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[1]. 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[2].

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

[2] 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[3]. 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 most developed wave energy device. A report has been published giving a detailed analysis of the performance and economics[4].

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

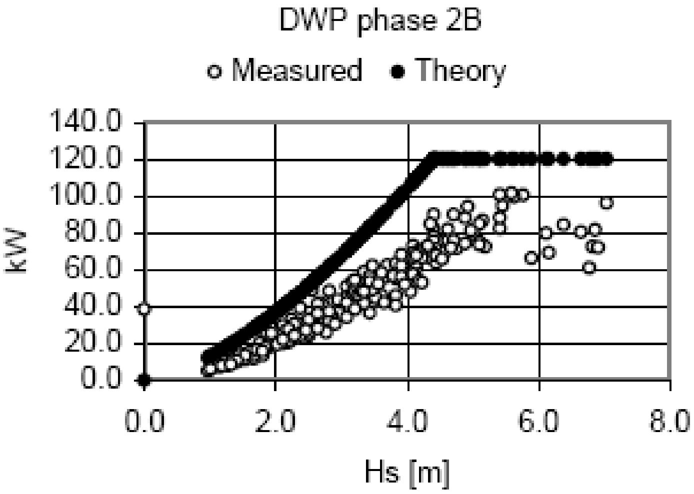
[4] *Pelamis WEC - Conclusion of Primary R&D Final Report*, DTI Report V/06/00181/REP, URN 02/1401 downloadable from www.dti.gov.uk

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[5].



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.

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

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

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[6].

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

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[6] 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[7].

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 averages 2m/sec. but can reach 3m/sec. The turbine is self starting at a cut in speed of

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[7] 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

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[8]

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 x 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 management planning. It states that all electrical and mechanical components will be sourced from reliable high quality manufacturers where performance guarantees are a

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

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 - $14.0\ \times10^9$ 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:

1. Project Definition including site and converter selection
2. Design, Permitting and Financing
3. Construction
4. 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[9]. 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.

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[9] 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.

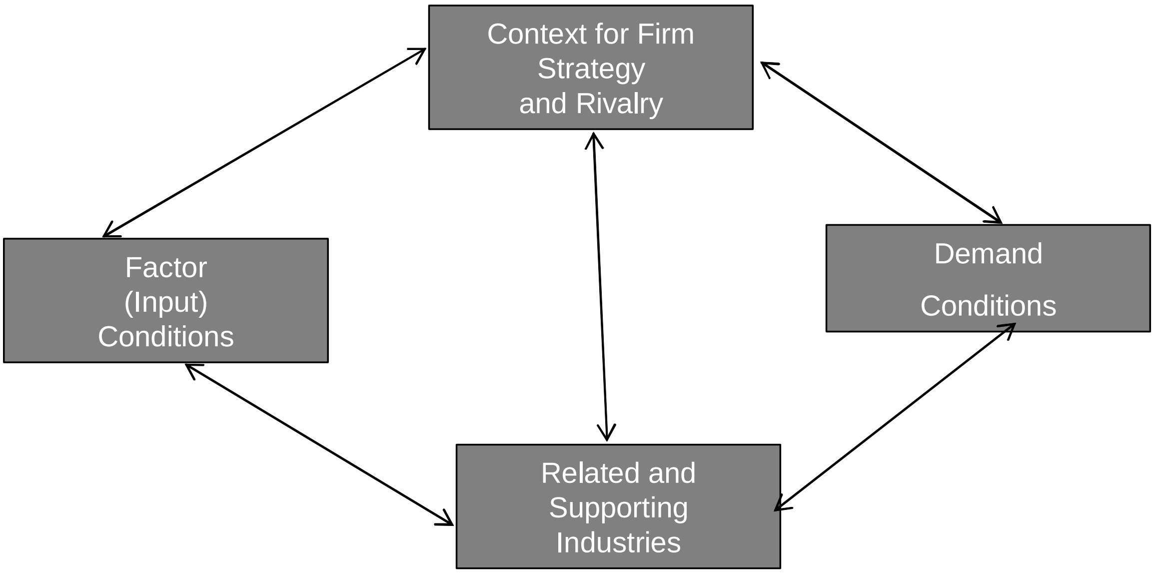
Dock and Boatyard Service Providers

- 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.