development opportunity. All indications are that the resource is a good one, in which promising converter systems should be expected to excel, and which would serve as a good marketing tool in dealing with potential clients from other parts of the world. The UK resource is the only one in Europe that is more attractive. On the basis of the projection developed in this report, it is estimated that an industry in Ireland with a total employment impact of 1,125 in 2020 is feasible, assuming installation of 40MW in that year. The export potential of technology developed would also be important. Total employment creation in the region of 1,900 jobs appears feasible on reasonable assumptions.

6. Evaluation of the outputs of the industry indicate a value in the region of 9.75c per kWh, compared to a current CER BNE price of 4.7c for CCGT production. It is estimated that a feed-in tariff of up to 9.75c per kWh would produce net benefits for the economy. This is close to estimates of the likely cost of producing ocean energy in the next decade and provides a preliminary conclusion that investment would be forthcoming from the private sector at these levels. On the basis of the development outlined the total value of output, when all impacts are included, is €227 million, in current values. If this is discounted at a public sector real discount rate of 2.5% to 2007, when the first prototype deployment is projected, the present value is €170 million.

7. It is recommended that policy should foster both home-developed converters as a matter of urgency and shared ventures with overseas developers. Where Irish-developed designs are concerned, the aim should be to maximise total return. Where designs developed elsewhere are concerned, the aim should be to maximise the potential for Irish players to participate as suppliers of services to these developers, either in the Irish market or elsewhere. A very important issue is that there is, at present, no mechanism for drawing firms together under the umbrella of ocean energy and alerting them to the challenges and opportunities that lie ahead. Such a mechanism is required, both to co-ordinate development and to approach the issue from the perspective of commercial enterprise development rather than simply meeting energy needs.

8. In the case of tidal energy, the projected costs do not auger well for barrage type projects on the Irish coast and this technology should not be pursued. Tidal stream technology holds greater possibilities but its feasibility is sensitive to the velocities that can be accessed in certain water depths. Informed strategic planning and decision-making is impossible in the absence of fundamental information on the resource. This information is simply insufficient in the case of Ireland. Some studies are available but these are not sufficiently comprehensive. It is recommended that a new phased survey be undertaken with the specific aim of tidal stream measurement for ocean energy purposes. Upon completion of the present tidal stream study being carried out under the auspices of SEI, it will be necessary to assess the location and extent of the resource at projected tidal stream 'hot spots' and the applicability of presently available tidal stream converters. If the resource proves to be technically and commercially significant, policy should consider implementing a feasibility study for particular areas. Otherwise, the policy should be to maintain a watching brief only. In summary, the consultants, while including the possibility of implementing a pilot study in this technology cannot reach a definitive conclusion in the absence of this fundamental information.

9. A number of conditions are required to achieve the successful realisation of benefits from ocean energy in Ireland. These include ensuring that:

- The Irish wave energy resource is proven to be of adequate magnitude and consistency, and that access is maintained for energy production.
- The conversion technology is successfully developed in terms of efficiency, cost, and quality of output.
- Development consortia have adequate strength in terms of management and technical experience, financial strength and back up for the particular market place.
- Appropriate funding arrangements are made available for the pre-commercial stage of development.
- Administrative procedures are streamlined.
- A consistent market is established with an appropriate feed in tariff.

10. A number of countries are developing competencies which suggest that, in the absence of a co-ordinated enterprise-oriented policy programme, Ireland, at best, may only exploit these resources without realising their full value added potential. However, much of the wealth creating potential of the OE sector is expected to be in activities related to the development and exploitation of the intellectual property encapsulated in the technology for the exploitation of this resource. Experience with many natural resources indicates that much of the wealth associated with exploitation does not arise from the presence of the resources in an economy but from the development of the expertise that is required to exploit these resources. While the presence of the resource is an important feature, it is not a vital requirement for competitive advantage, as can be seen from the valuable industry that has been developed in wind energy in Denmark. Rather, the vital requirement is that all the assets at the economy's disposal are harnessed to extract the overall wealth-generating potential that is present in Ireland's natural resources.

It should not be thought that the level of resources now being committed to ocean energy research and development in the U.K. automatically eliminates the possibility of success where Irish based development is concerned. Some Irish developers through their operations in Northern Ireland stand to gain from the UK funding, others may engage in joint operations with UK players as suppliers of specialist services. It should also be recognised that while the leading U.K. system (Pelamis) is based on the use of hydraulic systems for electricity generation, at least two other systems have been under development in Ireland. These are the McCabe desalination system focussed on meeting future fresh water needs in specific markets and the Reverse Duct Buoy equipped with rectifying air turbines for electricity generation. At the end of the day least cost per kWh is likely to be the dominating factor in the market place, all other things being equal, and it is not yet clear which system (Pelamis, Reverse Duct Buoy or Aquabuoy among others) will win out in this regard.

11. Experience, and research into industrial development, over recent decades, in Ireland and elsewhere, indicates that the concept of clustering, developed around a Centre of Excellence, is very important for the development of competitive industries. While the concept is not yet fully explored, it is clear that an important aspect is that development takes place in a co-ordinated manner. This applies to policy intervention as well as to commercial situations where policy plays a less important role, for example, the development of financial resources for the industry.

12. Looking forward, an active development programme is required, which takes due recognition of the following requirements:

- Actions/initiatives should be framed within an understanding of both the resource and the market to which it relates.
- Initiatives should be founded on a clear understanding of the conversion technologies and their unique positive and negative features.
- Actions should be proactive, but realistic in assessing what is achievable. The policy should aim to establish working ocean energy systems at demonstration level by an early date.
- While the programme should utilise, where possible, the joint expertise and resources (including available RD&D funding) of relevant state agencies, primary accountability for ocean energy development should rest with one agency.
- The policy programme should have clear goals, objectives and means of monitoring progress and expenditure on a project management basis.
- The programme should be developed in such a way as to minimise bureaucracy and maximise continuity in administration.
- Recognising the limited nature of the supporting financial resources likely to be available, policies should be supportive of the partnering concept between Irish and overseas-based players to the extent possible. For this to occur, Irish players will need support in maintaining credible profiles.

13. A development programme for this industry needs to be undertaken in a number of stages, with focussed objectives and indicators set for each. Such a process is captured in Table A.

Table A: Policy Objectives, Stakeholders and Institutions Responsible

Objective	Stakeholders and Institutions Responsible	Timing
Identify best option for development	Consultants, Marine Institute, SEI, DCMNR	2004
Decision to proceed	MI, SEI, DCMNR, Dept. of Finance, DOELG, CER, ESB	2004
Clarify responsibility	MI, SEI, DCMNR, DETE	2004
Create a detailed plan for development	Ocean Energy Development Unit (OEDU), ESB, CER, Dept of Finance, Universities	Early 2005
Develop funding	OEDU, Dept of Finance	2005
Investment in R,D,D	OEDU, Universities and research centres,	Ongoing from 2006
Initiate pilot project	OEDU, Universities and research centres, ESB, CER,	2006/7
Install pilot projects	OEDU, researchers ESB, industry	Starting 2007
Initiate Production	OEDU, private investors, financial sector, Dept of Finance, ESB, CER	2008
Investment in productive capacity	Private investors, financial sector, Dept of Finance, ESB, CER	Starting 2009
Industrial development	OEDU, DETE	Ongoing from 2010

The estimated cost of this development programme is €10.5 million. Most of this relates to research, development and deployment of pilot machines and would be spent in the period up to 2010. This estimate does not include the subsidy to producers in respect of the externalities associated with ocean energy compared to alternative energy sources. It is estimated that the total cost of incentivising the production levels projected would be in the region of €80 million.

14. This initiative has the ultimate objective of achieving installed capacity of 200MW in wave energy by 2020. An appropriate timeline is required to achieve this. One is proposed covering the period 2004 to 2020. The overall objective is that by the end of this period, Ireland will be at the forefront of this industry and will be in a position not only to exploit the energy producing potential of the natural resources that are available but, most importantly, the intellectual property that will be needed for the industry to develop in a number of countries.

15. The following series of recommendations is made to give effect to the proposed programme:

- All major stakeholders to pool expertise towards agreed ends as a matter of urgency.
- A mechanism should be established and funded with a research and enterprise orientation to identify research requirements, the required policy intervention, and the requirements for private sector involvement in the sector. In addition, there is a need to indicate how these requirements are to be met and to develop an operational strategy to do so. This should be established before the end of 2004.
- Information deficiencies, in terms of the resource, should be addressed in the short term. A study should be undertaken to measure, model and map the Irish tidal stream resource. This should establish its extent and identify areas that may have the necessary velocity levels, with a view to the future deployment of energy converters. The nature of the resource must be more clearly understood not only to avoid surprises and possible disappointment but to ensure that converter designers have the best information at their finger tips so that designs can be optimised.

- An Ocean Energy Development Unit (OEDU) should be created and charged with the development of the sector. This should have overall responsibility for driving development of the sector and should be located within an existing agency, such as the Marine Institute, to minimise costs through the reallocation of resources. Short term secondment of personnel from other organisations should be envisaged to develop a momentum on a task force basis.
- Adequate test facilities and verifiable standards should be provided so as to enhance the credibility of the technologies and incentivise investment.
- Strategic Development Zones on the basis of the natural resource should be identified and utilised for the pilot projects in the first instance. These should be further utilised to minimise delays and enhance credibility in order to facilitate investment in production in later years.
- The commitment by the public sector to this industry should go beyond funding, to ensure that appropriate actions are undertaken to remove all barriers to private sector investment by ensuring that appropriate fiscal, pricing and access regulations are introduced. In the R&D phase it will be important that those measures introduced in the Finance Act 2004 are sufficiently flexible to promote R&D in academic institutions
- Appropriate targets should be set for development. These include: the institutional developments identified above, the creation and funding of a targeted R&D programme from 2004, the establishment of three pilot programmes by early 2006 in wave, with the possibility – contingent on the results of the resource measurement – of a project in tidal stream.
- A target for investment in generating capacity of 200MW by 2020 should be set. This would be equivalent to 2.5% of total electricity demand in that year and would provide the required mass to drive development of supporting industries.
- The OEDU should have a significant focus on R&D in the early years. Then it should become more focussed on the creation and extraction of value through the promotion of exports and creation of regional employment, once initial commercial production has been achieved.

1. Introduction

This report assesses the potential to harness Ireland's ocean energy (OE) resources to produce electricity. It examines also the opportunity to develop an OE industry in Ireland. Existing work, both in Ireland and internationally, suggests that there are opportunities to develop a competitive industrial sector around the production of this type energy in Ireland. The potential is based on an outstanding natural resource, which is undeveloped. The technology to exploit this resource at an advanced experimental stage, with prospects of commercial production being possible in the near future. However, a key question is to assess whether the potential is sufficient to warrant Ireland engaging in a long-term programme of development. The aim of such a programme would be to place the economy at the forefront of this industry and ensure that it contributes to wealth creation in the longer term.

The work is undertaken against a background of a consultation document that was produced by *Sustainable Energy Ireland* and the *Maine Institute* in 2002. It underlines the potential of ocean energy development but also indicates that there are considerable risks. As a result, if left to the private sector alone, it is unlikely that there will be sufficient investment in R&D to enable Ireland to develop an OE industry that would realise the full potential of the resource.

The aims of the study are to identify the potential economic contribution of ocean energy to Ireland and to devise a rational, viable, and economically feasible strategy to promote the development of the sector. The objectives may be summarised as:

- Providing a comprehensive analysis of the potential of the ocean energy sector in Ireland;
- Examining the commercial viability of the industry, illustrate the challenges facing the sector that may inhibit development, and indicate requirements to achieve this potential;
- Indicating the potential economic contribution of a competitive ocean energy industry in Ireland;
- Identifying the optimal role for public policy in developing wave energy;
- Determining a strategic approach for Ireland that will realise the potential economic contribution of the industry; and
- Setting out a policy programme of initiatives to realise this potential.

The work covers the following main stages:

- An outline of energy demand projections for Ireland;
- A review of the ocean energy resource, the current stage of development of the industry and Ireland's potential in relation to it;
- The developments required to realise this potential, presented in terms of specific scenarios;
- The policy requirements to realise the potential;
- An examination of the potential benefits and costs of developing the industry, and;
- A proposed policy programme to realise the optimal level of development.

The study is structured as follows:

- The report begins with a projection of the likely level of electricity demand, under conditions of reasonable growth, to 2020. There is a brief discussion of the implications of this growth in terms of the generating plant and fuel types likely to be necessary to satisfy this demand. This is placed in the context of EU and Irish policies and obligations to control greenhouse gas emissions.
- The scale and nature of Ireland's latent ocean energy resources are identified and international trends in ocean energy, power conversion systems are reviewed briefly [1].
- The next sections of the report describe the current stage of development of the ocean energy industry internationally, with specific reference to policy as it has been developed.
- Possible scenarios for the industry's development in Ireland and the implications of each scenario are identified.
- The benefits of a preferred scenario for development are then evaluated.
- The resources required to achieve this scenario are set out and assessed against existing infrastructure, skills and supporting features of the economy.
- It is clear that a policy-based programme will be important in realising the potential of the industry to Ireland. Factors that influence the commercial well-being of the industry and its potential for growth are assessed, leading to an outline of areas where intervention is required to achieve the optimal level of development.
- This provides the basis for the development programme that is outlined. Objectives, timelines, areas of responsibility and indicative costs are identified.

[1] Details of the technical aspect of this industry and developments elsewhere are contained in the appendices to the report.

2. The Energy Context in Ireland

2.1 Electricity Demand and Supply Projections for Ireland

The projection of demand for electricity consumption in Ireland is taken from the ESRI's energy forecasting model, developed as part of the Institute's forecasting work for the *Medium Term Review*[2]. The estimates for the demand for primary energy in Ireland, in million tonnes of oil equivalent (mTOE), are shown in Table 2.1. On the basis of the ESRI's benchmark assumptions for economic growth, this shows that the economy's primary energy requirement will increase by about 20% in the period 2005-2020 to 18.58 mTOE.[3] This is approximately double the demand in 1990.

Table 2.1: Demand for Primary Energy (mTOE)

	1990	2000	2005	2010	2015	2020
Benchmark	9.85	14.36	15.44	16.76	17.87	18.58
High Growth	9.85	14.36	15.30	17.07	18.73	19.93
Low Growth	9.85	14.36	15.23	15.82	16.39	16.92

Source: ESRI Medium Term Review

Electricity production is an important part of overall energy needs. Projections from the ESRI model for electricity generation requirements, in gigawatt hours per annum (GWh), are shown in Figure 2.1 along with historical data for generation. This illustrates the growth that will take place. The projection shows that electricity demand will rise faster than overall energy demand, with a 35.5% increase expected in the period 2005-2020. In effect, this shows that while there has been some decoupling of economic growth from energy demand in the Irish economy, this does not imply that there will be a slowdown in the growth in demand for electricity.

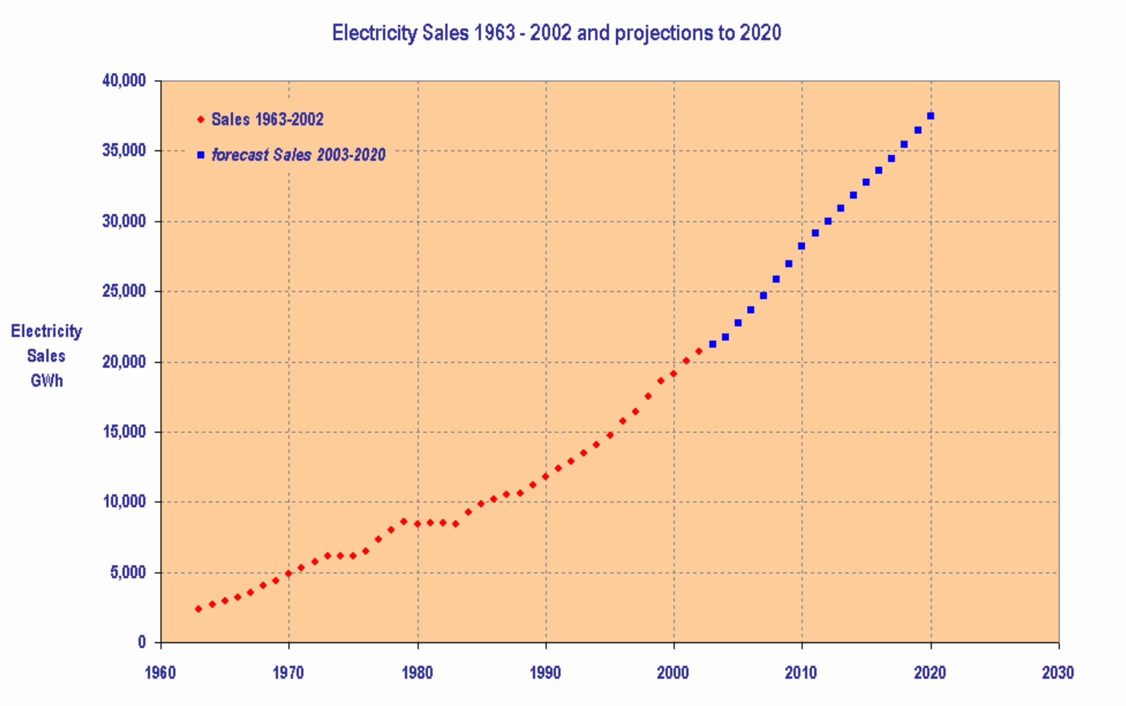
A variety of supply projections to meet this prospective growth in demand are currently being evaluated[4]. Decisions in relation to the optimal structure of supply are subject to a number of key considerations. These include ensuring security of supply, meeting current and future obligations under the *Kyoto* agreement, ensuring supply at minimum cost while achieving maximum return on funds invested, complying with EU Directives in relation to the electricity market, and achieving a technical balance between dispatchable plant, which will be mostly thermal generation, and renewable energy sources with limited or zero dispatchability, such as wind and wave power.

[2] ESRI (2003) Medium Term Review 2003-2010

[3] The model is calibrated on the basis of economic growth of 4% per annum in the period 2000-05, 3% to 2010, 2% to 2015 and 1.25% per annum thereafter.

[4] In the area of renewables see Department of Communications, Marine and Natural Resources/SEI (2003) *Options for Future Renewable Energy Policy, Targets and Programmes*

Figure 2.1: Projection of Electricity Demand in Ireland to 2020



The growth in energy demand and related issues have been the subject of several important reports since 1997[5]. In addition to the overall growth in the demand for energy, it is also worth noting the need to improve the security of supply of energy to the Irish economy in the longer term and the desirability of developing a better energy mix, which would contribute to security. A different mix is important also in the context of achieving the target to have 13.2% of Ireland's electricity produced from renewables by 2010. An important issue in this context, is to reduce correlations in operating time profiles as far as is possible. Accepting that wind energy will be the main renewable source, ocean energy (both wave and tidal) would improve the mix profile since the operating profiles of both are only partially correlated with wind. In addition, the wave time profile around Ireland means that the greatest energy is available during the periods of the year with the highest demand.

2.2 Ireland's Energy Policy and Renewables

It is clear that in the future a greater proportion of the total demand for energy will be met from natural gas, mostly in the form of CCGT, and renewable sources. Wind-generated electricity remains the most highly developed technology in the renewables area and may reach commercial viability in the next few years. Ireland has not yet developed a wind generating industry of significant scale.

[5] Notable examples include Department of the Environment and Local Government (2000) *National Climate Change Strategy: Ireland* and Department of Public Enterprise (1999) *Green Paper on Renewable Energy* Government of Ireland

Targets were set for renewable energy sources to contribute in the region of 7 TWh. to the electricity market by 2010. To date however, only about 200 MW of wind energy capacity has been installed. At a utilisation rate of 34% this would contribute in the region of 0.6 TWh per annum.

The case for promoting renewable energy technologies is based on their contribution to meeting objectives such as

- Climate change mitigation in line with international commitments
- Security of fuel supply through diversification and competition
- Moderation of the effects of fossil fuel price volatility
- Mitigation of air and water pollution
- Creation of indigenous industries and employment with new market potential
- Consumer demand
- Distributed energy generation
- Rural development

While these are objectives for renewable energy in general, they are particularly apt where ocean energy in Ireland is concerned, provided that a number of factors can be successfully managed. Renewable technologies typically require 3-5 years for initial demonstration and limited scale deployment, before moving to a larger scale, when the costs and risks are reduced and are more clearly understood. Thus, the main renewable resources that can be exploited in Ireland over the next decade or so are onshore and offshore wind and biomass.

Looking to the longer term, the *Technology Foresight Report* identified a significant role for ocean energy in Ireland, a position supported by the *Green Paper on Renewable Energy 1999*[6]. An overview on renewable energy sources and the ongoing search for possible future options that could be adopted has also been published[7]. This document notes that, ultimately, a 60% reduction in greenhouse gas emissions will be required to stabilise climate change and it is likely that more onerous emission targets will be required post 2012. It suggests that in the long-term renewables might supply 25% of Irelands total energy needs, implying generation of 50-60 TWh per annum (excluding large-scale hydro).

Regarding ocean energy, the policy target is rather ambiguous but can be interpreted as a stance that, along with solar energy[8], wave-power will contribute toward meeting the target that 13.2% of total electrical energy should come from renewables by 2010. The implications of the discussion document are to place ocean energy 'down the field' in energy delivery terms. However, 2010 is only six years away and if a 3-5 year initial limited-scale demonstration deployment is required before a serious

6 Forfás (1999) *Technology Foresight Report: Ireland*; Department of Public Enterprise (1999), *op. cit.*; Department of the Environment and Local Government (2000) *op.cit*

7 Department of Communications, Marine and Natural Resources/SEI, (2003) *Options for Future Renewable Energy Policy, Targets and Programmes*

8 Apart from the fact that both solar and ocean energy technologies remain largely experimental and very poorly understood, there is really no rationale for the two to be grouped together. Indeed, it is quite likely that the pace of technological development in both could diverge and that the underlying cost drivers will not develop in line. It is also clear that Ireland's natural resources in both energies differ considerably when placed in an international comparative situation.

commitment to invest in installations is to be realised, then there is little time available if any credible Irish-developed converter is to emerge.

In summary, while future renewable energy policy options are currently under review and provide for a clear commitment to further integration of renewable energy onto the electricity system, the emphasis is on wind and biomass with ocean and solar to follow.

2.3 Ireland's Ocean Energy Resources

2.3.1 Wave Power

Ireland's naturally occurring ocean energy regime takes two distinct forms. These are wave and tidal energy. Each of these is a diffuse energy form and, although the basic energy is free, the challenge is in finding feasible cost-effective ways to concentrate the power so that it can be drawn off to create a sophisticated high quality product in the form of electricity[9].

Because of the direction of prevailing winds and the size of the Atlantic Ocean, North Western Europe, including Ireland, has one of the largest wave energy resources in the world. While there is a lack of control over the availability of the underlying power and there are significant differences in seasonal levels of wave energy, output variation is expected to be more predictable than for some other renewable resources, such as wind. In addition, while the potential output of wave energy over any period of time will be correlated to an extent with wind energy, the correlation is far from perfect. In a sense, therefore, wave energy is a store of energy that smoothes the peaks and trough of the potential. As a result, harnessing more than one type of energy, e.g. wind and wave together, smoothes the overall output profile when compared with concentrating on wind alone.

Tidal energy is not only fully predictable but shows a very low level of correlation with wind and wave. This has important economic consequences since it means that for any given amount of energy from these two sources the implied spare generating capacity requirement in the system is reduced relative to a situation where there is only one source. Furthermore, there is good correlation between seasonal availability – and therefore electricity output – and demand.

The principal ways of extracting energy from waves rely, either separately or jointly, on the surge, heave and pitch of a floating converter, or changes in pressure or velocity from the passage of waves. The main converters currently under development are discussed in Appendix 2.
Based on meteorological correlations, the mean overall power available in deep water (100m) off the Irish coast has been estimated at about 25GW, of which about 12GW might at some stage be theoretically convertible into electricity. Figure 2.2 provides

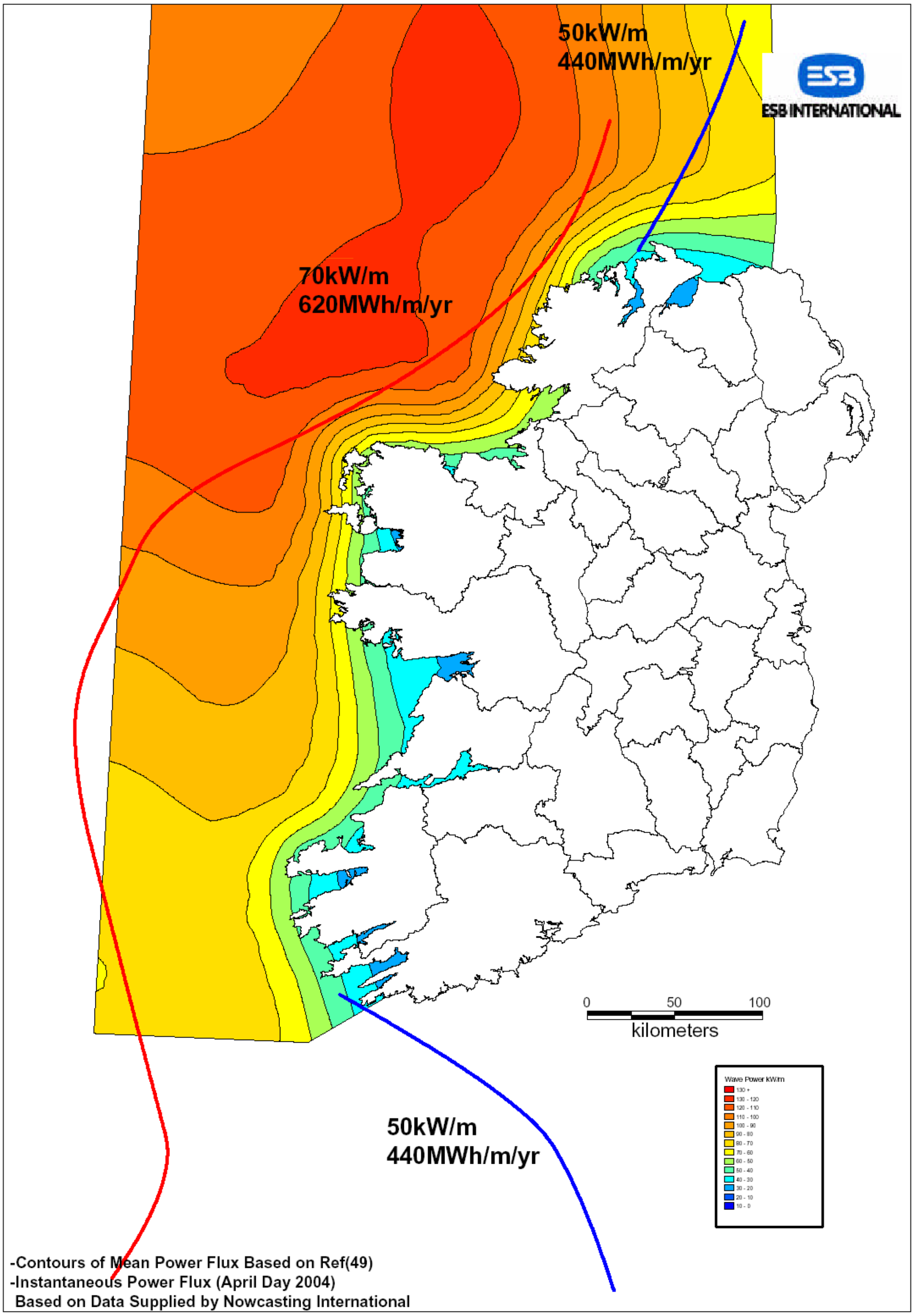
[9] Some of the main characteristics of the energy inherent in waves are listed in Appendix 1.

an indication of the location of these resources. This would have an annual resource value of 105 TWh/y, i.e. about 4 times the total present electricity requirement of the Irish economy. However, while wave conversion devices positioned in deep water offshore are projected to provide the most likely method of large-scale energy recovery in the longer term, the development of shoreline and near shore systems is further advanced[10]. Despite this, considerable development work remains to be done before even these can be considered to be reliable sources of electricity supply.

[10] For the purposes of this report "nearshore" may be taken to mean not closer to the coast than about the 100 ± 20m bathymetric contour. Typically this gives a distance off the relevant West Cork to Donegal coast line of 20 ± 7 km. The requirement is to provide a compromise between the need to keep sub-marine cables short to minimise both initial capital cost and electrical losses and the risk that adjacent land masses would reduce the incoming wave power flux due to bed shelving and directional sheltering relative to a more offshore location. Pending passage of legislation, nearshore may be taken as at or within the 20 km distance from the coast where sufficient depth and exposure exists for the functionality of the particular converter. Most floating converters require depth ≥ 50m.

Figure 2.2

Ireland: Indicative Wave Resource Levels



Based on a desk study consideration of 130 south and west coast sites between Donegal and Waterford, the feasible shoreline annual wave energy resource has been estimated at 7.5 TWh/yr[11]. However, for an estimate of the practical resource available for development within the timeframe being considered in this report, it is necessary to eliminate much of this resource on a variety of grounds. For example, given the EU's direction that the per unit cost of supported installations should not exceed 15€c/kWh, little more than a demonstration role could be envisaged for even the best of these sites in the short term[12]. However, alternative assessments have also been produced. One showed that at the 20m depth contour, the total Irish coastline received nearly ten times the annual generated output of the ESB system in 1998, and 33 prime sites were identified that could deliver 2 TWh/yr. at that depth[13].

In summary, it is known that there are substantial offshore wave resources in deep water throughout Ireland's economic zone off the south western, western and north western coasts. However, it would be premature to consider the potential of this area at present, as this requires considerable developments in technology and the passage of necessary legislation before development would be feasible[14]. In theory, most of the floating converters currently under development could be tuned for operation at distances of 2 to 300 km from the coast. However, the cost of mooring and servicing remote systems and bringing the energy onshore undermines the merits of such deployment. It is more appropriate and realistic therefore, to concentrate on the nearshore wave resource at this point in time where international development will first take place and to maintain a watching brief on deep-water developments elsewhere.

2.3.2 Tidal Power

Tides are caused by the gravitational attraction of the moon and the sun acting upon the oceans of the rotating earth. In the open ocean, the maximum amplitude of the tides is about one metre. This increases substantially towards the coast, particularly in estuaries, due to shelving of the sea bed and funnelling of the water by estuaries. In some cases the tidal range can be further amplified by reflection of the tidal wave by the coastline or by resonance. As a result of these various factors, the tidal range can vary substantially between different points on a coastline. Therefore, the amount of energy obtainable from a tidal energy scheme varies with location and time. Tidal

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[11] ESBI-ETSU (1997) *Total Renewable Energy Resource in Ireland*. Report to DGXVII of the European Commission

[12] See the results tabulated in Appendix 3 using an 8% discount rate

[13] 'Wave Power – Moving towards Commercial Viability'. Paper presented to seminar held by Institution of Mechanical Engineers, London 30 Nov. 1999

[14] Ireland has not developed a comprehensive legislative and regulatory framework for the development of marine resources outside the 12-mile (20 km approx.) limit except in the case of fishing. Draft legislation governing economic development outside this limit is still in preparation so that no formal mechanism exists for licencing ocean energy development there. Areas beyond this are within Ireland's economic zone although some issues of demarcation remain. A strategic environmental assessment by potential developers would be required before a licence could be granted. In addition, it remains to be clarified what Ireland would be willing to do in terms of protecting, researching and facilitating development in this wider area.

energy is, however, highly predictable in both amount and timing, in contrast to some other sources of renewable energy, with the available energy approximately proportional to the square of the tidal range.

Two main methods to harness tidal resources have been developed. The older method involves construction of a tidal barrage or low dam across an estuary or bay or between islands in an area where the tidal range is large. However, the results of initial research suggest that tidal barrage is not likely to be a viable technology within the time period envisaged in this report. In addition, because of the relatively high capital cost of barrage type projects and their potential for environmental controversy, these are not considered in this report. More recently, attention has turned to the development of tidal stream or current generators which are located in areas where the currents, inherently involved in the movement of the tidal water mass, may be increased by obstructions such as headlands, narrow channels or seabed features. The capital cost of a tidal scheme is directly related to its installed capacity while its energy output depends also on the plant load factor achieved. The higher the load factor the lower is the unit cost of energy delivered. Tidal stream systems currently undergoing development are discussed further in Appendix 4.

The extent of the Irish tidal stream resource is not fully mapped although a project is now underway that will rectify this shortcoming, to some degree. Production of electricity by tidal streams seeks to avoid the capital cost and other effects associated with barrage construction. This involves placing fixed rotor driven generators in hot spots where the local bathymetry has increased the normally low current velocity to around 2-5m/s on good sites. The technology is at a relatively early stage of development but can draw upon technology developed for wind turbines and hydro bulb turbines to some extent by utilising the greater density of water compared to air to compensate for the lower velocities available. Research and development work on this technology has been carried out in the UK, Italy and Canada. HMRC of Cork is involved with EU-funded research and at least one Irish company (Sea Energy Ltd.) has been carrying out research for possible applications in Ireland. Research to examine the optimising of tidal current energy conversion systems has been undertaken utilising currents in the vicinity of the Arklow Bank off the Irish East Coast[15]. The limited information available from this research suggests that a capacity factor of 24% and costs of around 30c/kWh might be feasible for the particular combination of current regime and turbine chosen[16].

The output from a tidal stream is very sensitive to tidal velocity with production based on the cube of the velocity. It is also sensitive to the diameter of the rotor that is employed. As a result, the optimal depth of water for this technology is quite narrow being in the range of 20-50 metres. At this depth, environmental issues are likely to require considerable attention due in part to the effect of turbines on tidal flows and

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[15] Melville, G.T. *et al* (2001) *A Model to Optimise the Electrical and Economic Performance of Tidal Current Energy Conversion Systems*, , NaREC

[16] The report on the offshore wind resource at Arklow Banks was reviewed to identify relevant material. However, apart from some localised storm wave regimes for Galway Bay and the Kish Bank area – indeed, these are special cases designed to show extreme wave patterns rather than average long term conditions – it is considered that it contains only limited material to inform the current study.

scouring of seabeds. Interaction between turbine blades and large sea creatures may also be important.

Resource cost estimates have been provided for promising areas in UK waters.[17] These are shown in Table 2.2. The estimates provided are sensitive, not only to the underlying conditions but also to the size of installation that is projected – since some economies of scale are possible – and to the discount rate that is assumed, given the long payback period involved. These results indicate that for low discount rates, and installations where sufficient scale is achieved, this technology would be competitive with offshore wind in the better sites. However, if external costs are ignored and no value is attributed to the green credits that would be produced, the unit cost would need to fall to 2.9 to 4.3c/kWh if this technology were to compete commercially against existing fossil fuel energy sources. This would require a fall in the capital cost of the 30MW baseline scheme by 25-50% with a 5% increase in energy output.

Table 2.2: Projected Costs of Electricity from Tidal Power

Farm Size	Unit Cost of Energy €c/kWh		
1MW	10.6	14.0	18.4
5MW	6.6	8.9	11.7
30MW	4.9	6.6	8.7
Discount Rate %	5	10	15

Note: Estimates are based on an assumed 16m diameter rotor subject to a peak Spring Tide velocity of 3m/sec. in water depth of 30m.
Source: ETSU (1999)

While promising, tidal stream conversion technology is at an early stage of development internationally, although pilot plant application is being considered currently at a small number of favoured sites. Appendix 4 discusses potential tidal stream sites at Messina, Italy[18] and Lynmouth, North Devon, UK. Trials have also taken place at Yell sound in Orkney. In advance of any deployment, a first priority is the measurement, modelling and mapping of the Irish resource to establish its extent and identify areas that may have the necessary velocity levels. Consideration might also be given to hybrid barrage/tidal stream proposals but the research involved is outside the scope of this report.

[17] ETSU (1999) *New and Renewable Energy: Prospects in the U.K. for the 21st Century – Supporting Analyses*
[18] These installations were discussed in papers presented to Fifth European Wave Energy Conference University College Cork, Sept. 2003 and in the WAVENET Report

3. The Ocean Energy Sector Internationally

3.1 Research into Ocean Energy

The ocean energy industry has not yet acquired a high profile internationally. Most activity has necessarily been in the area of research and development where high costs and high intellectual demands mean that much of the work is the preserve of academic institutions with access to research funding or small specialist companies, often built around the dynamism and expertise of a single individual. In these situations a very modest revenue stream supports research and development work. The only exceptions arise among institutions that have sufficient critical mass to attract venture funds or the support of a large organisation. Progress is inevitably slow due to the absence of a supply of funding that permits forward planning, and the multi-disciplinary nature of the work which requires the involvement of competent professional personnel in all key areas.

The focus on research arises from the numerous key questions that remain unanswered and because funding has been available from national and EU sources. These technological questions must be resolved before the industry moves to a commercial mode. A feature of the changes in the international electricity market since the introduction of deregulation has been a reduction in research-oriented expenditure by power utilities. As a result, the use of utilities to achieve national objectives is no longer as readily available as in the past. It is probable that without the international co-operation sponsored by the EU the industry would be in a much weaker position but there is a perception that funding from this source will be more difficult to obtain in future. However, funding from national sources is growing, in some countries.

Most policy supports available to renewable energy appear as feed-in tariffs, capital allowances or tax breaks that are relevant to technologies such as wind, which are or are on the verge of being commercially viable. Ocean energy does not fit into this category. Yet, these programmes are important to the future of ocean energy for two reasons. First they allow for the various incentives to bring about development to be assessed and thereby indicate the supports that ocean energy might receive in the future. Second, they are gradually creating an environment where the true economic cost of fossil fuel energy is appreciated and the alternatives demonstrated. In addition, non-fiscal measures such as market liberalisation and regulatory reform are creating the basis on which new technologies can develop.

Uncertainty surrounds wave and tidal technologies, with many competing devices currently at an early stage of development. Furthermore, the cost of installing wave and tidal plants, € per kW, can vary considerably between sites, depending on the degree to which extensive civil engineering works are required for the supporting structure. Where additional network issues need to be addressed, this will add significantly to costs, if it is a small-scale project. If sufficient scale for mass production is achieved hardware costs should fall. However, it is unfair to make direct comparisons between the generating cost of ocean energy and the other major fuels sources – fossil fuel and nuclear fuel – as these technologies received significant

subsidies and they generate significant levels of pollutants. Engineering costs incurred per installed unit of power for wave and tidal energy should be balanced against the additional environmental costs of carbon dioxide emitting generation if the technology is to be considered to be competitive[19].

3.2 Review of Policy Internationally

3.2.1 EU Policy

The European Union has supported wave energy research, development and demonstration under several renewable energy and related programmes over the past twenty years because it is recognised as having good exploitation potential for decentralised small to medium-sized plants in various European countries. In recent years, the EU has driven policy development in many countries, including Ireland, and has been a catalyst for the integration of emissions control into Irish policy. The objectives of the Commission are to establish a reliable baseline on critical points such as investment cost, production cost, operational performance, environmental impact and socio-economic facts. Transfers from other technologies, utilisations that bring the technology closer to the market, better recognition of their own roles and participation by national authorities, utilities, industry and end users are seen as needing improvement and this is an area in which the Member States as partners of the Commission have a complementary role through their own national programmes.

Current EU renewables policy derives from the 1997 *White Paper for a Community Strategy and Action Plan* concerning the future of Renewable Energy in the European Union. Policy guidelines cover competitiveness, environmental protection, security of supply, external energy relations and include the promotion of energy efficiency and renewables. Three major objectives in the energy area are identified as having priority. These are:

- security of supply
- improving the competitiveness of European businesses
- taking environmental aspects into account, with an emphasis on the '*energy dimension of climate change*'.

The consideration of climate change brought about by carbon dioxide emissions from fossil fuels, and the possible reductions that can be brought about by use of renewable sources of energy, forms the basis for the promotion of renewable energy. The White Paper also sees a need to improve the co-ordination of programmes and policies in the Community and Member States and identifies a strategy to promote the market penetration of renewable energy sources, with a target of doubling their use by 2010, from 6% of total consumption in 1996 to 12% in 2010.

[19] See Memorandum submitted by the Scottish Energy Environment Foundation. www.parliament.the-stationery-office.co.uk/pa/cm200001/cmselect/cmsctech/291/1031402.htm.

The commitment to the *Kyoto Protocol* sets the framework for recent innovations in energy production[20]. The EU formally adopted the *Kyoto Protocol* and identified national responsibilities in 2001[21]. While the EU is a full party to Kyoto, the principal of subsidiarity was invoked, meaning that responsibility for meeting the obligations was essentially a requirement of national governments. The overall agreement requires that the EU would reduce emissions of greenhouse gases by 8% over the reference period. Individual requirements were identified for each national government with Ireland's requirement being to limit growth to 13% above 1990 levels. Individual states have also been obliged to adopt and publish targets for national consumption of energy from renewable sources for the next 10 years[22]. This Directive also requires member states to evaluate progress in meeting these targets every 2 years and they are obliged to ensure that producers have access to the grid and are fully aware of all associated costs.

The Action Plan formulated in the wake of the White Paper includes internal market measures in the regulatory and fiscal spheres, reinforcement of those Community policies which have a bearing on increased penetration by renewable energies, proposals for strengthening co-operation between Member States, and support measures to facilitate investment and enhance dissemination of information in the renewables field. An important part of the Action Programme is the Campaign for Take-off for Renewables designed to kick-start implementation of the Strategy up to 2004. This sets out a framework for action to highlight investment opportunities and attract the necessary private funding which is expected to make up the lion's share of the capital required. The Campaign also seeks to encourage public spending to focus on the key sectors. The renewables capacity promoted in the Campaign requires investment funding of around €30 billion with some 75-80% coming from private sources. The ALTENER programme has been the main promotional and co-ordination tool for the Campaign.

The Sixth Framework Programme (FP6) (2002-2006) is the main instrument for the funding of renewables research in Europe for all public and private entities, large or small. It aims at the creation of a European Research Area with scientific excellence, improved competitiveness and innovation in the field of renewables. The main support instruments are the Networks of Excellence and Integrated Projects with the aim of achieving critical masses of resources and improving the co-ordination of national research efforts. The overall budget for the four-year period 2003 to 2006 is €17.5 billion, representing an increase of 17% from the Fifth Framework Programme and making up 3.9% of the Union's total budget (2001), and 6% of the Union's public (civilian) research budget. There are no national quotas for FP6 funds. Under Priority 6.1: Sustainable Energy Systems, a total of €810 million is made available for research action. The focus is on integrated demonstration actions in order to accelerate the market penetration of renewable energy in the context of the objectives set for 2010. Two calls for proposals have been issued to date.

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[20] COM (97) 481 Final, (1997) *Climate Change: The EU Approach to Kyoto*.

[21] COM (2001) 579 *The Kyoto Protocol to the United Nations Framework Convention on Climate Change and the Joint Fulfilment of Commitments Thereunder*.

[22] Directive 2001/77/EC of the European Parliament on the promotion of electricity from renewable energy sources n the internal electricity market [Official Journal L283, 27.10.2001]

A somewhat different approach was used in supporting the European Wave Network where it was seen that the European offshore industry as a whole was rather fragmented and needed a single voice if it was to have credibility. In the belief that interaction and exchange of ideas would promote development, the EU established the European Thematic Network on Wave Energy funded under the Energy, Environment and Sustainable Development Programme. The aim is to promote the development and deployment of wave energy devices by addressing the main barriers to implementation that exist. Reports have been published and further reports are planned.

Although installation of working devices for wave energy conversion in the EU has been limited to date, research has been progressing. The projects that have gained support have done so as a result of a competitive process, with co-funding predicated on a joint EU/Industry basis. Examples of projects that have benefited from this mechanism are the Islay, Pico, and Wave Dragon projects.[23] It is perceived at EU level that ocean energy needs success to prove that the technology is mature enough for reasonable exploitation plans to be drawn up. It is expected to make an important contribution to the increase of the renewables share of the European energy balance and to produce electricity at a cost not exceeding 0.15€/kWh by 2005.

In EU support programmes, there is an expectation that supports provided should be additional to supports provided by national governments and that there should be synergy between EU and National programmes. One further issue that has arisen is the emerging possibility that competition between renewable energy sectors for research funds could intensify in the future. In this event it is possible that wave power systems could lose out unless improved performance is in line with potential customer and end user expectations.

3.2.2 National Policy in Selected EU Member States

Although there have been initiatives at EU level, the national level in member states remains the most important policy driver in relation to renewables in general and ocean energy in particular, and EU Directives have not created a harmonised community wide support system for research into renewable energy. Currently there are 14 EU companies or organisations with ocean energy development programmes, 7 of whom have demonstration schemes. The policy programmes of EU countries contain a range of measures including incentives to promote R&D with capital grants to promote demonstration projects, as well as providing feed-in prices. In addition, policy is providing support in the form of regulatory innovations and the co-ordination of developments.

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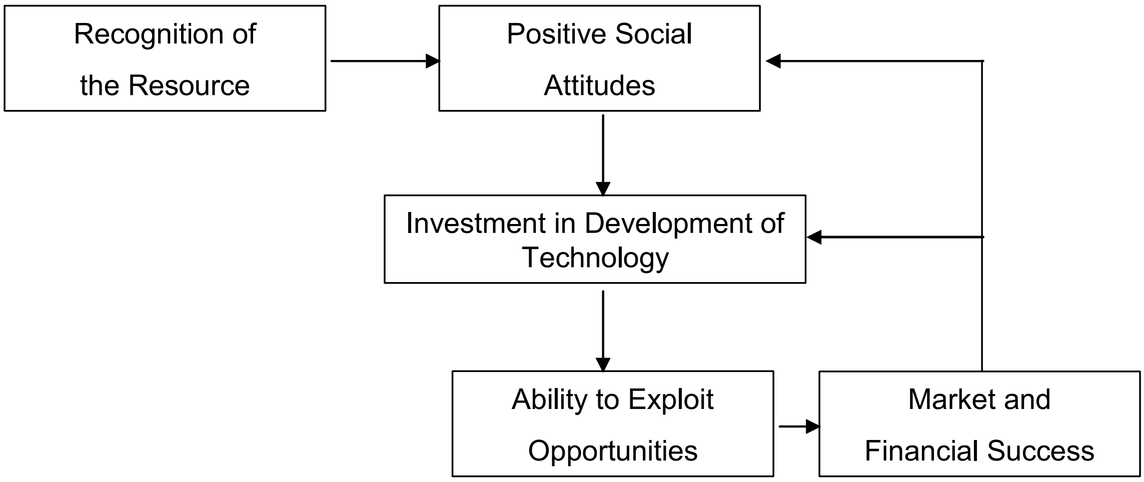
[23] For a discussion of the Islay project see Whittaker, T. et al. (2003) "Performance of the LIMPET Wave Power Plant – Prediction, Measurement and Potential", 5th European Wave Power Conference, Cork. The Pico experience is discussed by de Falcao, A (2000) "Shoreline OWC wave power plant at the Azores", 4th European Wave Energy Conference, Aalborg. The Wave Dragon project is discussed by Soerensen, H., et al (2003) "Development of Wave Dragon from 1:50 Scale to prototype", 5th European Wave Power Conference, Cork.

Most countries have not developed policy programmes specific to ocean energy but have policy programmes to promote the development of renewable energy sources. In some cases these are directed at specific technologies, but in many cases it can be assumed that policy makers have in mind a range of technologies including ocean energy. Some countries, such as Denmark in particular and latterly the UK, have been very successful in developing policy programmes for wind energy that build on inherent strengths in the economy. The development of the Danish wind energy industry is discussed in Appendix 5 as an example of this process. The Danish approach is summarised in Figure 3.1.

Figure 3.1: The Danish Approach to Developing the Wind Energy Industry



The strength of the Danish industry has been built on an early recognition of the importance of the resource leading to positive attitudes, in business, among policy makers and in society in general, towards its development and early investment in research. This allowed Denmark to be in a position to exploit opportunities as they arose and the financial success strengthened both the positive attitudes and the financial resources to create a leading position. The industry is now in a position where it can exploit its leading position to further increase its competitiveness.

Portugal

Portugal has been involved to a considerable extent, with wave energy R&D being undertaken at the Instituto Superior Técnico (IST) of the Technical University of Lisbon and the National Institute of Engineering and Industrial Technology (INETI) under the Portuguese Ministry of Economy. The research has produced design codes for turbines and plant control strategies. INETI has also co-ordinated projects for the European Union that led to the development of a common methodology for resource evaluation and characterisation. This was utilised in the production of the European Wave Energy Atlas for the deep water resource.

The Wave Technology Centre (WTC) was founded in 2001 as a joint initiative of the Dutch AWS B.V. and the Portuguese institutions IST and INETI in response to the perceived need to co-ordinate research and present results to potential commercial investors. A primary product of WTC will be independent performance assessment of devices and dissemination of information to investors, and scientific training has been

provided to allow this work to proceed. Directly as a result of the prospect of two pilot plants becoming operational in Portuguese waters, it was agreed that the centre would have its main office in Lisbon with branches close to the pilot plant sites.

The main objectives of the WTC are to provide:

- Detailed evaluation of realistic wave energy potential along the Portuguese coastline;
- Critical constraints (licensing, protected areas, navigation, fishery, military, sub-marine cables, grid connections points etc);
- Evaluation of different technologies with respect to implementation costs, risks and benefits, and the readiness of Portuguese business to participate.

Portugal has favourable wave power levels of 30-40 kW/m, with the highest being to the North. The overall resource has been estimated at 10GW, of which half could be exploited[24]. The major pilot project for energy production was for the construction of a facility on the island of Pico in the Azores archipelago. This project is now at scale prototype. Plans to construct a full-size wave energy plant on the island were initially put forward in 1986 and the project was incorporated into the European Union's JOULE programme in 1991. The EU contributed considerable amounts of financing to this project, partly on the rationale of developing an energy source for the island but also because of the availability of matching funds from the Portuguese government and the availability of an initial feed-in tariff in the region of 22^{C} per kWh. This led to the development of a 400 kW shoreline facility in 2000. The installation allows for R&D into testing turbine designs and control strategies, while also supplying a projected 8-9% of the island's demand for electricity over the next 25 years. Elsewhere, a full-scale 2 MW pilot project utilising the Archimedes Wave Swing (AWS) system has been constructed as a joint venture of the utility NUON, Teamwork Technology and other Dutch interests close to Viana do Castelo, in the north of Portugal using components from a number of countries.

The Wave Technology Centre was also responsible for calculating the remuneration scheme of the purchase tariff for Portugal[25]. This programme features monthly remuneration based on actual production and the Consumer Price Index and accounts for external benefits with multipliers for the environmental share, depending on the particular resource. The approach used in Portugal for the calculation of monthly remuneration is shown in Figure 3.2. The arrangement is limited to the first 12 years of operation, is restricted to the first 20MW installed on Portuguese territory and favours plants smaller than 5MW with energy storage. Typically after 12 years the remuneration value to a small ocean energy plant would drop to 4€c/kWh.

[24] International Energy Agency (2003). Status and Research and Development Priorities: Wave and Marine Current Energy

[25] Nueman, F. and M.T. Pontes (2004) Wave Energy Implementation in Portugal. Paper presented to BWEA Conference, Bristol

Figure 3.2: Calculation of Monthly Remuneration in Portugal

The basic formulation for calculation of monthly remuneration (Am) for month m is as follows:

$$Am = \frac{Bm^* (Amf + Amv + Ame * Z) * Cm\text{-}1}{Cr * (1-D)} \quad \text{where}$$

Bm = Modulation factor for operation during peak and off peak hours in month

$$= \frac{(1.25)\ (\text{Peak hour Production in Month}) + (0.65)\ (\text{Off Peak hour Production})}{\text{Total Production in Month}}$$

Amf = Fixed component of Am (recognising avoided cost of investment)
= P*Q*K

Amv = Variable Component of Am (recognising avoided O&M costs)
= S*T

Ame = Environmental Component of Am (recognising avoided CO_2 cost)
= U*V*T

Where:

Z = Specific Renewable Energy Source Factor (= 6.35 for first 20MW of wave capacity)

Cm-1 = Consumer Price Index for preceding month

Cr = Reference Consumer Price Index (Dec. 1998)

D = Decentralisation Factor (recognises avoided transport & distribution cost)
= 0.035 for < 5MW
= 0.015 for ≥ 5MW

Cm-1/Cr = 1.17 for a given month, (1-D = 0.965), thus $\frac{(Cm\text{-}1)}{(Cr^*(1-D))} = 1.17 \div 0.965 = 1.21$

P = Reference unit value of monthly avoided investment cost = 5.44€/kW

Q = Total production in Month ÷ (Production for December *0.8*24* No. of days in month)

R = (Lesser of Production for December or Production in Month)/(24 * No. of days in month)

S = Reference unit value of monthly avoided O&M cost (= 0.025€/kWh)

T = Total Production in Month m (kWh)

U = Reference Unit Value of CO_2 avoided = (.0000748€/g)

V = Reference unit value of CO_2 emissions from new fossil plant = 370g/kWh

As the high feed-in tariff will be limited to the first 10MW installed, it is clearly designed to seed development with the R&D payoff considered to be important. It is also clear that the policy aims to place Portugal at the forefront in the development of a cluster in this industry. However, there have been some difficulties arising from the remote location of the Pico installation (a grid connected facility) and concerns regarding the transferability of results due to the particular climatic and tidal conditions of the Azores. In addition, a considerable proportion of the manufacturing and the intellectual capital involved in these projects resides outside the Portuguese economy in institutions including:

- University College Cork (Model Testing);
- Queen's University Belfast (Electrical Aspects);
- Edinburgh University (manufacture of variable pitch turbine);
- Wavegen – UK (manufacture of variable pitch turbine).

Rightly or wrongly, U.K. references cite the availability of the attractive tariff rates in Portugal as being one of the most significant threats to the development of wave power in the U.K. as opposed to Portugal.

The UK

There are significant natural ocean resources available to the UK, along with extensive capabilities across the supply value chain, including existing engineering manufacturing firms with relevant offshore experience. Supply chain products depend on the success of the end user products, with the supply chain market size proportional to the end user market size. In the majority, industry cannot occur without supply chain investment. These supply chain partners can prove invaluable in terms of experience and for potential financial 'benefits in kind'. The supply chain also provides the basis for scaling up manufacturing, with faster problem solving using the existing knowledge base and better financial management[26]. In an analysis of the supply chain position for the U.K., and Scotland in particular, it is projected that ocean energy technologies will be commercially available by 2010-15 and that they will have a significant role to play in the energy mix of 2020, with possibly 1300MW – 3900MW being installed in the UK by then, with exports in addition[27].

Originally the UK held a wait and monitor position with regard to funding the development of renewable energy technologies, when they perceived poor market prospects for the technologies. This applied to wave, tidal and geothermal. Nonetheless, from 1974 to 1983, the UK government spent approximately $20m on a national program for wave energy R&D, most of it administered by the Energy Technology Support Unit at Harwell. Coincidentally, work also began in Norway in the mid 1970's with the national government spending approximately $12m on R&D, culminating in 1984 with the construction of two wave plants, totalling a combined capacity of 850 kWh. The cost of design and construction of these demonstration plants was distributed equally between government and industry[28].

Following a prolonged period in which ocean energy was accorded very little attention as an energy source in the UK, interest has grown in the past few years. This renewed interest was initially prompted by some design successes in private engineering firms with related interests and then by a number of high profile research and policy reports. These included the *UK Marine Technology Foresight Report*

[26] Initial examination indicates that many parallels can be drawn between the relative starting positions of Ireland and the UK in relation to ocean energy. However, it must be acknowledged that there is only a limited offshore oil and gas industry or industrial base to build upon in Ireland and the supply chain is likely to be weaker.

[27] UK Dept. of Trade and Industry (2004) *Renewable Supply Chain Gap Analysis*

[28] Hagerman, G., & Heller, T. (1988), Wave Energy Technology Assessment for Grid Connected Utility Applications.

(1999) and a report by the Royal Commission on Environmental Pollution (2000)[29]. The Department of Trade and Industry has identified ocean energy as a potentially important future energy source and has set out policy frameworks to maximise the contribution of the industry. This is being done although it is unlikely that wave energy will to make a significant contribution to UK targets for energy from renewable sources or greenhouse gas emissions reduction by 2010. Progress is being made on the basis that ocean energy could be an important option should more demanding targets be set after that date. However, prospects for commercially exploiting this resource remain uncertain: the time-scale for any potential commercial return is long, and this is likely to limit industry investment as industry is used to much shorter investment return periods. The strategy for a DTI programme has identified the following objectives[30]:

- To move existing well developed device concepts forward to the prototype scale where their performance could be evaluated and verified. This would include tackling areas of outstanding technical uncertainty to reduce the technical and commercial risk.
- To support the initial evaluation of less well developed device concepts through initial design studies and, perhaps, wave tank testing. The aim would be to verify the concepts, estimate their energy capture potential and evaluate predicted energy costs.
- To support industry in the development and evaluation of individual innovative components, where these seem likely both to improve prospects for the successful commercial exploitation of wave energy in the UK and to stimulate export opportunities for UK companies.
- To co-operate closely with the Engineering and Physical Sciences Research Council in order to encourage fundamental research in areas where innovation is required, and to encourage co-operation between industry and academia.
- To co-operate with European Commission and International Energy Agency programmes, where this will complement UK activities, strengths and business interests, and help to ensure the best value for money for the UK.
- At the appropriate time, to encourage the demonstration and deployment of proven design concepts.

The DTI has formed the conclusion that wave power devices can be made to work, but it has not yet been demonstrated that they can be made to work cost-effectively, with economically attractive prices for the energy generated. Despite this, three projects have been awarded contracts under the Third Scottish Renewables Order (SRO), the first Renewables Order to be open to wave power. Although the prices to be paid for the electricity from these three projects are commercially confidential, they are higher than the cap price under the new Renewables Obligation, though not substantially so. However, these prices are well below the bid prices for UK wind power in the first tranche of the Non Fossil Fuel Obligation (NFFO) for England and Wales, and the first GW of wind energy capacity in California. They are also comparable with predicted electricity costs from the first offshore wind farms.

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[29] Royal Society of Edinburgh (1999) Marine Technology: Report of the Eighth Foresight Seminar; Royal Commission on Environmental Pollution (2000) *Energy: the Changing Climate* (22nd Report), UK Parliament

[30] Department of Trade and Industry (2002) *Sustainable Energy Technology Route Maps: Wave Energy*

The first of the SRO projects is the LIMPET device, a 500 kW shoreline oscillating water column (OWC) deployed by Wavegen (Inverness) on the Scottish island of Islay in November 2000. In the second project, Ocean Power Delivery of Edinburgh is developing Pelamis, a floating offshore device. Towards the end of 2001, the company evaluated a 1/7th scale model in the sea and has now deployed a 750 kW device which is currently undergoing testing. The third SRO contract is for a Swedish wave power concept. In addition to the power output from these projects, they are expected to generate a lot of valuable information to clarify the commercial prospects of this technology and the key development issues facing wave power.

Development is driven by obligations under the EU Renewables Directive and other carbon control policies and imminent financial penalties as the external costs of electricity generation increase. One result is that dedicated renewable energy specialists (including wave) are now entering into partnership with utility firms who are diversifying into renewables energy sources[31]. While in the short term, emissions trading and energy efficiency are expected to reduce emissions. In the longer term greater reliance on renewables to achieve deep cuts in CO_2 emissions will become critical. In addition, assuring future security of energy supply and potential export receipts are also key drivers. Collectively, these considerations give renewable energy significant social and economic significance and make the development of the technologies appear practical. The current UK thinking is that, while CO_2 reductions could be met by importing commercially proven renewable energy technologies, instead of developing them nationally, this path would negate the positive spillover effects that are being achieved as the UK develops a competitive renewable industry, attracting sustained private sector money. This is happening slowly with wave and tidal technologies, with a number of wave developers at work. The UK is now actively promoting and encouraging the development of wave and tidal technologies, and public policy aims to build on work in other renewable developing countries such as Portugal and Denmark. However, the UK industry has recently expressed concern about lack of practical support in the Government's Renewables Innovation Review.[32] Nevertheless, six companies presented full-scale wave and tidal stream generators at the Renewable Power Association's WATTS 2004 conference while other companies have developed theoretical/wave tanks or scale prototypes.

Recent policy initiatives in the UK have included:

- Activities of the Energy Research Review Group
    - Carbon Trust has been established
    - The Dept. of Trade & Industry Sustainable Budget for 2002-6 has been set at €496m
    - A spending review identified an additional €61m for the period 2005-6
    - Research Councils have been allocated a budget of €45m

[31] The Renewables Obligation was introduced in 2002 and requires electricity suppliers to source an increasing percentage of their electricity from renewables. The percentage rises from 3% in 2003 to 15.4% in 2015/2016. Under the Obligation, the Government as committed nearly £350m from 2004-2008 in capital grants and R&D for emerging technologies including wave and tidal stream energy. A Fundamental Review of the Renewables Obligation will be undertaken in 2005-2006.

[32] See Carbon Trust and Department of Trade and Industry (2004) *Renewables Innovation Review*. February

- New Planning Guidelines on Renewables (PPS22) have been developed
- The Marine Test Centre Orkney has been established, supported by the Carbon Trust, the Highlands & Islands Enterprise Board, Scottish Enterprise, and the Orkney Islands Council
- A Carbon Impact Assessment has been developed
- The Sustainable Energy Policy Network is operating including input from
    - Carbon Trust, Energy Watch, Environmental Agency
    - Small Business Service, Energy Saving Trust, Others
- Non Fossil Fuel Obligation/SRO/NIO – Renewables Obligation Certificate systems have been promoted
- Supported projects in wave energy include: Pelamis, Wavebob, Seavolt, Aquabuoy, Frog, Wave Dragon, Evelop, Shoreline Package and the Design Code Package.
- Projects in tidal energy include Stingray and Tidal Stream Package
- In addition to the above a £50 million fund to help "ensure that the U.K. is a world leader in harnessing wave and tidal power" was announced as recently as August 2004 (Hewitt). The emphasis is on bringing first class research and development to market.

The Carbon Trust was set up by the UK Government with support from industry and with a total spending budget of €75m over 2003-6. Recognising the UK government commitment to deep cuts of 60% in CO_2 emissions by 2050 and that, while these might be met at lowest first cost by using imported technologies, the potential exists for the UK to turn the situation to advantage by capitalising on its own industrial expertise and natural resource to build a competitive position in global markets, the Carbon Trust seeks to advance this option by reducing the uncertainty that currently surrounds specific ocean energy technologies. This also requires that financial, market and institutional barriers are recognised and overcome. Thus, it has launched the £2.5m Marine Energy Challenge where selected device developers and have been paired with engineering consortia so that key issues of cost and performance improvement can be resolved. Both grant and venture capital funding issues have been addressed and the Orkney test centre has been provided with a 3 year grant support programme (£1.2m) so that commercially credible performance standards can be verified under realistic ocean conditions.

Difficulties faced by UK wave and tidal developers include the cost effectiveness of installation and maintenance; the identification of materials for offshore environment, and environmental and exportation issues. In addition, issues surrounding energy capture, reliability and survivability need to be overcome at sea. 'Plug and play' commercial trial sites aim to speed up the development process. The institutional constraint of grid connections and related planning is probably the single most serious problem facing successful exploitation of wave and tidal energy in the UK[33]. Nonetheless, wave and tidal industries are benefiting from the growth in the offshore wind sector, due to the synergy of many of the issues: consenting, licensing, public

[33] Carbon Trust (2003), *Building Options for UK Renewable Energy*. The Carbon Trust is supporting the development of marine energy via its Marine Energy Challenge. The Trust has provided significant support to the marine energy industry to-date by directing resources to device developers and centres of excellence.

acceptance[34], the legal framework and as a result of the deployment of technologies themselves[35].

Research in recent years identified a number of important weaknesses in the UK industry.[36] The main conclusions of this work were that:

- The industry was poorly co-ordinated, as teams worked independently to maintain secrecy.
- Teams tended to be relatively small with limited industrial backing. Multi-discipline demands were too broad to be handled by a small team. Slow progress leads to lack of investor confidence and lack of significant industrial support. Investment has been small compared to other renewables.
- Although some technological gaps were identified, no major technological barriers exist that could not be addressed by technology transfer.
- Wave industry must be selective about importing costs and technology from the offshore oil industry as the latter is prototype driven, unlike the wave industry which must seek design repeatability and economies of scale for viability because the unit return on investment is much lower.
- There are many issues e.g. permitting, cabling, moorings, grid connection, O&M strategies common to both the offshore wind and wave industries.

This work recommended that, as high initial project costs, particularly for offshore converters, constitute a significant barrier to prototype development, Government support should be directed at proving of prototypes, thus improving confidence and encouraging industrial and investor support. It also recommended the creation of a supported, co-ordinating body to encourage technology transfer to the industry and specific transfer of technology studies relevant to the needs of prototype deployment, power station development, generic research and development. It also recommended that the industry should build investor confidence by demonstrating and proving the technology as soon as is reasonably practicable. Policy initiatives undertaken in recent years mean that all these recommendations have now been implemented.

One difficulty faced by the UK is that most of the highest potential wave and tidal energy sites are on the west coast of Britain, and at some considerable distance from likely large users of electricity. Hence the total costs for design and erection of the energy generators, and the power transmission system must be analysed and estimated in relation to the market, and the price that the market will pay. Fixed feed-in tariffs are beneficial in this regard. An accelerated staged commercial trial to discover whether a feasible cost-effective solution can be developed is the preferred option in the UK[37]. This is supported by the activities of the NaREC, a national centre of excellence based on key industrial and academic partnerships, with the aim to fast-track R&D from a national hub.

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[34] Hansen et al (2003), 'Public Acceptance of Wave Energy' [Proceedings from the 5th European Wave Energy Conference, UCC] concluded that public acceptance and mitigation must not be ignored. If mistakes are made before large-scale deployment takes place, it may prove difficult to make wave energy acceptable to the vast majority of the population. The overall recommendation is dialogue instead of defence, which demands early consultation.

[35] Goodall, N. (2004). 'Turning political imperatives into reality'. BWEA Seminar..

[36] Arup Energy (2001) Wave Energy: Technology Transfer & Generic R&D Recommendations

[37] See Renewables Innovation Review. Carbon Trust and DTI. February 2004.

3.2.3 Other Areas

In recent years the United States has not had an active, high-profile, centrally-administered ocean energy research and development programme for commercial ocean energy applications. However, a number of companies have continued to develop wave converter designs as private ventures, and the Electric Power Research Institute (EPRI) has recently initiated a four phase offshore wave power feasibility demonstration project with a projected duration of 5-7 years. The four phases for the 500 kW pilot plant are:

(1) Project Definition including site and converter selection
(2) Design, Permitting and Financing
(3) Construction
(4) Operation and Evaluation

The programme is a collaborative one involving the state energy agencies and utilities in Maine, Massachusetts, California, Washington, Oregon and Hawaii together with EPRI and Dept. of Energy. Nineteen offshore wave energy converter developers world-wide (including two in Ireland) have been invited to submit proposals for assessment against the wave resource specification using stated criteria including simplicity of design, readiness for offshore testing and willingness to licence fabrication to local manufacturers. Funding will be via in kind contributions, private owner, collaborative financing, EPRI, DOE and state energy agencies contributions at different phases of the project. Further details are contained in Appendix 6.

Japan, through the pioneering work of Masuda, took an early lead in the development of wave powered navigation buoys and research into large-scale wave converter systems, although the wave flux in the Sea of Japan is significantly less than that in countries at the end of long ocean stretches. The rationale was that if converters are successfully developed in countries such as Japan they will find a ready market in countries having a more active wave resource. Australia, being on the edge of the Southern Ocean, is one such country but has technology under development. Good relations were forged between Saga University and University of Limerick and between the Pacific Society (Japan) and University College Cork and in both cases it was possible to develop further the research work initiated in Japan. However, Japan has now abandoned its wave research programme.

3.3 Issues for Consideration

This review of the current stage of development and the focus of policy indicates a number of important issues that will affect the future performance of the industry and the areas where policy intervention will be required.

As there is no clear technology solution, unlike wind, projects are likely to remain backed by government supported schemes in the medium term. This should reduce risk for investors in the long term. The risk profile would suggest that government support is directed best at research and deployment, not development, as the development stage can attract high risk capital technology investors. However, there is a danger that Government supported investment in technology could crowd out private sector technology investors[38]. A further important point is that, as testified by wind, small incremental steps will not achieve the economies of scale required to get costs to a competitive level. Support from government at deployment stage will help to assure take-off with a joint venture model that utilised matching funding having the potential to support targeted deployment grants.

It is clear that review of planning and related permitting requirements needs to proceed in parallel with technology development. A policy of fixed feed-in tariff, as is being advanced, is required for this. This tariff arrangement limits risk for government while reducing the uncertainties for the project developer in general. It allows also for better cushioning against significant operating expense variations.

The lack of a common set of standards for testing, cost assessment and output of results has hampered funding and investment in competing ocean energy systems at international level as it has been difficult to make meaningful comparisons between performance claims in the absence of such a baseline. The *International Energy Agency* has tried to remedy this situation by identifying a limited number of laboratories suitable for testing ocean current and wave energy systems.[39] Some of these are discussed further in Appendix 7. The recognised laboratory in Ireland is at HMRC in University College Cork. Standards have been set and adherence to this standard would improve credibility and understanding within the wave power industry. The content of the draft protocol prepared by HMRC has been circulated to corresponding Danish personnel involved in drafting of the IEA document and is expected that the two, which are rather complementary, will be integrated over time in a ‘de facto’ way if not formally. The aim is to reach agreement by consensus on a comprehensive documented approach to prototype development to the benefit of both developers and potential investors or decision makers.

It is difficult to estimate realistically the unit costs of electrical energy produced from the waves since outputs from existing projects have been limited. However, the estimated costs have shown a steady decrease with time, despite the little financial support received in recent years[40]. As the renewable energy is not an established asset class, venture capitalists have little expertise in this sector and as a consequence a limited number of funds are interested in early stage investments. At present, wave and tidal energy technologies lack a large corporate sponsor. This weakness is of

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[38] A recent report from the Scottish Parliament concluded that a disproportionate emphasis on offshore wind energy is hampering the development of the ocean energy sector by depriving it of scare human and investment resources. See “Support for Wind ‘hampering tidal and wave development’ says report”. *Professional Engineering*, 7th July 2004

[39] IEA (2003) *Development of Recommended Practices for Testing and Evaluating Ocean Energy Systems: Implementing Agreement on Ocean Energy Systems, Annex II*

[40] See International Energy Agency (2003), *Status and Research and Development Priorities: Wave and Marine Current Energy*.

critical importance and arises to an extent from the lack of credibility of the sector. Recently a trade association "Seapower" (sponsored by British Energy) and the associated Marine Technologies Network was announced that will provide a platform from which to address some of these issues, but a significant financial sponsor for development is still the major requirement[41].

[41] Memorandum submitted by the Scottish Energy Environment Foundation. See www.parliament.the-stationery-office.co.uk/pa/cm200001/cmselect/cmsctech/291/1031402.htm.

4. Scenarios for Ocean Energy Development in Ireland

4.1 Strategic Options

The EU Wavenet study investigated the global wave energy market using a number of criteria and device-types capable of functioning in wave climates of at least 10 kW/m. This research considered the technical resource for both fixed shoreline/near shore oscillating water column devices and also for offshore point absorbers. Depending on the device the results were as shown in Table 4.1.

Table 4.1: Estimated Potential Global Wave Energy Market

Location/Type	Annual Resource	Annual Value	Implied Capacity	CF
Shoreline/OWC	5-20 TWh	€0.4b-16b	2.3 – 9.1GW	0.25
Offshore/PA	140-750 TWh	€100b-800b	53.3 – 285GW	0.3

Note: CF means 'Capacity Factor'
Source: EU WAVENET Report (2003)

The enormous scale of the offshore market relative to the shoreline market is clear from this table.[42] Clearly, even successful Irish exporters could only hope to attain a fraction of this market through a mixture of direct roles, subcontracting, licencing, positioning and other means to maximise their market impact. Realising this potential is a major challenge that will require significant stakeholders – such as the State and the financial system – to plan, lead, organise and control the development of the industry. However, investors are unlikely to be attracted to the industry with its current profile. There is a problem of credibility both in terms of establishing the facts of ocean energy and in the self-belief that the country or anybody in it has the resources and expertise to bring the potential of this resource on-stream, either for home use or for export of technology.

A number of serious challenges would have to be faced in realising the potential of the sector even before considering the specific challenges that would face investment in deep water offshore generation. These would include:

- Understanding the technology fully and getting it functioning efficiently and reliably;
- Getting the timing right in market terms;
- Building up financial and human resources commensurate with technological and market demands;
- Managing cash flow;
- Ensuring that contractual agreements with clients, licencees, subcontractors and others are watertight and that clients are credible;
- Maintaining a sustainable R&D programme to maintain and consolidate Ireland's position;
- Avoiding overly-rapid expansion and exposure to particular markets or contracts;

[42] In the context of this reference "nearshore" would probably be limited to depths of about 20-30m unlike the deeper figures (100 ± 20m) more generally utilised in this report.

- Maintaining robust but simple project management system;
- Maintaining technical awareness and competence;
- Minimising the hijacking of intellectual property and imitation by others;
- Avoiding commercial claims and litigation by others;
- Avoiding infringing on the rights of others; and
- Avoiding being locked into limited or declining markets.

Many of these challenges are commercial. However the initial technological breakthrough is crucial to starting the process and in this area there is a major role for a planned developmental programme. Against this background, a range of alternative strategic approaches have been set out. Three strategic options were offered for consideration in the joint public consultation document issued in 2002.[43] These were:

(1) Seek to become a technology leader in the field of ocean energy by committing to a significant development programme for ocean wave and tidal energy, targeting at least one operational indigenous Irish pilot plant deployed in Irish waters by 2007.
(2) Seek to provide Ireland with the means to utilise its wave resource and develop an exportable core of research excellence.
(3) Maintain a watching brief in the field of wave and tidal energy.

Apart from the third, which almost amounts to a 'do nothing' option, the other options are clearly focussed on exploiting the wave resource to varying degrees. No reference was made to the market scenarios likely to be prevailing, with the emphasis placed on developing or obtaining functional technology per se. In this there is a premise that OE development will happen. It is necessary to consider these options in order.

Option 1 proposes a significant development programme for wave and tidal energy. Based on bringing one of each to fruition, and ignoring the tidal barrage option on grounds of cost, this would imply:

- Field measurement of the resource at prime locations and/or intended test sites;
- Endorsement of general arrangement design concepts;
- Tank testing of hulls at multiple scales;
- Corresponding performance software development;
- Utilisation of full range of multi-discipline design and specification and pricing skills to develop and test hull power take off systems;
- Cable laying and network connection at sites;
- Construction of preproduction prototypes for 2007 launch; and
- Commissioning and testing.

It is assumed that the permitting process can be fast-tracked to avoid delays, as the conventional process applicable to both onshore and marine elements is open to ongoing objection. Based on developmental expenditures quoted for Pelamis, Wave Dragon and Aqua Buoy, the above programme would probably cost around €10 million for a wave converter of several hundred kW capacity and perhaps €5 million for a tidal stream turbine. These estimated developmental costs are based on

[43] Marine Institute and Sustainable Energy Ireland, (2002) *Options for the Development of Wave Energy in Ireland (Consultation Document)*

published information from several sources[44]. This gives a total cost of €15 million for Option 1.

Option 2 proposes that Ireland would have the means to utilise its resource and develop an exportable core of research excellence. The implications of this option are that:

- Concentration is on wave resource only;
- This resource is fully defined and understood;
- Niches within the overall 'wave to wire' process continue to be researched, probably with a strong focus on working as part of developer teams where the Irish participants research efforts go to the team as a whole;
- Conversion devices developed elsewhere are identified and tailored to exploit the Irish resource; and
- The expertise developed in the above resource is then available on a consulting or contracting basis to others.

The desired outcome is that Ireland would have sufficient expertise to make the right choice of system developed elsewhere, (possibly with Irish participation), for use in Irish waters and to apply this knowledge in third-party projects. The estimated cost of this approach, based on consultations, is €3 million.

Option 3 proposes that the country should maintain a technically informed, but not an administrative, watching brief on development elsewhere in both wave and tidal energy. This would involve little more than the cost of attendance at meetings, travel and report writing either by public servants, consultants, nominated university personnel or a combination of both. By observing international developments it might be possible to:

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[44] The cost estimates are based on the following projects. In relation to wave energy:

- The Ocean Power Technology project with a rating of 1 MW had a development cost of €7 million: *Wave Power – Moving towards Commercial Viability* Seminar, Institution of Mechanical Engineers, London, 30 Nov. 1999;
- Wave Dragon (1 to 4.5 scale) has a rating of 20 kW and a development cost of €7.89 million: Soerensen, H.C., *et al*. (2003) "Development of Wave Dragon from 1:50 scale to Prototype" Paper presented to 5th European Wave Power Conference, Cork;
- Archimedes Wave Swing is a 1.5MW project with a cost of €4 to 6 million: Bedad, R. and G Hagerman (2004) *Offshore Wave Energy Conversion Devices*, Washington DC: Electric Power Research Institute;
- Ocean Power Delivery Pelamis has a rating of 750 kW and cost €17 million: Bedad, R. and G Hagerman op. cit.;

For tidal energy:

- The MCT Seaflow project has a rating of 300 kW and a cost of €5.5 million: Fraenkel, P. (2003), *Professional Engineering*, Institution of Mechanical Engineers;
- Hammerfest Strom has 320 kW and cost €9.4 million: "Power in Europe", Issue 411, p.17, 13 October, 2003.

While these costs are not directly comparable and do not refer to projected costs of production units, they provide an insight into the cost of the different paths to prototype development have been taken by the respective players. The figure for Pelamis is unusually high but it is known that the initial prototype has been designed, built and tested to conservative standards. The mean costs are €9.2m (wave) and €7.45 (tidal). It is felt that with the increased amount of published information now available, some of the pioneering costs involved in these projects and carried out in high cost economies UK, Denmark, Netherlands, Norway might be avoided and hence somewhat lower figures are projected for Ireland.

- Assess the efficiency and cost levels bring attained elsewhere;
- Avoid the potential costs of wasted effort;
- Suggest changes in the framing of national regulations that would facilitate ocean energy utilisation; and
- Passively promote the participation of Irish organisations in joint activities with others

Measurement of the Irish resource is not included under this heading and the total cost is estimated to be in the region of €0.25 million.

4.2 Scenarios for Development of Ocean Energy

If ocean power technology can achieve parity with wind power technology in terms of cost and availability, it will take a share of the renewable element of installed capacity. However, the rate at which wind power came into the Irish system, at an annual average of only 21MW in the years 1993 to 2003 was very slow. This was the result of a range of failures including, difficulties with the design of the AER process, planning, financing, network connection, and other problems. In the case of wind power the wind turbines were virtually all of designs that had already been tried and tested elsewhere. This contrasts with the situation for wave energy where only a few leading prototypes have reached the sea trials stage. Given the need for test programmes of a few years duration to prove the effectiveness of these prototypes it is difficult to see more than a few pilot converters being deployed in Irish waters much before 2010 with the possibility of the first commercial production close to this date.

The analysis earlier in this report projected electricity demand of approximately 28,500 GWh for 2010 rising to 37,500 GWh in 2020. System and own use losses will amount to approximately 9%, giving total generation requirements of 31,065 GWh in 2010 and 40,875 GWh in 2020. The total generation plant portfolio made up of fully and partially dispatchable plant forecast for 2010 is 6,387MW. Three growth scenarios for the years 2003-2010 give total electricity requirements of 32,929 GWh (high), 31,997 GWh (median), 29,817 GWh (low) for 2010.[45] Utilising similar plant loadings, the required plant capacity for 2020 can be projected at 8804MW (high), 8186MW (median) and 7908MW (low). It is possible that some of this will be met by an Irish Sea interconnector with the U.K. system[46]. Thus, somewhere in the order of 8,200MW of plant will be required for the system in 2020 with a range of individual capacity factors between 0.35 and possibly 0.9. This means that, by 2020 each percent of capacity penetration by ocean energy would equate to 80MW of plant being installed.

Parallels with the level of economy-of-scale reached by the wind industry may be somewhat overstated at present but the offshore wind industry serves to provide target

[45] Eirgrid (2003) *Generation Adequacy Report 2003-10*

[46] It is also likely that the present low availabilities on the existing conventional plant will have been rectified and that a higher system generation availability will be registered despite the effect of increased presence of renewables in lowering the generation plant capacity factor for the system.

rates to which wave power converters must aspire if they are to be competitive. A wave climate of 50kW/m and an initial rate for 2010 of 8-10€C/kWh and a later 2020 rate of 5-6€c/kWh provides a basis for identifying potential penetration scenarios.

Pelamis and Aquabuoy are undergoing sea trials in the current year, AWS may do so, and Wave Dragon is also undergoing sea trials but at a scale of 1 to 4.7. It is suggested that – assuming a positive outcome to the trials and allowing 3 years for proving, modifications and fabrication of a production version – a pilot converter of any of these types could be deployed in Irish Waters in Summer 2007. It is believed that possibly a further 2 years of development and validation of these devices would be necessary (assuming the availability of funds) before deployment of a production machine could begin. This would also suggest 2007 as a date by which a prototype must be ready to launch.

This provides a basis on which a high and low scenario can be described. On the low scenario – Scenario A below – it is assumed that development and investment proceeds in the period 2010 to 2020, following research and deployment of pilot installations in the years prior to 2010, so that by 2020 ocean energy provides 1% of the energy required, i.e. there is a total of 80MW installed and operational. For a high scenario – Scenario B below – it is assumed that following a fairly slow start, total installed capacity in 2020 reaches 200MW or 2.5% of total generating capacity in Ireland. The target is quite high although, as discussed below, the gradual growth will act to reduce the overall risk associated with achieving this outcome. This latter scenario requires an underlying assumption in relation to the origin of the technology. The consultants believe that achieving this would require that a combination of technologies developed in Ireland and elsewhere would be accessed for this level of development. Scenario C retains the ultimate level of penetration but is based on non-investment in R&D in Ireland, while Scenario D results from a failure to develop a programme and failure to map the resource. These scenarios are summarised in Table 4.1.

Table 4.1: Protected Development Scenarios

Scenario	Description	2010 (Total)	2020
A	Development and adoption of an Irish sourced floating wave power converter but overall policy stance is cautious	Prototype(s) only 1.5MW (Total)	80MW
B	Application of floating converter systems developed both in Ireland and overseas with support for Irish participants with target to develop competitive supporting industry	Prototypes only 5MW (Total)	200MW
C	Adoption of floating converters developed exclusively by external interests	1.5MW (Total)	200MW
D	As in (c) above without mapping of Irish resource.	1.5MW (Total)	60MW

Note: It is assumed in scenarios A, B and C that mapping of the Irish nearshore wave resource is carried out and made available to all participants

These levels of installation and operation are based on the assumption that pilot units are sufficiently successful to allow ongoing verification and refinement of basic designs, leading to potential penetration of overseas markets in parallel with developments projected here for the Irish market. The main differences between these

scenarios are that while both Scenarios B and C aim to develop a high level of investment in capacity, Scenario C adopts a position of adapting technologies from overseas. As a result, the initial uptake is a bit slower and there is a smaller supporting industry developed. Scenario A represents the cautious but supportive approach to development while in Scenario D, the industry is left to develop at its own pace.

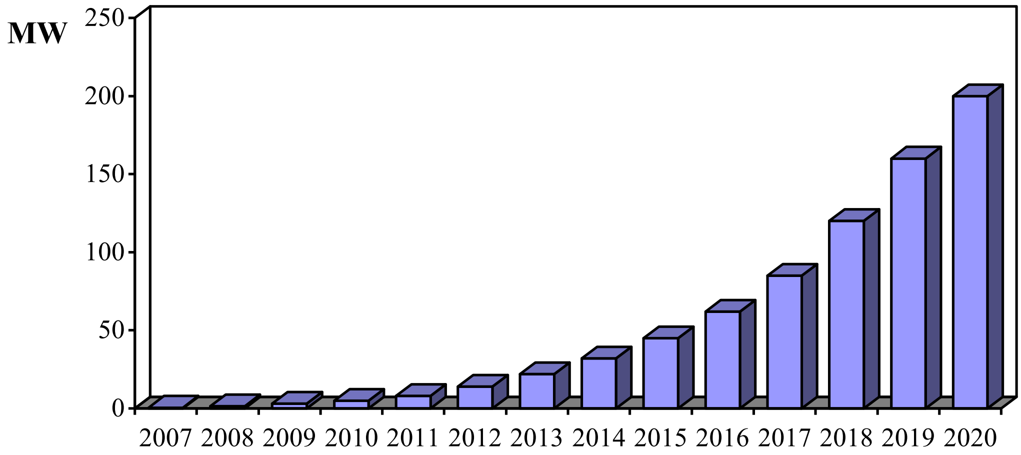
Utilities are inherently conservative and, subject to Government direction, seek to discharge their obligations using the most reliable systems that deliver energy at least long term cost. In addition to its use as a source of power, electricity is a premium product and legally binding international standards apply to ensure quality of supply. Thus, it may be expected that a high level of validation of both systems and supplier credibility will be required where developments associated with ocean energy resources are concerned. Progress in markets elsewhere is usually carefully monitored before commitments are entered into for Ireland. Any comparison of the prospects of ocean energy development with the wind sector and the cost declines that have been achieved in generation requires that development costs be spread over a very large number of units, typically several thousand[47]. However, because wave generation can only be implemented on particular coasts rather than in inland areas it is expected that this process will take longer than it took for wind. Thus, a somewhat conservative approach has been taken in projecting market penetration.

A rate of penetration leading to ocean energy accounting for 1% of total installed capacity in 2020, as implied in Scenario A, would be wholly inadequate to achieve much beyond Option 3 above and would certainly not achieve Option 1. Scenarios B and C lead to a larger industry but there is an important difference in the origin of the underlying technologies. The consultants conclude that many of the main benefits of ocean energy can only be realised if an industry of sufficient size to maintain a competitive cluster can be created. As a result, Scenario B based on achieving penetration of 2.5% by 2020 with support for development in Ireland is required. This would involve the installation of 200MW of capacity by this date. A comprehensive regulatory and development policy would be required to realise this objective.

Assuming that policy is aimed clearly at the development a competitive supporting industry, it is necessary to outline a development profile. This is done in Figure 4.1. This shows growth of the industry in each year up to 2020 to achieve 200 MW of installed capacity. The underlying assumption in this outline is that the installed capacity grows at an average rate of about 50% per annum over this period.

[47] Carcas, M (2004) National Wave and Tidal Energy Conference, BWEA, Bristol

Figure 4.1: Installed Ocean Energy Capacity, Scenario B



The actual MW installed and the annual growth implied by this scenario is shown in Table 4.2. This shows a target of 200MW by 2020 with 40MW being installed per annum by this date.

Table 4.2: Installed Ocean Energy Capacity, Scenario B (MW)

	Cumulative Capacity	Annual Increment
2007	0.5	0.5
2008	1.5	1.0
2009	3.0	1.5
2010	5.0	2.0
2011	8.0	3.0
2012	14.0	6.0
2013	22.0	8.0
2014	32.0	10.0
2015	45.0	13.0
2016	62.0	17.0
2017	85.0	23.0
2018	120.0	35.0
2019	160.0	40.0
2020	200.0	40.0

There are several important implications emanating from this scenario. For a competitive wealth-creating sector to emerge in Ireland, a clear and sustained approach to development is required, with deployment of prototypes from 2007, and with production beginning in 2009. A target production capacity of 200MW by 2020 should be adopted. However, adoption of technology from abroad exclusively would not maximise the returns to the Irish economy and the development of a competitive cluster around this core demand is required. Finally, investment in basic research, in areas such as mapping of the resource, is required to reduce risk and incentivise investment at a faster rate.

5. Assessment of Potential Economic Benefits

5.1 Approach to Identifying Benefits

Having identified the underlying potential in Ireland's ocean resources and outlining a viable scenario for realising this, it is necessary to examine the potential value that would accrue to the economy as a result of the development of a successful industry based on ocean energy. Formal methodologies, such as cost benefit analysis and cost effectiveness analysis are an option. However, there are two difficulties with adopting a highly formalised approach in the case of ocean energy.

Only those effects that can be quantified are included in a formal Cost Benefit Analysis (CBA). If important non-quantifiable impacts are present then the outcome of the CBA will be limited. In the case of ocean energy this is very important as there are difficulties in placing an accurate value on many of the effects that arise. This is particularly the case in relation to impacts such as the contribution to a better regional balance of economic activity or improving the security of supply. Perhaps the most intransigent problem arises with the evaluation of R&D expenditure. Such expenditure is a cost to the economy and is included as such. The benefit is the value of the knowledge that is created. The problem is that there are no reliable methodologies for placing a value on this beyond valuing the output according to the cost of the inputs. In the context of the programme for the development of ocean energy, R&D expenditure would be the major element of expenditure. Valuing output as being equal to expenditure casts no light in terms of the decision since the same value would be included on both sides of the sum.

The second difficulty arises due to the long payback period and the extreme uncertainty that would exist in relation to a policy to develop this industry. A time-period of 20 years would be quite normal for the evaluation of capital expenditure, where recognisable annual returns could be identified for the period. However, in the case of ocean energy, the returns really depend on the outcome of the process and cannot be predicted with any degree of confidence. The most that can be said is that, on the basis of the analysis in this report, Ireland would appear to have a competitive potential to develop this industry provided certain actions are taken as outlined in subsequent sections of the report.

While a formal CBA is not undertaken here, it is possible to place some values on the benefits that would emerge from the successful development of the industry along the lines identified. This section examines the value of the economic activity that would result from developing this industry e.g. impacts such as the level of employment created. The discussion includes the value of the power produced, the contribution to regional development, the environmental benefits, and the contribution to security of supply. The results below provide indications of the values that could be expected.

5.2 Employment Potential of the Industry

Because there is not yet an established ocean energy industry from which to derive supply chain costs and other factors it is necessary to draw analogies with broadly equivalent renewable resources such as wind. A number of sources have been used in deriving the inputs and associated costs below[48].

The UK Dept. of Trade and Industry (2004) in a preliminary assessment provided an approximation of employment created per MW of renewable generating capacity installed under different conditions. The work estimated that the current UK renewables sector sustained domestic employment, including both direct and indirect employment, of 5,500 jobs after adjusting for the impact of imports to the sector. In addition, it estimated that there were 630 jobs sustained by exports related to the renewable industry. Applying the Treasury multiplier for induced jobs sustained, the work estimated total employment of 7,730 related to the sector. This gave a weighted average of 10 jobs per MW installed in renewable energy. This provides an order of magnitude figure for employment in the sector.

Two renewable energy scenarios for the UK in 2020 have been developed.[49] The first scenario is based on achieving a high level of wind penetration but with low ocean energy input with installed wave capacity reaching only 900MW. If this were to be installed from a standing start over the eight years 2012-20 without importation of non-UK equipment, then this would provide 3,600MW years on average by 2020 i.e. an average of 8 years with 450MW. The DTI report estimated that the number of job years necessary to achieve this over the 16 year period 2004-20 would 16 x 1500 = 24,000 job years. Thus, there would be 1,500 jobs on average in the UK. Put another way, this estimate indicates 6.7 jobs/MW created to produce the 3,600MW using UK sourced equipment only. However, the methodology is based on an average for employment in a period that exceeds the period of actual deployment. The work further estimated that if non-UK equipment is imported, the corresponding number of job years falls to 16 x 1200 = 19,200 job years resulting in 5.3 Jobs/MW, i.e. 19,200/3,600 = 5.3 Jobs/MW.

The second U.K. scenario was based on a more balanced development of wind, biomass and ocean energy with an increased wave input resulting in an installed wave capacity of 3,000MW. Again, the calculation was based on this capacity being installed from 2012 onwards over 8 years giving 12,000MW years by 2020. The work estimated that installing wave energy capacity to this level, without imported equipment, would result in 5,200 sustained jobs being created on average. Over the 16 years, this amounts to 83,200 job years, or 6.9 Jobs/MW. If imported non-UK equipment was used to supplement domestically produced equipment then it was estimated that the number of jobs would fall to 4,200. This would result in 67,200 job years in the period 2004-20 and the creation of 5.6 Jobs/MW. Thus, this work

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[48] EU WAVENET Report (2004); European Commission (2001) *Strategic Environmental Assessment*, Directive 2001/42/EC; UK Department of Trade and Industry (2004) *Renewable Supply Chain Gap Analysis* London: HMSO; Christensen, L. (2004) Personal Communications; European Commission (2001) *Concerted Action for Offshore Wind Energy in Europe*

[49] See Table 4-7, Department of Trade and Industry (2004), *op. cit.*

provides an estimate that the number of jobs created per MW of ocean energy installed in the UK would be in the range of 5.3 to 6.7 depending on circumstances[50].

Data are also available from a Danish assessment of employment creation in the Wave Dragon project[51]. This work also indicated that the number of jobs created will vary over time with increased production and deployment. However, the methodology used means that the results are not comparable to those obtained in the UK study. Table 5.1 shows the estimated derived for employment per MW in Denmark. This shows a declining scale for the number of jobs/MW in construction and deployment.

Table 5.1: Estimates of Jobs per MW Based on the Danish Wave Dragon Project

	2006	2019
Construction/Deployment (Direct)	10	4.6
Construction/Deployment (Direct & Indirect)	15.3	7.0
Operation + Maintenance	0.32	0.32

Note: The Wave Dragon indirect employment multiplier was estimated at 1.53
Source: European Commission (2001), Directive 2001/42/EC

These Danish figures for employment in O&M reflect their experience with offshore wind farms. The notable feature of the Danish approach is that the rate of job creation in 2020 is close to the average estimated for the UK. This suggests that the UK estimates may be somewhat on the low side in the initial years when experimentation is required along with deployment without economies of scale being available, but it indicates that a long term estimate of a ratio of 7 for the number of construction/deployment job years to MW years in the period, plus 0.32 O&M Jobs/MW, would be a reasonable consideration for estimation purposes. In the shorter term, jobs in construction and deployment per MW could be double this long term level. Manufacturing of wind-turbine components does not take place in Ireland but, if it is assumed that the field construction of wind and wave systems have roughly the same labour content, then these may be used as a basis for estimating job creation.

The preferred scenario for development in Ireland indicated a target 200MW installed in 2020 with deployment beginning from 2007. This amounts to 758 MW years for this period given the deployment profile outlined earlier. Using the UK approach, this would result in a total of 5,306 job years (at a rate of 7 job years per MW year) for the period. In 2007 to 2020 this would give average employment of 379 people in construction and deployment. However, this would vary considerably from the start of the period when construction is low to the end when construction is much greater. Table 5.2 apportions these jobs on the basis of the amount of capacity being installed each year. It also weights the number of jobs per MW in the early years to allow for the fact that the labour input will be greater in the initial stages[52].

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[50] A similar analysis for tidal energy in the UK suggests that 9 jobs per MW installed will be created. However, it should be remembered that these figures assume that there is sufficient technological development to make the sector commercially viable. If this does not happen but the government supports the sector sufficiently then the number of jobs is likely to be higher. However, this would involve greater risks as policy is unlikely to continue to support that sector unless the rate of development is considered to be acceptable.

[51] European Commission (2001) and Christensen (2004)

[52] It is assumed that there are 14 jobs per MW in 2007 but that this declines progressively to the average of 7 by 2012. This is a fairly minor adjustment in terms of the overall employment.

O&M employment would also arise and is estimated at 0.32 jobs per MW installed. This employment is also shown in Table 5.2.

Table 5.2 shows construction employment reaching 1,061 in 2019 when 40MW are installed[53]. It is interesting to compare these figures with the UK estimate that, currently, renewable energy in the UK sustains 10 jobs per MW installed. By 2020 the 200MW of wave energy in Ireland would sustain 1,125 jobs, i.e. 5.6 jobs per MW. Given that the Danish projections indicate that the employment content of ocean energy will fall by around 50% in this period this would appear to be a reasonable estimate of the employment that can be created.

Table 5.2: Projected Employment in Wave Power in Ireland (based on UK estimates)

	Total MW installed	Construction Employment	Operation & Maintenance	Total Jobs
2007	0.5	26.5	0.2	27
2008	1.5	46.2	0.5	47
2009	3	60.3	1.0	61
2010	5	70.0	1.6	72
2011	8	91.4	2.6	94
2012	14	159.2	4.5	164
2013	22	212.2	7.0	219
2014	32	265.3	10.2	276
2015	45	344.9	14.4	359
2016	62	451.0	19.8	471
2017	85	610.2	27.2	637
2018	120	928.6	38.4	967
2019	160	1,061.2	51.2	1,112
2020	200	1,061.2	64.0	1,125

Note: Installations in 2007-08 refers to 3 pilot projects of 0.5MW each. The employment estimates for 2012 to 2020 have been derived on the basis of weighting the average construction employment in these years in the text according to the rate of construction in each year.

Employment in construction and deployment in the earlier years should be interpreted as including all employment associated with the sector apart from the planning and administrative jobs that may arise in the earlier years as indicated by the timeline in Table 7.2 below. Thus, the scenario put forward would result in approximately 1,125 full time manufacturing and construction jobs in the wave energy industry by 2020. If construction continued at a rate close to 40MW per annum then employment close to this level should be sustained with the additional O&M employment compensating in part for further savings due to efficiencies. .

[53] Note that the implied 27 jobs in construction per MW in 2021 should not be compared with the UK estimate of 7 jobs on average per MW year as the UK figure, which forms the basis for these estimates, is for average employment over a longer number of years. In many of these years actual construction would have been very low. Neither is this figure comparable with the Danish projection as contained in Table 5.1 since it cannot be assumed that employment in construction on a particular project lasts for only 1 year.

Employment Creation from Exporting Opportunities

The projection for generation and therefore, the number of jobs relates to electricity production in Ireland only and so is only part of the potential. A policy programme devised on the basis of placing Ireland in a competitive position to supply machines internationally would provide considerably more employment. The UK data above indicated that employment within the UK economy could vary by up to 1,000 when machinery is imported. If it is assumed that the UK industry grows as projected and comes to represent 50% of the European industry by 2020 and that Ireland can gain a 20% share of the imported element of the UK market, then this would result in the creation of 200 jobs from exporting to the UK and a similar number from exporting to other markets. As these jobs are primarily in the manufacturing sector, these firms will tend to have strong multiplier effect in the economy, provided the inputs they require and the skills required can be accessed locally. Research indicates that the total employment effects of these sectors will give rise to a multiplier of 1.84[54]. This would indicate the total employment effect of these exports would lead to the creation of a further 760 jobs, (i.e. 400*1.84). This would place total employment creation in the region of 1,900.

5.3 Valuation of Energy Produced and Other Impacts

Quantification of Net Benefits of Wave Energy

The benefits to the economy from the development of the ocean energy sector can be estimated under a number of headings including the energy produced, the environmental benefits through lower emissions, avoidance of hidden subsidies to fossil fuels, regional development, and increased security of supply.

Energy Value

Placing a value on the energy produced is straightforward since it is equal to the cost of electricity that does not need to be produced by other means. The CER's 2003 model produced a price of 4.7c per kWh as the BNE price, €47 per MWh.

Lower Emissions

Ireland has commitments in relation to greenhouse gas emissions and it has been made clear in numerous reports in recent years – including the *National Climate Change Strategy* – that the limits that have been set will be extremely difficult to achieve. This means that any saving on emissions will have a marginal value greater than zero. Placing a value on these emissions is difficult but indicative estimates are available. The most commonly used approach for estimating the value of the pollution avoided by renewable energy is to place a value on the tradable credits that would be produced in the existence of a developed market for the trading of credits. The UK has led the way in developing this market. Initial estimates suggested that

[54] O'Malley, E. (1995) *An Analysis of Secondary Employment Associated with Manufacturing Industry*. Paper No. 167, Dublin: ESRI

these credits could be worth in the region of €15,000 per GWh[55]. This would give a value of about €43 per tonne of CO_2. Obviously, such estimates are subject to considerable error as the market is not fully developed, but the evidence to date from the UK suggests that these values are being exceeded by the prices being paid in the traded green credits market. However, the prices currently being experienced include a high risk premium and, as the market develops, the risk will gradually be removed and the price will fall. Estimates of the stable market value have ranged as low as €5 per tonne and the ESRI has recently adopted an intermediate value of €20 per tonne of excess CO_2 emissions.[56]

CCGT electricity generation produces 346 kg of CO_2 per MWh of electricity. As a result, each MWh of electricity produced from renewable sources will save 346 kg of CO_2. At €20 per tonne, this implies a saving of €6.92 for every MWh of energy produced by ocean energy i.e. not produced by CCGT. Thus there is a value created of approximately €7 per MWh.

Hidden Subsidies to Fossil Fuels

Subsidies given to fossil fuels in the global context work to keep down the price of electricity generated from oil and gas. In contrast to the approach that would be required if the fiscal system and energy prices were correctly aligned with the objectives set under Kyoto, EU countries provide large fossil fuel subsidies, often under the guise of promoting competitiveness. Research shows that the total value of subsides to renewables is substantially below what is allocated to fossil fuels and is probably less than what is provided to nuclear energy alone[57]. In total, it is estimated that while renewables in the EU receive in the region of €4 billion per annum, subsidies and other supports to fossil fuels amount to over €70 billion while the nuclear industry receives a further €10 billion. Transfers and tax reliefs to fossil fuels in Ireland have been estimated to exceed €90 million, split between solid fuel and oil and gas, with only around €10 million going to renewables. Thus, the energy output of the ocean energy sector would reduce the cost of these transfers, although it is not possible to place an accurate estimate on this.

Security of Supply

A second important cost associated with fossil fuels that would be reduced by developing indigenous renewable energy sources is the risk associated with the overwhelming reliance in Ireland on imported fossil fuels for the country's energy requirements. There are two sources of risk:

- a price risk associated with statistically predictable market volatility and forecast error,
- and security of supply risk associated with unforeseen circumstances.

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[55] *The Energy Review*. Report by the Performance and Innovation Unit to the Cabinet Office, February 2002. London: HMSO

[56] ESRI (2003) *Medium Term Review 2003-2010*

[57] See Oosterhuis, F. (2001) *Energy Subsidies in the European Union*. Amsterdam: Institute for Environmental Studies

While this report was being written the spot price for natural gas in the U.K. tripled during the course of one day. This was not due to political instability but because a cold snap had increased demand. Over the longer term, world energy demand is estimated to increase by at least 70% over the next 30 years. [58] Due to its island position and non-existent or weak connection with other electricity networks, security of supply has been of particular concern and Irish energy policy places a priority on improving security of supply. Among OECD countries only UK and Canada are currently self-sufficient in energy needs and, within the next decade, the UK itself will become a net importer (with Russia as a significant supplier), as North Sea oil reserves are depleted and the growth of the CCGT sector increases. Being at the tail-end of the European gas grid, Ireland must ensure that it has both the plant capacity and the source-diversity to guard against the threat posed by:

- Fluctuations in world energy prices
- Over reliance on importers
- Unreliable supply sources and probably from Atlantic.
- Unreliable gas quality
- Gas transit risks and
- Terrorism.

It is necessary to include a cost in relation to fossil fuels arising from this relative insecurity of supply and price. It seems reasonable to assume that forward prices will contain errors in the region of ±5%. Indeed this would suggest low volatility and a very efficient market. In addition, serious supply disruption once every 40 years seems a reasonable assumption. Together, these mean that a contingency cost of 5% of the fuel price is required to be able to state with 100% certainty that fuel will not cost more than the price included.

In the CER's electricity pricing model, gas from the UK is estimated to cost €0.414 per therm giving a price of €0.0291 per kWh of electricity exported. A 5% contingency cost would be valued at €1.5 per MWh and should be included as a cost of maintaining reliance on imported fossil fuels as would be the result of new CCGT generation.

Regional Development

An important non-marketed hidden benefit of the development of ocean energy would be its potential to create incomes and employment in lagging regions of the country. This is a major objective of Irish economic policy as expressed in a number of publications such as the *National Development Plan* and the *National Spatial Strategy* in recent years.

To get an estimate of the value of this impact, it is assumed that construction materials are largely imported to the region, and therefore do not contribute to regional distribution, but that construction and operational expenses create incomes in the region in which the facility is located. Assume that O&M expenditure accrues 100% to local residents but it is assumed that incomes to the value of 80% of this would

[58] Scoping Study for an Environmental Impact Field Programme in Tidal Current Energy' Robert Gordon University for UK DTI (Pub./URN 02/882) 2002

have been earned in any case. Management and professional fees will also arise but it is likely that 50% of these accrue to local residents and again that 80% of this is displaced. Based on estimates for offshore wind energy, generation will create additional wealth as a result of regional employment in O&M with an annual value of €3,550 per MW and management income with a net wealth value of €480 per annum. Together, these have a value of €0.0012 per kWh of output.

The construction phase will also give rise to regional incomes but in the year of construction only. It is assumed that 50% of planning costs will accrue locally and that 20% of expenditure accrues as local income from employment in construction with a displacement of 80% in both cases. At construction costs to produce output in the region of 10c per kWh this means net additional value is created in lagging regions with a value of around €10 per MWh of output produced[59].

The Value of Knowledge

A final issue inherent to the development of ocean energy is the need for R&D to encourage investment into this new industry. Additional value can be created through the prospect, based on Ireland's relative competitiveness in terms of its wave resources, that wave generation can emerge as a very valuable national wealth-creating sector in the future. R&D output is very difficult to evaluate but, in general, expenditure on technology development in the ocean energy field may be expected to yield returns under several headings[60]:

- A better understanding of the ocean wave and tidal resources, their character, magnitude and distribution and amenability to commercial development.
- Improved and realistic understanding of the cost and timescale implications of ocean energy development and its integration into the Irish sustainable energy portfolio.
- Setting the scene for introduction of commercial ocean energy conversion systems, developed by either home or overseas developers, in Irish waters.
- Potential for development of ocean energy export industry with consequential improved employment and wealth creation opportunities.
- Fostering of consulting, project management and project development expertise with import substitution and export potential.
- Integration of disparate teams and organisations so that administrative, technological and manufacturing capacity of the country becomes more streamlined, focussed and competitive.
- Improved university teaching resources in the several technological fields that find application in ocean energy research

[59] Foreshore payments to DCMNR would also provide a net contribution to the economy that could be recycled to the regions.

[60] Respondents to the questionnaire distributed in the course of preparing this study were asked to estimate the value of intellectual property that would be likely to be created in the first 5 years of a programme to develop ocean energy. The values in the replies varied from €100 million to €500 million but it was clear that these estimates were based on guesses. This underlines the difficulty of valuing this activity. However, one point of consistency was that all believed that the knowledge value would be much greater when production was underway than in the earlier experimental stage.

Estimates of the potential returns from supporting R&D in renewable energy R&D strongly support government investment in this area.[61] This SEI report identified the potential role of demonstration projects in terms of contributing to knowledge and incentivising investment, and estimated that the cost to the State, of bringing forward a 50MW offshore wind demonstration project would be in the range of €47 million, whether grants or feed-in tariffs are used. At this level, there would be a positive NPV return on the investment. If no grants are allocated then the PPA is estimated to cost €8.1 million per annum in order to achieve the 50 MW offshore. If the demonstration project is taken to represent R&D support then this means that investment of €16 per MWh in R&D into offshore wind generation will provide a positive return.

Wave energy is at a much earlier stage of development and, as argued above, the potential for Ireland to create a leading position holds the prospect of creating a valuable industry in exporting the knowledge gained. This is not an option in wind given the relative underdevelopment of Ireland in an industry where the technology has matured rapidly in recent years. As a result, higher returns are possible in the case of wave energy. It is beyond the scope of this study to replicate this research for wave energy, but it is argued that the returns could be double those possible in the case of wind. This would mean that the knowledge created by a supported programme of development and R&D in wave energy would have a value equal to €32 per MWh of output produced.

Total Value of Outputs

These estimates can be combined to provide an indicative estimate of the value of ocean energy output. This is shown in Table 5.3.

Table 5.3: Estimated Value of Ocean Energy Produced in Development Period

	Value per MWh (€)
Electricity	47
Emissions avoided	7
Security of supply	1.5
Regional development	10
Knowledge created	32
Total	97.5

The value of subsidies to fossil fuels that could then be avoided would increase this further. The total value in this table of €97.5 per MWh (9.75c per kWh) is well below the current possible cost of production of ocean energy but is very close to the levels that have been identified as possible in the future. It is possible that with ongoing technological developments production at a cost level of close to 9.75c per kWh will be achieved between 2010 and 2020.

[61] SEI (2002) *Cost Benefit Analysis of Government Support Options for Offshore Wind Energy*. Report prepared by Byrne O Cléirigh for Sustainable Energy Ireland.

5.4 Summary of Economic Benefits

This analysis indicates the projected outline for the development of the industry resulting in 200MW of installed capacity in 2020 would support the creation of 1,125 jobs in the economy by that year. In the period 2007 to 2020, this equates to 5,631 job years or average annual employment of 402 in the economy. If the potential to develop export markets is realised then this estimate rises to 1,900 jobs in 2020.

The economic value of the output of the industry has been assessed under a number of headings including the electricity produced, the atmospheric emissions avoided, the contribution to improving the security of energy supply, the positive impact on regional development and the value of the knowledge created. Together, these effects indicated a value of €97.5 per MWh. If it is assumed that the installations have a capacity utilisation of 35% during this period then total energy output will amount to 2.32 TWh. The total value of this output when all impacts are included is €227 million in current values. If this is discounted to 2004 at a public sector real discount rate of 2.5% then it has a present value of €158 million (€170 million if discounted to 2007 when the first prototype deployment is projected).

The analysis also suggests that a supported programme where the price paid for the energy is around 10c per kWh would produce positive returns to the economy. However, as stated earlier, it is very early to place an indicative value on the feed-in tariff that should be paid and estimates in future years could have greater accuracy.

6. Industry Requirements and Potential

6.1 Requirements for Development

Ireland's natural resource provides the basic rationale, along with the need to develop new renewable energy sources, for examination of the potential for ocean energy. However, for wealth to be created and reside in the economy it will be necessary for Ireland to be able to do more than merely extract this energy. In other words, it is important that the intellectual property that will determine the technological and economic viability of ocean energy technologies resides in the economy. As discussed below, this means that, along with demand for these products, basic research and development inputs and a supporting policy environment, Ireland needs to ensure that the supporting sectors of the economy are able to extract value from the development of the industry.

An optimal sequencing of events is necessary for successful harnessing of ocean energy. The first stage is resource characterisation in order to understand the envelope of resource parameters thoroughly before a major commitment can be made to that resource for energy supply purposes. Quite simply the resource must be proven to be as perceived. For offshore, much useful data are available from satellite and the ocean weather buoys of the UK Met Office and the Marine Institute. However, this does not provide the location-specific data that would be necessary for wave converter deployment. Attention should be concentrated on perceived hot spots and favourable locations at moderate distances from the shore, (2-12 km) or where water depths exceed 50m. The second stage is the creation of a commercial climate. Without an operational converter in Irish waters it is unlikely that decision makers, politicians and the general public will alter their existing level of relative indifference to ocean energy. Third, it is necessary to study converter characteristics through physical modelling in wave tanks and utilising software capable of detailing the motions of floating bodies under wave action

At this stage it will be necessary to match the resource to the commercial climate via appropriate converter characteristics. This is an iterative procedure ideally involving confirmation of the resource, assessment of likely converter performance in that resource and adjustment to the commercial regime to make at least demonstration projects possible. Institutional issues such as availability of foreshore licences, network connection and planning permission need to be resolved at this stage. Finally, project implementation will require a commitment that may go beyond what has been provided in AER projects. The extent to which EU funding will be eligible for use in this type of project and the mechanisms for verifying its use will need to be researched and confirmed.

Among the stakeholders with an interest in the development of the Irish ocean energy industry are:

- Researchers: Interested individuals or teams primarily located at four universities at Cork, Limerick, Maynooth, Belfast focussed on particular aspects of ocean energy research which must be self supporting. In the longer

run, this group will also include private financiers and small entrepreneurial companies[62].

- Facilitators: Government or quasi government bodies such as Marine Institute, Sustainable Energy Ireland and Enterprise Ireland.
- Professional Participants: Engineering consultants, Accountants, Lawyers, Patent Agents, Market Development, Public Relations, Insurers.
- Potential Developers, Utilities, Independent Power Producers.
- Regulators: Dept. of Communications, Marine & Natural Resources, Commission for Electricity Regulation, Commissioners of Irish Lights, Coastguard.
- Fabricators, Suppliers and Contractors selling labour, materials and services.
- Financiers: Banks; Venture Capitalists, Investors.
- Potential customers: Public Utilities, Independent Power Producers

Along with capital for investment this amounts to a substantial body of skills that are required.

Skill Requirements

The potential ocean energy industry in Ireland may be regarded as consisting of two components – that which is visibly associated with knowledge creation in the research and development as conducted by the universities and others, and the extant manufacturing/fabrication capacity. Different sets of skills are required at different stages in the evolution of an ocean energy conversion system but, with a few exceptions, these are skills that can be grafted on to an individual's existing skill set by further training and experience. At the Prototype Construction, Commissioning, Test & Development stages the skills include:

- Fabrication Trades
- Management, Marketing, Accounting, Legal
- Project Management
- Marine Health & Safety
- Marine Operations

All of these disciplines, with the exception of naval architecture and hydrodynamics, are catered for by universities in the Republic of Ireland while Queen's University has a naval architecture programme. The primary skill constraints lie in the areas of computational hydrodynamics, naval architecture and electro-mechanical power engineering design. Once the respective systems have been evolved and verified, detailed specifications, designs and working drawings can be readily prepared for pricing and fabrication purposes. The Conceptualisation, Design, Development Phase

[62] The producer group may be taken to include at least the following known organisations:

- University College Cork (Hydraulics and Maritime Research Centre, Dept. of Applied Mathematics and Dept. of Electrical Engineering;
- University of Limerick, Mechanical and Aeronautical Engineering Department
- National University of Ireland – Maynooth, Dept. of Electrical Engineering
- Queens University of Belfast (Dept. of Mechanical Engineering, Dept. of Electrical Engineering and Dept. of Civil Engineering)
- Hydam Technology Ltd., Wavebob Ltd., Ocean Energy Ltd., Sea Energy Ltd., Wavegen Ltd

will require skilled personnel. The skills required and an indication of availability in the Irish economy are shown in Table 6.1.

Table 6.1: Expertise and Facilities Requirements of Ocean Energy and Skills/Facilities Gap Analysis for Ireland

Area of Expertise	**Application**	**Converter Type**	**Personnel Availability**	**Expertise Gaps**	**Facilities Required**	**Facility Availability**	**Facility Gap**
Aerodynamics	Air Turbine Design	OWC Converter	Limited continuity due to post graduate dispersion	Full Turbine Design Knowledge	Wind Tunnel, CFD Computer Software	U.L., QUB. Ultimately full scale test site	Large scale random reverse flow wind tunnel
Hydrodynamics	Wave impact and motion analysis	All fixed and floating types	Limited at advanced level (UK)	Comprehensive analytical analysis	Test Tank and Software, Test site later, comprehensive wave records	HMRC, QUB to medium scale (≈ 1 : 30). No test site	Large test tank and later test site.
Naval Architects	Refinement of hull shape and materials. Compliance with classification society rules (Lloyds, DNV)	All floating types	Limited and specialised (UK)	Comprehensive understanding of dynamic behaviour	Stability software codes & standards. Later test site for stability verification	Test tanks (as above) Software & Computing facilities	Large test tank and later test site
Applied Math	Time, Frequency domain, Dynamic Analysis & Response Optimisation	All floating	Limited, UCC, QUB, Spec. Consultants	Supportive interface with other disciplines	Computing Capacity & Tank Configuration	Specialised	Large scale tank or open sea test site
Civil/Structural Engineers.	Structural design, mooring design installation, load analysis	All fixed and floating	Available, universities, consultants	Interfacing experience with marine environment	Computing Software, ultimately test site	Reasonable for computing. No test site in Ireland	Final test site.
Power system analysts	Interfacing with Grid/Network, Fault Behaviour	All grid connected	Limited outside utilities and spec. consultants	Input information from utilities	Computing, Network Understanding, Spec. Software, Measurement Equipment.	Limited outside utilities, Universities	Interface location/ arrangement

Table 6.1 (contd.)

Computer Simulation Capacity	Various in support of other specialisms,	Fixed and floating	Specialised to be of value in assisting other disciplines	Supportive interface with other disciplines	Computing capacity, bespoke software verification	May be limited in particular cases, Universities & Commercial Agencies/Consultants	Depends on Developer or funding agency needs
Electrical Engineering: (EE) • Power • Instrumentation • Control • Measurement • Communication • Transmission	Generator spec. performance, selection, elec. Control system Fabrication & Commissioning QA Protection & Transmission	All electrical connected to grid at medium voltage	Specialised Specific Consultants Universities (UCC, QUB, Maynooth) cover particular areas	Capacity to produce specs. And fully designed and functional modules that meet EE needs in areas listed	Test equipment special comp. software	Associated with specialised groups. Equip. can be hired. Ultimately tests will require utility participation.	Utility interest, commitment
Mechanical Eng. (ME) • Rotating Machinery • Materials • Stress & Vibration • Fatigue • Pressure Systems • Lubrication/Cooling • Welding Systems	Air turbine, hyd. turbine, hydraulic system spec. Design Manuf. Test & Commission Hull fabrication Manufacture & assembly. Corrosion Protection, Seals, Pumps, Valves, QA system simulation	All floating converters	Available but not short term	Capacity to produce specs. and fully functional modules that meet ME needs in areas listed in (Col. 1)	Codes & stds. Testing Rig, Fab. Shop facilities, Rolling, Shaping, Welding, fitting, Moorings, X-Ray, ultrasonics	Small-medium scale available or can be mobilised, if costs underwritten UL has 'niche' position.	Ready and timely Team access to all 'signed up' industrial facilities for prototype production.
Marine Engineering	Marine Eng. Practice, Design, Survey, Rules Permitting, O&M.	All floating converters	Limited availability	Understanding of differences between converters and conventional vessels	Access & Manuals	Reasonably O.K.	-
Environmental Specialists	Environmental Measurement & Impact assessment	All fixed and floating	New field but personnel available	Acquisition mobilisation of data to meet new demands	Sit Access + Records	Satisfactory records may be weak.	Test site would allow pilot measurements

Table 6.1 (contd.)

Fabrication Trades	Steel workers, fitters, welders, riggers, electricians, instrumentation	Floating	Applied Marine expertise weak.	Personnel	Vary with converter type	Full shipyard to small scale. Cost a key factor.	Size limits in ROI. Harbours
Project Mgt.	Bring Project on Stream	Floating	Reasonable	Understanding of needs of the technology	Pricing, Scheduling support	Available	Application of PM to technology
Marine Operations	Marine Health & Safety, Towing, Mooring, Diving, Cable laying, Dredging, Recovery	Floating	Specialist	Few	Training Facility	Unavailable	Ops. Simulation
Company Mgt.	Plan, lead organise, control business	Floating	Sparse	Few	Funding, PPA	Uncertain	PPA uncertain funding
Marketing	Business Development	Floating	Few in experience of new area adaptation of new area O&M support	Few	Office/Comms	Available	Track record
O&M	Safe, viable operation	Floating	Utility, ex utility	Wave farms	Actual Plant mock up	Nil	Wave farms conceptual only.

While the breath of the range of skills required means that it is difficult to generalise, it would appear that there is some availability of most skills but that the numbers available in some specialist areas would be limited, particularly in the short term. However, this could be addressed through consultation with training and education providers as the programme is developed.

In terms of facilities, the assessment is much clearer in that there is an obvious gap relating to test facilities in the form of a large scale tank and the identification of a test site. This will require intervention to identify the site and to provide the funding required for the test facility. However, this should be possible given a clear commitment to overcome these deficiencies within the timeframe envisaged in the development projection in this report.

6.2 The Accessible Industrial Base in Ireland

Appendix 8 outlines an industrial structure that might be expected to emerge around a developing ocean energy sector. It indicates the inputs that would be required, the supply chain that would be created in the context of a growing sector, and has an indicative listing of Irish firms engaged in these sectors that would be in a position to supply products to the emerging OE industry. This provides an indication of the industrial base that the industry would need to draw on to supply products.

Associated with unprecedented growth in some manufacturing sectors during the past decade, Ireland has experienced rising costs with corresponding vulnerability to competitive forces arising from the new trading countries. The correct response has been to emphasise the need to ensure that costs do not rise out of line with the underlying wealth-producing capacity of the economy, as expressed in terms of productivity or more broadly in measures of competitiveness, while increasing value-added activity in the economy. The need to continually improve the value-added activity in the economy means that the changing industrial structure of the economy will be ongoing and that new industries must be developed that are characteristic of a modern knowledge driven economy. R&D has a major role to play in this and the policymaking system has increasing begun to recognise this in Ireland[63].

Productivity trends over the past decade largely reflect the role of new and multi-national owned industry rather than the traditional metal working sub-sector that would be most closely concerned with the development of the ocean energy sector beyond the initial experimental stages. Under the NACE classification of industrial activities, these industries are categorised in NACE sectors 28, 29, 313 and 351.[64] Table 6.2 provides data on the firms in these sectors. In summary, this indicates that there are in the region of 1,000 firms employing in excess of 26,000 people in related sectors of the economy. These firms had turnover of around €3.3 billion in 2002.

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[63] See ERA Steering Group (2004) *Building Ireland's Innovation Society: An Action Plan for Raising R&D Intensity to 2010*

[64] NACE 28 includes the manufacture of fabricated metal products excluding machinery and equipment. NACE 29 includes machinery and equipment. Section 291 (domestic equipment has been removed). NACE 313 is wire and cable, while 351 covers boatbuilding.

Table 6.2: Relevant Manufacturing Enterprises in Ireland

NACE	Description	No. of Enterprises		Turnover €m		Employees	
		2001	2002	2001	2002	2001	2002
281	Structural Products	273	323	656	698	5,404	6,005
282&3	Tanks, Containers	35	36	110	115	1,108	1,050
284	Forging, Pressing, Rolling	11	11	40	36	498	395
285	Treating and Coating	76	89	84	12	1,280	1,470
286	Cutlery, Tools	53	57	151	133	1,614	1,471
287	Other Metal Fabrication	112	123	395	441	3,285	3,286
291	Power Production/Utilisation	54	55	385	385	2,877	2,724
292	Other general purpose	127	116	777	738	4,771	4,266
293	Agricultural & Forestry	30	29	97	82	690	690
294	Machine tools	35	31	80	69	277	625
295	Special Purpose Machines	99	91	188	190	2,105	2,116
313	Wire and Cable	25	23	440	376	2,351	1,810
351	Ships & Boats	28	24	37	27	479	345
Total		958	1,008	3,440	3,302	26,739	26,253

Source: CSO *Statistical Bulletin*

A range of other industries that have grown very rapidly in Ireland in recent years could also be considered to be relevant to the ocean energy sector. These include industries such as electronics, control systems and communications. However, care needs to be taken with respect to assessing the impact of these sectors on the development of ocean energy. In a positive sense, they indicate that there are specific skills in Ireland and that Ireland is competitive in these sectors. However, there are two important negatives. The first is that firms in these sectors are mostly large multinationals with manufacturing plants in Ireland. R&D has been low in these sectors – relative to the operations of these firms in total but high relative to indigenous Irish firms – although there is now a specific policy drive to address this. Targets are being developed for Irish R&D expenditure up to 2010 with an overall target for R&D investment to amount to 2.8% of GDP.[65] The targets aim to raise expenditure by foreign owned firms in Ireland substantially with over 50% of forms engaged in R&D activity. Indigenous firms are also targeted for expenditure to rise from €319 million in 2001 to €825 million in 2010 and participation by a much greater number of firms. Along with sustained support from the public sector, a key area will ensuring that the required human resources are available. Current projections indicate a number of deficiencies in key areas. This is the second issue. The existence and rapid growth of these firms place a strong demand for the skills that will be required in the ocean energy sector and forces up costs.

Although these sectors are dominated by large foreign owned firms, smaller Irish firms exist. Table 6.3 provides an indication of the size of these firms. The data indicate two important features. First, the Irish firms are much smaller than the foreign owned firms in each of these industries in terms of both output and employment. Second, the Irish firms account for a much lower percentage of output than employment in each industry, indicating lower productivity. Together, these features suggest that the Irish firms in these industries are operating in different sub-sectors than are the foreign firms. Clearly, the existence of these industries indicates

[65] ERA Steering Group (2004) *op. cit.*

an important skill base to draw on. However, it is unclear to what extent the ocean energy sector would be able to compete to access these skills.

Table 6.3: Irish Firms in High Tech Sectors (2001)

NACE	Description	Enterprises		Turnover		Employees	
		Number	% of sector	€m	% of sector	Number	% of sector
30	Office machinery & Computers	42	58	530	2.7	2,420	11.7
31	Electrical machinery & Apparatus	138	73	537	22.4	5,703	37.8
32	Communication equipment	34	52	342	5.6	2,208	14.7
33	Precision instruments	75	54	339	10.0	2,775	15.4
Total		289		1,748		13,106	

Source: CSO *Census of Industrial Production*

Enterprise Ireland estimates that the Irish Metal and Allied Manufacturing Industry has an annual turnover in excess of €800 million and employs over 9,000 persons. In addition there are a number of smaller employers that would not be included in the EI database. Companies run the full scale from state of the art high technology high precision units selling internationally to smaller jobbing type operations that cater for a local market. The industry is probably strongest in the south east and south west while a number of high precision firms are located in the greater Dublin area. About 50% of product is successfully exported suggesting that these firms are internationally competitive. Indeed, a small subset of companies would be European or even world leaders in their particular market niches with expertise in stainless steel fabrication based on the foundation of the food and related processing industries. It is likely that some firms have spare capacity and would be interested in taking on fabrication or subcontract work to designs by others. Various stress/detail design analysis services are available from specialist companies. Numerous small high precision companies also produce components such as gears and fittings for international manufacturers. While shipyard facilities are limited, fabrication of up to 25m hull size should be possible even if it meant setting up simple 'out of town' fabrication facilities to ease component transport problems. In the electronics/software sphere there are approximately 14 sub-supply information technology companies and clusters of companies specialising in development of utility operating products in the fields of SCADA and other distribution and transmission systems. These are strong exporters to major international utilities.

While this is clearly a sector with a meaningful scale and potential, a number of points need to be made. Many of the enterprises are likely to be quite small, others are primarily engaged in service and repair while in other cases it is possible that the same company is listed under several different headings. Furthermore, with turnover of about €125,000 per person employed per annum, productivity in this sector is far below the industrial average for the economy. In 2001, this was just below €400,000 for all industrial sectors.[66] This feature is important since manufacturing industries in mature sectors in the Irish economy have been affected by the rapid rise in costs in recent years. Earnings in industry in Ireland are a multiple of emerging economies and have been growing rapidly in these sectors, being pulled up by the tight labour market and competition for skills from the high productivity leading sector that are

[66] CSO *Census of Industrial Production*

dominated by foreign owned MNCs. Earnings for workers in these sectors rose by an average of approximately 40% in these sectors in the 5 years 1998 to 2002.

In summary, therefore, while it would not be correct to dismiss the industrial base as a factor that could not aid the growth of the ocean energy sector in Ireland, there are distinct weaknesses. The relevant industries are not among the leading sectors of the economy, the sector is quite small in terms of overall employment accounting for only about 1.5% of industrial employment, and wage costs in recent years have threatened to undermine its competitiveness. As a result, this sub-sector cannot be considered to be a particular strength of the economy although the skills that would be required would be likely to be available.

Regarding materials, it is still unclear whether the principal material likely to be used in floating wave converters will be steel, concrete, or a combination of both. In contrast to the wind industry, it is unlikely that significant quantities of glass or carbon-reinforced plastics will be used, on grounds of cost. Because of its general utility, steel is used in most prototype floating converters. It is conventionally assumed that floating converters must be constructed in shipyards or dry-docks. Like wind turbines, once the master design has been developed and proven, it may be more cost effective to bring modules together at an assembly and launch point close to the final site. This raises the possibility of sub-system fabrication and testing at smaller facilities and final assembly using mobile craneage at a jetty, slipway or barge landing facility from which the completed units could be towed to site. Thus, provided the pricing was competitive, there would appear to be an option for local fabrication and import substitution. This, in turn, might require additional planning approval for shore based works in coastal areas groups. However, the scale of operations would of course be much smaller than what might have been envisaged in support of the offshore oil/gas industry in the past.

6.3 Infrastructure

The Electricity Network

The relevant hard infrastructure that will influence development relates primarily to the layout of the existing and planned electrical network and also, insofar as they are relevant, gas pipelines, seabed cables, harbour installations and other specialist facilities such as testing sites. However, it is important that other elements of infrastructure relating to the generating of knowledge, and the associated institutional infrastructure that is required to take and implement decisions, are also included in the assessment.

The electricity network has evolved to serve the needs of electricity customers and is strongest in the most populous areas of the country. This raises the possibility that there may be deficiencies in terms of the availability of some infrastructure where production is concentrated away from population centres, as would be the case with wave energy. Apart from a few locations, e.g. in the Shannon Estuary area and in

isolated coastal towns, the high voltage (≥110 kV) network does not reach the west coast, which is served by medium and low voltage distribution systems (10-38 kV).[67] At first sight these are major disadvantages and similar concerns have been identified as contributing to the relatively slow development of wind power deployment. However, there are differences. As ocean energy systems have not yet reached the maturity of wind power systems, connection to the high voltage network will not be an issue for some time. It would be necessary to put in place the required network infrastructure at the medium voltage level before connection at the higher level can be considered realistic.

Test Facilities

Both the UK and Denmark have prototype test sites. The difficulties experienced by Teamwork Technology (Netherlands) in trying to utilise the pilot AWS site in Portugal for test purposes, and by the Portuguese themselves with the distant Pico plant in the Azores, underscore the merits of having a test site close to home. In the absence of a national test site, would-be Irish developers are faced with permitting and providing their own site or using Orkney or a site in Portugal. In none of these locations would the wave regime necessarily match that envisaged off the coast of, for example, Kerry, Clare or Mayo. There is little point in envisaging a test site merely as an expensive status symbol. It has to serve two clear functions: to provide an Atlantic test point for serious Irish or overseas developers and to provide clear evidence of performance to decision makers and investors.

In the context of providing tank testing services internationally, HMRC has been quite successful over the past decade, usually as part of EU supported cross- frontier shared projects. There are limits to the facilities that can be maintained at Cork, however, and it is important to ensure that whatever standard is adopted does not militate, through lack of scale or excess emphasis of academic precision where are small marginal benefits, against laboratories whose test tanks and wave-making systems are not large enough to conduct in house tests on large scale models in the range of say 1:15 to 1:4. In other words, it is important that planned progress finds a balance between pragmatism in order to enable development and rigorous testing and reporting to underpin credibility. It is possible that reduced funding of cross frontier wave research by EU would pose something of a threat to the activity level at Cork, with consequential loss of expertise there. Cork has important advantages in terms of flexibility both for Irish and overseas developers, additionally it offers close proximity for Irish developers and it is logical that it should be linked through information sharing and co-operation with an Atlantic test site if one should be developed[68]. This would not preclude such a site being linked to other universities in respect of their own particular areas of expertise.

[67] The low voltage network is being upgraded from 10 kV to 20 kV throughout the country and this will facilitate acceptance of significant quantities of power from pilot plants should these materialise

[68] One issue of relevance to note is that where public money is being spent to fund research there is a strong argument that the results of the research should be provided publicly, albeit within predetermined agreements.

Ireland's strengths are not in heavy industry and in economies with a longer industrial history and expertise in large-scale metal working and machinery sector there is inevitably a deeper and broader skill and knowledge set that could be applied to overcome the challenges in the development of ocean energy. This raises a question as to whether Ireland should wait for this to happen in a more industrialised country and then access and apply this knowledge to the natural resource to produce energy. However, this is very much out of step with the approach of current industrial development policy in Ireland which emphasises the promotion of R&D and the creation of knowledge and risks locking Ireland into a role as a knowledge user rather than a knowledge creator with the potential to access the wealth that is inherent in knowledge creation.

6.4 Regulation and Support

The main entities involved in the regulatory field include:

- Commission for Energy Regulation (CER);
- Dept. of Communication, Marine & Natural Resources, particularly in respect of foreshore licencing;
- Local Authorities through the planning permission regulations
- Navigation Regulations

In general, the Irish regulations as they would apply to ocean energy are largely untried. However, there are reasons for concern given the experience to date in terms of the planning delays that have been experienced in many areas of development including renewable energy. However, there is no over-riding problem that should prove to be a binding constraint, provided technological developments required to reduce costs to viable levels can be achieved. Researchers and developers who have attempted to implement Ocean Energy (particularly wave) projects overseas have reported rather prolonged negotiations as being necessary, sometimes with a plethora of official bodies some of whom are unclear as to their exact roles as a result of being unfamiliar with such projects.

The CER regulations largely empower the network or grid operator to implement the Distribution Code or Transmission Code as appropriate. The experience of accommodating Irish wind energy projects on the system has shown the extent of problems that can arise, with the industry virtually stalled at a very low level of capacity. If lessons are learned, this may be useful where wave power is concerned, and may lead to practical revisions of the approach taken.

Full opening of the Irish electricity market will occur in 2005. The broad outline of the proposed pool market arrangement (with 30 minute clearing and dispatch regime) has been published and the detail is being fleshed out in respect of renewables. The CER has indicated that it favours supporting renewables *via* a mechanism outside of the market trading arrangements in order to allow true market signals to be seen, minimise market distortion, minimise system and market operating costs to the final customer, and provide greater transparency. A number of barriers to the deployment of renewable energy sources exist. These arise from the technologies themselves (and

therefore differ somewhat between technologies), the market, and differences between the established framework for conventional energy sources and that required to facilitate renewables. Particular barriers to entry that have been identified include:

- Lack of familiarity among decision makers.
- Lack of confidence in reliability of supply and performance
- Electricity supply industry attitude.
- Electricity supply infrastructure and operational characteristics.
- Remoteness from high demand areas.
- Administrative procedures.
- Financing.
- Weak industry lobby.
- Hostility due to Local Environmental Impacts.
- Taxation Policy.
- Uncertainty due to market liberalisation.
- Perceived high cost

Renewables are unlikely to penetrate the liberalised market at the rate required to meet environmental objectives in Ireland without further market stimulation and adjustment of the legal and administrative framework where necessary. In effect, the market and its source of supply will need to be managed to facilitate the greater participation of renewables on grounds of sustainability. To the extent that ocean energy can reduce or avoid these barriers its position is strengthened relative to other renewables. However, with the emphasis that is placed on the cost/kWh of production, utilities are unlikely to be seriously interested in ocean energy, until the cost/kWh produced by ocean technologies lies at or below that of wind energy.

Foreshore lease regulations were written primarily to cater for farms of sea-bed mounted wind turbines. It is important when dealing with wave energy that these are applied appropriately to ensure that only material relevant to the specific wave or tidal power project is dealt with in the EIS. It is therefore important to conduct an effective scoping exercise in advance. Gas pipelines and communication cables on the seabed are also subject to Foreshore leases and their positions are well established. Depending on the particular circumstances, methods exist for crossing these systems where necessary and these will be built into the terms of an ocean energy site lease issued by the Dept. of Communication, Marine and Natural Resources.

For a recent buoy installation, it took 15 months to process the necessary Foreshore Lease Application through DCMNR, following due process, albeit in a climate of constructive co-operation where the respective officials were concerned. Unless a ‘fast track’ system is introduced it appears that future installations would face similar bureaucratic delays. The merits of developing a prototype test site have been raised in a Marine Institute discussion paper and various researchers have called for the provision of such a facility. However, a number of decision factors have tended to cloud the issue, including the selection of a representative site and the availability of the required permits. These issues need to be clarified in preparation for a comprehensive development programme.

There is a need to ensure that Local Authorities and other local and regional development agencies build into their planning and development strategies recognition of the possibility of renewable ocean energy development taking place along their coastal margins. Many such areas now carry special designations that were applied without any evident consideration for their potentially restrictive effects on these important energy resources. The ability of individuals and special interest groups to frustrate planning applications, aspects of which they find unacceptable, has been amply demonstrated over recent years. The fact that new guidelines for wind farm development have had to be issued both in UK and Ireland is an indication of the need to restore balance in the process and it is to be hoped that ocean energy development can benefit from the experience.

Finally, a new start is required regarding power sale regulations and other instruments to incentivise investment, either through access, fiscal incentives or market instruments. At this stage, given the stated termination of the AER process, the replacement arrangements to be used for such agreements are unclear.

Ireland has the basic natural resources to develop substantial renewable energy industries but has failed to do so. The ocean energy industry has parallels with the wind energy sector some decades ago, in terms of being at a stage where the technology remains under-developed and non-viable commercially, but has huge potential. As a result, a development approach that mimics the approach adopted to-date offers little prospect of success. This leads to the following conclusions.

- First, Ireland needs to develop and implement a comprehensive and consistently applied policy framework for the development of ocean energy if it is to exploit the resources available and make a meaningful contribution to reducing emissions of green house gases in the longer term.

- Second, this approach must be wide-ranging, ensuring that all potential barriers to development – such as financial, risk, regulatory, access, the underdevelopment of markets to provide values for outputs such as the contribution to reducing CO_2 emissions, and knowledge-creation and technology-transfer – are addressed. Clearly, a start-stop approach or an approach that addresses only some of the issues – such as a stand-alone fiscal incentive – will be inadequate.

- Third, the availability of a natural resource is no guarantee that the economy will gain a competitive position although it provides an important input against which the opportunities for development can be assessed.

- Finally, the development of ocean energy should not be viewed in a sectoral manner. In other words, it can not be classified simply as a marine issue, or an R&D issue, or an energy issue. Rather, the approach required is one that views development as an enterprise-issue akin to industrial development policy as implemented in recent decades.

6.5 Factors Determining Future Competitiveness of Wave Energy in Ireland

It is clear that there will be differing views about the appropriate structure of the industry and how it should advance, but at present there is no forum within which constructive debate can take place. Credibility problems associated with a lack of comprehensive baseline standards for converter development, particularly where this impacts on decisions by investors or in the allocation of public funds, means that there is not a consistent stream of funds. This is seen as a primary cause of the sometimes indifferent rate of progress charted in wave converter development in most countries, and has led to an inefficient, intermittent or 'stop-go' rate of progress while research teams scramble around seeking to secure funding[69]. As a result of ongoing research, it appears reasonable to assume that an agreed set of standards will be in place perhaps within the next year or so.

Ocean energy is at a disadvantage relative to other renewable energy projects due to the demands to offer competitive and secure returns to attract the capital needed for development. The availability of investment funds will inevitably be better for projects that utilise technologies that are perceived to be mature and better understood and for which a clear policy framework exists. Ocean energy, being at the developmental stage, suffers in this respect. High level debt financing has been available where projects hold power-purchase agreements but much lower levels, only, are available to other projects. Where partial funding is to be available, under research, development and demonstration programmes, some participants report extreme delays in getting approval, even on relatively simple projects. Delays at an early stage in a research project may not be possible to make up later and can result in a serious loss of competitive position.

Knowledge of the underlying resource, its location and its potential for exploitation must be considered to be a key element in underpinning the credibility of the sector. International wave atlases and daily wave forecasts cover Irish waters at various resolutions and SPECTRUM, a near-shore wave model has been developed by HMRC. There is a lack of comprehensive tidal current information, particularly for the west coast. The result of this is that would-be ocean energy developers face a factual information gap when evaluating potential converter performance in Irish waters.

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[69] The Marine Institute has commissioned work to address this deficiency and HMRC has prepared a Development and Evaluation Protocol primarily for wave converters. This a multi-phase test programme that is rather wider than that advocated by the IEA Annex II report and includes:

- Phase 1 (Model Scale 1:100 to 1:25) involving Theoretical Review followed by monochromatic wave tests to verify the basic concept, confirm performance and response and conduct preliminary optimisation.
- Phase 2 (Model Scale 1:100 to 1:25) involving tests under panchromatic (irregular) waves to include all relevant converter variables and monitor their influence on overall response, performance characteristics and converter optimisation under relevant range of sea states.
- Phase 3 (Model Scale 1:10 to 1:4) involving large scale process tests in large scale tank or outdoor site testing to validate earlier model results with emphasis on power take-off and survival.
- Phase 4 (Model Scale 1:2 to Full Size) with final tests in an appropriate sea location.

The draft protocol also includes time and cost estimates for the respective phases.

In competitive terms, ocean energy has first to become competitive with offshore wind. Different factors will affect the extent and rate at which this is achieved. Wind turbines today are a multiple of the typical size a decade ago. Experience has shown that offshore wind turbines can be scaled up to the 3-5 MW machine size with relative ease and considerable economies of scale have been achieved. However, the same level of mass production with consequent economies of scale that has been achieved in the wind sector cannot be anticipated in ocean energy because of the technology.

Specific material consumption is a screening level method of assessing the relative cost of competing renewable systems. A simple initial approach is to consider wt/kW of rated capacity for units of roughly equivalent output, for example, for installation with an annual output of 20 GWh. Table 6.3 shows that the specific material consumption in wave converters is much higher (10 to 40 times) than for production wind turbines[70]. It should be noted that while much of this weight is likely to consist of low cost sand, concrete or water ballast, it is likely there will be environmental costs associated with the production of some of this material.

Table 6.3: Specific Material Consumption of Wind Turbines and Wave Devices

Unit	Weight (tonnes)	Rated Capacity (kW)	Wave Climate kW/m	Tonnes per kW
Wave devices				
Wave Dragon	33,000	7,000	36	4.7
Pelamis	380	750	55	1.97
Orecon	1,250	1,000		1.25
Wind turbines				
Vestas 2 MW	205	2,000	-	0.102
Vestas 1.65 MW	169	1,650	-	0.102
Bonus 1.0 MW	125	1,000	-	0.125

Source: Based on a review of manufacturers brochures and technical catalogues

The fact is that the physical characteristics and material contents of wave devices tend to grow more in line with output than is the case with wind. Because of this, while gains should not be ruled out, achieving competitiveness will be more difficult than experience with wind might initially suggest is possible. On the other hand, the fact is that the energy density of ocean waves is the highest among the renewable resources. Research, ongoing over the past thirty years, has led to technology developments that have reduced predicted costs by an order of magnitude over the past 20 years, but it is still uncompetitive with conventional generation and the most developed renewables. If Ireland is to exploit its ocean energy resources, wave power must become cost competitive with wind, solar and biomass with a long-term production price of 0.04 – 0.05€/kWh. Such investment as has been available to the industry for R&D purposes

[70] Material used in foundations for wind turbines and in mooring wave energy devices has been excluded from this table as the usage of this material can vary considerably.

has led to a downward cost/kWh projection, with time, to around 10€c/kWh.[71] However, more information is needed as it is often difficult to interpret the findings due to the range of wave conditions in which the converter may be operating and the completeness of the converter system pricings.[72] In common with virtually all technological innovations, prototype costs of wave converters are significantly more expensive than units designed for quantity production are likely to be. This represents the first major hurdle for developers and is the reason why many concepts proceed no further.

[71] Thorpe (2000) Paper presented to Fourth European Wave Energy Conference, Aalborg,

[72] Recent projections for the Aquabuoy system (based on 400 x 250 kW units installed in a 100MW wave farm) claim a cost of 4.5€c/kWh in a wave regime of 38 kW/m (18% capacity factor) with correspondingly reduced figures for more energetic wave regimes. Pelamis on the other hand is projecting approximately 11€c/kWh at a mean wave flux of 55 kW/m. At the other end of the scale a third converter, Wave Dragon is projecting costs of (4€c/kWh) using 7MW rated units under Atlantic conditions in a low wave climate of 36 kW/m by 2010-16. This is based on measured output from the 1:4.5 scale model and a series of assumptions on possible detailed improvements in output.

7 Policy Design and Development Programme

7.1 Role of Policy

The analysis of the ocean industry, its current stage of development and the barriers it faces, indicates that a number of policy interventions will be required. For a start, a clear commitment is required to implement the initiatives needed for the development of renewables. Prior attainment of public support is also vital, particularly since projects are often small in scale and their greatest impacts occur at the community level. This requires innovative awareness campaigns etc. Renewable energy schemes can stimulate local investment, employment and social cohesion, especially in rural or remote regions.

A clear long-term policy measure backed by a clear policy continuum to 'pull' development through each phase is critical. This will also require a continuous funding stream to avoid any project development shortcomings. It is important that this is achieved in conjunction with the development of an overall national energy plan, with clear official targets for the level of up-take of renewables.

As a supply chain is crucial to the development of an engineering-based industry, promotion policies to attract supply chain firms to develop or to locate in Ireland are critical. In addition, a flow of innovation from R&D on more cost-effective materials, design and construction methods are also important. Forfás, FAS and the industrial development agencies are ideally positioned to support this element of the developmental process, i.e., the commitment must be cross-departmental. In addition, the provision of commercial incentives along the supply chain will support linkages.

The commitment of government and local authorities to streamline planning and regulatory processes is critical, e.g. adequate pre-planning and planning for grid connections, licensing, financing and supply chain development. The first step in this regard is awareness on the part of policy makers. Also, an appropriate legal framework needs to be in place to support development. Lack of practical support at regional and local level to stimulate development of renewable energy projects, constrains project rollout.

Public grant mechanisms have been shown to be complex and can create significant lags in programme advancement. This can be prevented by employing dynamic and highly knowledgeable teams to undertake adequate due diligence. Clearer demarcation of roles and streamlining of the grant process would be a beneficial move. This would include outlining the procedures surrounding the disbursements of capital grants, the process for application, the conditions for obtaining aid, clarification on whether or not a grant can be revoked, and eligibility. The best way to address these issues is to ensure that an enterprise-oriented approach is adopted form the start with the focus on the development of the industry as distinct from energy production.

A willing financial community that recognises the key role of renewable energy technologies as a significant future proportion of the energy balance and that seeks to positively invest into it will be an important element of competitiveness. This requires

awareness and engagement programmes to encourage the development of appropriate financing systems, but improving the underlying credibility of the technologies as commercially viable methods of production is a very important issue. Lessons in this regard from the deployment of wind energy will prove important. A framework should be developed and financed to ensure early definition of standards and quality to improve the credibility of the underlying technologies and allow for comparative analysis to be undertaken reliably. This will enable the industry to show good practice in assessment methods from an early stage. In addition, an appropriate feed-in tariff structure and the provision of a long-term stable pricing structure will give additional impetus to wave and tidal energy technological developers. Alternatively, a green power market/green certificate trading also stimulates the market for technology suppliers.

As highlighted, the barriers to market development arise from thresholds, social and economic factors, and uncertainties about costs and future policies. Thresholds and non-linearities often exist in the early phases of a technology's development. High initial costs, coupled with uncertainties about the extent of cost reduction that will be achieved in the future, and uncertainty regarding the extent to which economic policies to decelerate climate change will continue to be developed and implemented so as to provide support to renewable energy technologies when developed, can present an appreciable entry constraint. This emphasises the needs for R&D and risk-sharing arrangements between the public and private sectors in the early stages of development, and why such policies may need to be complemented by market development policies once the R&D phase is over. The government, in this regard, should pay close attention to augmenting its understanding of the potential for cost declines and of the factors and interventions that might drive or constrain them by funding research within Ireland. This would ensure that the results are available and that they are appropriate to Irish conditions. Oscillating public priorities, inefficiencies in the policy making and implementation system institutional inertia will hamper the process of wave and tidal energy technology development.

7.2 Policy Design

The main conclusion that emerges from the review of policy is that ocean energy policy in Europe remains patchy at best and focussed on R&D. However, many countries have well developed policy programmes in relation to renewable energy and a few have developed strategies for wave energy. In some cases, these are being backed up with investment. Two aspects are important. The first is that the development of an effective renewables policy creates an environment from which ocean energy can benefit in the future although many of the provisions such as tax breaks and feed-in prices are not currently meaningful, given the economics of the ocean energy sector. The second is that the sustainable development of the industry requires a comprehensive approach, which builds on national strengths and addresses weaknesses, if sustainable wealth creation is to be achieved. Thus, intermittent policy initiatives, or an approach that is based simply on the belief that the natural resources will provide a competitive environment within which a sustainable wealth creating sector will emerge, are insufficient. Rather, policy must address all aspects of the

commercial environment including the creation of consumer demand for this energy source.

The fact is that Ireland is far from this situation at present. Irish renewables policy has not been successful in creating a vibrant industry and Ireland may find it difficult to reach stated targets. In addition to financial difficulties, the business environment remains difficult, the network is unsuited to the demands of renewables and the policy-making system in relation to energy still produces inappropriate decisions, such as additional peat burning capacity. This means that, while the natural ocean resources provide opportunities, the country is far from creating the environment within which these can be productively exploited. Economic history has shown that the exploitation of a natural resource is no guarantee of wealth creation for an economy and that the economy must be able to extract and hold onto the value that is created. As a result, in moving towards an optimal policy programme, it is essential that development takes place within a rational framework in order to avoid either under exploitation of the resources – as is currently the case with renewables in Ireland – or exploitation in a manner that does not result in the creation of wealth in the Irish economy.

While Ireland's natural resource represent a strong starting point, it is by no means an adequate basis on which a competitive industry can emerge, and any policy initiatives to stimulate such development must take place in a structured manner if they are to be successful. R&D is a very risky type of investment and an important issue is to minimise these risks. The evidence – from academic and theoretical research, observance of the structure and locations of leading business sectors and from the decisions made in key sectors such as financial markets – suggests that competitiveness and development is best achieved in industrial clusters and that industrial and related policies can have a constructive role to play in forming clusters.

The idea of clustering is examined in Appendix 9. Rather than a single typology, there may be an array of clusters in a given industry in different locations with different levels of sophistication. Global innovation centres are actually quite rare and restricted to a few industries. Many clusters focus on manufacturing, service functions or act as regional assembly centres. However, it is firms in the more advanced clusters that often seed firms in clusters in other locations to gain some advantage such as lower costs or market access. This is the model of MNC investment in Ireland in recent years. However, whatever the particular type of cluster that is likely or possible, the challenge for an economy looking to specialise in a particular industry is to move away from isolated firms to a cluster of related firms and then to deepen the cluster through increasingly higher-value activities.

The interactions and interdependencies that exist in a cluster mean that the existence of particular strength in one element – for example a natural resource – offers the opportunity for other elements to develop on the basis of this strength. In a sense, the potential role of policy is to make this happen, ideally by strengthening each point of the diamond. In terms of the standard model shown in Appendix 9, natural resources clearly enter into the factor conditions box and would have an important role in determining the structure of related and supporting industries. Thus, this model is appropriate to use in analysing the conditions that would lead to the emergence of a competitive ocean energy industry in Ireland. Indeed, to ignore parts of the model

would be to develop a policy programme based on a comparative advantage view of the world.

Having identified the appropriate sectoral objectives, policy will need to aim to create a core in Ireland around which an industrial cluster can be developed. The natural resource offers the opportunity for this. However, this is only one part of the requirements if a successful industry is to emerge in Ireland. The industry needs to be built around a core set of activities with expertise in R&D. Each element of the required supporting infrastructure must be developed. Finally, the approach taken must aim at a high rate of development that places Ireland at the forefront of development in key areas

7.3 Outline of a Development Programme

A development programme for this industry needs to be undertaken in a number of key stages with objectives and indicators set for each. This process is captured in Table 7.1. An important element of this is the establishment of a project management unit during 2004/05 with responsibility to undertake subsequent development work. Initially, this would centre on research and co-ordinating activity but would subsequently move to be a much more enterprise/industry development activity.

Table 7.1: Policy Objectives, Actions and Indicators

	Objective	Actions and Indicators
1	Identify best option for development	Analysis of the potential and opportunities Agreement among stakeholders
2	Decision to proceed	Agreement by policymakers Public statements of intent
3	Clarify of responsibility	Assignment of responsibility for development Identify institutional arrangements and funding requirements Obtain indications of agreement to co-operate from key players
4	Create a detailed plan for development	Outline a detailed development programme and provide a clear outline of action Research available resource Identify potential blockages e.g. policy, legislative, regulatory etc. and indicate actions required
5	Develop funding	Assign a multi-annual R&D budget Commitment to provide funds going forward
6	Investment in R,D,D	Produce structured programme of R&D involving selected centres of knowledge Provide funding to approved R&D programmes Provide feedback and disseminate results Provide funding to private R&D and access results
7	Initiate pilot project	Identify appropriate pilots Secure funding
8	Install pilot projects	Install 3 projects in wave (and possibly 1 in tidal stream). Assess results

9	Initiate Production	Establish conditions for private sector production – set conditions for access, feed-in tariffs, fiscal assistance etc.
10	Investment in productive capacity	Ongoing investment and production by the private sector Monitor and evaluate response to production incentives
11	Industrial development	Promote and monitor uptake of Irish systems Provide assistance in marketing etc. Ongoing R&D assistance

An important element in this outline is an appropriate timeline. This is indicated in Table 7.2. The overall objective is that by the end of this period, Ireland will be at the forefront of this industry and will be in a position not only to exploit the energy producing potential of the natural resources that are available but, most importantly, the intellectual property that will be needed for the industry to develop in a number of countries.

The timeline is based on three stages of development covering the period 2004 to 2020. In the first stage, roughly covering the years 2004 and 2005 when objectives 1 to 5 are to be achieved, the main targets are to get agreement on the optimal way forward and to ensure that the basic requirements such as the policy programme, institutional requirements and a budget for development are agreed and implemented. It should be noted that the first two objectives are covered by the main content of this report, assuming it is adopted by policymakers. The second stage covering objectives 6 to 8 is focussed on promoting research, development and deployment (R,D,D) and ensuring that this is undertaken in a co-ordinated manner. This involves not only technical research but also research into the evolving commercial realities of the technology and into the resources that are available in the economy. This stage would also see the implementation of pilot projects and the assessment of the results. Much of this work needs to be undertaken in the years 2006 to 2008 but should also be maintained until private investment in capacity is well established and an internal growth dynamic emerges. The third stage is targeted at achieving private investment in production and the development of the industry, although it also foresees that there will be ongoing incentives to promote R&D. This stage involves energy production for the feed-in to the Irish grid and also the export of technology that has been developed in the economy. At this stage, the institution that has been charged with the development of the industry will have become, in effect, an enterprise focussed agency comparable in outlook to existing enterprise agencies.

Table 7.2: Timeline for Policy Development and Implementation

Year / Objective	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
13																	
Total MW Installed				0.5	1.5	3.0	5	8	14	22	32	45	62	85	120	160	200

Note: The capacity installed in 2007-08 relates to 3 pilot projects of 0.5MW each

A number of public sector institutions and private sector entities should be involved in realising this programme. Table 7.3 identifies the main players at each stage of development. Once the Ocean Energy Development Unit is established, neither the Marine Institute nor SEI is identified as having direct responsibility. However, it is envisaged that both of these agencies will be involved in the ongoing development of the sector and that the OEDU is likely to be based in or between these agencies.

Table 7.3: Objectives, Stakeholders and Institutions Responsible

	Objective	Stakeholders and Institutions Responsible
1	Identify best option for development	Consultants, Marine Institute, SEI, DCMNR
2	Decision to proceed	MI, SEI, DCMNR, Dept. of Finance, DOELG, CER, ESB/IPPs
3	Clarify responsibility	MI, SEI, DCMNR, DETE
4	Create a detailed plan for development	Ocean Energy Development Unit (OEDU), ESB/IPPs, CER, Dept of Finance, Universities
5	Develop funding	OEDU, Dept of Finance
6	Investment in R,D,D	OEDU, Universities and research centres,
7	Initiate pilot project	OEDU, Universities and research centres, ESB/IPPs, CER,
8	Install pilot projects	OEDU, researchers ESB/IPPs, industry
9	Initiate Production	OEDU, private investors, financial sector, Dept of Finance, ESB/IPPs, CER
10	Investment in productive capacity	Private investors, financial sector, Dept of Finance, ESB/IPPs, CER
11	Industrial development	OEDU, DETE

The Department of Finance would be involved also at a number of stages, principally in the allocation of funds for research and in the decision regarding the level of support to be given to electricity production using this technology. It is possible to provide some initial estimates of the cost of this programme excluding any funds for providing a subsidy to producers. This is done in Table 7.4.

Table 7.4: Programme Costs

1	Identify best option for development	No additional costs
2	Decision to proceed	No additional costs
3	Clarify responsibility	Staff reallocation costs - €100,000
4	Create a detailed plan for development	Some additional administrative costs - €200,000 Consultancy fees - €200,000
5	Develop funding	No costs at this stage
6	Investment in R,D,D	€3 million
7	Initiate pilot project	No additional costs
8	Install pilot projects	€6 million
9	Initiate Production	No additional costs
10	Investment in productive capacity	Costs to be borne by private investors plus fiscal supports
11	Industrial development	€1 million

It should be noted that it is assumed that many of the operating costs of the OEDU are met from within current budgets by reallocating responsibilities so that the additional costs identified are not the full costs of undertaking the work. The figures are based on the following indicative costs:

- Large scale deployment of machines @ €2 million per MW;[73]
- Prototypes twice as expensive per MW as machines; 3 prototypes with 500kW each giving capital cost of €6 million;
- Non-capital costs of €2 million in R&D prior to 2009 and €1 million thereafter

This estimate provides a total programme cost of €10.5 million. Most of this – probably about €9 million under the current timeline – would be spent in the period up to 2010 with some ongoing costs.

The costs to the State from being involved in supporting production cannot to be identified with any degree of accuracy at this stage as they will depend on the rate of technology development which will govern the cost of ocean energy. However, some indicative estimation can be provided. Assume that production is undertaken as outlined so that the ocean energy sector provides 2.5% of Ireland's electricity needs in 2020 i.e. about 1,000 GWh. Assume that technological development means that the 1.5MW of productive investment takes place in 2009 as identified and on the basis of a price paid being the existing BNE plus 6c per kWh. The same price is paid in 2010 and thereafter technological improvements mean that the price falls by 0.5c per kWh per annum. This would give a price in 2020 of BNE plus 1c for ocean energy. On this basis, the annual 'cost' rises to €10 to €12 million per annum after 2015. The total cost for the production outlined up to 2020 would be about €80 million. However, it must be emphasised that this is not a cost to the economy and not necessarily one to the exchequer. The subsidy could be provided by means other than exchequer funds e.g. a levy on electricity. Furthermore, the policy will only be implemented if the benefits to the economy exceed this payment. The analysis above indicates that this would be the case once the total cost fell below 10c per kWh.

7.4 Incentivising Activity

As well as securing funding, the success of this programme will depend to a considerable extent on the ability of the project management unit to co-ordinate activity – including ensuring that the results of research are disseminated – and on removing obstacles to development. In this respect, planning is a key issue that has the potential to greatly increase the risks that are associated with investing in this emerging sector. In addition, undue delays would greatly inhibit Ireland's ability to

[73] Estimate based on Bedad, R. and G. Hagerman, (2004) *Offshore Wave Energy Conversion Devices*, E21 EPRI WP-US-004, Washington DC: Electric Power Research Institute; and Royal Academy of Engineering, UK (2004) *Costs of Generating Electricity*. A questionnaire distributed to relevant personnel during the preparation of this study requested estimates of production costs. The replies indicate that the costs are expected to fall quickly within the first 5 years of a programme as the quantities of machines being produced increase. While there was considerable variation in the cost estimates for the initial prototypes, the estimates converged to the range €2.5m to €2.25m per MW within 5 years. It was estimated that the prototypes could cost 2 to 3 times this much.

emerge as a leading centre for the industry. As a result of the importance of this issue, the consultants conclude that development should take place within Strategic Development Zones (SDZs) identified for the purposes. Initially, these would be used for the pilot projects but should be developed to simplify the procedures facing potential investors in the sector. While planning is the key issue in this context, these SDZs could also be used to identify areas where specific incentives for the industry would be allocated. An important result of the identification of these SDZs would be the signal to key individuals in Ireland and abroad, that the country is serious about realising its potential in this industry.

Experience with the wind sector indicates that the mechanisms used to encourage investment will be very important. Four options are worthy of consideration.

- Supply Push – Competitive Tender as used in the Alternative Energy Requirement Programme. The question of how appropriate it is to use the AER or similar mechanism as a vehicle to bring ocean energy technology on stream in Ireland needs some consideration since the expectation that a pilot or prototype plant should be seen to pay for itself is unreasonable. An AER type competition could only benefit a converter system that has already passed its developmental phase and is ready for production and even then the effectiveness of this approach is open to question particularly in the context of an objective to foster an Irish based wave power industry.
- Supply Push – Fixed Feed Tariff mechanisms have been widely used in countries such as Denmark, Germany and Spain with impressive results and low administrative costs. It is predictable and consistent for developers, reduces their risk and costs and enhances borrowing capability. The Portuguese model involves a high fixed feed tariff for an initial limited tranche of wave resource development. For a developmental technology it has much to commend it as it provides clear goal posts for all concerned.
- In a Supply Push – Production Credit system (corporate) owners of renewable projects earn a payment or tax credit for each kWh supplied to the network from their facility. If no means to decrease the premium exists customers may pay higher prices than necessary and unless a limit is imposed on total capacity, continued success may put pressure on networks and result in constraining off. Realistically, this mechanism is more appropriate for larger scale projects such as multiple wind farms and may not be suitable for ocean energy projects in the early years.
- Finally, a Demand Pull – Renewable Obligations and Tradable Credits systems relies on renewable obligations targets that are imposed on supply companies or their customers which are obliged to make wholesale purchases of the targeted percentage or pay a penalty for the shortfall. In addition to the price of the electricity sold to the supply company, generators may earn tradable green certificates that reflect the benefit of producing the electricity from renewable sources. These systems favour least cost mature technology as opposed to developmental technology so separate technology bands may have to be introduced.

The CER has indicated that it favours supporting renewables *via* a mechanism outside of the market trading arrangements. This is in order to allow true market signals to be seen, market distortions, system and market operation costs to be minimised to the final customer and provide greater transparency. This approach appears to argue against the simple fixed feed tariff arrangement endorsed above. However CER has also to think in terms of over one thousand MW of installed renewable capacity whereas the object here is to examine the most effective way of getting ocean energy on to the system at all for developmental purposes and laying the ground if possible for a wealth creating industry. It would be relatively easy to signal change in support mechanism after a number of years if it became evident that this was necessary.

It is possible to divide policies in this area broadly between those that aim at a particular quantity of electricity from renewables and provide the incentives that are believed will achieve this, and price incentives that set the price and accept what is produced. The operation of different approaches to incentivising the development of renewable energy sources has been examined by Menanteau *et al*[74]. Having examined experience in a number of EU countries the authors conclude that while price-based and quantity-based approaches to proving incentives would be comparable methods to achieve targets in an ideal world, this is not the case when uncertainty is taken into account. If priority is given in policy to controlling the cost of the incentive scheme rather than the attainment of targets then the quantity-based approach, as has been used in the AER process in Ireland, is the most effective. In contrast, when priority is given to achieving installed capacity, price-based approaches such as the fixed feed-in tariff have given far better results. The difference is explained by the attraction of fixed prices, which project developers see as ensuring a safe investment with better predictability and a stable incentives framework.

It is arguable that in a system of fixed feed-in tariffs, there might be less incentive to lower costs, since drops in production costs are not automatically reflected in the feed-in tariffs but the authors find that this conclusion is not automatic. If a greater volume of new installed capacity is achieved it can lead to cost reductions through technological learning on the part of national manufacturers. Furthermore, feed-in tariffs enable manufacturers to invest more heavily in R&D and to consolidate their industrial base. This is evidenced by the fact that Denmark, Germany and Spain, who have used this approach, are the world leaders in wind turbine production. On the other hand, bidding schemes, such as are favoured by France and Ireland, are not conducive to a sustainable dynamic process of cost and price reductions. Thus, while the relative non-competitiveness of ocean energy would appear at first hand to suggest that feed-in tariffs within almost any range that is likely to be implemented are irrelevant, the analysis suggests that a policy programme that combines narrowly targeted financial aids to R&D combined with a broad development programme based on incentivising feed-in tariffs offers an appropriate long term framework for development of renewable energy sources.
This brief review suggests that whichever approach is adopted, it appears unlikely that the appropriate mechanism for the development of wave energy will be the best for

[74] Menanteau, P., D. Finon and M.L. Lamy (2003) 'Prices versus quantities: Choosing policies for promoting the development of renewable energy'. *Energy Policy*, Vol. 31 (8) pp. 799-812

technologies, such as wind, that are at a different stage of development[75]. This is a key issue that has not been reflected in Irish policy, which has adopted single platform approach to development.

The timeline set out is clearly ambitious but it is designed on the basis of two principles that the consultants consider are key if a successful policy programme is to be developed. The first is that there is little prospect of success if a half-hearted approach is taken. While this industry will not necessarily emerge with strict a winner-take-all structure, this will be present to some extent so that it is necessary for Ireland to be at the forefront of developments if it is to be in any position to realise the potential that exists. The second is that a highly co-ordinated approach is essential with clear commitments by all interested parties including the public sector and its agencies if there is to be a successful outcome. Within this, the creation at an early stage of a single institutional entity with clear responsibility for the development of the industry and funded appropriately is very important. Together, these two vital requirements mean that Ireland will have the opportunity to develop the required expertise and competencies, including economies of scale, to be at the forefront of the industry, and will have the ability to avail of this opportunity.

[75] The Alternative Energy Requirement (AER) competition was used as a mechanism to bring forward the introduction of an ocean energy (wave power) project but did not prove successful.

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Appendices

List of Appendices

Appendix 1: Some Characteristics of Wave Power

(1) Wave power is an irregular source of energy that varies significantly with location and time. It is however more predictable than wind.

(2) There can be a factor of 2 between highest and lowest yearly mean wave energy value at a particular location and it can vary ten-fold from one week to the next.

(3) The occurrence of storms inflates the mean value. Wave energy in one storm can be five times higher than the mean value for the week of the storm.

(4) Wave energy in groups can be up to fifty times the wave energy level between groups.

(5) Wave converters moderate the incident wave power in terms of frequency, direction and energy level extracted.

(6) Wave energy records may be averaged on an annual, monthly, weekly, daily, hourly, minute or second basis, the longer the time base the smoother the curve. Conversely a short time base will reflect the influence of wave groups and waves of differing size. (Refs. 28, 29)

(7) Because of the arrival of wave flux in wave groups or 'packets' rather than as a smooth sequence of waves it is important for converters to be capable of spilling excess energy and, if possible, utilising some of the excess to tide over the following slack period between groups. This may come from the momentum of the converter as it moves in heave, pitch or surge or from the existence of a small reservoir as in the Wave Dragon.

(8) As noted above the wave power level will in general be less than the mean value due to the inclusion of storms in the latter. Converter design has to be such that it can go on extracting power in these lower regions while still being capable of riding out storms.

(9) A series of persistence curves relating power levels to the durations with which they occur may be drawn up from wave records. In general, the lower the power level the longer the duration for which it will persist.

(10) Although more energy is available at open ocean sites, it requires a converter with much broader efficiency curves than at a near shore site to extract the same percentage of total energy. The implication is that the nearshore site may offer a better overall total efficiency in addition to the economic advantage of reduced capital investment necessary to assure survivability.

Appendix 2: Wave Energy Converters

This section is limited to devices for which prototypes have been built and tested, or have undergone sufficient laboratory scale tests for there to be sufficient data available to draw conclusions about their likely power output and costs. Many hundreds of device concepts have been proposed but very few have reached the stage of prototype deployment. Much has been written regarding the expected performance of as yet unbuilt device concepts but until a device has been tested, at the very least at model scale in the laboratory, then published claims regarding its power output must be treated with caution.

A2.1 Oscillating Water Columns (OWCs)

LIMPET

The LIMPET (Land Installed Marine Pneumatic Energy Transformer) is a shoreline Oscillating Water Column wave energy device. Its collector is built into the shoreline near Portnahaven on the island of Islay and comprises sloped reinforced concrete triple chambers with an opening beneath the waterline into which wave driven water flows and ebbs. The device uses a Wells turbine - a self-rectifying turbine that rotates in the same direction irrespective of the direction of airflow through it. The LIMPET is a successor to a 75kW prototype unit built by the Queens University of Belfast (QUB) with the support of the DTI. This device was commissioned in 1991 and operated as a research tool for a period of eight years until it was decommissioned at the end of its useful life in 1999. The LIMPET was built in 2000 with EU funding by a consortium led by QUB. Monitoring was carried out on the device until the summer of 2002. The device has a nameplate capacity of 500kW, but the monitoring results indicate that the power output of the device has been considerably less than anticipated (an average of 21 kW compared with target of 200). The reasons for this were identified as; 1) the sea floor profile differed from that identified in surveys prior to construction and caused a greater attenuation of the energy reaching the device's inlet, 2) problems during construction prevented the excavation of a tapered gully, 3) the design of the acoustic attenuation system reduced the overall efficiency of the turbine and 4) the low overall load factors on the generator and inverter mean that losses from these are relatively high. The device developers contend that with more appropriate equipment selection and design, the device could have been made to yield its design output. No capital or operating cost data have been published to date.

However, it is generally thought that, based on the analyses conducted by Thorpe in 1992, that shoreline OWCs are unlikely ever to achieve commercially competitive electricity prices because of the combined effects of attenuation of wave energy by the seabed and the high civil engineering component of the capital cost.

Offshore OWCs

Several offshore OWC device concepts have been put forward, usually consisting of a buoy containing an oscillating water column within it. The combination of higher wave power available further from the shore and the lack of civil engineering

involved means that they have a better chance of eventually being able to generate commercially competitive electricity. However, these same factors also mean that survivability is more of an issue, because of the more energetic wave climate, and that cabling to carry the generated power ashore is likely to be more expensive. These devices are currently in an earlier stage of development than are shoreline OWCs. Offshore navigation buoys are routinely powered by OWCs, but these are small, generate only enough power for a light and are used in an application where the cost of power is not an issue.

IPS buoy

The IPS buoy was developed by Inter Project Service AB of Sweden. Instead of using the motion of the water column to drive an air turbine, it drives a piston which in turn drives a generator. The device has been tested in the sea and the developers claim that their device is capable of generating electricity at a price as low as 3.5 US¢/kWh. No published test results appear to be available to confirm this. The device does not appear to be undergoing further development and a successor device concept, the AquaBuoy, a combination of the IPS buoy and the hosepump, is now being promoted by AquaEnergy Group Ltd of Washington State USA. More information can be found at www.ips-ab.com and www.aquaenergygroup.com.

Sloping IPS Buoy

A team at Edinburgh University has developed what they call a “sloped IPS buoy”. This is still very much at the research stage and no sea trials have been conducted. More information can be found at www.mech.ed.ac.uk/research/wavepower/

Plymouth MOWC

A team at Plymouth University developed a multiple OWC buoy originally called the “Sperboy” under an EU funded programme. It consisted of a set of tubes of different lengths resembling a set of organ pipes that extend to different depths beneath the surface. The rationale behind this was that each tube would have a different resonant frequency enabling the device to extract energy over a wider range of frequencies than would a single OWC. Tests at sea were conducted but the device came away from its moorings twice, the second time leading to irrecoverable damage. Insufficient data were obtained to confidently estimate the power output of the device. The development of this device is currently being taken forward by a Plymouth University spin off company Orecon (www.orecon.com) which hopes to deploy an array of devices off the South West of England. No economic analysis has been published.

Mighty Whale

This Japanese device is a large floating OWC. Construction of the prototype cost about 1.0 billion Japanese Yen in 1998[76]. Tests carried out over a period of 970 days in a wave climate averaging 5 kW/m over a whole year (minimum 2kW/m in February, 10kW/m in August) gave an average output of 5.85kW[77].

[76] See www.mext.go.jp/english/news/1998/07/980704.htm

[77] Presentation given by Hiroyuki Osawa at IEA Workshop, Brighton, 30 October 2002

A2.2 Overtopping devices

Floating wave power vessel

This device is being promoted by Sea Power International AB of Sweden. A sea test appears to have been conducted but cost and output data do not appear to have been published.

Wave Dragon

The Wave Dragon is an offshore wave energy converter of the overtopping type. It consists of two wave reflectors focusing the waves towards a ramp, a reservoir for collecting the overtopping water and a number of special low head hydro turbines for converting the pressure head into power. In the period from 1998 to 2001 extensive testing on a scale 1:50 model was carried out. During 2003, testing has started on a prototype of the Wave Dragon in Nissum Bredning, Denmark (wave climate in scale 1:4.5 of the North Sea). The prototype has been grid connected in June 2003 as the world's first offshore wave energy converter. During the coming 2 years an extensive measuring program will establish the background for optimal design of the structure and regulation of the power take off system. Planning for full-scale deployment of a 7 MW unit within the next 2-3 years is in progress[78]. Power output data are in the process of being collected.

A2.3 Other devices

Pelamis

The Pelamis is a floating near/off shore device composed of cylinders linked by hinged joints with the whole device spanning successive wave crests. The wave-induced motion of the joints is resisted by hydraulic rams that pump high-pressure oil through hydraulic motors. The device is being developed by Ocean Power Delivery Ltd of Edinburgh. It is intended to be moored in 50-60m of water typically 5-10km from the shore. Several devices can be connected together and linked to shore through a seabed cable. The device has undergone a series of model and prototype tests at increasing scale culminating in a 750kw full-scale prototype that has recently finished construction and is being tested at the Orkney test centre this year. This prototype is 120m long and 3.5 m in diameter and will contain three Power Conversion Modules each rated at 250MW. Each module contains a complete electro-hydraulic power generation system.

Previous to this a $^{1}/_{7}$ scale prototype has been tested and power output and cost estimates have been published based on this. The Pelamis currently appears to be the

[78] H.C. Soerensen et al (2003), "Development of Wave Dragon from Scale 1:50 to Prototype" Fifth European Wave Energy Conference, Cork

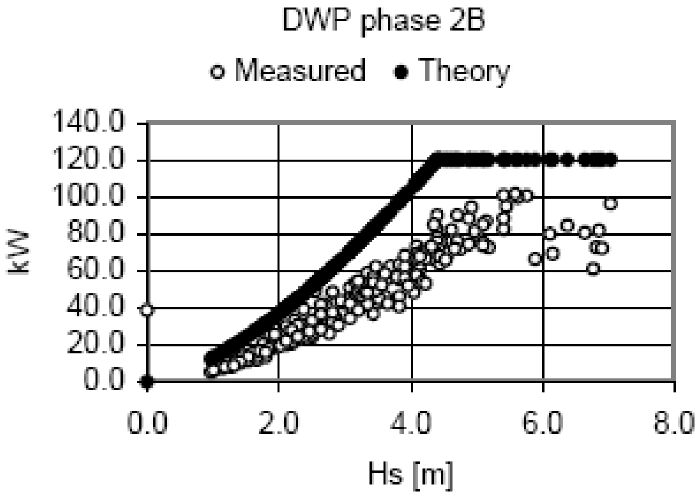
most developed wave energy device. A report has been published giving a detailed analysis of the performance and economics[79].

Frond

The frond is a near shore device intended for water depths of 10 to 20 m. It is being developed by The Engineering Business Ltd of Northumberland, UK. It consists of a paddle hinged at the seabed and protruding into the air-water interface. Incident waves cause the paddle to oscillate and this drives hydraulic cylinders which in turn drive a hydraulic motor and generator. The device has currently undergone laboratory scale tests and large scale tank tests are planned.

Danish point absorber

The Danish Point Absorber is a floating buoy reacting against the seabed. The buoy is connected to the seabed by a polyester rope. The buoy moves up and down relative to the seabed activating an onboard hydraulic pump. Survival tests were completed in a tank at the Danish Maritime Institute June 1998. Energy production tests completed June 1999. Open sea testing at scale 1:10 was completed January 2000. Danish Wave Power Concept Catalogue reproduces the graph below[80].



Archimedes wave swing

The Archimedes Wave Swing (AWS) is a submerged piston & cylinder that moves in response to changes in pressure caused by waves at the surface. A prototype device is in the process of being tested off the coast of Portugal. More details can be found on www.waveswing.com. Results from the tests are not yet available.

79 *Pelamis WEC - Conclusion of Primary R&D Final Report*, DTI Report V/06/00181/REP, URN 02/1401 downloadable from www.dti.gov.uk

80 Graph taken from Danish Wave Power Concept Catalogue (Bølgekraftforeningens Konceptkatalog) November 2002 - available from www.waveenergy.dk.

A2.4 Irish Devices

McCabe Wave Pump

This device is being developed by Hydam Technology Ltd of Killarney, Co Kerry, and is similar in principle to the Pelamis but instead of cylindrical sections it consists of two pontoons connected by hinged joints to a central platform fitted with a submerged damping plate. The pontoons move only in one plane whereas in the Pelamis they move with two degrees of freedom. Tests have been conducted by HMRC in the mouth of the Shannon. Results have not yet been published. The developers are promoting the device mainly for supplying potable water (obtained via reverse osmosis) for isolated island communities, which suggests they do not currently expect it to be able to deliver competitively priced electricity in a developed country.

Wave bob

This converter is being developed by Wavebob Ltd., a Wicklow based company and has been undergoing mathematical analysis and tank testing. Details are commercially confidential at present but it is understood that the project has received funding from a number of industrial and other agencies and that work continues on a specific programme.

Table A2.1: Summary of Wave devices

Device	**Annual output**	**Capital Cost**	**Annual Operating Cost (fixed component)**	**Annual Operating Cost (variable component)**	**Lifetime of plant**
Islay Limpet	21 kW average compared with target of 200				
Pelamis - 1st 25 MW farm	90 GWh “yield” × 95% “availability” = 85.5 GWh	27.5M GBP(2002)	1.55M GBP(2002)/y	Site lease 2% of revenue + reactive power charge 0.43p/kVARh	15 y
Pelamis - 2010 25 MW farm	as above	19.3	0.6	as above but with no reactive power charge	as above
Frond - farm of 10 500kW machines	1178MWh/y	13.96M GBP(2003)	275k GBP(2003)		not stated

Appendix 3: Quantification of Shoreline Wave Resource (LIMPET Type)

Table A3.1: Ranked Practicable Shoreline Wave Power Resource Versus Price per kWh using an 8% Discount Rate (Irish sites)

Site No.	Name	Ranked Shoreline Flux (Elec) kWe/m	Projected Installed Capacity MW	Annual Output GWhr	Unit Price €c/kWh) 8%
20/24	Deelick	7.04	36.2	131.6	23.1
20/10	Killurly	7.13	17.8	66.6	22.7
3/10	Rosson	7.15	17.9	66.8	22.7
17/12	Carrickfadda	7.22	27.1	101.2	22.5
17/10	Castlepoint	7.22	5.4	20.2	22.7
17/2	Kerry Hd. (Castle	7.22	21.6	80.9	22.5
6/20	Downpatrick Hd.	8.04	8	30.1	20.8
6/18	Togherclogheen	8.16	5.1	19.1	20.6
6/2	Moyteague	8.4	10.5	39.3	20.0
1/9	Ardnamalin	9.19	6.9	25.8	18.8
1/10	Malin Hd.	9.19	6.9	25.8	18.6
1/5	Crocnaclogher	9.71	12.1	45.4	18.06
20/20	Beenaman S.	9.71	30.4	113.5	18.06
24/9	Balteen	9.85	4.9	18.4	17.9
16/8	Duggerna	9.86	6.2	23	17.9
3/11	Glenlough	10.08	6.3	23.6	17.7
3/9	Malinmore	10.32	25.8	96.5	17.1
6/1	Dooega	10.47	6.5	24.5	17.1
3/1	Darbys Hole	10.54	13.2	49.3	16.9
3/2	Tullaghan	10.54	6.6	24.6	16.9
7/2	Lackmeeltaun S.	10.86	6.8	25.4	16.3
7/3	Lackmeeltaun N.	10.86	16.3	60.9	16.3
6/3	Benmore	11.11	22.2	83.1	16.3
17/14	Spanish Pt.	11.21	2.8	10.5	16.3
6/6	Benwee	11.39	2.8	10.6	16.1
6/15	Renaglana	11.39	11.4	42.6	16.1
6/7	Annagh	11.55	14.4	54	15.9
6/8	Termoncarragh	11.65	8.7	32.4	15.9
6/11	Glenlara	11.55	8.7	32.4	15.9
6/12	Erris Head W.	12.78	12.8	47.8	14.95
6/9	Scotch Port	12.78	6.4	23.9	14.95
6/10	Doonan	12.78	6.4	23.9	14.95

Table updated from "ESBI-ETSU (1997) Total Renewable Energy Resource in Ireland. Report to EU DGXVII Contract XVII/4, 1030/T4/95/IRL"

Appendix 4: Tidal Stream (Current) Systems

A4.1 Introduction

Interest is the harnessing of the currents that are a feature of the mass movement of the sea water that gives rise to the changes in the tidal level has increased in recent years. In the general sense the movement is diffuse and may be contradictory but in particular areas e.g. around particular head lands or between islands or in the vicinity of underwater shallows or depressions, it can speed up. This can lead to well known races, overfalls and standing waves particularly when the current runs counter to the wind direction. In such cases the sea surface will also be relatively turbulent.

Numerous oceanographic studies have been carried out using computer models and sample calibration measurements combined with bathymetric survey data for a variety of purposes. The Admiralty tidal stream atlas has been available as a tool for surface navigation. However, neither of these data sources can be considered suitable for determining the siting of tidal stream converters save in a very preliminary way. If the velocity profile between bed and surface has been measured over a sufficient period for marine biological transportation studies the information might prove useful but recent studies suggest that much more detailed measurements will be required at any site where tidal stream power conversion is contemplated[81].

A4.2. Tidal Stream Converters

Six tidal stream converter systems have been described recently in varying levels of detail and may be summarised as follows.

Type	Horizontal Propeller	Oscillating Vane	Horizontal Propeller	VACT	VACT	Vortec
Name	Seaflow	Stringray	Strom Kubold	ENEMAR	Salter	Vortec
Country	UK	UK	Norway	Italy	UK	N. Zealand
Installation	Bristol Channel	Yell	Hammerfest	Messina	-	-
Current m/s	-	-	< 1.5	1.2 – 2	4	2.5
Depth. M	20/30	-	-	20		35
Offshore Distance	-	-	-	150m		200
Diameter	-	N.A.	20m	6m x 5m	50m	
Rating	-	-	300kW	25kW	12MW	1.3MW

[81] The complexity of the flow pattern between sea surface and bed has been described: see Holmes, 5th European Conf.; Salter, Wavenet

Seaflow

The Seaflow project was constructed by Marine Current Turbines Ltd (MCT) [www.marineturbines.com]. Their concept is a pile mounted horizontal axis turbine resembling an underwater windmill- probably the simplest tidal stream energy concept although not necessarily the simplest to develop. A prototype machine has been built, with EU and DTI funding, off Lynmouth in the Bristol Channel. This is currently producing data that will be published in a project report when the monitoring is completed but are as yet unavailable. The Seaflow project involved design and construction of a 3m diameter monopole mounted 300kW single motor pilot plant off Lynmouth U.K. Each monopole is socketed into the seabed and extends above the surface to allow overwater access by retraction of the turbines upward for maintenance. The depth ranges envisaged are 20m-30m with a single rotor and 15m – 30m with a double rotor. In practice it is projected that the turbines will be arranged in rows of about 10-20 machines across the current stream. As this project is partially EU funded publicly accessible report will be available.

Stingray

The Stingray device consists of a horizontal hydroplane, resembling the wing of an aircraft, mounted on a hinged arm attached to a vertical column attached to a gravity base resting on the seabed. The angle of the hydroplane is controlled to produce lift either upwards or downwards depending on the position of the arm. This causes the arm to reciprocate up and down driving a hydraulic cylinder pumping oil to a hydraulic motor and generator. A 150 kW prototype device has been constructed and tested twice at Yell Sound in Shetland. Two reports have so far been published[82].

Hammerfest Strom

This is a horizontal axis turbine similar to MCT but mounted on a tripod-style gravity base rather than a pile drilled into the seabed. A prototype device has been installed in a Norwegian Fjord in January and February 2003 and is grid connected. The device is claimed to be capable of generating 0.7 GWh/year, but no economic information has been published. Hammerfest Strøm is owned by a consortium of large companies. More details can be found on www.e-tidevannsenergi.com.

Enemar

The Enemar project was constructed by Ponte di Archimede of Italy in the Strait of Messina (the gap between Italy and Sicily) under an EU grant. A full description of the project is given in the report of the European Thematic Network on Wave Energy (available from www.wave-energy.net). This covers the power output of the device but not capital and operating costs. The device consists of a floating barge with a 3-blade vertical axis turbine (called a Kobold turbine) mounted beneath it. The ENEMAR prototype consists of a 10m diameter x 2.5m deep raft supporting a 6m diameter x 5m high three bladed vertical axis Kubols turbine in 20m depth of water. The raft is moored using four 3.5T concrete blocks in an area where the current

[82] Research and Development of a 150kw Tidal Stream Generator", DTI report T/06/00211/00/REP, URN 02/1400; and "Stingray Tidal Stream Energy Device – Phase 2", DTI Report T/06/00218/00/REP, URN 03/1433, both downloadable from www.dti.gov.uk

averages 2m/sec. but can reach 3m/sec. The turbine is self starting at a cut in speed of 1.2m/sec. The measured overall efficiency in terms of electricity produced is 23% and it has been noted that the environmental impact is negligible but that anti-fouling requires further investigation. The system is feasible at the scale developed but projected power costs do not appear to be available.

Blue Energy

Blue Energy Inc of Canada is promotes a device they call a "Davis Turbine". This is a ducted vertical axis turbine and has been around for longer than any other tidal stream device. So far, however, they do not appear to have reached commercial implementation. More details can be found on www.bluenergy.com. A report has been published dating from 1986 giving results of tests and engineering assessments that claiming to show that the device is capable of achieving an electricity price of 8.0 US¢/kWh at 1986 prices.

Vortec Tidal Stream Converter[83]

This concept being developed by a New Zealand company Vortec Energy involves enclosing the propeller in a peripheral double skinned diffuser shroud that can incorporate stator vanes and a ring generator in the shroud. The effect of the expanding shroud is to create a low pressure region downstream of the rotor thereby increasing the flow rate through the turbine together with its power output. The whole assembly is rigidly mounted and must be yawed to face the prevailing current. Tangential slots are used to inject flow through the diffuser inner skin to re-energise flow and prevent boundary layer breakway with consequential increase in drag. Although tidal currents are much smaller than typical wind speed, Vortec contend that this is outweighed by the facts that the energy density of flowing water is so much greater than that of wind and that the resource is guaranteed and predictable in advance. A Vortec assessment of the global potential for sub-sea generation at sites in depth of 20m-50m of water with current speeds between 2-3m/sec. suggested that the width of coastline between these limits averaged 200m and that 5% of coastline might have an average current speed of 2.5m/sec. This would lead to turbines with rotor diameters of 15m, diffuser diameter 25m and spacing of 100m at an average depth of 35m. The targeted capital cost for a 1.3MW rated turbine is $1,000/kW installed. As the average of 200 countries considered had 3000km of coast it was suggested that there was an annual technical resource of 3 billion MWh (worldwide consumption in 2000 was 12.5 billion MWh) assuming a capacity of 35%. This corresponds to a global market of 6×10^5 machines with capacity approaching one million MW (30% of installed world capacity in 2003).

A major constraint in the design of subsea turbines is cavitation which limits rotor top speed to 8m/s. At typical rated water velocities of 2-3m/s this leads to a high solidity turbine operating at low tip speed ratios and relatively high swirl. The potential exists to insert guide vanes to minimise consequential blade losses. Vortec hopes to reduce installation and maintenance costs by floating modular units to site, the use of innovative installation systems and a very high focus on product reliability and risk

[83] Rudkin E. and H. Loughnan (2001) *Vortec – The Marine Energy Solution*. MAREC Institute Of Marine Engineers, Newcastle-Upon-Tyne pp 151-159

management planning. It states that all electrical and mechanical components will be sourced from reliable high quality manufacturers where performance guarantees are a priority consideration. At present VORTEC is engaged on pre prototype development work only.

A4.3 Technical Issues

It is clear that while prototype systems have reached testing stage there are many technical difficulties that require successful resolution before they could be considered to be to commercially viable. These include:

Site Issues

- Need for detailed surveys of soundings and stream velocity profiles and fields.
- Clarification of flow pattern velocity texture at given site.
- Hydrodynamic output impedance and forcing function at given site.
- Effect of high channel filling fractions and redistribution to adjacent channels.

General Converter Issues

- Longlife sealing against high pressures in corrosive and potentially abrasive medium.
- Cavitation and corrosion.
- Biofouling.
- Wake vortices (particularly for vertical axis units).
- Disconnection of power input both during installation and following loss of electrical cables.
- Cable installation on swept rocky beds.
- Impact of underwater sound on marine life.
- High installation, access, removal costs.

Particular Hardware Issues

- High torque, low speed power conversion with variable speed input connected to synchronous network.
- Geometrically tolerant, high load/low speed compact bearings suitable for underwater use.
- Material finishes that ensure hydraulically smooth surfaces combined with cavitation and corrosion resistance to reduce skin friction and drag.
- Blade pitch changing system, controllers and governors.
- Easily deployed anchors with high capacity, matched to particular site needs.
- Capacity for surface piercing units to withstand severe combinations of wave and tidal loads.

Table A4.1: Summary of Tidal Devices

Device	Annual output	Capital Cost	Annual Operating Cost	Lifetime of plant	Price of Electricity generated	"cut-in" speed
MCT	No published data	No published data	No published data	No published data	No published data	No published data
Stingray	10.63 GWh	6.3M GBP(2003)	236k GBP(2003)	Not stated - assume 25y	87.5 GBP(2003)/MWh @ 10% interest	not stated
Enermar	12 kW @ 1.5 m/s (= 28 kW at 2m/s). Annual output not stated	Not stated	Not stated	Not stated		1.2m/s
Blue Energy (Submerged Unit)	8670 kWh	5.610M USD(1986)	535k USD(1986)	Not stated	10.5 US¢(1986) @ 10.75% interest	
Blue Energy (Surface Unit)	10384 kWh	5.231M USD(1986)	508k USD(1986)	Not stated	8.0 US¢(1986) @ 10.75% interest	
Hammerfest Strøm	No published data	No published data	No published data	No published data	No published data	No published data
Severn Barrage	17TWh	10.3×10^9 - 14.0×10^9 GBP(2002) or 8.283×10^9 (construction) + 1.230×10^9 (grid strengthening) GBP(1988)	Not stated	120 y	60GBP(2002)/MWh	N/A

The Severn Barrage was expected to create 35,000 jobs in construction at peak and 30,000 jobs when operational

Appendix 5: The Development of Danish Wind Power Technology

It is instructive to consider briefly the development history of Danish wind power technology in terms of the way in which proactive policy can complement and promote the dynamic growth of an industry from an existing competitive base. In most cases, the underlying competencies had been developed in response to specific, often pressing, needs but when advances were made the learning was then codified and applied to create an advantage.

Table A5.1: Brief Chronology of Danish Wind Turbine Technology

Date	Primary Need	Client	Developer/Design	Outcome
1891	Rural Electricity	Danish Govt.	Prof. La Cour	Traditional Windmill, DC. Dynamo, hydrogen storage
1887	Better Scientific understanding	Designers	La Cour	Wind Tunnel/Test Station
1903	Widen Expertise	Danish Profession	La Cour	Assoc. of Danish Wind Engineers.
1908	Commercial Application.	Lykkegard Co.	Lykkegard/La Cour	72 No. @ 30kW DC generators built
1914-18	Ease WW1 Shortages	Customers	Lykkegard	Add DC generators to small grids
1920	Scientific Analysis	Industry	Betz	Applied Aerodynamics*
1940-5	Ease WW2 Shortages	Customers	F.L. Schmidt	7 No. 50/70kW 3 blade
1942	“ “	Germany	MAN-Kleinhenz	10MW Design (not built) *
1941-45	“ “	Vermont PS	Smith-Putnam	1.25MW *
1950	Orkney Supply	NSHB	J. Brown	100kW *
1957	Modernised Design		Juul	200kW Gedser
1958	Grid Evaluation	EdF	Best Romani	800kW synch. Generator
1958-68	Low Speed Commercial	Allgaier	Hutter (W34)	100kW GRP blades *
1976-86	Field data /Software Dev.	NASA	Juul	Gedser reactivated
1978	Demonstration	School	School	Tvind
1978	US Self Sufficiency	US Citizens	-	US Nat. Energy Act *
1980	Demonstration	US Markets	US Developers	NIBE (A + B) 630kW each
1980	Customer Confidence	Industry	Industry	Joint Type Certification
1983-7	Californian Market	Numerous	Numerous	7000 Danish Machines shipped
1986	US Tax Reform	US Markets	All	Tax Credits end, Market shrinks
1988-90	European Markets	UK, Denmark, Spain, Germany	All	Develop new WTGs for European Mkt. 250/400/500kW (Bonus 450, Micon 600, Vestas 500 Micon 1.5MW)
1992-6	1-1.5MW Prototypes to reduce unit cost	EU/Danish Govt.	Bonus Nordtank Vestas	WEGA II Development Programme
1996	World Market	Various	Various	Six Danish companies share 51% of World Market

1997	More Capacity	Danish Govt.	Various	"Action Plan for offshore Wind Farms"
1996-04	Offshore Market	Various	Various	2-3MW, (4.5MW Dev.) *

* Contemporary Developments outside Denmark that provided useful input.

The present state of the world wind energy owes much to early developments in Denmark and California. Unlike other countries that once employed wind mills, the use of wind power never completely ceased in Denmark, partly because of that country's lack of fossil fuel reserves. Research, development and manufacture of wind powered DC electrical generators had taken place for many years before the 1973 oil crisis led to a new generation of wind turbines for farm scale operations, manufactured by small agricultural engineering and other companies e.g. Nordtank, (a milk tanker maker) and LM Glasfibre (a boat builder). At Tvind schools, faculty members and students built a large prototype on campus to demonstrate the feasibility of large machines.

California provided the proving ground in which, as a result of tax credits introduced to stimulate electricity generation from wind, large numbers of relatively small machines (60-120kW) from manufacturers such as Nordtank, Bonus, Vestas and Micon found a ready market during the period 1981-87. Taking advantage of their home market experience, the Danes had shipped over 7,000 machines by 1988 aided by a favourable foreign exchange rate for the US$.

Although there were problems with early Californian installations, the suppliers were able to recycle profits to support design and development of larger machines, utilising EU support. By 1990 the wind capacity installed in Denmark had reached 343MW. With a rapid doubling of size, 200-250kW and 400-500kW machines were available by about 1990-91.

The Danish Wind power experience may be summarised as follows.

1. Recognition of the existence of the local wind resource and its potential in addressing existing problems.
2. Willingness to attempt resource development via trial & error for practical application
3. Development of improved scientific understanding and capacity.
4. Unexpected energy shortages create a need for a reinvigoration of the industry and present an opportunity.
5. Need and willingness for small industries to diversify.
6. Good market opportunity following major oil crisis and good positioning to be able to access these opportunities.
7. Identification of key customer needs.
8. Profits recycled into further development, leveraged with Government/EU support.
9. Modernised product line available.
10. Head start in world market.
11. Maintaining position in maturing world market (competition, rationalisation, joint ventures, subsidiaries, licencing agreements, ongoing development).

In summary, this approach can be characterised as:

Recognition of Resource → Positive Social Attitude → Investment in Development of Technology → Ability to Exploit Opportunities → Market Success

Appendix 6: Ocean Energy Policy in the United States

Introduction

In recent years the United States has not had an active high-profile centrally administered ocean energy research and development programme for commercial ocean energy applications. However a number of companies have continued to develop wave converter designs as private ventures or to meet other requirements. Recently the respected Electric Power Research Institute (EPRI) has initiated an ambitious four phase offshore wave power feasibility demonstration project as of January 2004 with a projected duration of 5-7 years and a budget of $M 2.5-4. The overall project objective is to demonstrate the feasibility of wave power to provide efficient, reliable, environmentally friendly and cost-effective electrical energy and to create a push towards the development of a sustainable commercial market for this technology in the U.S. thus providing economic benefits and job creation there. As the scope of this project is quite wide it is described here in some detail. There does not appear to be an equivalent tidal energy programme.

Wave Power Credibility

It has been observed that unlike the wind industry, published data on offshore wave energy converters seldom provide sufficient detail i.e. curves or tables relating generated power to sea state, to assess the accuracy of power production claims. A goal of this study is to determine whether the wavepower industry has reached a level of commercial maturity that can provide customer confidence in claimed levels of power production and associated cost of energy. This will make it possible to compare the likely performance of different converters in a given wave climate and establish a baseline against which industry improvements can be assessed. It will allow the best device to be selected for each of the several states participating in the project. Extensive technical performance documentation is sought from each would-be developer and converter ranking criteria are stated.

Outreach to and development of a network of cluster companies working together to use the indigenous offshore wave resources of each state is a feature of the programme. These are technological institutes, marine engineering companies, shipbuilders and other manufacturing industry potentially interested in the fabrication of wave energy conversion devices, distribution utilities and independent power producers.

Nineteen offshore wave energy converter developers world-wide (including two in Ireland) have been invited to submit proposals for assessment against the wave resource specification using stated criteria including simplicity of design, readiness for offshore testing and willingness to licence fabrication to local manufacturers.

Project Phasing

The programme is a collaborative one involving the state energy agencies and utilities in Maine, Massachusetts, California, Washington, Oregon and Hawaii together with EPRI and Dept. of Energy. Funding will be via in kind contributions, private owner,

collaborative financing, EPRI, DOE and state energy agencies contributions at different phases of the project.

The four phases for the 500kW pilot plant are:

(5) Project Definition including site and converter selection
(6) Design, Permitting and Financing
(7) Construction
(8) Operation and Evaluation

Good wave records made for periods of 10-20 years have permitted the production of wave scatter diagrams for reference stations at each of the states. Further work is intended to produce a preliminary wave energy resource map for each state and an environmental design data set that includes annual and twelve monthly joint probability distribution of significant wave height and peak wave period at the selected demonstration site with characterisation of the 100 year storm event that must be survivable in terms of wind, wave and current conditions at that site. Sea floor bathymetry and geotechnical conditions for mooring system design will be included.

This common resource specification has been circulated to all would be developers for use as input in estimating the performance of their respective converters.

Programme Outline

- Following preliminary assessment, one site per state will be selected for more detailed evaluation against a set of criteria that include such potentially negative issues as NIMBY, regulatory complexity (due to the plethora of organisations having mandated coastal roles in U.S.) and social issues (other users such as fishing and recreation).
- Based on information provided by converter developers a preferred wave power converter type will be matched with each of the selected sites.
- A conceptual level design, performance assessment and cost estimate will be made to rank the six site device combinations.
- A preliminary environmental assessment of the sites and respective converter types will be made as the respective roles of some statutory bodies on the US seaboard are unclear where energy production is concerned.
- An assessment of the permitting status of this new type of development will also be made.
- The optimum two site-converter combinations will be selected from the above.
- Preliminary Level Design, Performance and Cost Estimates will be developed for these combinations at the 500kW (pilot) and 100MW (Commercial) scale levels based on stated criteria from which a single site will be selected.
- Environmental effects including Life Cycle Impact Analysis for the single selected site will be assessed.
- Implementation planning.
- Final Design, Permitting, Ownership, Financing (1 – 1.5 yr.).
- Construction and Commissioning (1 yr.)
- Operation and Evaluation (2 yr.)
- Go/No go decision points are built in.

Conclusions

This programme is a challenging one that has been well put together although the funding appears to be on a relatively modest scale with some expectation that would be developers will contribute toward the costs involved. Although there will only be one 'winner' it appears that there is nothing to prevent other competitors taking up opportunities that may arise from the programme in other states and at other sites.

- It is interesting to recognise that the attractiveness of a particular site and proposal is now being regarded as inversely proportional to the number of Federal, State and other empowered agencies involved, all of which add to the project overheads. (Here Ireland may have a distinct advantage in that the number of corresponding bodies is small). In the Aqua buoy (Makah Bay) pilot project (State of Washington) it was noted that 25% of the budget was absorbed in satisfying such agencies on environmental and other issues.
- The concept of matching particular converters to specific sites is an interesting one as most developers would probably argue that their devices are intended to be as near universal as possible to maximise their market potential. Clearly this match could change over time as converter characteristics are improved.
- It is likely that only perhaps half of the companies invited to participate will have sufficiently developed systems of the relevant size to compete in the time frame available.
- The initial stages of the competition only require the submission of data which should result in useful market research feedback for participating companies.
- The clustering concept has already been alluded to elsewhere in this report. The area over which such clusters might spread within a particular state in the US might suggest that a cluster could occupy an area equivalent to the whole of Ireland.
- The extent to which local fabricators become drawn into the process for pricing purposes is unclear. It may depend in some cases on their willingness to invest in special fabrication equipment and processes. It is also unclear whether an incumbent fabricator could quote for local fabrication of several types of converter from different developers without potential conflict of interest.
- The effect of this project is likely to give much needed visibility and to boost a world-wide range of wave power conversion systems that are currently moving towards viability while also establishing links with manufacturers in the United States who may wish to position themselves for future fabrication opportunities.
- The approach also implies that EPRI and its consultants are taking upon themselves a significant work load in wave resource mapping, converter cost estimation converter functionality assessment and estimation of cost/kWh produced in the respective wave climates. It is recognised that the specific costs associated with the pilot plant (500kW) will be significantly higher than for the projected 100MW commercial installation for which a path will have been cleared if this project proves it to be viable.
- There is much to be learned from monitoring the progress of this project.

Appendix 7: Scale Model and Prototype Relationships

The Annex II Report to the IEA Implementing Agreement on Ocean Energy relates to the measurement of waves both at sea and in scale hydrodynamic model testing[84]. It recommends that a series of standard tests using defined parameters should be carried out as the design of a wave power converter evolves so that there can be clear understanding of the performance as measured in the model and projected for the prototype.

Table A7.1

Parameter	Model	Full Scale
Length	1	S
Area	1	S^2
Volume/Mass/Force	1	S^3
Time	1	$\sqrt{s}$
Linear Speed	1	$\sqrt{s}$
Power	1	$S^{3.5}$

The increase in power between model and full size prototype is particularly important as it permits dramatic scale up of power measured in relatively small models to represent the full size case on the one hand, but equally requires the such measurements be made with extreme accuracy and also prevents quite large models from producing anything like full scale output, thereby potentially damaging credibility unless these facts are fully appreciated.

Test variables used to describe sea and model conditions include:

- Hm Mean Wave Height (m)
- Hs Significant Wave height (m)
- Tz Mean Wave Period (sec.)
- Tp Peak Wave Period (sec.)
- Te Energy Period (sec.)
- Pw Wave energy flux (Power/metre) (kW/m)
- S(f) Wave Energy Spectrum (Plot of Energy (y axis) against frequency content of train of waves (x axis)) (Recognised spectra exist for different seas and conditions. The directional spreading of the waves may be estimated by multiplying the spectrum by a spreading parameter s).
- (Hs, Tz) Scatter diagram is a long term tabulation of the number of occurrences of particular significant wave height/mean wave period pairs.

Different test programmes using the above variables are prescribed in the IEA report. The currently available HMRC test facility is limited in size and the larger scale models have to be tested at facilities elsewhere. An extensive range of standard tests is recommended in Annex II and is summarised below.

[84] IEA (2003) *Development of Recommended Practices for Testing and Evaluating Ocean Energy Systems* (Annex II Report)

Table A7.2: Recommended Standard Model Tests for Wave Converter Validation

Test	Description	Flume	Basin
Series 1	PM Spectrum (long crested)	2D	2D
Series 2	JONSWAP Spectrum	2D	2D
Series 3	Period Variation	2D	3D
Series 4	PM Spectrum (short crested)		3D
Series 5	Spreading Parameter Variation		3D
Purpose	Wave Power Conversion		
Series 1	PM Spectrum (long crested)	2D	2D
Series 4	PM Spectrum (short crested		3D
Purpose	Survival Fatigue		
Series 6	JONSWAP	2D	2D
Series 7	PM Spectrum – Period Variation	2D	3D
Series 8	PM Spectrum – Spreading Variation		3D
Purpose	Survival – Design (10, 50, 100 year)		

Typically in a suitably equipped laboratory the complete range of tests should be possible in 0.5 days maintaining required levels of accuracy. Power take off measurements using calibrated equipment are stipulated. In addition the collection of measured sea state and environmental data appropriate to full scale prototype testing are stipulated.

Appendix 8: Outline of an Emerging Sector

A8.1: Input Matrix for Ocean Energy Systems

The following list identifies areas that are both cost centres and potential points of wealth creation where ocean energy projects are concerned. Clearly the wealth creation derived from the sale of product must outweigh the costs incurred in generating the sale allowing for interest, and capital repayments, profit and taxation.
It also indicates the widespread of the challenges that may face would-be developers of integrated ocean energy producing systems.

Industry: Specification, Design, Fabrication, Procurement, Fabrication, Storage, Shipment

Mechanical Engineering Systems:
- Hull specification design, fabrication, testing
- Corrosion proofing + protection
- Steel and non metallic ducting
- Structural steelwork and fabrications
- Valves
- Gear box systems
- Hydraulic systems
- Turbines and rotating machinery
- Vibration Management systems
- Auxiliary Mechanical Systems
- General Assembly, test, commissioning
- General Mechanical Contracting services
- Code Compliance, Quality Assurance, Manuals, Support Services

Electrical
- Generator manufacture, testing, commissioning
- Generator control systems
- Power conditioning electronics design and supply
- Switchgear, metering
- Wiring and Cabling
- Instrumentation/data acquisition and logging, SCADA
- Electrical protection and control systems, fault management
- General electrical contracting services
- Code Compliance Quality Assurance, Manuals, support services
- Communications

Civil Engineering Systems
- Site development, laydown, drains, fencing, coastal protection (rock armouring), erosion management
- Roads, buildings
- Dredging, drilling, blasting, excavation, spoil management
- Mooring elements
- Cable trenching

- Structural foundations and heavy fixed structures
- Oceanography wave measurement systems

Marine
- Submarine cable installation, protection
- Towage and tug boat services
- Work boat and safety services
- Marine Installation and salvage contracting
- Navigation + positioning services
- Mooring design

Fixed Base Facilities
- Dry dock/yard/construction or service facility
- Fabrication, assembly, test sheltered areas
- Haulage and crane services
- Laydown and storage, warehousing
- Work boat, barge, tug berthage
- Test Tanks and facilities
- Accommodation
- Catering Supply
- Waste Management
- Power
- Communications
- Water Supply
- Rentals

Professional Services and Facilities
- Aerodynamics (Engineers, Analysts, Draughtsmen)
- Mechanical Engineers (Engineers, Designers, Draughtsmen, Technicians, Fitters, Welders, Helpers)
- Electrical (Power) Engineering (Engineers, Electrical Fitters, Electricians, Draughtsmen
- Electrical (Electronic/software) Engineering (Measurement Control, Software Engineers, Technicians)
- Civil/Structural Engineering (Engineers, Draughtsmen, Technicians, Construction Trades)
- Marine/Insurance Surveying (Vessel Survey and Classification Personnel)
- Naval Architectural services (Naval Architects, Draughtsmen, Analysts)
- Hydrodynamics, Dynamic Analysis
- Computing Services
- University Support services
- Planning, Permitting, Environmental Services (Planners, Management, Environmentalists)
- Accounting, Financial and legal services, (Accountants, Clerical/Admin. Staff, Purchasing, Legal, Secretarial)
- Marketing services, Public Relations (Market Development Personnel, Media)
- Corresponding Technical and other support services

Wealth Creation
- Sale of Intellectual Property Rights
- Sale of Product Systems
- Licencing of Systems
- Installations of Sale of Energy
- Investment Management
- Sale of Services
- Research decisions
- Funding Management

A8.2: Ocean Energy Supply Chain

Construction & Installation Phase

Tier 0: Site developer
- Overall project definition, site selection, device selection, project management, procurement, planning applications, raising finance

Tier 1: Goods & services bought by site developer
- Devices (from device supplier).
- Installation work (mixture of suppliers including civil engineering contractors, offshore handling contractors, seabed drilling (if necessary), cable laying)
- Advice (technical, legal, financial, public relations etc)
- Environmental surveys
- Environmental impact assessments
- Auditing (financial health & safety, environmental, due diligence)

Tier 2: Goods & services bought by Tier 2 suppliers

2.1 - Goods & services bought by device suppliers
- Testing & accreditation
- Software (off the shelf and bespoke)
- Electronic equipment (plc controllers, SCADA systems etc)
- Advice (technical & scientific)
- Off the shelf hardware (motors, pumps, hydraulic cylinders, generators etc)
- Bespoke hardware (metal bashing, other materials (e.g. GRP))
- Transport to site
- Fabrication services
- Machine tools
- Materials

2.2 - Goods & services bought by installation contractors

- Hire of ships/tugs/barges etc

Operation Phase

Tier 0: Site operator
- Management of the site and sales of electricity to consumers via the grid

Tier 1: Goods & services bought by site operator
- Spare parts (from device supplier)
- Maintenance services
- Testing & inspection (acceptance, routine monitoring)
- Advice (technical, legal, financial, public relations etc)
- Auditing (financial, health & safety, environmental, due diligence)

Tier 2: Goods & services bought by Tier 2 suppliers
- Materials

Goods & services bought by inspections & testing contractors
- Inspection & testing equipment
- Software
- Vehicles

A8.3 Potential Suppliers of Engineering Fabrication Services (Indicative only)

- Aardvark Metal Works, 56 John St., South, Ardee St., Dublin 8.
- Accord Engineering Ltd., Unit 2, Blackhorse Industrial Estate, Blackhorse Ave., Dublin 7.
- Allpipe Engineering, 60 Clooney Rd., Maydown, Derry, BT47 6TP, N.I.
- E. Buttimer & Co., Carrigeen Industrial Estate, Cahir, Co. Tipperary.
- Cronin Buckley Steel Fabrication, Killimney, Ovens, Co. Cork.
- Coolock Engineering, Grange Works, 68 Grange Close, Dublin 13.
- Eirfab Engineers Ltd., Slieverue, Waterford.
- EPS Environmental, Quartertown Industrial Estate, Mallow, Co. Cork.
- JBS, Ashford, Co. Wicklow.
- Kiernan Structural Steel, Carrigglas, Longford.
- Fingal Fabricators, Unit 6, Dunshaughlin Industrial Estate, Dunshaughlin, Co. Meath.
- Finnegan Steel Fabricators, Unit 3, Knockmitten Business Park, Knockmitten Lane, Dublin 12.
- L. Lynch & Co., 16 Fonthill Industrial Park, Fonthill Rd. N., Clondalkin, D. 22
- J. McDermott, Trumra, Mountrath, Co. Laois.
- Mercury Engineering, Mercury House, Sandyford Industrial Estate, Dublin 18.
- Murphy International, Great Connell, Newbridge, Co. Kildare.
- Joseph Murphy Ltd., Shanowen Rd., Dublin 9.
- H.A. O'Neill, Waterways House, Grand Canal Quay, Dublin 20.
- Olympic Engineering, Unit 5, Clondalkin Commercial Park, Clondalkin, Dublin 22.

- Radley Engineering, Killadangan, Dungarvan, Co. Waterford
- Steele & Co., The Quay, New Ross, Co. Wexford.
- Stratton Industrial Services, Unit 4, Channel Commercial Park, Queen's Road, Belfast BT3 9OT
- Unifab Ltd., Celbridge Industrial Estate, Celbridge, Co. Kildare.

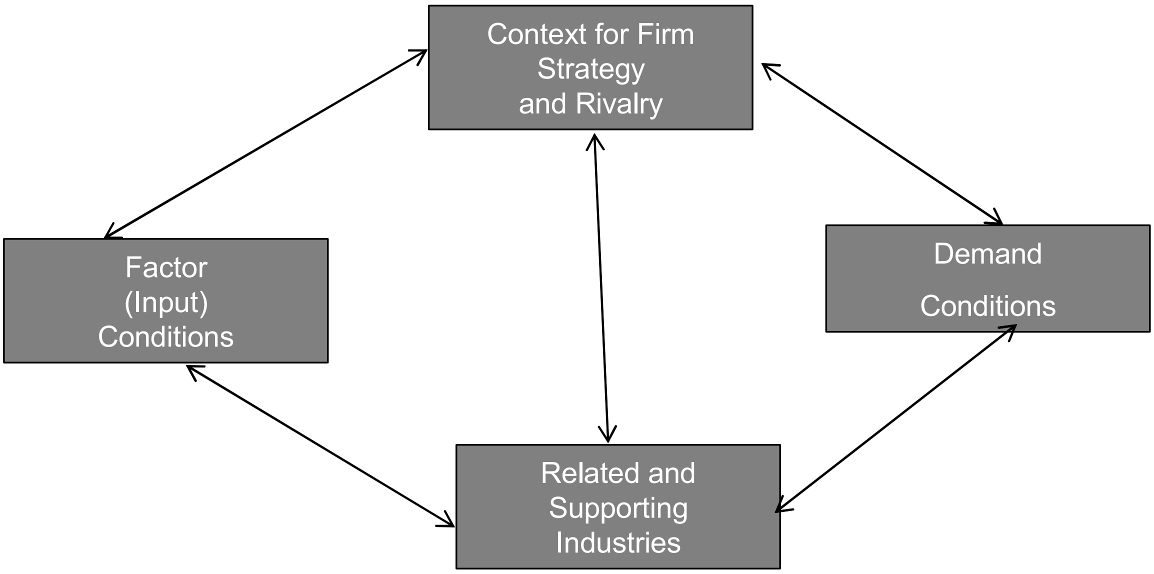
Dock and Boatyard Service Providers

- Dublin Dry Dock Ltd., Alexandra Rd., North Wall, Dublin 1.
- Dublin Ship Repairers Ltd., Transit House, East Rd., East Wall, Dublin 3.
- Harris Pye Dry Docks Ltd., Alexandra Rd., North Wall, Dublin 1.
- Howth Boatyard Services, West Pier Howth.

Appendix 9: Industrial Clusters

The key concepts in relation to clusters remain encapsulated in Porter's 'Diamond'. This is shown in Figure A9.1. His thesis is that national competitiveness in particular sectors is built not on the performance of isolated firms – although instances of success in this form exist they tend to be erratic and difficult to determine by policy actions – but rather through the advantages that firms gain through the external economies and benefits of being part of a cluster. The benefits of clusters may arise from factors such as information flows promoting innovation, scale economies for producers, and access to skills. For sustainable clusters to emerge and achieve a competitive position it is necessary that all four points of the diamond are strong and interact in an optimal manner.

Figure A9.1: Porter's Diamond Model of Competitive Advantage



The internal workings of the cluster are captured by the arrows in the Figure which shows that the performance of each element is at least partly dependent on each other element with the implication being that a weakness in one will affect all others. Factor Conditions, appears a natural starting point but rather than simplistic measures of endowment of projections of potential based on such measures this element relates to conditions in the markets for factors, i.e. what factors are created in the economy or how competitive is their availability. Factor conditions are affected by firm strategies in a cluster since rivals to a firm can stimulate input creation. Perceived national challenges will also contribute. Demand conditions will clearly influence investment priorities thereby affecting input availability, while related and supporting industries will create factors such as knowledge and skills that may be transferable. Demand conditions will be influenced by the degree of rivalry in an economy and the existence of supporting industries through improving product delivery – the usual interpretation of the benefits of competition to consumers – and through providing recognition that a country is a leader in that industry i.e. is competitive. The level of domestic demand will obviously affect the performance of related industries and even their existence while a concentration of supporting industries will require specialised inputs particularly skills and investment capital in high risk ventures. In this way, each point

of the diamond is both a determinant of and dependent on the situation in relation to each other point.

This interaction and interdependency indicates the dynamic nature of the model since a particular strength in one element offers the opportunity – but not the probability – that other elements can be stimulated by this strength. In a sense, the potential role of policy is to make this happen, ideally by strengthening each point of the diamond.