FORESIGHTING REPORT
Low Cost Renewable Energy (LCR)

Addressing technologies required to drive down the cost of wind, wave and current energy

For Members Only

17th March 2005
V1.0

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ITI ENERGY INTRODUCTION

ITI Energy is one of three operating groups that make up ITI Scotland. Together with ITI Techmedia and ITI Life Sciences, we will be investing in excess of £450 million over the next ten years in research and development. Publicly funded, but 100% commercially driven, our collective aim is to create new technologies and stimulate business growth in Scotland.

ITI Energy will select and invest in programmes based on assessing future market needs, identifying technology opportunities, and responding to ideas, initiatives and proposals from the research and business communities. We will use our £150 million funding to commission and direct applied research projects in collaboration with partners from industry, academia and finance.

Throughout this process, we will protect the Intellectual Property (IP) that our investments generate, enhancing its competitive positioning, and helping to bring the resultant technology to market.

Participation in our activities and projects is open to all businesses and research organisations, regardless of where they are located. We are based in Aberdeen, but our scope and vision is global. We closely follow research activities in other countries, and welcome involvement and collaboration from overseas. Our success depends on being able to develop new technologies that address market needs around the world.

Further information on this foresighting study and ITI Energy may be obtained from:

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EXECUTIVE SUMMARY

This report provides a summary of ITI Energy's initial foresighting study on the market for Low Cost Renewables (LCR) technology, focused specifically on wind and marine energy. In the context of this report, wind refers to onshore and offshore and marine covers wave and current (tidal and ocean). The report aims to:

- Provide a structured analysis of LCR market needs and technology opportunities on which ITI Energy might focus
- Present conclusions to ITI member companies for their review and input
- Catalyse further discussion and development of LCR technology development projects and proposals

The ITI approach to foresighting aims to consider key market trends and emerging business needs which may create market pull for new technology - using this analysis as a basis to identify and explore specific technology development opportunities. The conclusions of this study are the result of a highly consultative approach engaging over ~100 companies and organisations across the sector and involving over 200 individuals with a broad range of industry expertise and experience. This approach sought to leverage ideas and input from operators, technology users, technology suppliers and researchers.

Onshore wind is likely to sustain strong growth in the coming decade. Offshore wind and marine renewables (wave and current energy) offer huge promise but substantial challenges and uncertainties remain

The wind power market is likely to see appreciable growth in the coming decade – potentially 15% per annum for onshore and in excess of ~30-40% per annum offshore. This growth will provide a platform for new technology developments. However, in the case of offshore wind, the extent of technical and economic challenge requires more substantial technology developments. Indeed, technology will be a critical determinant of whether a large scale offshore market can indeed be established and sustained. Similarly, the marine (wave and current) energy market is even more uncertain, and the development and demonstration of technology will, alongside substantive market support mechanisms, determine whether a viable commercial market can be established at all. The following summarises key factors likely to shape market and technology developments in the coming decade:

Market - Macro

- Strong global growth in LCR renewables fuelled by:
  - Energy security and diversification objectives
  - Environmental and energy policy objectives e.g. fulfilling CO_2 reduction targets (e.g. EU)
  - Countries with limited fossil fuel power supply, seeking options to fuel rapid economic growth (e.g. China)
- Onshore wind continues to dominate renewables in terms of scale of ongoing commercial activity and projected growth but other "alternatives" will make progress and compete, for example:

  - Onshore wind already constitutes a sizeable industry (2003: cashflow of $12Bn , 2004 total installed capacity: 48 GW)
  - Offshore wind starts from a small base, but is expected to grow rapidly (2004 total installed capacity: 780 MW)
  - Marine energy may achieve an initial breakthrough into commercial development within the next 5-10 years
  - Other forms of distributed generation not within the scope of this work (PV, Solar, hydro small and large scale and biomass) will also see appreciable growth
- Despite rises in fossil fuel prices, conventional power sources (such as gas fired generation) still represent the lowest cost option and this sets the competitive target for renewable energy sources
- However, the wind industry has achieved spectacular reductions in cost-of-energy in the last 20 years and in some instances, where a site offers high quality wind resource and straight-forward grid connection, the economics are competitive with other power generating options without subsidies or other government support
- Offshore wind and marine energy remain significantly more expensive than conventional power sources

Resource Availability

- Wind and marine energy remains a massive untapped resource:
  - Germany sets the standard for exploiting wind resource and is already harnessing a large proportion of the wind energy economically exploitable using available technology
  - Most regions in the world have barely scratched the surface of the available resource e.g. Scotland is estimated to have harnessed less than 1%
  - Exploitable wind resource globally is estimated as 53,000 TWh, sufficient to supply global demand 3 times over.
  - Exploitable wave and current resource are estimated at similarly large numbers, although such figures are highly uncertain given the limited availability of research data and the very early stage of commercial development
- Total availability of resource is not, therefore, a limiting factor
- Several factors relating to availability and type of resource will have a major influence on market and technical developments
- For wind there are four broad areas of opportunity:
  - Onshore
  - Offshore
  - Low wind speed
  - Small scale (for instance in urban environments)
- For marine renewables there are similar variations:
  - Wave energy can be segmented as: onshore, nearshore and offshore
  - Current energy can be classified as: tidal (bi-directional) and ocean current (uni-directional)

Commercial Development - Barriers and Issues

- Not limited by resource availability, the key barriers to commercial development are an array of technical, political, social and economic factors which will largely determine the scale and pace of growth, for instance:
  - Resistance to large scale onshore wind-farms in wilderness / sensitive sites and adjacent to existing populated areas
  - Patterns of resource availability (intermittency) resulting in the requirement for back-up generation or large scale power storage to enable balancing of supply and demand
  - Inadequacy of existing infrastructure to accommodate transmission of renewable power from source (often remote areas) to demand centres (primarily high density populated areas)
  - Cost of energy, particularly for offshore and marine
- Technology can play a role in over-coming some, but not all, of these issues

Market Support and Regional Differences

- Market stimulus and support by governments is an essential element in allowing renewable energy industry development (such as in Denmark with onshore wind), however, this may expose the industry to stop-go effects, as happened in the USA
- Onshore wind is likely to receive less ongoing government support to sustain growth whereas offshore wind, wave and current will need significant support over the coming 5-10 years:
  - Offshore wind is likely to emerge most strongly in Europe
  - Developments in wave and current are more uncertain but several regions are showing increased interest and willingness to provide substantive market support mechanisms, including; EU (particularly UK and Portugal), potentially the US and a number of pacific nations

Industry Structure and Developments

- Wind industry consolidation is creating a top tier of turbine manufacturers who play a major role in influencing technology developments
- Certain operators are creating leadership positions within regional / national markets (e.g. FLP in the US, ScottishPower in the UK) but this aspect of the wind market is still quite fragmented
- Offshore market remains much less mature with greater uncertainty over who will dominate the sector
- Similarly, wave and current markets are even less mature and for the moment are largely being defined by the device developers

A range of innovations will be critical to establishing and sustaining scale of offshore wind, wave and current development, similarly there are a range of innovation opportunities which could help strengthen the growth in onshore wind

Before focusing in on specific technology development opportunities, the study reviewed the wider context of wind, wave and current technology development. Particularly with a view to establishing some of the factors that will influence further evolutions of the technology.

Consideration of further developments for wind technology in particular must be made in the context of 20 years of ongoing development:

- Technology maturity: most of the commercial wind turbines (WT) today are fundamentally based on technology available for many years
- Size evolution: the industry has made massive progress in up-scaling turbine technology – this trend is expected to continue for some time
- Convergence: many of the key components of WT technology offered by leading suppliers are essentially the same
- Limited pace of innovation: the pace of wind industry technology uptake is severely constrained by the financial risk of having a major high profile failure
- Penetration of new technology: most substantive new technology opportunities must focus on new build with limited opportunities for retrofitting until assets reach end of life (referred to as repowering)

However, offshore wind energy still has significant scope for technology and commercial development:

- Recent and near term developments are being served by marinisation of existing onshore technologies e.g. Vestas at the Horns Rev project or RE Power within the Beatrice project
- Significant opportunities exist to reduce foundation and maintenance costs and over time, we expect a new offshore wind turbine design to emerge, different from onshore technology

The context for marine devices is also quite different:

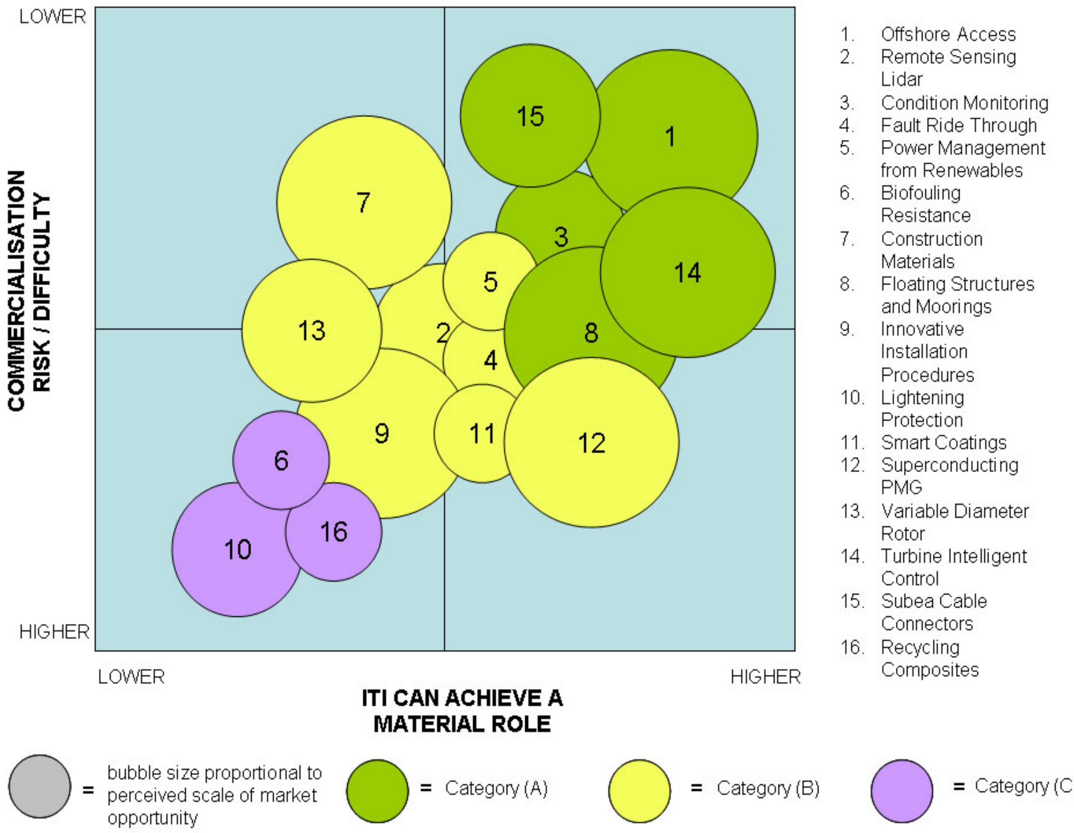
- Technology maturity: technologies are at an early stage of development with no commercialised products as yet
- Multiple device developers: many companies are striving to develop their own device concepts in a race to become equivalent of the 3-bladed, pitch controlled wind turbine for marine applications
- Investment: investments in the last 2-3 decades have largely focused on innovative, entrepreneurial companies leveraging a combination of private, institutional and public finance
- Many interested parties: investors, support activities/initiatives, lobbyists, research institutes and potential new entrants watching closely (e.g. major oil companies)

In summary, the need for innovation is clear but the route to successful commercialisation is challenging. ITI Energy's investment approach will therefore focus on:

- Opportunities with greater prospect for rapid adoption and / or opportunities for retrofitting
- Close partnerships with major players in the market, focusing not just on WT manufacturers but also on component manufacturers, developers, operators and financers
- Aspects of enabling technology that can benefit multiple device developers unless specific devices emerge as clear front-runners
- Harnessing innovations from SMEs and researchers with smart ideas but limited cash and partnerships to create viable technology programs
- Partnership opportunities with world leading research institutes and organisations
- Establishing close relationships with other potential investors e.g. Carbon Trust, Venture Capitalists, utility companies

This study has provided an extensive (long-list) of technology development opportunities and from this an initial prioritisation of 16 areas on which ITI Energy should focus

A structured process of brain-storming activities and desk-top research provided an initial long-list of around 300 technology opportunities (Appendix A). This long-list was then filtered and prioritised to create a short-list of 16 technology areas on which to focus. Further research and analysis generated short summaries for each of these areas. This then formed the basis for prioritising how ITI Energy should move toward generating specific R&D projects, as summarised in the following diagram:



The top right quadrant of this diagram represents technologies which are perceived as offering stronger possibility of projects where ITI Energy can play a key role and where there is a reasonable potential to achieve commercial success. The 16 technology areas are categorised (as per the colour coding) as follows:

Category (A): ITI Energy will look to develop specific program or project proposals using it's own resources (e.g. conduct initial scoping / feasibility study to define specific technology gaps, estimate the scale of market opportunity for technologies to fill these gaps and assess the potential for successful capture of related IP and scope the feasibility of onward licensing and commercialisation of the technology beyond the ITI research project)

Category (B): ITI Energy will seek to engage with a targeted set of companies and researchers to explore in more depth the potential technology opportunities in this area (e.g. exploratory discussions with other parties and networking to bring interested parties together to build a clearer case for initiating more resource intensive project scoping / feasibility studies)

Category (C): ITI Energy will adopt a more passive approach looking to other parties to bring forward specific project proposals - of course 3rd parties are also open to bring forward technology proposals relating to any of the 16 technology areas.

The prioritisation of these 16 areas – as discussed above – is only for the purpose of allocating ITI Energy's own resources (i.e. staff time) in proactively developing project proposals i.e. categories A and B. The 16 technology areas have all been selected from the long-list as having significant potential for new technology development.

Therefore, project proposals in any of the 16 technology areas will go through the same project screening and selection process i.e. the categorisation does not imply a pre-allocation of R&D project funding biased toward those areas categorised as A or B.

To move forward on these areas, consistent with the above prioritisation, ITI Energy is initiating a range of activities, including;

- Further one-to-one discussions with companies and research organisations
- Workshops or other forums to stimulate proposals of potential R&D projects
- Scoping / feasibility studies to develop specific proposals

However, ITI Energy remains open to 3rd parties bringing forward proposals in other areas outside the list of 16 – the prioritisation simply highlights where most of ITI Energy's time and resource will be focused in the near to medium term.

1 INTRODUCTION

1.1 Purpose and Objectives

This report concludes ITI Energy's Low Cost Renewable foresighting study. The study has focused on market and technology development opportunities associated with wind and marine energy. In the context of this report, wind refers to onshore and offshore and marine covers wave and current (tidal and ocean).

This report serves two broad purposes. Firstly, the document communicates the basis for ITI Energy's focus on certain areas of Low Cost Renewable technology - allowing members to test and challenge this focus, as well as consider ideas and proposals they might wish to present to ITI Energy for consideration. Secondly, the report provides a collation of information which member companies and organisations might find useful in developing their own business and technology development plans.

In particular, the document sets out to define the objectives of ITI Energy's market foresighting exercise for the Low Cost Renewable market, to detail the work activities carried out as part of this exercise, and to highlight the technology priorities identified and proposed next steps. The purpose of issuing this report to members is as follows:

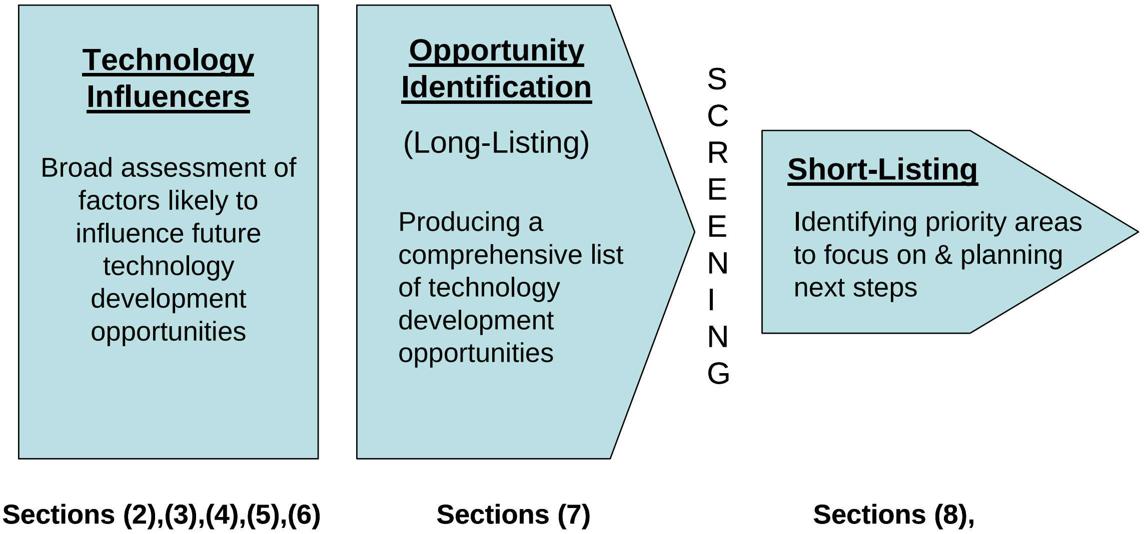
- To share with members a summary of the market and technology information gathered and analysed through the foresighting process
- To communicate to members what areas of technology emerged as priorities from the foresighting work
- To allow members to comment on the resulting technology priorities and to consider if they have particular project proposals or ideas they would like to bring forward for consideration

1.2 Report Structure and Foresighting Process

The report is structured into 8 sections (including this introduction) as follows:

(2) Resource
(3) Low Cost Renewables Market
(4) Technology and Developments
(5) R&D Expenditure
(6) Summary of Technology Influences
(7) Technology Opportunities
(8) Short-listing of Opportunities

The following diagram summarises the overall approach adopted during this foresighting study alongside the overall report structure:



The foresighting study harnessed a broad range of inputs and sources, including:

- Desk-top research
- Workshops
- Conference visits / networking
- One-to-one interviews
- Focus groups

Desk-top research formed a key element of this study as, indeed there has been much prior work investigating the market and technology for renewable energy. However, though there is a substantial volume of published material, most of this prior work has focused on either market/commercial topics or on more specific technical/technological issues - whereas the purpose of this activity was to investigate the interaction between both market/commercial factors and technological developments. Appendix (B) provides a summary of some of the key desk-top research material.

Two workshops were held, one on “Wind Turbines” and one on “Offshore Access and Installation.” The second workshop embraced offshore wind and marine renewables. Confidentiality surrounding development of new wave and marine current devices was a matter of great concern for developers and, hence, a workshop was considered to be an inappropriate vehicle for ascertaining investment opportunities in this area. It was therefore decided that the exchange of information would be limited and a series of private discussions particularly with device developers was undertaken. The workshops were designed to bring together a substantial cross section of expertise in numbers which would facilitate active discussion. The key objective was to “brainstorm” opportunities for investment for ITI Energy.

Conference visits and related networking included: AWEA 2004, BWEA 2004 and EWEA 2004.

A number of one-to-one meetings were conducted to gather more in-depth, qualitative perspectives from a range of parties directly involved and influential in shaping technology developments. These meetings covered a range of topics as follows:

- Company perspectives on future markets and technologies
- The nature and extent of activities
- Drivers for investment and any anticipated risks
- R&D needs and any shortfall in provision of these
- Synergies with ITI Energy

As the study progressed and certain areas of technology began to emerge as potential priorities a number of focus groups were conducted to further inform the short-listing of technology opportunities:

- Condition Based Monitoring
- Turbine Control
- Grid Compliance

In total, the foresighting activities included contact with more than 200 individuals in more than 100 companies and organisations (listed in Appendix B), and synthesis of an extensive list of existing published material such as conference / technical papers and market analyses.

2 THE RESOURCE

The technology requirements for any type of energy or power source are heavily influenced by the type, availability and distribution of energy resource. Within the scope of this analysis, focusing on wind and marine resources, there are a number of key factors associated with the resources which have a direct bearing on technology:

2.1 Scale: resources are abundant and hence scarcity is not a major limiting factor. However, the key challenge is in developing and deploying technology / systems that can economically capture and deliver this energy to the ultimate end users

2.2 Remoteness from market: wind, wave and current energy are often most abundant in remote areas far from demand centres

2.3 Intermittency: resources are intermittent and this creates challenges in matching supply to demand and/or providing back-up power generating capacity

2.4 Location factors: the particular location of resources provides different challenges. For example, wind developments offshore bring substantial challenges versus onshore. Wave energy capture is a significantly different proposition depending upon whether the site for capture is onshore, near-shore or deep-water. Marine energy can be split between tidal and ocean current, the former being bi-directional the latter unidirectional.

The following short section sets out to discuss the scale of the renewable resources available for exploitation. The enormous potential for wind is already well known and documented and is not addressed here. The potential for wave and current is less well known and is summarised here.

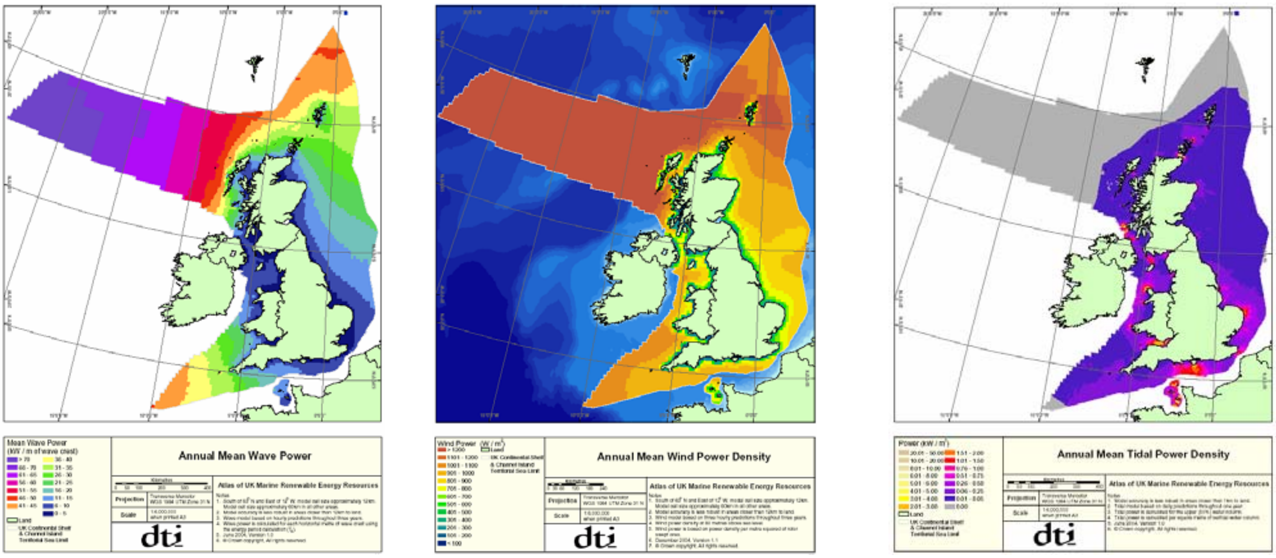


Figure 2.1 UK Continental Shelf Renewable Energy Map (DTI)

Figure 2.1 shows maps taken from a recent study undertaken by the UK Department of Trade and Industry [1] which illustrates the offshore renewable energy resource for the UK. The UK is relatively rich in renewables and hence should not be considered as typical. The maps show the level and location of the resource. Renewable energy resource assessments typically begin with maps like those in Figure 2.1. Gross energy yield can be calculated by assuming a certain deployment density of machines. Removal of areas subject to practical constraints such as shipping lanes, areas protected on environmental grounds, or areas of unsuitable seabed characteristics, reduce this gross energy yield to a so-called feasible yield. In a similar way that oil and gas reserves vary as new discoveries are made or as technology opens up new areas, renewable energy resource estimates change with assumptions on the deployment range, deployment constraints and conversion efficiencies of the technology.

For wind, wave and current resources, the key point is that the *potential* resource outstrips our ability to consume it. It is our ability to harness it, and the cost of so doing, which places practical limits on the exploitable resource. The details are unimportant in the present context; the fact is that the market potential is not limited by resource.

Renewable energy exploitation by the marine industry is already starting in the UK and it is clear that the resource is vast both here and abroad. Only a very small proportion needs to be exploited to provide a thriving global business just as has already happened with wind.

Resource assessment, to ascertain the viability and attractiveness of a particular location, remains an important and complex activity which in itself presents a number of technical and economic challenges.

3 LOW COST RENEWABLES MARKET

3.1 Introduction

Renewable Energy is somewhat awkwardly defined, in that it includes all energy from sources that can be ‘renewed’, i.e. there is infinite availability of sources and/or there is a closed energy chain. As such it includes energy from rivers, seas, wind, sun, internal heat of the earth. It also includes energy from closed carbon chains, e.g from planted trees, animal waste, etc. It serves as a term to separate from the conventional, ‘non-renewable’ energy sources, like oil, gas and coal. The general understanding is that Renewable Energy is more environmentally friendly than conventional fossil fuels.

Renewable energies have always been an integral part of worldwide energy supply, but the environmental agenda and market liberalisation have created a commercial renewable energy industry. When we consider the current Renewable Energy market, the major share is taken up by hydro (from rivers or mountain lakes) and increasingly onshore wind and biomass. Other renewable sources have no scale to speak of yet. This is mainly due to technical maturity and the overall cost of energy. As we will see later on, a significant increase in the installation of wind turbine capacity is expected, both onshore and offshore, as well as an uptake at scale of wave and current energy. In this foresighting study we focus on these forms of energy.

Governments at local, country and regional level provide strong support for the implementation of a renewables industry. The key drivers behind this are security and diversification of fuel supply, and meeting Kyoto targets on greenhouse gases, like CO_2. Additional commercial interests come from VC and other financial organisations.

The UK government has set a target to achieve 10% of total electricity supply from renewable sources by 2010 and 20% by 2020[1]. The Scottish Executive has set itself an even higher target of 18% by 2010 and an aspirational figure of 40% by 2020[2]. This level of interest and commitment to renewables is clearly not exclusive to the UK with many other governments actively supporting the growth of Low Cost Renewables, as is proven by fiscal and other monetary support, as well as granting planning permissions. Without continuous government support, the LCR industry would not be possible – this does, however, bring the risk of stop-start investment cycles as has been evidenced in the USA.

It is immensely difficult to compare the cost of power generated by different sources and any comparison has the potential to result in a furious debate. Rather than getting involved in such debate, we have presented in Figure 3.1 the views from various 3rd party sources[3], to provide an idea of ranges of costs. The costs are for generation only and exclude transmission costs. Furthermore, in some cases they

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[1] For precise definition see Renewables Obligation Order 2002 in England and Wales and the Renewables Obligation (Scotland) Order 2002 in Scotland

[2] For precise definition see Securing a Renewable Future: Scotland’s Renewable Energy, SE Strategy Document

[3] 'Survey of Energy Resources', World Energy Council; 'The World Offshore Renewable Energy Report 2002 - 2007', Douglas Westwood Limited; 'The Cost of Generating Electricity', Royal Academy of Engineering; EPRI Review

are based on assumptions for production at scale, as there are no operational generators yet (e.g. for marine renewables). Although the ranges used in the figure all include similar cost items like capital depreciation and financing, installation, operational and maintenance cost, they do vary significantly in either including or excluding cost items like: decommissioning cost, life duration of device, cost of environmental impact (CO_2, etc.), government subsidies, etc. It should therefore be regarded as a rough guide only.

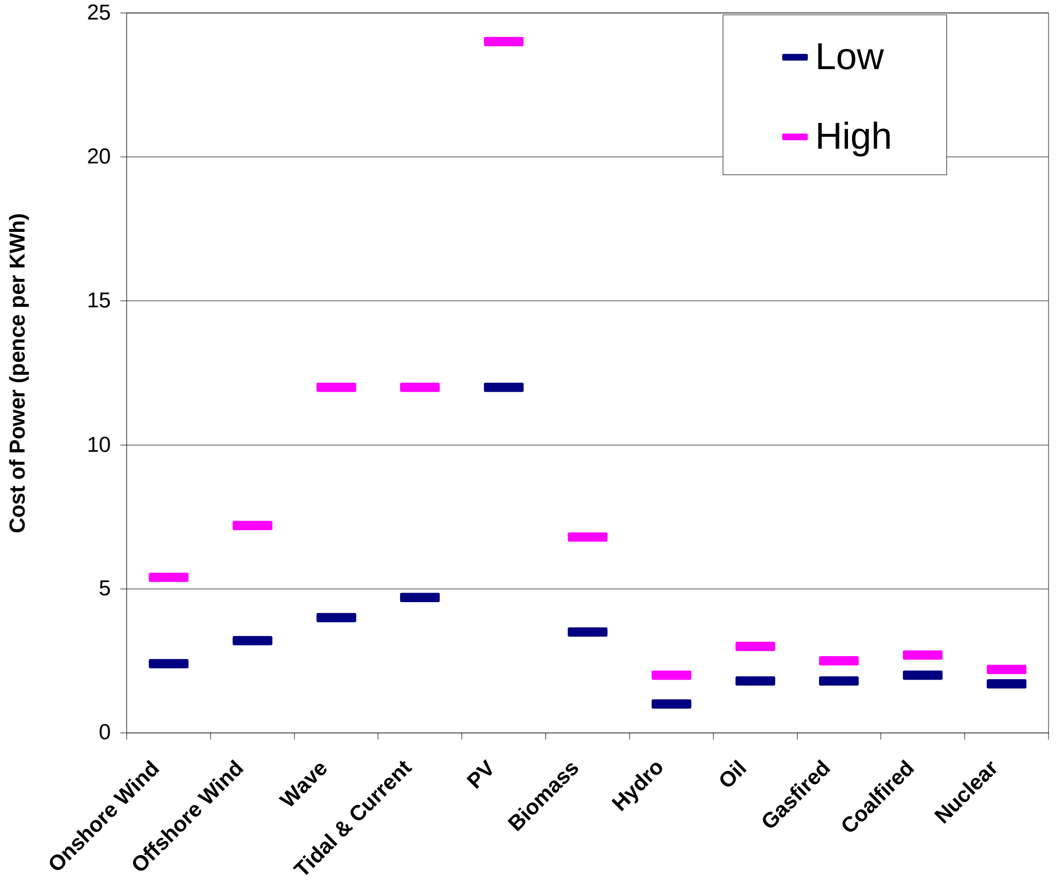

Figure 3.1 Cost of various power generation sources in pence per KWh[4]

From this picture we can see that LCR generated power is not yet price competitive with power derived from most conventional power sources. However, the price per KWh from LCR has come down considerably over the years, especially onshore wind. Offshore technologies still require significant reductions of CAPEX and OPEX.

In the next sections, we will provide a specific market analysis for wind and for wave and current. However, there are market requirements that are important for the development of both wind and marine technologies. Table 3.1 below shows broadly what the various market forces and technology drivers are for LCR.

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[4] The upper limit cost for tidal & current is taken to be the same for wave devices– there is only limited data for tidal & current available

	Onshore Wind	**Offshore Wind**	**Wave / Current**
Availability / Reliability	░	▓	▓
Durability	░	▓	▓
Efficiency Improvement	▓	▓	▓
Electricity Network Integration	░	░	░
Construction		░	░
Access		░	░
Cost Reduction (CAPEX & OPEX)		░	░
Environmental Considerations	░	░	░
Societal Issues	░		

▓ Critical Issue ░ Significant Issue

Table 3.1: Key market drivers for LCR technology development

3.2 Wind Energy Market

A good summary of the wind energy market, technology and regulatory issues can be found in Reference [6], a comprehensive report published by the European Wind Energy Association. The following subsections provide a short summary of key considerations.

3.2.1 Worldwide growth

Wind energy has dominated growth in renewable energy over recent years. The industry has built a track record over the last 20 years, in which technology and manufacturing efficiencies have brought down cost significantly, whilst turbine size has increased from 100kW to over 2 MW.

Until 2003, growth in installed capacity stood at approximately 30% a year and continued growth is expected, albeit at a slower pace. Offshore wind, which to date has played a minor role, will become increasingly important.

Figure 3.2 below shows growth in wind energy to-date (the pink line) and then fitted trend lines to projections by the International Energy Agency, IEA [2] (red line) and BTM Consult [3] (green line). BTM provides the wind industry's most widely recognised projections. Figure 3.3 shows BTM's expectations for each year to 2008 split by onshore and offshore. Note that onshore continues to dominate for the foreseeable future.

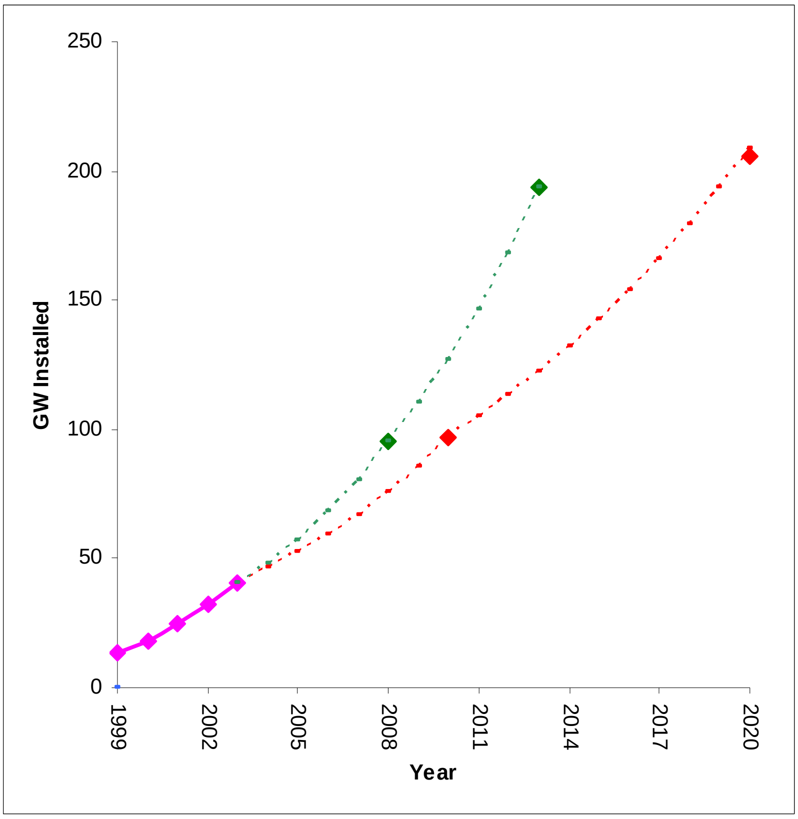

Figure 3.2 Wind energy projections

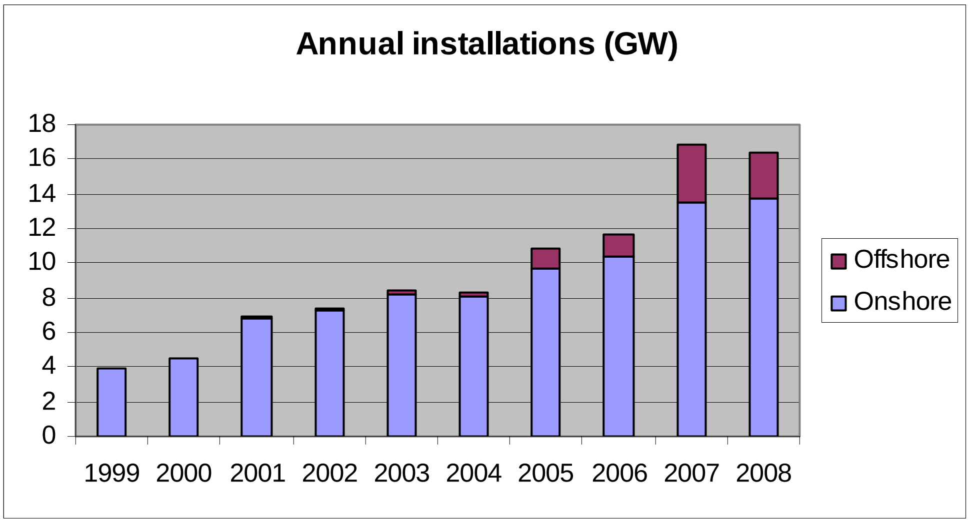

Figure 3.3 BTM 5-year projections (2003)

BTM’s growth predictions up to 2008 are based on actual wind farm projects at the various stages of planning and permission. Beyond 2008, predictions are based on trends and assumptions including, for example: global demand, wind power economics, CO_2 trading and competition between utilities.

3.2.2 Wind Market Segments

Onshore wind

Onshore, modern wind turbines can be installed, and operate satisfactorily, in a wide range of climates and conditions. More often than not, it is the extra cost, or reduced yield, of operating in difficult conditions – such as cold climates or low wind speeds – which limits deployment, rather than its technical feasibility per se. There are turbines available for all locations where there is adequate wind. Markets with more generous remuneration tend to allow room for a wider deployment range. Next to the ‘conventional’ wind energy capture, we can identify new wind segments:

- Offshore wind
- Re-powering and upgrading of old, existing turbines
- Devices to capture energy from low wind speeds (at 5 to 6 m/s)
- Small turbines (up to 100 kW)

Offshore wind

Offshore wind is currently limited to water depths up to 30-40 meters and most operational farms are in shallower waters. Key factors driving offshore evolution are:

- The marine environment – combined wind and wave loading, electrical connections, erection techniques, corrosive environment and reduced human proximity present opportunities for design optimisation to an environment which is quite different to that onshore;
- Cost of energy – offshore wind energy is, unlike onshore, a relatively immature technology and, as it matures and moves into volume production, the cost reduction will be a key driver. Turbines designed specifically for offshore applications will emerge and they may be quite different to their onshore cousins.

Repowering

Repowering is the name given to the process in which existing turbines are replaced by higher-rated turbines. It is now a feature of the onshore market. It is attractive due to the rapid increase in the size of commercial machines, whereby more energy can now be extracted from a site. Consenting a change in turbine size on an existing wind farm site can be more straightforward than consenting a new site. The use of a smaller number of larger machines is often considered by environmental authorities to be a bonus. Repowering is limited to the relatively ‘old’ markets in Denmark, Germany and the USA.

Low wind speed

Until now, wind turbine designers and manufacturers have had little need to look beyond designing for sites with conventional wind resource. This has allowed them to progress steadily toward larger rotor diameters and incrementally lower costs. However, studies indicate that more complex design improvements will be required to achieve the greater decreases in cost of energy needed to be competitive at low wind speed sites. Technology improvements for low speed wind technology are needed in three principal areas:

- Turbine rotor diameters must be larger to harvest the lower-energy winds from a larger inflow area without increasing the cost of the rotor.
- Towers must be taller to take advantage of the increasing wind speed at greater heights.
- Generation equipment and power electronics must be more efficient to accommodate sustained light wind operation at lower power levels without increasing electrical system costs.

Small wind turbines

Small wind turbine technology is distinctly different to that of commercial turbines discussed above. There is a variety of designs and any manner of deployment possibilities – from installation in a back garden, roof top, boat, caravan to an offshore oil rig. Few doubt its enormous potential, but it is difficult to quantify – partly because of its variety and partly because of its ad hoc application. A review of the potential market undertaken in 1998 [4] estimated a total market value of £476M by 2005, with over half of this coming from village / rural electrification schemes. This value has not been achieved but it does give an indication of potential. In a small wind turbine industry “roadmap” published in 2002 [5], the American Wind Energy Association states a goal of 50,000 MW by 2020, equivalent to 3% of US electricity demand. The cost of sales in this market is substantially higher than in the more conventional market; it is a different business and one that remains to be exploited. This study has not researched small wind market in great depth – this may be a subject for further ITI foresighting work at a later date.

3.2.3 Regional Markets

An in-depth review of individual markets can be found in reference [6]. Here we give a high level overview of the key market trends in the most important wind energy countries.

Figure 3.4 shows BTM predicted total wind capacity per region. Clearly, Europe remains the dominant region for wind energy. Europe, particularly Germany, Denmark and Spain, account for some 40GW of installed capacity by 2008, almost half the global capacity.

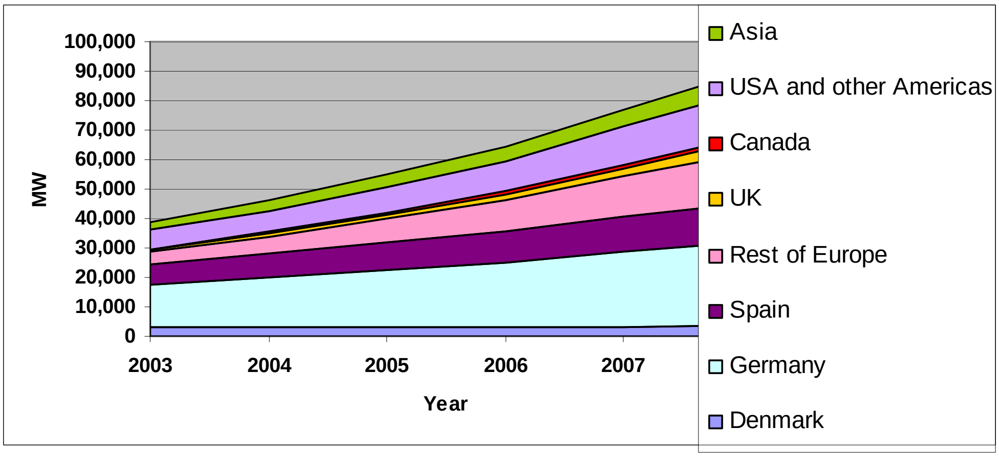

Figure 3.4 Regional installed capacity projections

The onshore new capacity is depicted in Figure 3.5. Again growth is dominated by Germany. Offshore capacity, as depicted in Figure 3.6, will predominantly be built in Europe, mainly Germany and the UK, with a few, large projects in other European countries and in the USA.

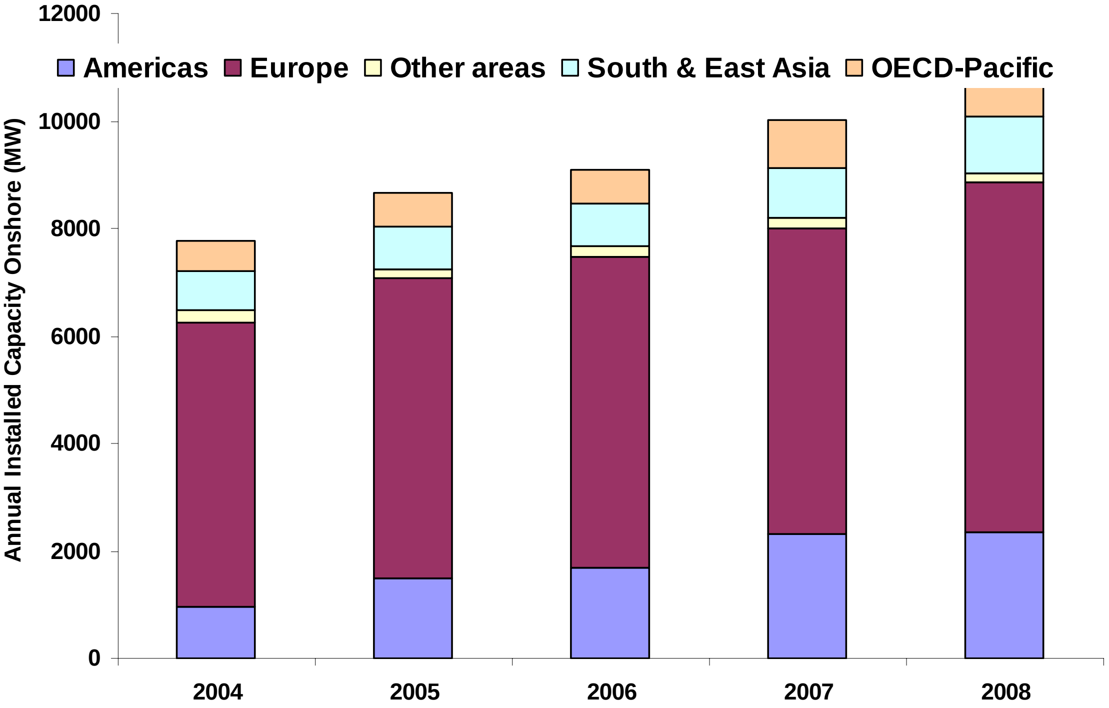

Figure 3.5 Regional new installed onshore wind capacity projections

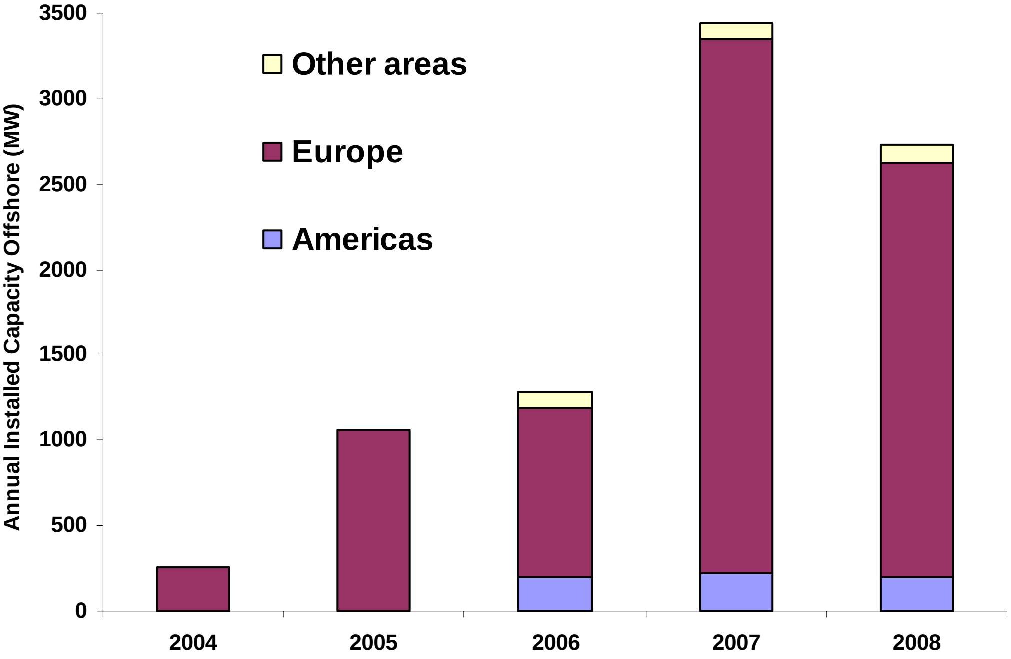

Figure 3.6 Regional new installed offshore wind capacity projections

Some important observations on regional trends are as follows:

Europe*:*

Within Europe the largest existing markets by far are Germany, Spain and Denmark. In absolute terms, the main growth is expected in UK and Germany.

As an already established market, growth rates in Europe overall are expected to remain relatively stable; underneath this trend there will be growth in individual emergent countries alongside saturation of more mature country markets. Installation rate in Germany is expected to slow, the Spanish market is likely to stay at its present rate, while Austria, France, Portugal, UK and Poland are all expected to see increasing levels of development. Significant offshore activity is expected for Belgium, Denmark, France, Germany, Ireland, The Netherlands, Poland, Sweden and the UK.

North America*:*

A reduction in installation rates occurred in 2004, reflecting the ongoing state of uncertainty surrounding extension of the US PTC[5] (tax credit) system. Installations are expected to return to a level in excess of that seen in 2003 in 2005, as a result of the recent extension to the PTC system to the end of 2005. The role of the PTC post-2005 is uncertain and it appears likely that a period of suspension, similar to that of 2004 where the installation rate dropped substantially to 200 MW, will be seen in 2006. A rise in the level of installations is expected in Canada, where increasing activity has been seen through 2004.

Asia:

Following the trend of the last few years, the most growth in the region is expected from India, China and Japan. South Korea is viewed as a potential entrant to the market, and other Asian countries have plans.

Rest of the World:

Central and Southern American markets are expected to grow steadily, with the most opportunity expected in Brazil, which has already seen positive steps towards wind development. Mexico follows Brazil with good forecast growth rates resulting from favourable wind conditions. Moderate levels of new development are expected in Australia, New Zealand, Africa and the Middle East

Countries that have successfully established wind power industries are characterised by substantial inward investment by suppliers who see a future market in that country, and who see the benefits of local supply. The US system has singly failed to achieve this goal but it should be recognised that the PTC was not introduced to establish an industry but rather to increase the installed renewable energy capacity.

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[5] Production Tax Credit – the US incentive system which allows owners of renewable energy plant to obtain credits for a 10-year period.

The most successful in this respect has been Spain, which now has not only a substantial installed wind capacity, but also a substantial wind energy industry. Eight years ago it had neither.

At first sight it seems that the Premium Tariff (PT) approach, which has been used in Spain and Germany, is demonstrably the most effective both in establishing a market and in establishing an industry. However this analysis is rather superficial. The PT approach has been used in countries with an overt, firm commitment to the stimulation of renewable energy and hence it is not the system itself which has led to this level of success but the commitment behind it. Other systems could have been equally successful. The PT system has the major benefit of being simple and transparent. The essential qualities which are required are (i) stability and (ii) a reasonable price. Each could be provided by other stimulation methods and they are not the sole preserve of the PT.

An understanding of the policy environment is crucial for assessing market potential. BTM revises its forecasts every year, and predictions do alter based on new information such as a new government. Another example of the fluid nature of market potential is Ernst & Young’s country wind index [7], which is regularly revised and reflects investment prospects in key countries. Table 3.2 below details some statistics and comments from BTM’s analysis.

From the information set out in Table 3.2 it is possible to identify the “hot spots” for wind energy development. The three big markets have historically been Germany, Spain and the US. In addition, several other countries are emerging as areas of significant potential growth, namely: France, India and potentially UK, Italy, Austria Canada and Australia.

Offshore activity will be limited largely to those countries which are both densely populated and benefit from relatively shallow water around their coast: the North Sea and the Baltic Sea countries, Ireland and possibly the USA.

Country	BTM March 2004-2008		Main market segments	Main physical limitations
	Onshore	*Offshore*		
Spain	6580	220	Onshore.	Environment, grid
UK	1006	2094	Onshore and offshore.	Environment, Social, grid, site access, machine access offshore, sea depth
USA	6800	600	Onshore.	Grid, environment Major research effort to exploit low wind speed areas.
Germany	12723	4087	Onshore and offshore	Grid, environment, machine access offshore, sea depth
Portugal	800		Onshore.	Environment
Italy	1500		Onshore.	
Netherlands	830	320	Onshore and offshore.	Environment, social
France	2048	52	Onshore primarily.	
Ireland	322	603	Onshore and offshore.	Grid, environment, site access
Greece	700		Onshore.	Grid, environment
Denmark	270	160	Repowering onshore and offshore.	
Australia	1570		Onshore.	Grid.
Sweden	382	538	Onshore and offshore.	Environment, social, machine access offshore, sea depth
Belgium	240	400	Onshore and offshore.	Social, machine access offshore, sea depth
Norway	1050		Onshore.	Environment, site access, cold climate
India	2800		Onshore.	Grid
Finland	450		Onshore.	Environment, cold climate.
Canada	1030	20	Onshore.	Environment
Austria	1100		Onshore.	Environment, site access

Table 3.2 Ernst & Young top wind energy markets and BTM projections

Onshore “hot spots” are indicated by brown and offshore by blue

Finally it is instructive to analyse the ways in which the different national markets have developed and the trends which are likely in the future. In Figure 3.7 a schematic diagram of the present wind energy market is provided. The market structure is a direct consequence of the market incentives and national characteristics. At one end of the spectrum is Germany which is characterised by small wind farms sponsored by small groups of private individuals and the largest possible turbines. At the other end is the USA where the wind farms and the sponsors are largest but the turbines are relatively small. In the figure the colour of the circles represents the maturity of the market and their diameter the size of the typical developer.

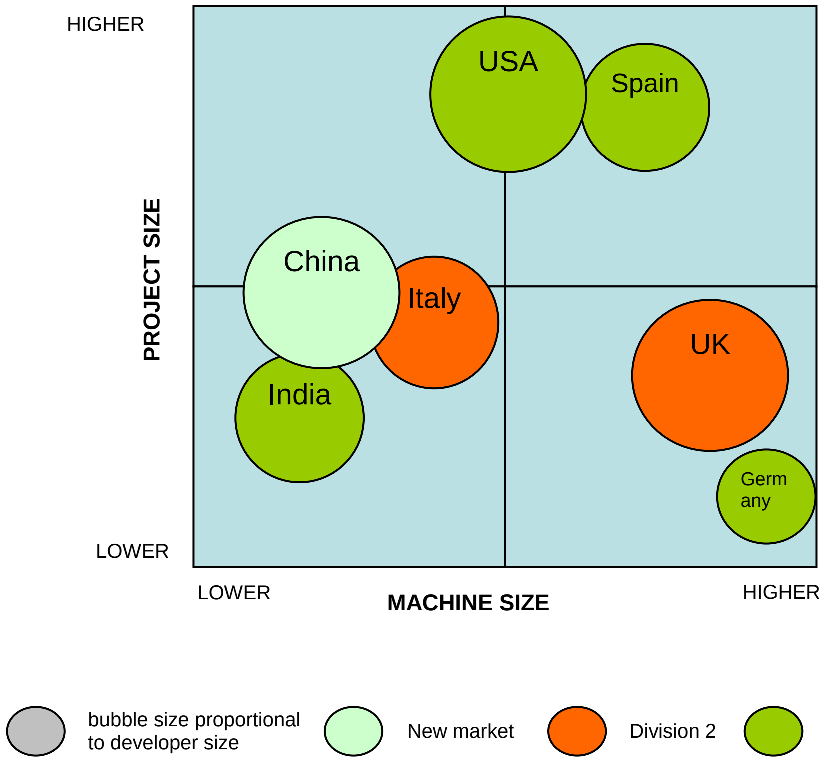


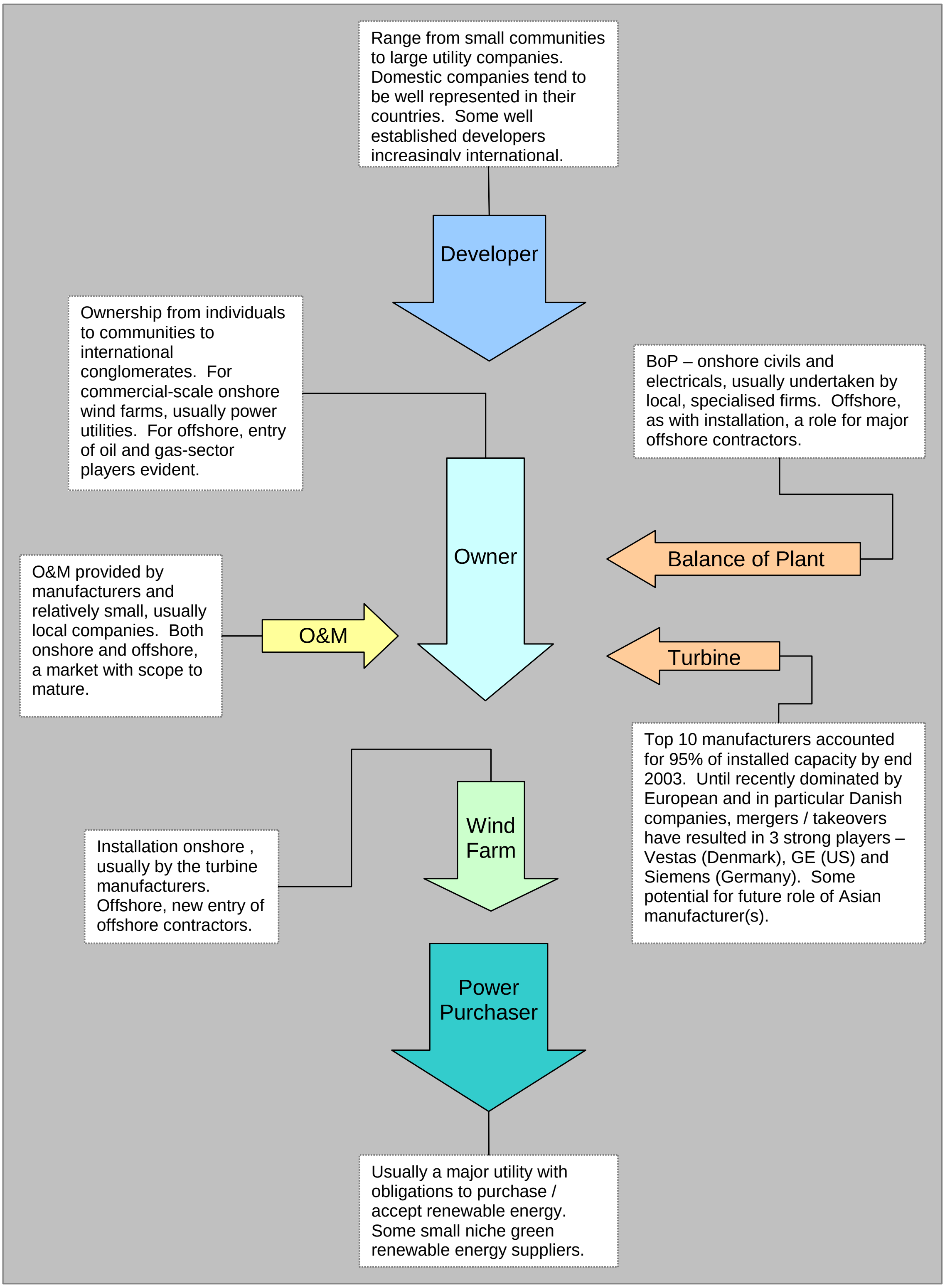
Figure 3.7 The different wind energy market characteristics

Although some small scale development will continue, a migration towards the top right hand corner of this figure is expected and the market will be dominated by large scale organisations.

3.2.4 Industry Make-up

Wind energy is served by a maturing, competitive industry for the full development process from site finding through to installation, operation and power take-off. It continues to evolve through time, notably through market entry of large, conventional sector companies who now perceive the established and growing nature of the industry.

Figure 3.8 presents a basic overview of the structure and makeup of the wind industry. It is worth noting that there is increasing vertical integration from development, through to ownership and power purchase – namely major utilities undertaking the full cycle in-house (albeit via separate businesses) in order to meet their own demand for renewable energy. However there is a reduction in the level of integration between manufacturer and developer.



Range from small communities to large utility companies. Domestic companies tend to be well represented in their countries. Some well established developers increasingly international.

Ownership from individuals to communities to international conglomerates. For commercial-scale onshore wind farms, usually power utilities. For offshore, entry of oil and gas-sector players evident.

BoP – onshore civils and electricals, usually undertaken by local, specialised firms. Offshore, as with installation, a role for major offshore contractors.

O&M provided by manufacturers and relatively small, usually local companies. Both onshore and offshore, a market with scope to mature.

Top 10 manufacturers accounted for 95% of installed capacity by end 2003. Until recently dominated by European and in particular Danish companies, mergers / takeovers have resulted in 3 strong players – Vestas (Denmark), GE (US) and Siemens (Germany). Some potential for future role of Asian manufacturer(s).

Installation onshore , usually by the turbine manufacturers. Offshore, new entry of offshore contractors.

Usually a major utility with obligations to purchase / accept renewable energy. Some small niche green renewable energy suppliers.

Figure 3.8 Wind Industry Value Chain

Installation of wind turbines offshore is naturally quite a different prospect to installation onshore, and therefore the industry has expanded to accommodate new (to the wind industry) players. Principal amongst these are offshore foundation manufacturers and operators of offshore installation vessels.

Offshore wind turbines are usually fixed to the seabed using a monopile (a single steel pile), or weighted down using a concrete gravity foundation. Use of the former employs thick walled, large diameter steel tubes, similar in structure to the steel tower but necessitating large rolling equipment. To supply this market, some specialist manufacturers of large piles, jackets and pressure vessels have entered the market. Gravity foundations employ the capabilities of large civil construction companies.

Offshore wind farms also create a demand for various offshore vessels for survey work, construction and installation, cable laying, piling and drilling. This demand has been supplied by a variety of existing and purpose-built vessels, in both instances drawing heavily from experience in the maritime and offshore oil and gas sectors.

The requirement to install foundations and turbines in particular has initiated the development of specialised vessels to be able to move rapidly between locations and establish a stable working platform more independent of weather conditions, either by traditional jacking mechanisms or by the use of suction anchors.

Figure 3.9 provides an overview of the cashflows in the global wind industry in $Bn in 2003 from a farm owner perspective. It illustrates where money comes from and how it is spent. If we assume a 15-25 year equipment life, one can see that there may be room to make a profit as an owner. However, capital and revenue inflows are inadequate to pay for current new capacity levels, Furthermore, the figure indicates that although the majority of money is spent on turbines and turbine components, significant sums go to ‘service related’ activity, including financing cost, planning permission, site preparation and O&M. In an offshore environment, these service costs will further increase.

The wind industry continues to be commercially challenging, particularly for the turbine manufacturers and other suppliers. The market leader, Vestas, is finding it difficult to produce robust profit margins and the financial markets have realised this. Wind farm developers and operators will try to lock-in revenue streams before commissioning new farms, to reduce financial risk. The turbine manufacturers don’t have this luxury. This pressure, combined with continuing technology standardisation, has resulted in company consolidation and M&A activity from large players, for example GE entry into the market and Siemens recent acquisition of Bonus. We expect this trend to continue.

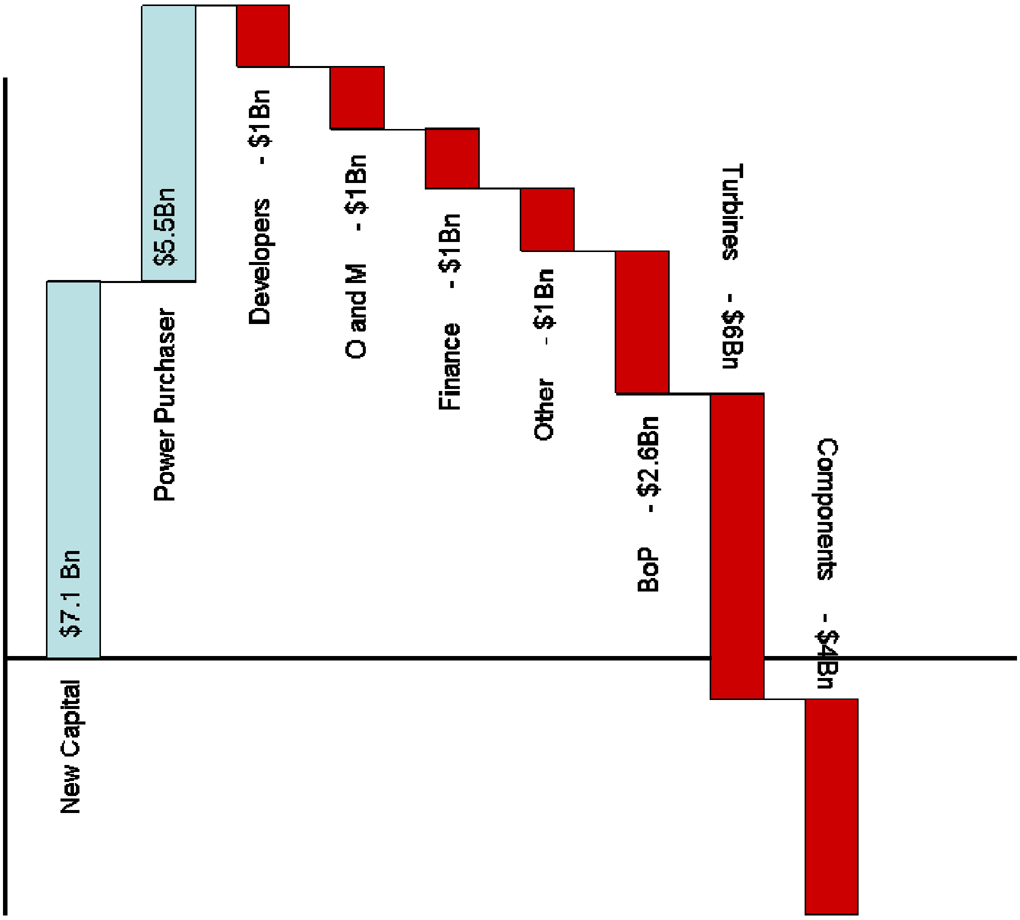


Figure 3.9 Illustrative Cash Flow (note: BoP = balance of plant)

3.2.5 Market Drivers

Market growth of wind power (both onshore and offshore) will not happen because it provides the lowest cost energy. It still requires significant government subsidising. The main market driver therefore is the political agenda, particularly in Europe, the USA and ANZ. In some S.E. Asian countries (notably China), the demand for new power capacity is so enormous, that there is a strong demand for renewable energy capacity, next to a surge in new fossil fuelled power generators.

However, onshore wind energy is one of the cheapest renewable energy sources and further efforts to reduce cost per kWh are underway. This can be achieved by increased turbine efficiency and/or by reducing capital and operating cost of the installed plant. In both cases, technology has and will continue to have a significant role.

Additionally, as more wind capacity is installed, the impact on the transmission and distribution networks becomes clearer, as can be learnt from E.ON Netz experience[6]. Due to the intermittency of wind, there is a need for 'spinning reserves' – conventional power generation in stand-by mode – up to 80% of wind capacity. Wind predictability is poor and high energy demand tends to appear in low wind periods. Furthermore, significant investments are required in new cabling, to transport power

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[6] E.ON Netz annual wind report 2003

from generation locations (with little local consumption) to the consumer centres. Lastly, the complexity of the electricity networks increases significantly, due to the increase in number of generators from a few large predictable ones, to tens or hundreds of wind farms with more unpredictable behaviours and causing bi-directional power flow. These issues will be further discussed in ITI Energy's Future Power Networks foresighting report.

Onshore, modern wind turbines have a wide potential deployment range. Extreme climates can reduce lifetime or energy production, and severe terrain is a limitation on access. Offshore, available technology places a limitation on water depth of deployment.

The cost of producing wind energy per unit of output is related to the capital cost of the equipment, installation costs, maintenance costs and the amount of energy produced. It is cheapest where there is a good, accessible, resource (high average wind speeds). The *value* to an investor is related to the price paid for wind energy, which in turn is related to policy support for wind energy, as well as flexibility and predictability of power availability.

Table 3.3 summarises the key deployment limitations for onshore and offshore wind energy. It follows that innovations to remove these limitations offer opportunities for technology development.

Limitation	Onshore	Offshore
Site Accessibility	Wind turbine components are typically transported to site by road, with sharp bends, bridges, and poor load bearing capacity posing obstacles. The turbine blade is often the limiting component – presently manufactured in one piece, remote from the site.	Components are transported and installed with the use of offshore vessels. Sites need to be accessible to these vessels and o reasonable weather window in which vessels can operate.
Machine accessibility	Onshore machines achieve high availabilities through easy access.	Machine accessibility for O&M is a key issue for offshore wind energy, which is currently restricted by availability of safe personnel transfer methods in a range of weather conditions.
Grid availability	Adequate grid connection is a key site selection consideration. It is probably the main limiting factor for future expansion of onshore wind in Europe and the US.	As for onshore, a key consideration. There is discussion of new offshore grids spe for wind turbines.
Grid compatibility	After a certain level of penetration, the intermittency of wind energy necessitates some changes of practice in order to maintain overall power quality. The nature and size of this is very dependent on the particular grid system.	
Environmental conditions	Extremes of cold, heat or moisture can affect wind turbine operation. For instance, icing of wind turbine blades compromises energy production levels.	As for onshore, but also including the challenges of a corrosive salty environment.
Wind speed	The average wind speed has a very strong influence on energy production, which determines profit. Therefore wind speed is the key determinant of economic viability.	
Ground / seabed conditions	Turbine foundations are designed according to local ground conditions – standard civil engineering solutions are adequate	Uncertainty in sea bed conditions presents a significant risk to offshore installations for both structure and electrical connection.
Sea depth	N/A	Current foundation designs are limited to around 40m depth, either because of the inherent design or prohibitive size (for viable transport to site).
Environmental conflicts	Environmental interests sometimes express concern over the potential impact on flora, fauna and landscape / seascape.	
Social conflicts	Proximity of turbines to dwellings causes conflict.	There is potential impact on interests such as operation of radar systems.

Table 3.3 - Limitations to market acceptance of onshore and offshore wind

Of course, the focus (above) on looking at key limitations which need to be addressed is within the wider context and ultimate objective of driving down the total cost of delivered power. The following sections provide greater insight into the key components of wind turbine costs

Overall costs for onshore wind power have declined considerably as can be seen in Figure 3.10 (please note that figures in this diagram are not the total price per kW electricity produced and delivered to the grid).

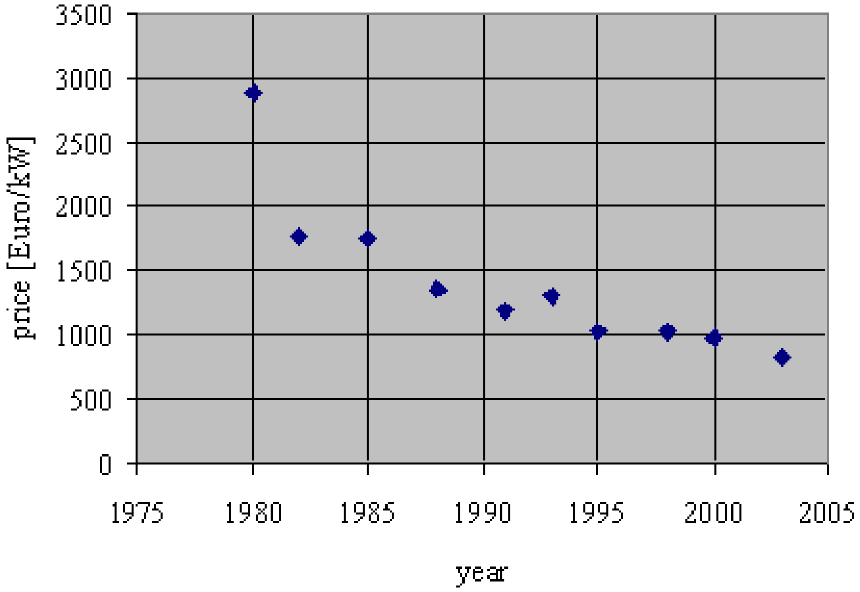

Figure 3.10: Price of turbines per kW from Bonus (now Siemens) pricelist

Another important cost element is the time and cost related to downtime as result of planned and unplanned maintenance**.** Figure 3.11 shows the share of down-time attributable to different types of fault. Alongside this, the figure also shows the number of fault occurrences. Apart from the cost of the repair itself, there is a reduction in power output and maybe a related penalty payment. Onshore, the current statistics on downtime are most important, as many include only minor, quick repairs. However, the number of incidents becomes increasingly important when taking technologies offshore, because access time will play a more important factor.

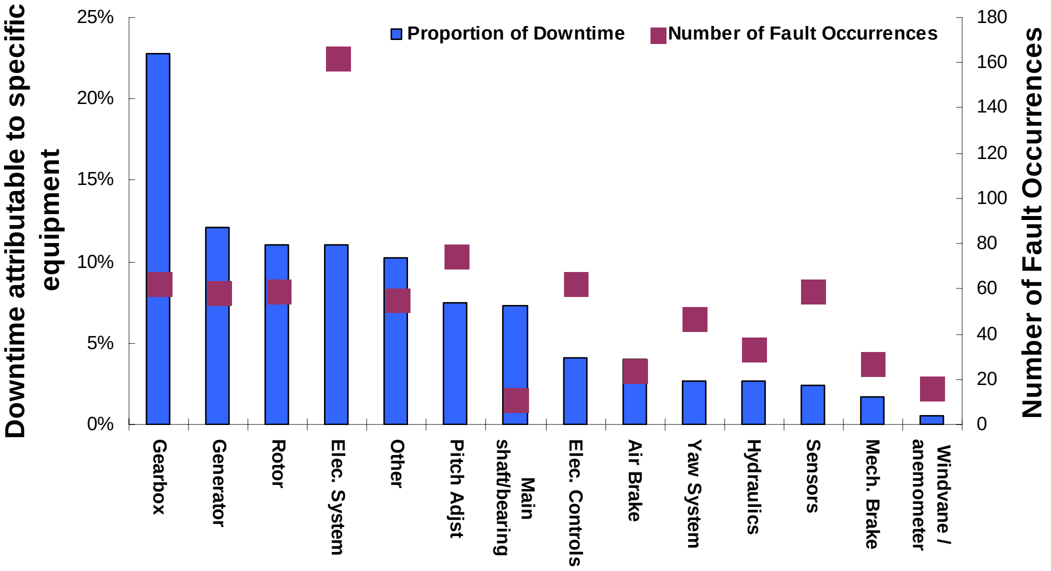

Figure 3.11: German market equipment downtime in 2003 – Windstats Newsletter

Over the years, a lot of work has focused on improving the design of key wind turbine elements, including gearbox, blades, generators, etc. This has resulted in increased robustness and reduced cost through better design. At the same time, increases in size have resulted in economies of scale, bringing down the cost per kW capacity. Offshore wind doesn't have a history of cost improvement yet and, as can be seen in figure 3.12 the turbine foundation is a significant cost element. The various structures for offshore foundations include: gravity based, monopiles, tripods, lattice structures and more in the future floating platforms. Figure 3.12 shows how the balance of various cost elements shifts in going from onshore to offshore wind turbines.

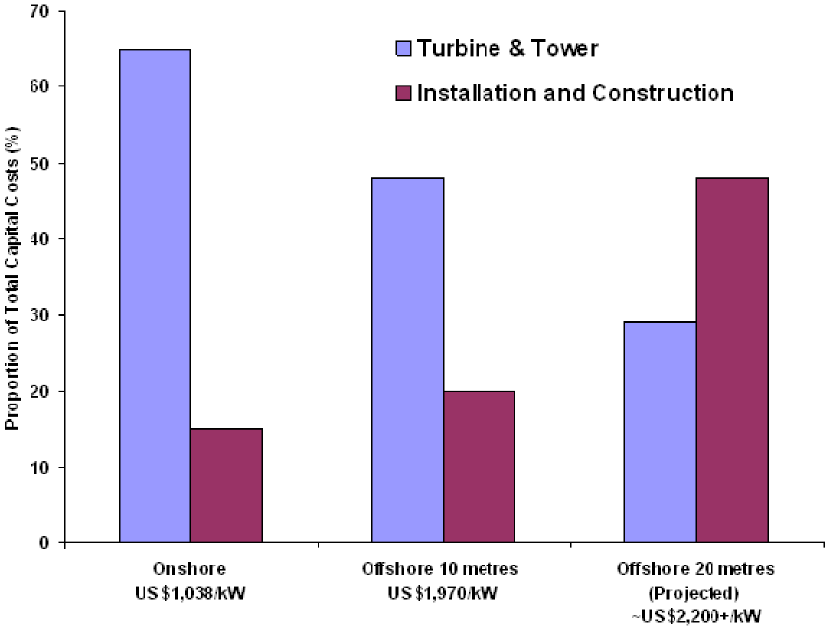

Figure 3.12: cost breakdown for onshore versus offshore wind

3.3 Wave and Current Energy Market

There are substantial difficulties associated with relying too heavily on only one source of renewable energy, such as wind. Hence, many countries are likely to develop a diversity of renewable energy to satisfy requirements for less reliance on fossil fuels, the maintenance of reliable supplies and an acceptable environmental / social impact from new power generation sources. As a result, a number of countries have re-invigorated wave and current technologies through enhanced grants and market support mechanisms. Supplementary to this, there has been interest from commercial venture capital. At present there is a wide variety of device designs with no clear view on what a large-scale commercial wave or marine current energy industry will comprise.

3.3.1 Wave and Current Market Overview and Market Growth

Current designs for wave energy devices are extremely diverse in design, location and size. A distinction which is often made is whether a device is shoreline, near shore or offshore. Devices may also be categorised by which part of the vertical sea column they occupy. A database of 100 wave energy projects[7], splits capacity in: offshore (58%), near shore (34%) and shoreline (8%).

Shoreline devices

This designation applies to wave energy devices mounted on the shoreline – which the Limpet device (by Wavegen) is a leading example. In terms of the total potential for wave energy, the shoreline resource is relatively small. Cliff height and water depth requirements for a device like a LIMPET are rather restrictive. However, when one considers the potential of engineered structures like breakwaters, bridges and causeways, the market widens.

To-date, rated capacities mooted for these devices are in the 20-250kW range. Engineered structures offer the possibility of multiple deployment, but total installed capacities are likely to be limited by unit size. Unit size may increase if viable marine current applications are found. Although the market is, in relative terms, small, shoreline and other land-accessible devices exhibit a number of advantages, namely:

- Accessibility
- A relatively benign environment
- No moorings or offshore cabling

Civil engineering costs for shoreline devices are substantial and cost-competitive sites are likely to be limited to remote, niche applications. Where the device can be embedded within other civil structures, such as a break-water, the incremental civil costs can be minimised and the economics are more favourable.

Nearshore

Nearshore devices are for moderate water depths of less than approximately 20m. Many bottom-mounted devices (both wave and current) are in this category.

Offshore

These devices exploit the more powerful wave regimes of the open sea. Devices include those which float, or which have parts which move up and down from a fixed structure on the seabed. Because of the challenging environment and distance from shore, offshore devices are further away from commercial deployment than nearshore and shoreline devices. The lure of high energy yields has produced a proliferation of many and varied concept designs.

Given the lack of experience, deployment limitations for nearshore and offshore devices are relatively unknown. Experience from offshore wind is certainly relevant, in terms of impact of civil works on the seabed, subsea cabling, sea users and the environmental effects on undersea and sea surface fauna and flora. Some differences which are starting to emerge include:

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[7] Westwood, 2004. “Ocean Power: Wave and Tidal Energy Review.” In REFOCUS, Sept/Oct 2004.

- Leakage of fluid from underwater parts
- Moorings failure
- Lower visibility – a plus point for environmental impact but it creates a requirement for navigation aids
- Greater uncertainty of impacts in the far offshore environment
- The effect of subsea structures, especially moving structures, on marine life (e.g. sharks and rays)

Market Size

The wave and current industry still needs to establish itself and the current market size is virtually zero. The first companies start to present themselves as manufacturers. These are all SMEs, of whom some have managed to secure third party capital. Both national governments and commercial investors hope to back the 'winning' technology. This commercial investment in the marine renewables has occurred at an earlier stage than in wind.

Although there is no functioning market for wave energy, political support for wave energy is notable in a number of countries. Current energy has been supported in Canada, China, France, Russia and the UK, but primarily in the form of tidal barrage projects. Other countries have evaluated their potential for this type of technology.

ITI Energy analysis on BWEA indicative numbers for new capacity build in wave and current over the next years is shown in Figure 3.13. From this we can expect a global total installed capacity of approximately 50MW by 2008. The Westwood database of 100 projects totals 615 MW of capacity installed or under development by 2008. These are still very small numbers, almost two orders of magnitude smaller than wind installation in the same period and, as indicated by the spread in forecast capacity (50MW versus 615 MW), subject to great uncertainty. However, strong growth may start once these 'pilot projects' have delivered positive results.

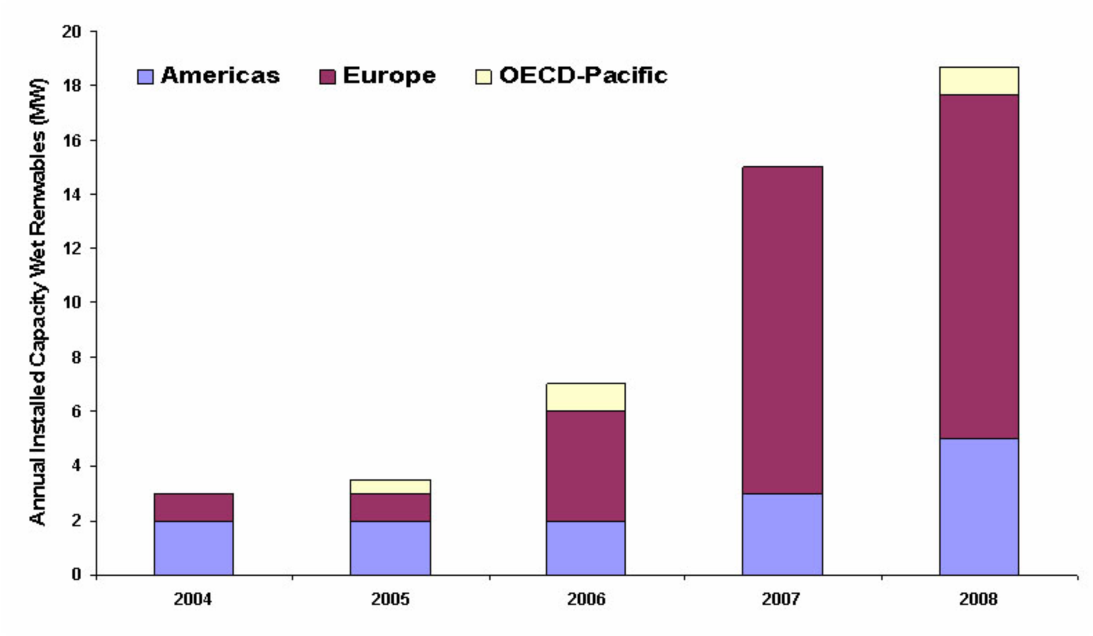

Figure 3.13: Wave (& Current) indicative capacity installation

3.3.2 Regional Markets

Estimates of the 615 MW installed (predominantly wave) capacity to 2008 are: UK (48%), Portugal (21%), Spain (10%), USA (12%), Australia (6%) and Denmark (3%). The geographical location of likely near-term developments seems to have been identified. For wave energy the list of countries which have shown an interest is longer than for current energy. There are two countries, the UK and Portugal, which have taken the significant step of establishing a combination of R&D, test centres and an incentive scheme to promote commercial applications and, hence, these two must be seen as the countries which will pave the way towards widespread application – the wave energy ‘hot-spots’.

For current energy the leading countries where device development is taking place are Norway and the UK. The developments are underway because these countries possess significant marine current energy potential. They should therefore be considered as the marine current ‘hot-spots’.

There are a number of US-based promoters of devices, albeit mostly at the very early stages of development. But should the government alter its view on prospects for these energy sources, budgetary allocations could outstrip those of European countries. The US has traditionally funded renewable energy at generous levels compared to European standards.

Below is an overview of key (governmental) activity in the most advanced wave and marine current power developing countries.

Australia (Wave)

The Australian Government has sponsored development work on two wave energy devices, designed for near shore locations. Both these devices are currently under construction.

China (Wave)

Since the beginning of the 1980's China's wave energy research has concentrated mainly on fixed and floating oscillating water column devices and also the pendulum device. By 1995, the Guangzhou Institute of Energy Conversion (GIEC) of the Chinese Academy of Sciences had successfully developed a symmetrical turbine wave-power generation device for navigation buoys (60 W). Over 650 units have been deployed, mainly along the Chinese coast, with a few exported to Japan. Two projects are currently supported by the State Science and Technology Committee, with a view to shoreline and offshore wave power stations.

Denmark (Wave)

Denmark has been a strong supporter of wave energy and is a member of the IEA's Implementing Agreement. In 1998 the Danish Energy Agency launched the Danish Wave Energy Programme 1998-2004. The Programme has a maximum 80 million Danish Krone at its disposal for broadly supporting development projects initiated by inventors, private companies, universities etc., covering a wide range of possible converter principles. This provided developers with the facilities to undertake some basic research on their devices.

India (Wave)

The Indian wave energy programme started in 1983 at the Institute of Technology (IIT) under the sponsorship of the Department of Ocean Development, Government of India. Initial research identified the OWC as most suitable for Indian conditions: a 150 kW pilot OWC was built onto the breakwater of the Vizhinjam Fisheries Harbour, near Trivandrum (Kerala), with commissioning in October 1991. The scheme operated successfully, producing data that were used for the design of a superior generator and turbine. An improved power module was installed at Vizhinjam in April 1996 that in turn led to the production of new designs for a breakwater comprised of 10 caissons with a total capacity of 1.1 MWe. The National Institute of Ocean Technology succeeded IIT and continues to research wave energy including the Backward Bent Duct Buoy (a variant of the OWC design).

Ireland (Wave)

Wave energy research has been undertaken in Ireland since 1980, much of the work being conducted at University College Cork although other universities (such as Limerick) are now playing an increasing role. In addition to testing various devices, the College has also co-ordinated the European Wave Energy Research Programme and has collaborated in the development of the European Wave Energy Atlas and mapping the wave energy resource for Ireland. In 2003, the Marine Institute and Sustainable Energy Ireland completed a consultation study on a strategy for exploiting wave energy in Ireland. [see www.irish-energy.ie/uploads/documents/upload/publications/wave.pdf] Ireland is a member of the IEA's Implementing Agreement.

Japan (Wave)

Extensive research has been undertaken in Japan, which is a member of the IEA Implementing Agreement. Particular emphasis has been placed on the development of air turbines and on the construction and deployment of prototype devices (primarily OWC's), with numerous schemes having been built.

Norway (Wave)

Research into wave energy in Norway has been centred on the Norwegian University of Science and Technology (NTNU), Trondheim for the past 25 years. Two commercial schemes (a 350 kWe Tapchan and a 500 kWe OWC) operated successfully for a prolonged period during the 1980's. Both schemes have ceased to function and subsequently NTNU has conducted extensive theoretical research into optimum control and phase control of wave-energy converters. Since 1994 NTNU has collaborated with Brødrene Langset AS to develop the Controlled Wave-Energy Converter. In 1998 ConWEC AS was formed to undertake further technical development, demonstration and global marketing.

Portugal (Wave)

Since 1978 Portugal has played a significant role in wave energy R&D. This work has been undertaken at the Instituto Superior Técnico (IST) of the Technical University of Lisbon and the National Institute of Engineering and Industrial Technology (INETI) of the Portuguese Ministry of Economy. Most of the research on wave energy conversion has been devoted to OWC's and associated turbines. Early work concentrated on theoretical and experimental studies of the device hydrodynamics and the behaviour of Wells turbines (including monoplane and biplane rotors, as well as contra-rotating and variable-pitch designs). This included the building of a pilot 400 kW OWC plant on the island of Pico in the Azores, which was completed in 2000 with funding from the European Commission.

Portugal is well placed to take a lead in wave energy for two main reasons:

- The Portuguese Government is attracting inward investment with enhanced prices paid for electricity from wave energy devices (initially approximately € 0.22/kWh) and preferential loans; it has set itself a target of 50 MW of wave energy by 2010
- In 2003 the Wave Energy Centre was set up with the objective of providing dissemination, promotion and support to the implementation of wave energy technology and commercialisation of devices. The Centre has a number of ongoing projects

Edinburgh-based Ocean Power Delivery (OPD) recently secured a contract from the Portuguese electricity company Enersis for a 3-5MW demonstration project in the Bay of Biscay.

Spain (Wave)

As part of its revised market support for renewable energy, Spain provides special remuneration for wave and marine current-generated electricity which is more generous than that for wind energy. At present it offers 90% of a set price called the TMR, for the first 20 years of operation, which is for 2005 equivalent to approximately €0.066/kWh. Developments in Spain include a recently announced JV between Iberdrola (a Spanish power utility), the US wave energy promoter OPT, the Cantabrian Development Agency and the Spanish Energy Agency, for installation of a 1.25 MW wave power station off the Cantabrian coast. Iberdrola owns 70% of the JV, OPT 10%, and the remaining two partners 10% each.

United Kingdom (Wave)

At one time the UK had one of the largest government-sponsored R&D programmes on wave energy, covering a wide range of devices. This was greatly reduced in the early 1980's but research continued at several universities, in particular at Edinburgh and Queen's University, Belfast. The profile of wave energy has recently seen a resurgence, with the UK Government and other bodies supporting several initiatives and substantial political support is apparent for wave devices. Some indication of the change in fortunes for wave energy in the UK can be gathered from the following activities:

- A marine energy test centre has been established in the Orkney Islands, providing subsea cables, a monitoring station and other facilities for wave devices that operate in 50m water depth. Its aim is to stimulate and accelerate the development of marine power devices (see www.emec.org.uk);
- The Carbon Trust has issued a Marine Energy Challenge, whereby device teams are assisted by working with engineering companies who can help them through a cost engineering exercise that will produce information relating to the technical viability and economics of their device. (see www.thecarbontrust.co.uk)
- The Supergen Initiative, launched in 2001 and formally inaugurated in November 2003, has set aside £2.3 million of funding in wave and marine current power research and development in universities (see www.see.ed.ac.uk/research/IES/supergen)
- Regen SW (the Renewable Energy Agency for the South West of England) is proposing an environmental impact assessment of offshore renewable energy developments, to facilitate the deployment of large-scale schemes in that region. To this end, they have commissioned an initial review of the region's wave resources which will map wave and current resources and identify areas with good renewable energy potential. They have also commissioned an engineering study to design an offshore hub (the Wave Hub) and a parallel business case study to provide arrays of wave energy devices with a connection to the mainland grid (see www.regensw.co.uk) which was published in February 2005
- A major new initiative aimed specifically at encouraging marine renewables was announced by the UK Department of Trade and Industry in January 2005 - providing a combination of power price incentives and capital grants. This plan is presently undergoing consultation but there are clear political signs that some market incentives will be put in place soon.

United Kingdom (Marine current)

The only significant government programme on marine current energy is that of the UK. The DTI has supported the development of several different marine current devices, one of which received the largest investment given by the DTI as part of its marine renewables programme. Some of the other activities noted for the UK under wave energy (i.e. the Marine Energy Challenge and the Supergen Initiative) also apply to current. In addition, expansion of the marine energy test centre in the Orkney Islands is being considered to provide facilities for current devices (e.g. subsea cables and a monitoring station). and other facilities for wave devices that operate in 50m water depth. Its aim is to stimulate and accelerate the development of marine power devices (see www.emec.org.uk/pdf/pdf5).

USA (Wave)

Interest in wave energy has recently resurfaced in the United States of America, where the Electrical Power Research Institute has carried out a review of wave energy developers as a first step in helping to formulate the Government's strategy in this area (see http://www.epri.com/). The US Government, through the Department of Defence, has sponsored the development of two wave energy devices, one of which is starting to be deployed worldwide.

3.3.3 Industry Makeup

As mentioned, at the moment there are a number of SMEs exploring a large number of mainly diverse technologies, predominantly wave power related. Some of these technologies have financial backing of some kind (e.g. Wavegen, OPD, OPT, Archimedes), but significant additional investments are required to take any of these technologies into production and into larger scale project development.

Some of the device developers exhibit similar characteristics to the early wind energy pioneers – small, ambitious, R&D companies operating in a high risk, and as yet virtually zero return environment. As well as any core IPR, much of a company's value is in its expertise and in its readiness to exploit available markets. These companies are ill suited to competing openly in world power markets. The point at which focus moves away from R&D to competing for sales, will be an important stage in their development. Success is likely to be marked by either massive growth and maturity in the individual companies, licensing of their technology, or take-over by a large corporation.

There is no established service, manufacturing or power purchase sectors. Where demonstration devices have been built and installed, work has been undertaken largely by local contractors. Financial backers, like project financiers are interested followers at this point in time, but marine energy is not in their direct field of interest yet. Some large corporates are investigating the potential for wave or current commercial production, but nobody has made a significant move yet.

In the meantime, supporting organisations, like the shipping industry, offshore industry, insurance, consulting and certification organisations (e.g. DNV) are very active and starting to establish the communication, insight and standards that will be required for this industry to mature. These activities are centred on locations where there is money available, particularly regions with government support (Portugal, UK).

3.3.4 Markets Drivers

Similar to the wind industry, cost and energy efficiency drivers are the key to market acceptance with the added focus on "survivability". Table 3.6 summarises a number of key issues affecting development of wave and current devices and provides obvious pointers as to where technology can help accelerate commercial development.

Limitation	Wave	Marine current
Site Accessibility	Devices will need to be transported to site. At present this is not a major limitation since the devices are relatively small. However as the size increases it will become a hindrance. Likely solutions will be towing.	The problems and solutions for construction and erection will be similar to offshore wind except that there will additional challenge of high currents which are normally avoided on offshore wind sites. Construction solutions to accommodate this aspect of the technology have not yet been devised and hence this is a constraint.
Machine Accessibility	Machine accessibility in operation will be important for these devices in exactly the same way as it is for wind. For wave and possibly for marine current the devices may be removed for maintenance which will provide both additional challenges and additional solutions.	
Grid Availability	Adequate grid availability will be a vital constraint for all renewable energy devices. The onshore element of the grid connection should not be underestimated and has provided an important constraint for offshore wind.	
Environmental Conditions	In addition to the sea state the saline environment will be a challenge for these devices and must be properly treated.	
Sea Conditions	The wave climate clearly has a very strong effect on both the energy production and also the extreme loads. A key to economical exploitation of the wave resource will be the compromise between these two characteristics. Proper estimation both of the energy production and the extreme loads remains a challenge. Design against the latter in an economic way is a key challenge.	The compromise for the current devices is between good energy producing marine current flows and ease of construction. It is presently acknowledged that some of the best resource may not be available because of difficulty in construction. Understanding the way in which the wave climate affects the turbine loads will also be important and is presently not well understood.
Sea Bed Conditions	Provisions of mooring is one of the most expensive aspects a wave device and hence identification of good ground conditions will be crucial. Means of dealing with less than ideal conditions would be a benefit.	The combination of good sea bed conditions without significant slopes and with good foundation material will be crucial. In order to avoid significant constraint of the resource an ability to find economic solutions for difficult sea bed conditions will be important.
Sea Depth	Wave devices operate at much deeper depths than marine current devices or offshore wind turbines. Provision of the necessary infrastructure both electrical and structural in deep water will be a challenge.	Sea depth is not expected to be a major consideration.
Environmental Conflicts	Interaction between sea life and the operational devices will be a constraint both for mechanical and electrical aspects. These matters are only starting to be investigated and are likely to provide significant limitations/costs.	It is likely that the conflict between marine current devices and other environmental interests will be the most severe. Current devices require very particular local conditions to be viable and moving the solution which is possible for wind and wave will not be easy for current devices.
Navigation	Proper inclusion of navigation warning and other regulatory matters still requires thorough treatment and until this is done it will remain a hurdle - although not a serious limitation.	
Standards and certification	The absence of mature standards and active certification bodies will be a hindrance to the development of the technologies.	

Table 3.6: Impact of market drivers on wave and marine current device technologies

In addition to overcoming the above constraints, the critical imperative for wave and current technology is reduction in the delivered cost of power. Cost elements are discussed more fully in section 4.2.

4 TECHNOLOGY DEVELOPMENTS

Before considering future technology development opportunities, it is vital to consider historical and ongoing activities. This section considers developments across wind, wave and current technology, including trends in factors such as scale, maturity and costs.

4.1 Wind Technology

In parallel to the development and commercial exploitation of wind energy, there have been dramatic developments in the technology itself.

4.1.1 Machine Scale

Technology developments have been most marked by the increase in machine size. Figure 4.1 shows, in a schematic form, the development of the turbine size over the last two decades. This has been a quite remarkable story ending, at present, with turbines of the order of 120m in diameter. Turbines started at about 50 kW, grew to a plateau of 400 – 500kW in the mid 90's, and then grew rapidly to reach the present commercial size of 1–2 MW. There are some manufacturers (at least Nordex, RePower, Vestas and Enercon) presently designing 5 MW, 120m diameter, turbines. RePower commissioned its 5 MW prototype late in 2004. On this basis, it seems reasonable to assume that the average size of machines will continue to increase with time. Indeed, most commentators expect that there will be further size increases, and manufacturers are already offering machines rated in excess of 3 MW.

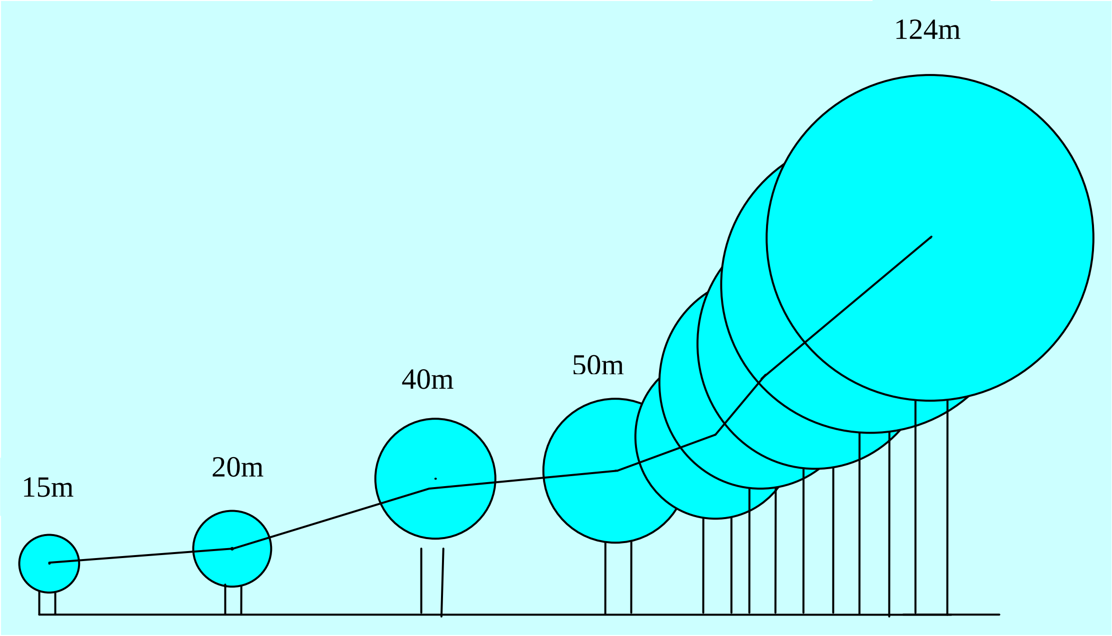

Figure 4.1 The growth of commercial wind turbines

There are practical limitations on size for particular applications, there will also be engineering limits but it is not yet clear what these limits are. The driver behind the largest machines is the offshore market, where size limitations are ultimately likely to be much less of a constraint than onshore.

The largest machines on the market are not necessarily the most cost-effective, but onshore, fewer, larger machines are often more environmentally acceptable. It is likely that for onshore sites, turbine size will soon level off for less accessible sites.

4.1.2 Design Consensus

Of equal importance, but somewhat less clear, is the way in which the configuration or design of the turbines has changed over a similar period and has now almost reached a consensus. Figure 4.2 shows how the consensus has been formed, together with the passage through a large variety of different types of turbines along the way. Any turbine configuration must have three characteristics chosen from the left hand column. The figure shows the evolution from the original main stream architecture, stall regulated, fixed speed and with geared transmission to the present, pitch regulated, variable speed and with direct drive transmissions appearing. The exploitation of variable speed devices in the US is somewhat hampered by a patent owned by GE and Enercon.

These design changes have not been a path to cost reduction. Variable speed may offer a little more energy capture but this is largely offset by added cost. The design changes have largely been driven by market demands - better acoustic noise regulation, better output power quality, avoidance of gearbox problems etc. Cost reduction has mainly come through volume.

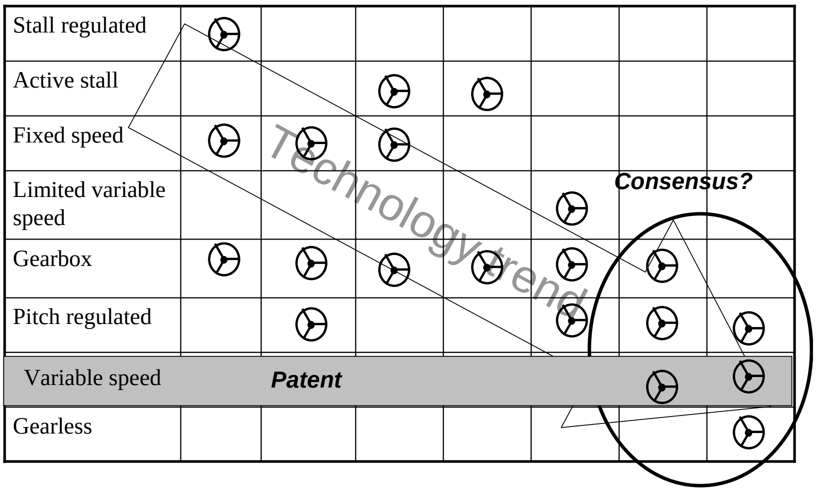

Figure 4.2 The development of the consensus configuration for large wind turbines

4.1.3 Machine Mass

While there is consensus on the turbine configuration, there is evidence of an emerging disparity on the mass of machines. Figure 4.3 compares “normalised mass" for three multi-megawatt turbines. The Vestas machine is a lightweight design, compared to its competitors. One might speculate that lightweight, larger machines are achievable through sophisticated "control" to minimise loads; certainly the V-90 contains such control. This development offers interesting possibilities for ITI Energy.

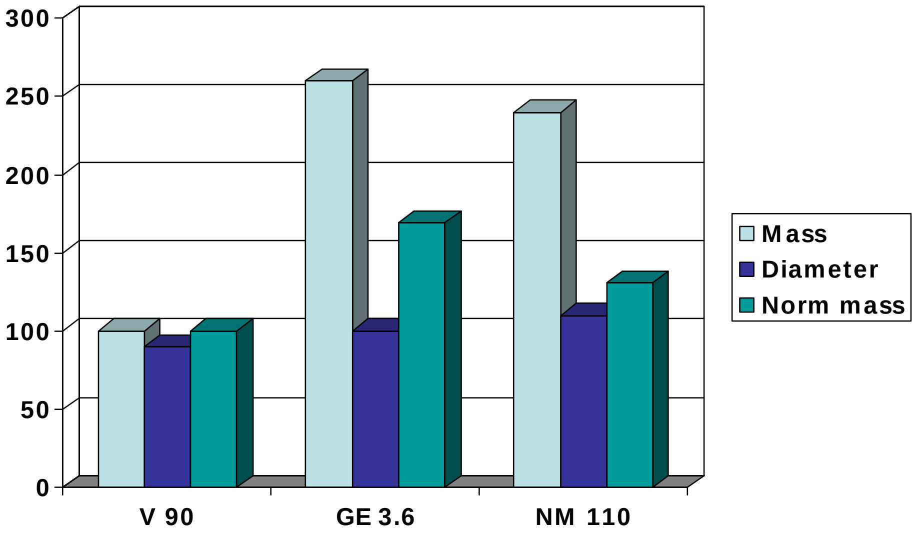

Figure 4.3 Normalised mass comparison

4.1.4 Blade Design

Epoxy based resin systems predominate blade manufacture and carbon fibre reinforcement is increasingly used in big blades. Some manufacturers produce wholly carbon blades and many use carbon in cap spars. One company has developed means of effectively combining carbon with wood laminate. If the trend towards increasing use of carbon continues and the offshore market develops substantially, the wind industry could lead world demand for quality carbon fibre and drive further cost reduction of carbon fibres and prepregs.

4.1.5 Economies of Scale and the Learning Curve

Thus modern wind turbines are more sophisticated and adaptable than their predecessors on account of technology development but much cheaper, (discounting inflationary factors) on account of market expansion. Market expansion has promoted incremental technolgy improvements in design, materials, processes and logistics that have contributed very significantly to cost reduction. There are significant gains from technology advances but no significant cost reduction has come from the most visible changes in main stream technology direction – variable speed, direct drive, predominant pitch regulation.

Since the initial commercialisation of wind energy in the early 1980's, there has been substantial cost reduction which is a direct consequence of the huge growth in the market and associated efficiency benefits – often referred to as an industries "learning curve".

4.1.6 Cost Competition

Wind energy is a very cost-conscious industry, and all suppliers must compete on price if they are to secure orders. Turbine prices have dropped dramatically over the years, as illustrated in Figure 4.4 which shows the Bonus list price suitably adjusted for inflation. Bonus is a useful example as it has remained under the same ownership for the duration shown (although it has recently been purchased by Siemens). Wind turbine price reductions like these have been achieved through volume, engineering improvements, and through economies of scale.

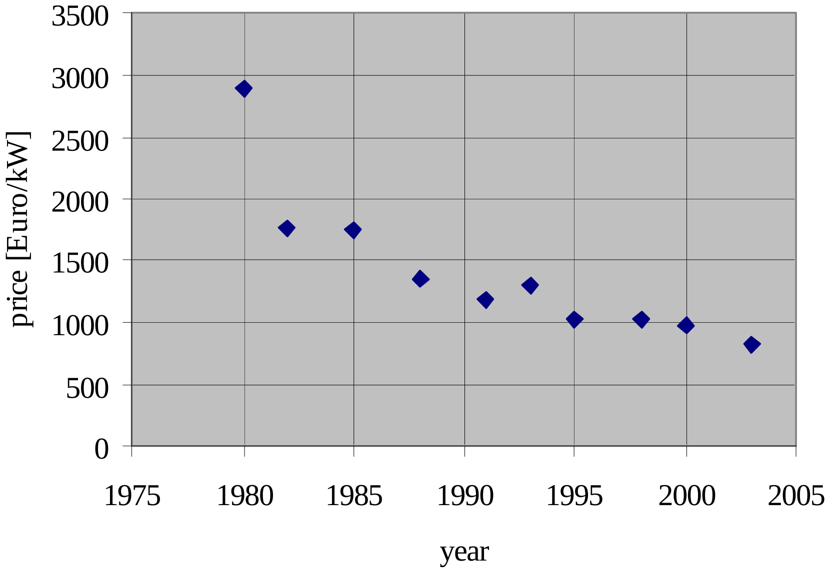

Figure 4.4 Bonus list price

4.1.7 Capital Expenditure (CAPEX)

The price is market dependent. The market has seen *total installed* capacity prices for wind farms in 2003 ranging from US$850 to US$1300 per kW. The US and Spanish prices tend to be at the bottom end of the spectrum and the German prices tend to be at the top end. This pattern coincides with the size of the projects with Germany having the smallest projects and the US the largest. A typical breakdown of capital costs is shown in Figure 4.5, Figure 4.6 shows a breakdown of turbine component costs.

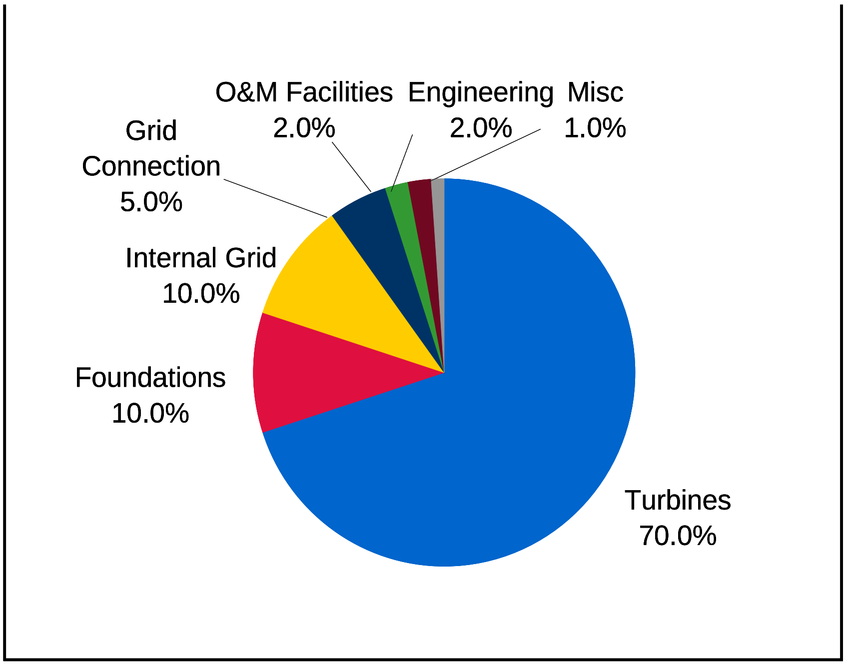

Figure 4.5 Onshore capital cost breakdown

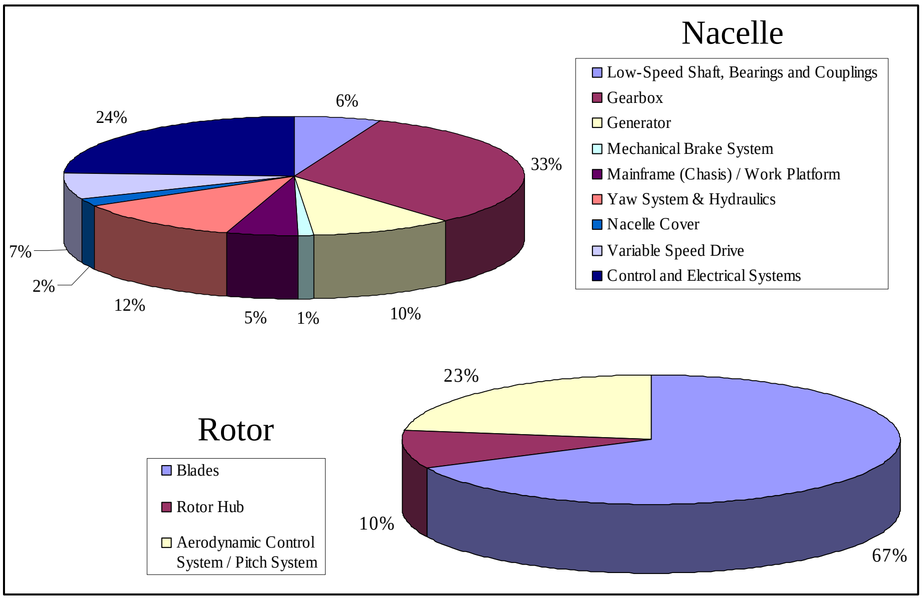

Figure 4.6 Breakdown of costs for the nacelle and rotor

There is much less experience in offshore wind energy, and hence, costs are subject to uncertainty. There is also much more scope for cost reduction through “learning by doing” and cost reductions associated with volume production. Garrad Hassan undertook a review of offshore wind costs and the scope for cost reduction as part of the UK DTI’s recent innovation review, Figure 4.7 and Table 4.1 below reproduce the main results of the current cost assessment, while Table 7.2 in Section 7 comprises the assessment of cost reduction possibilities set out in [8].

Project name	Rated power [MW]	Date installed	Capital cost [€M]	Specific capital cost [£M/MW] [4]
Vindeby	5	1991	10.3	1.45
Lely (Ijsselmeer)	2	1994	4.5	1.58
Tuno Knob	5	1995	10.4	1.45
Dronton / Irene Vorrink (Ijsselmeer)	17	1996-97	20.5	0.85
Bockstigen	3	1997	4.7	1.32
Blyth	4	2000	6.3	1.11
Utgrunden (Oland) [1]	10	2000	13.9	0.97
Middelgrunden [2]	40	2000-01	51.3	0.90
Horns Rev [3]	160	2001-03 [5]	300.0	1.31
Samsoe	23	2002-03	35.0	1.07
North Hoyle	60	2003 [5]	105.7	1.23
Nysted	158	2003 [5]	268.8	1.19
Scroby Sands	60	2003-04 [5]	107.1	1.25

Figure 4.7 Typical breakdown of capital costs (UK Round 1)

Notes:
1. Confidential – figures shown are based on budget costs and possible rating of 10.5MW, not 10MW restriction.
2. Derived from figures published for half the project owned by Middelgrunden Co-operative, with estimate added for grid connection
3. Verbally advised by Techwise July 2002, including grid connection. Vestas have announced that turbine supply contract price is DKK 1 Bn (€134M).
4. Based on exchange rates: €1 = £0.70 = DKK7.44
5. Works still underway – not necessarily final costs

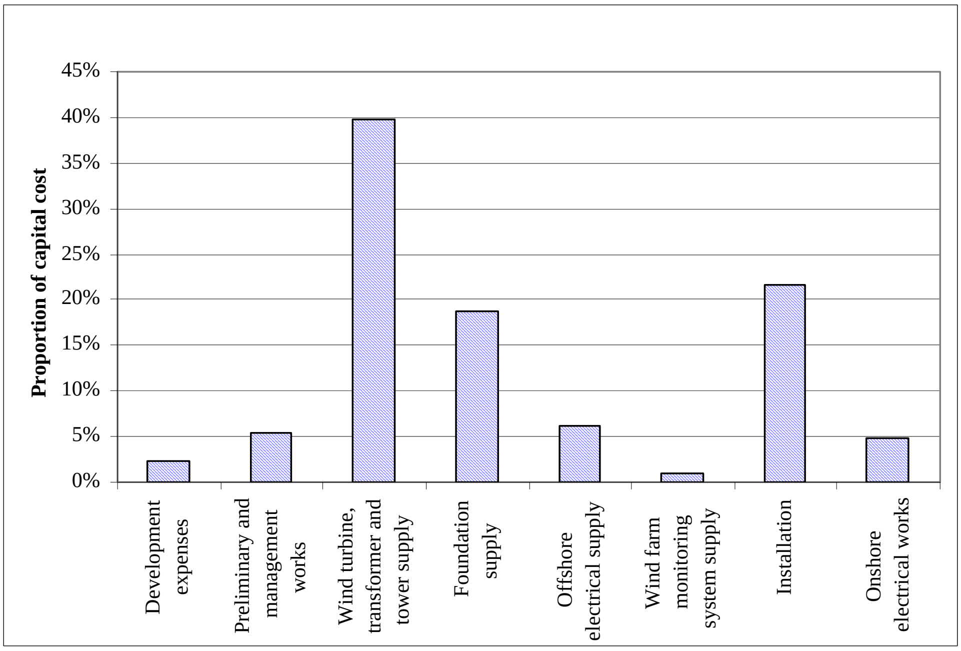

Table 4.1 Published total technical capital costs for offshore wind farms

4.1.8 Operating Expenditure (OPEX)

Typical onshore operation and maintenance costs include routine and non-routine maintenance, repair, insurance, imported power, land rental and taxes, which, over the lifetime of a project comprise some 20-25% of total levelised cost per unit of energy. A detailed discussion of O&M costs can be found in [Reference 6]. If grid connection or grid upgrade costs are charged annually, O&M costs increase.

Data on offshore operational costs is even sparser than that for capital costs. For the DTI review [Reference 8], Garrad Hassan quoted £70,000 per turbine excluding rental or any future annual grid charges. This figure is however subject to uncertainty and experience to-date is of a large variation in estimated O&M costs.

4.1.9 Conclusions

This section explored the trends in wind technology with an emphasis on cost reductions that have generally been achieved through the market forces of competition and economies of scale driving technology improvements. In terms of CAPEX and OPEX there is significant potential for ‘learning by doing’ leading to cost reductions. Market forces will continue to drive technology developments particularly when expanding into the offshore sector where significant improvements are both possible and likely.

4.2 Wave and Current Technology

Present day wave and current energies can be compared to wind energy some 20 years ago – namely a plethora of different designs, with no clear consensus as yet. In wind energy, consensus marked a maturing of the industry. It remains to be seen whether this will be the case for wave and current energy. It may be that a number of different designs will emerge as economically viable, but inevitably there will be significant convergence from the present state of affairs.

4.2.1 Trends

Wave and current technologies have the benefit of drawing from the experience of wind energy in reaching commercial maturity. There are many transferable lessons, such as the importance of design and performance standards, and certification by recognised classification societies. Adopting these lessons offers an opportunity for achieving accelerated development in a number of areas. The designs for different wave and current devices tend to focus on three common objectives – survivability, efficiency and/or ease of installation.

In order to understand the value in any wave device, it is helpful to consider three basic elements:

- A means of collecting and concentrating energy in the waves
- A turbine to generate power
- Protection against the waves.

Differences between devices are in the design solutions to these requirements, and where the device is situated – on the shore, the seabed or floating. Devices must be effective in extracting power from the waves, and at the same time be able to survive the waves. These are often conflicting design requirements.

Basic concepts – such as the use of hydraulics or air turbines – are usually not unique to any one device. If new concepts for power take-off or power concentration are incorporated, it may simply add complexity to an already challenging endeavour. Device developers add value in the combination of elements, in optimising design of each element to its purpose, in ensuring that the device can survive, and in creating an overall product which works. It must provide an acceptable trade off between survivability and power take-off.

It is interesting to compare these requirements with those for wind energy technology. A key consideration for a wind farm site is the ratio of the extreme wind speed to the mean wind speed. The first determines the cost and the second determines the income. In fact the square of this ratio needs to be considered to provide loads. An excellent site in the “roaring forties” will have a ratio of perhaps 8 whereas a site in the tropical cyclonic belt might have a ratio of 100. This ratio will be crucial for wind, waves and tide. The source of the loads will be different but the importance of their ratio will be the same.

Under a collaborative public / private development programme, the US-based EPRI recently undertook a review of wave energy devices, with a view to establish which, if any, might be suitable for scale deployment [9]. The study reviewed 12 devices against technical, economic, corporate and US state “fit” criteria.

It is important to note that the EPRI assessment was time-constrained, in so far as it envisaged a near-term deployment programme. Devices which were further progressed in the development process therefore scored highly. It was also dependent on information provided by device promoters, which was variable. It is by no means certain which device(s) will ultimately prove to be “winners”, and it is likely that further designs will emerge as plans hitherto under wraps, are revealed. This possibility was demonstrated recently by the Norwegian firm Fred Olsen (already a wind farm developer) announcing demonstration plans for its own wave energy device.

Drawing on the wind energy analogy it is likely that a consensus will eventually emerge, but that process may take some considerable time. In the meantime there is a pressing need for development and refinement of the existing devices with a view to increasing reliability. Cost reduction is likely to occur at a later stage. Wave energy is at the stage where real innovation can bear considerable fruit.

4.2.2 Diversity of Device Concepts

One particular feature of wave and current technology which differentiates it from wind power is the sheer diversity of device concepts under development. The following short section describes some of this diversity.

Wave Devices – Essentially all wave devices harness either potential energy, by following the wave motion, or the kinetic energy, by harnessing the surge associated with the wave motion. A view on the diversity of concept design may be obtained by considering the primary means of energy extraction. All devices examined currently harness one of the following five means of energy capture and transfer from the motion of the waves:

- Air Pumps (OWC’s)
- Sea Water Pumps
- Hydraulic Fluid Pumps
- Magneto Hydro Dynamic Devices
- Overtopping Devices

The innovation and hence the difference between individual devices are essentially in the detail design and tuning of the systems to optimise energy capture and efficiency, particularly in variable sea states.

In terms of the device embodiment a huge variety of designs are evident, however no one device design, around any of the five primary energy capture means has yet emerged as the best/most cost effective. In terms of installation some devices float (at various water depths), others are fixed to the seabed, and others yet are fixed to shore with no real design convergence yet identified.

Current Devices – there are three main variables in marine current device technology:

1. Means of Energy Extraction

    - Axial rotors
    - Cross Flow Rotors
    - Hydroplane Wing Device
    - Harnessing Venturi Effect
    - Magneto Hydro Dynamic (MHD) Device

2. Type of Installation

    - Surface mounted
    - Mid depth installation
    - Bottom mounted

3. Power Take Off Method

    - Hydraulic Power Take Off
    - Electrical Power Take Off

Again the innovation and difference between the devices of individual companies is essentially in the detail design of the systems to optimise energy capture, efficiency and means of installation, operation and maintenance.

The range of solutions is indicative of the maturity of the technology and hence, also the scope for innovation. [8]

4.2.3 Economics of Wave Energy

Wave energy is at an interesting point in its development. The first full size prototypes are being built and, depending on the experience gained, the economic prospects will be determined with greater clarity.

Future generating costs for wave energy have been cited as US 3-4 ¢/kWh – without reference to the wave climate, discount rate or other variables. These are the costs required for any technology to be truly competitive in the open market. These costs have been achieved by onshore wind turbines at the optimum locations. Wave energy devices operate in harsh environments, and it will be a major challenge for a wave energy device to achieve such low costs.

Using the values provided in the EPRI Review and other public source material, together with allowances for aspects of the schemes which were not included for some devices (O&M, grid connection, etc.) the range of potential generating costs have been estimated for a small scheme (2-50 MW depending on the technology) at suitable locations. The results are shown in Figure 4.8 (using a 10% discount rate

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[8] EPRI, 2004. "E21 EPRI Assessment. Offshore Wave Energy Conversion Devices."

over the lifetime of the project) for the technology in its current state of development and assuming each aspect fulfils its potential.

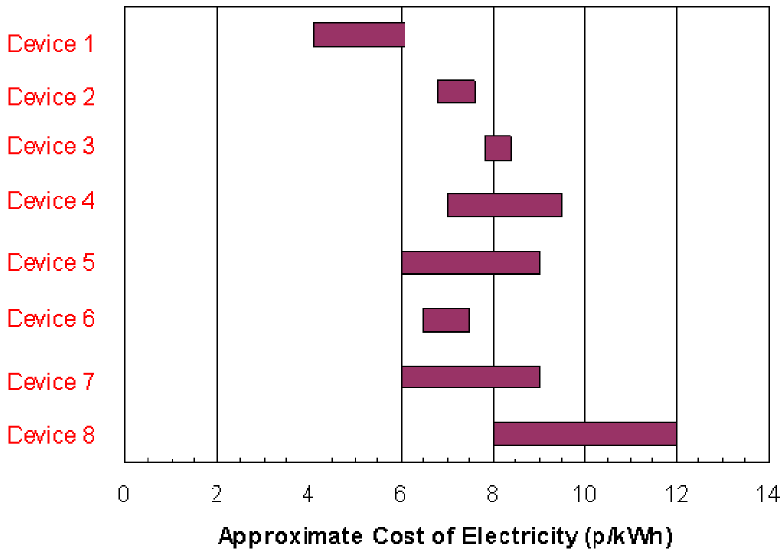


Figure 4.8 Predicted costs of electricity based on EPRI Review

Several caveats should be borne in mind when using these results:

- They are comparative and not absolute; as the level of detail in the EPRI report is limited (e.g. previous independent assessments by the author have predicted slightly lower costs for Device 1 and much lower costs for Device 5).
- The costs do not take into account future R&D.
- The costs are for a wave farm, assuming each device lives up to its potential – generating costs from the first prototypes will be 2-3 times higher, because of mobilisation and grid connection charges.

Nevertheless, it indicates that there are several devices potentially capable of generating at 5-6 p/kWh.

Figure 4.9 and Figure 4.10 examine the main cost centres for a variety of Oscillating Water Columns (OWCs) and offshore devices.

In both cases, the main cost centre is the civil construction costs, hence achieving replicability and economies of scale or R&D into alternative materials or reduction of conservatism in design codes would be of greatest cost reduction benefit to future devices. The next biggest cost centre is M&E equipment. Here, replicability leading to cost reductions and redesign leading to greater efficiency is the main ways to benefit the economics of these devices. It is interesting to note that the distribution of costs is very similar to those for an offshore wind farm. When comparisons are made with wind energy, they should be made with offshore rather than onshore applications.

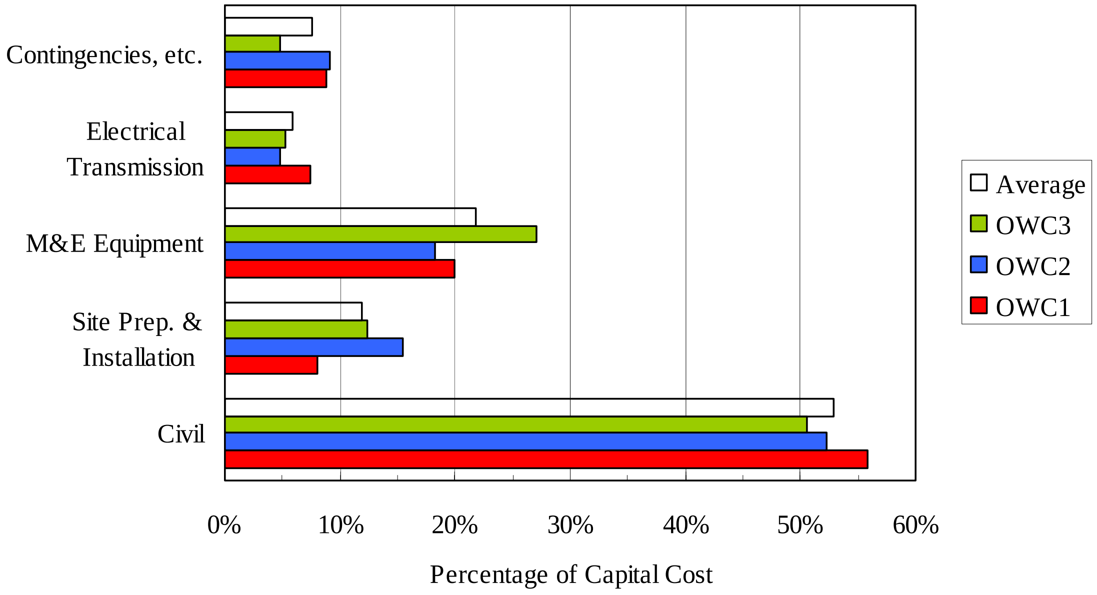


Figure 4.9 Breakdown of major cost centres for OWCs

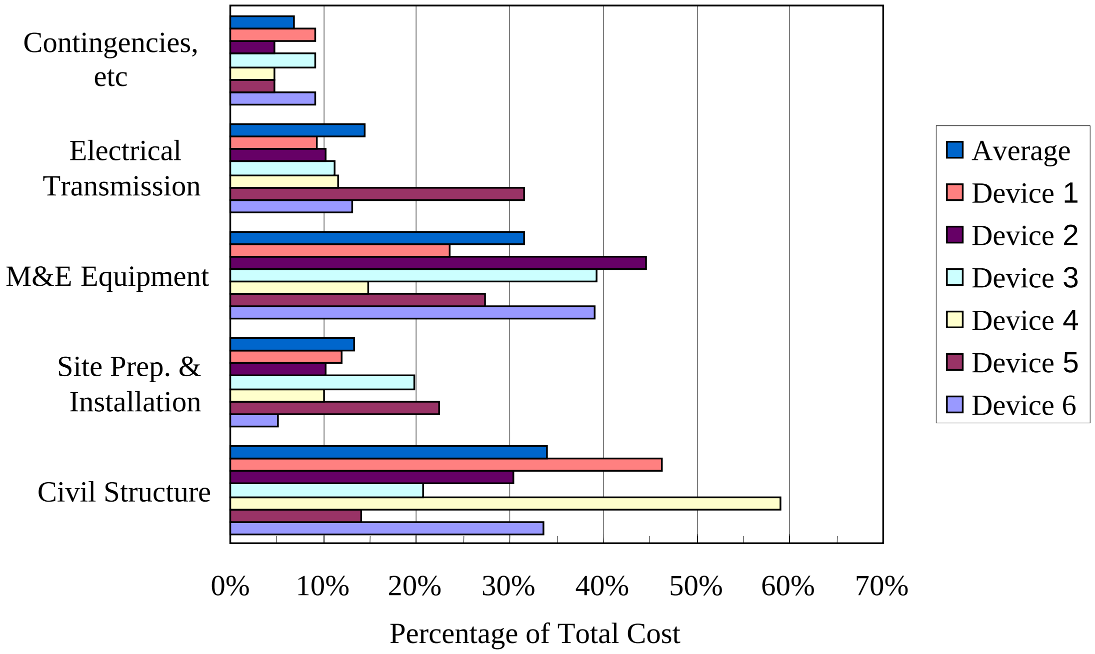


Figure 4.10 Breakdown of main cost centres for offshore devices

4.2.4 Economics of Current Energy

An assessment has been undertaken on representative devices for deployment in the UK. Some assumptions are as follows:

- In the absence of models or larger-scale devices, the cost of the system has been evaluated by using similar technologies. These technologies already have the benefits of being “nearly mature” and include economies of scale. Therefore, the costs are those predicted for a mature current device. It is expected that the first prototypes and demonstration schemes would be between two and four times more expensive than the cost of mature devices.

- The capital costs include connection of the scheme to the nearest suitable part of the transmission grid.

The lack of proven commercial schemes means that the cost and performance of current generation can be only an estimate. In addition, the costs will vary significantly with device location, distance to grid, water depth, etc. Therefore, these predicted costs and performance of current energy technologies should be taken as representative of a mature technology.

The breakdown of the capital costs of a scheme of 30 devices each rated at 1 MW is shown in Figure 4.11. Despite the difference in design and cost breakdown, the total costs are similar: £35 million compared to £41 million which is broadly comparable to the offshore wind capital cost per farm.

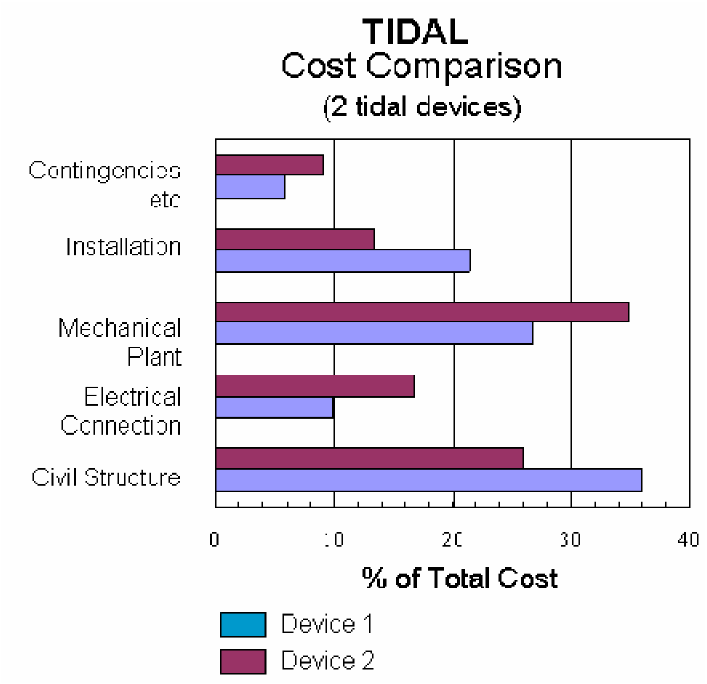


Figure 4.11 Capital cost breakdown for marine current devices

4.3 Conclusions

Onshore wind turbines have reached a level of maturity and convergence where there are unlikely to be major, disruptive technology changes in the foreseeable future. However, offshore wind development is currently relying largely on marinised versions of onshore turbines – in the view of ITI Energy, in the medium to longer term, there are prospects for more significant innovations to provide devices designed specifically for the marine application.

The marine renewable energy devices, both marine current and wave, are further from commercial viability than wind. Marine current devices are progressing quickly towards that goal and wave energy devices are following more slowly. The concept for the marine current devices is broadly similar across suppliers whereas there is still a plethora of different wave devices – in the view of ITI Energy this is likely to remain the case in the short term until there is convergence around a small number of device designs which prove to be most effective, in terms of cost of energy, in the medium to long term.

5 RESEARCH AND DEVELOPMENT EXPENDITURE

The broader picture of R&D investments (historical and ongoing) is the final aspect of context which this study considered before progressing to the stage of creating a long list of technology development ideas. Clearly, ITI Energy must be aware of other organisations investing in R&D as this creates areas of competition and, potentially, opportunities for collaboration. The following section provides a high level overview of both public and private research.

5.1 General R&D Expenditure

Table 5.1 shows total R&D energy expenditure for IEA member countries. More detailed discussion of renewables R&D expenditure can be found in [10,11]. Of the in scope renewables (wind and marine), wind takes the biggest share with 1% of the total IEA budget.

R&D Budgets in IEA Countries by Technology	**Budget by Technology 1974-2002 (million US$)**	**Shares in Energy RD&D 2002 (%)**	**Budget by Technology 1987-2002 US$)**	**Shares in energy RD&D 1987-2002 (%)**
Nuclear Fission	137,529	47.3	52,663	39.7
Fossil Fuels	36,842	12.7	16,284	12.3
Nuclear Fusion	30,562	10.5	14,615	11.0
"Other" Technologies	29,212	10.0	18,613	14.0
Renewable Energy	23,550	8.1	10,234	7.7
Solar Heating and Cooling	*3,024*	*1.0*	*885*	*0.7*
Solar photo-electric	*6,354*	*2.2*	*3,636*	*2.7*
Solar thermal-electric	*2,555*	*0.9*	*666*	*0.5*
Wind	*2,910*	*1.0*	*1,465*	*1.1*
Ocean	*754*	*0.3*	*128*	*0.1*
Biomass	*3,578*	*1.2*	*2,083*	*1.6*
Geothermal	*4,088*	*1.4*	*1,221*	*0.9*
Large Hydro (>10MW)	*93*	*0.0*	*93*	*0.1*
Small Hydro (<10MW)	*49*	*0.0*	*49*	*0.0*
Conservation	23,479	8.1	14,872	11.2
Power and storage technology	9,844	3.4	5,500	4.1
Total all energy	291,020	100	132,781	100

Table 5.1 R&D expenditure in IEA countries

A summary description of the R&D expenditure of the main IEA countries in wind and marine is provided in graphical form in Figure 5.1. Of the leading wind energy manufacturing countries (Denmark, Germany and Spain) only Germany is spending appreciable funds. The UK has spent the most on marine technologies. The US data does not indicate what proportion of a significant R&D budget is spent on wind energy R&D and as such has not been included in the figure. On average the US has spent approximately $122m per year (from 1974 -2002) on wind and solar pv, a significant proportion of this investment has been on wind technology. Historically the US Government has not supported R&D in marine energy.

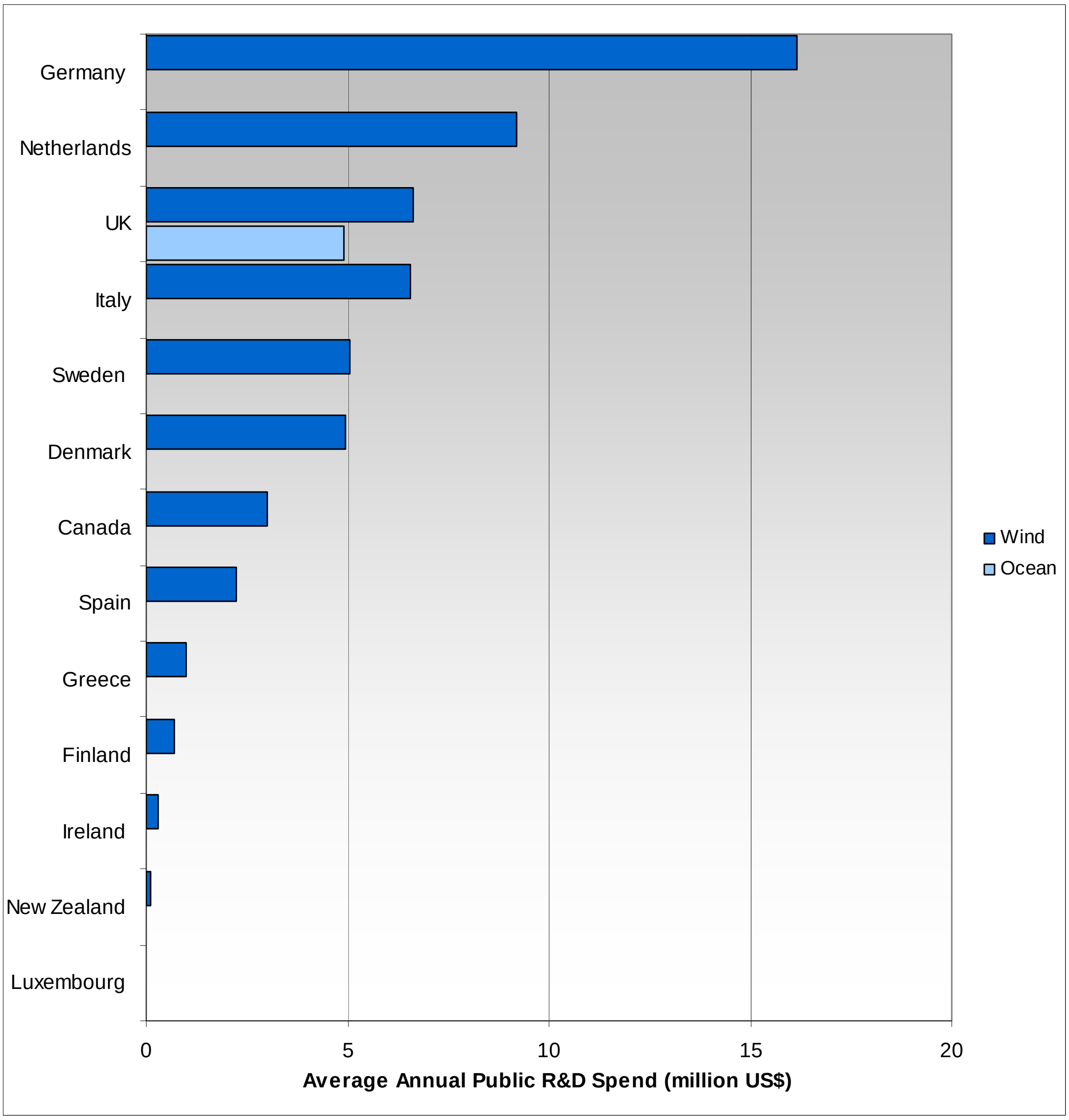


Figure 5.1 Summary of Wind, Wave and Marine Current R&D expenditure in most significant IEA countries

5.2 Wind Energy R&D

A number of governments have allocated public funding specifically to wind energy.

The current wind industry is relatively conservative with respect to research. A limiting factor in the scope for step changes in design is the significant role that non-recourse Project Finance plays in the development of projects. Most financial institutions prefer to invest funds in proven technology with a demonstrable track record. This means that turbine manufacturers have an interest in producing turbine designs that have a direct relation with earlier designs in order that the track record of these earlier designs may be relied upon.

As a result, most pure research is performed by academic institutions and start up companies. The larger companies have tended to limit their activities to development. The market entry of GE and Siemens may, however, change this position since these two companies are able to call on substantial corporate R&D resource which will allow cross fertilisation from other fields, and substantial financial warranties which can underwrite more innovative solutions.

The wind industry is now at a stage where it is regarded by some as mature technology. However, much of the development that is being performed at present is associated with manufacturing techniques, particularly in blade manufacturing. Other major areas of current development are offshore technology and load limiting by intelligent control, which is being addressed by many manufacturers at the current time. The control of loads will be critical to manufacture of larger units in a cost effective way and depends crucially on the control system. As explained above, the light weight of the Vestas V-90 is due, in a large part, to the use of the control system in this way. It might be called the first “intelligent turbine”.

Table 5.2 below summarises the main areas of R&D activity for the major manufacturers as:

- Blade Materials and Process Development
- Aerofoil and Aerodynamic Design and Related Developments
- Intelligent Control of Loads
- Direct Drive Transmission Systems
- Grid Compatibility.

Turbine Manufacturer	Wind Turbine Market Share 2003	Highlighted R & D Interests
Vestas (Denmark)	21.7%	High quality composite development (resin infusion and prepregs especially via subcontractors Hexcel and SPS), single bearing development with SKF for main rotor, intelligent control to mitigate loads – specifically individual pitch control of blades. Mass reduction measures generally and specifically towers recently (magnetic attachment of sundries to avoid stress concentrations associated with welding). Cast iron strength research for accurate design data. Collaboration with Hansen (BE) on new drive train.
GE Wind (US, Germany)	18.0%	Resin infusion and carbon blade development, high lift aerofoils, low noise tip shape, twist flap coupling to regulate loads, portable blade plant, and advanced control for load reduction. Widespread research efforts. Some question as to the level of integration and coordination in respect of integrated machine design. Development of DVAR (dynamic VAR) control for ease of integration. Offshore handling design development is inferred as their equipment is quite distinctive. Fundamental research into turbulence in wind farms.
Enercon (Germany)	14.6%	Distinctive technology involving direct drive generator with wound field rotor. Little publicity about their R&D. , New aerofoil design including high lift aerofoils has been evident with production of recent high efficiency blades. In-house blade manufacture is supplemented by external sourcing. Reduction of aerodynamic losses at blade nacelle interface using CFD modelling to inform on root shape is claimed. Enercon has positions itself as a leader in grid compatible systems and is addressing how to operate WTs more like conventional power stations especially in regions with high levels of wind generation.
Gamesa (Spain)	11.5%	Vestas derived technology. Advanced control for load mitigation being explored. Major cost reduction efforts.
NEG Micon (Denmark) (now merged with Vestas)	10.3%	Development via UK acquisition (formerly Aerolaminates) of hybridization systems for carbon-wood and carbon-glass which may have significant future impact. Stall/active stall regulated rotors (historically) giving way to pitch regulated probably accelerated by recent merger with/takeover by Vestas.
Bonus (Denmark) (now Siemens Energy (Germany))	6.6%	A number of patented aerodynamic ideas (dinotails – for reducing tip noise). Soft mounted rotor development but reverted to more conventional rotor support systems. Thermoplastic blades now coming into production. Outwardly conservative but a lot of background R&D has been undertaken, now part of Siemens.
REPower (Germany)	3.5%	Collaboration on gearbox (Renk) development for 5 MW design. Some gears only simply supported. Design has evolved originally from the expertise of the German engineering design consultancy Aerodyn through various commercial associations and company transformations. Generally conventional design but focused on offshore and large systems.
Nordex (Germany)	2.9%	Evolved from Danish technology expanded into German market, owned for a period by Deutsche Babcock. Using Maag multi-pinion lightweight gearbox (UK source technology long since acquired by Swiss interest)
Mitsubishi (Japan)	2.6%	Moving (quite slowly) up a learning curve from very conventional early technology in 1980's. Working with TPI on resin infusion, some involvement in development of direct drive generators.
Suzlon (India)	2.1%	Hydraulic torque converter (innovative use of industrial off the shelf component) to circumvent GE Wind variable speed drive patent in certain market areas.
Others	6.2%	
Total	100%	Blade materials and process development, aerofoil and aerodynamic design related developments, intelligent control of loads, direct drive transmissions systems, grid compatibility are central R&D activities.

Table 5.2 Manufacturers' R&D Main Activity Areas

5.3 Wave and Current R&D

In comparison to other renewable energy sources, wave and current energy have received little funding, despite having been an area of active research for over 30 years. In general the funding has taken two forms:

- National and International R&D Programmes. These have concentrated on areas of generic R&D (usually through academic institutions) plus providing some support for individual prototype devices to be built by wave and current energy companies.
- Small developers of wave and current devices. These companies were often funded in the early stage of development by Governments and other grant funding bodies. However, going on to produce a prototype has usually required these companies to raise cash through equity, typically from venture capital firms. The intense commercial nature of these partners means that it is normally impossible to determine the funding achieved.

This section describes some of the national R&D programmes and funding on wave and marine current energy and a brief overview of private sector R&D. This is far from comprehensive but provides a general picture. The first sub-section describes the UK programmes, the EU schemes, and other national programmes before concluding with a short review of private sector activities.

5.3.1 UK

The original funding for wave energy within the UK was almost totally from Government. A £15 million (1985 monies) programme in the late 1970's early 1980's for a target design of 2,000 MW for the first wave energy schemes produced mainly academia-led designs for colossal schemes that had high predicted generating costs and large capital costs for the first prototype designs. Hence, the Wave Energy Programme was significantly run down.
Work did continue at a much lower level of funding by the Government on small-scale schemes (in total less than £3 million), especially the shoreline OWC, which was deployed on Islay in the early 1990s.

Work on wave and current energy began anew in the mid-1990s with a relatively large R&D programme of £15 million since 1998 in wave and marine current energy, with several large projects currently being funded. Other smaller projects at an earlier stage of R&D have also been funded. There are other significant sources of 'semi-governmental funding' available in the UK.

- **The Carbon Trust**. This organisation has made several considerable investments related to wave and marine current.
  - Marine Energy Challenge - £ 2,500,000. This initiative seeks to accelerate the marine energy sector by identifying if, and to what extent, the cost of energy of existing wave power and marine current power generation technologies can be reduced
  - Direct investment in Ocean Power Delivery - £ 1,500,000
  - European Marine Energy Centre - £ 1,200,000 over three years
  - Five devices – smaller investments

- **EPSRC.** This body continues to fund early-stage R&D (typically a few tens of thousands of pounds) but has as its main activity The Marine Energy Research Consortium. This commenced in October 2003 following the award of £2.6 million under the EPSRC's SUPERGEN Programme. It will fund research into marine renewable energy conversion and delivery. The consortium is undertaking collaborative research with the intention of achieving a step change in the development of generic marine energy technologies.

- **DTI’s Energy Technology Theme:** under this scheme (part of the DTI’s Technology Programme) has a budget of £7 million which covers all the renewables and embedded generation and includes wave and marine current.

- **DTI’s Marine Renewables Wave and Current Energies Demonstration Scheme**. Finally, the DTI have recently announced a major new initiative in January 2005. Under this scheme, £42 million will be spent on marine renewables through a combination of capital grants and revenue support. At present this document has been released for consultation and it is expected that the programme will be confirmed.

5.3.2 European Commission

The European Commission has supported a range of projects on wave and current energy, aimed at both generic research (e.g. resource assessment) and equipment development as well as supporting various devices. The main contracts to date are listed in Table 5.3.

Prog.	Title	Country	Leader	EC Funds (kEuro)
Joule 1	Wave Studies and Development of Resource Evaluation Methodology	Portugal	INETI	120
Joule 1	European Pilot Plant	Portugal	IST	400
Joule 2	Offshore Wave Energy Converters	Denmark	Ramboll	400
Joule 2	Atlas of Wave Energy Resource in Europe	Portugal	INETI	300
Joule 2	Tidal and Marine Currents Energy Exploitation	Italy	Techno mare	300
Joule 2	Air turbine development and Assessment for Wave Power Plants	UK	Coventry University	200
Joule 2	Electricity Generation by Pilot Realisation of a Wave Energy Generator	Greece	University of Patras	200
Joule 2	European Wave Energy Pilot Plant on the Island of Pico, Azores	Portugal	IST	550
Joule 2	The deployment and Testing of a Prototype OSPREY Wave Energy Converter – Phase 1	UK	Wavegen	550
Joule 2	A European Wave Energy Pilot Plant on Islay	UK	QUB	550
Joule 3	A Variable-Pitch Turbine and High-Speed Valve for the Azores OEC	UK	Edinburgh University	800
Joule 3	Detailed Design, Manufacture and Commissioning of a Prototype WOSP Wind/Wave Energy Plant	UK	Wavegen	650
Joule 3	European Wave Energy Pilot Plant on the Island of Pico, Azores – Phase 2: Equipment	Portugal	IST	1,000
Joule 3	Broadband Seapower Energy Recovery Buoy	UK	Starwell Ltd	45
Joule 3	Low-Pressure Hydro Turbine and Control Equipment for Wave Energy Converters (Wave Dra	Denmark	Lowenmark Consulting Engineers	45
Joule 3	World's First Pilot Project for the Exploitation of Marine Currents at a Commercial Scale	UK	IT Power Ltd	1,058
Joule 3	Optimising the Performance (Electrical and Economic) of Tidal Current Turbines	UK	Robert Gordon University	531
Joule 3	Performance Improvement of OWC Power Equipment	Portugal	IST	414
Joule 3	Islay Wave Power Plant	UK	Queen's University, Belfast	1,443
Joule 3	Wave Energy Device - Broadband Seapower Energy Recovery Buoy	UK	Starwell Ltd	481
Joule 3	Low-Pressure Hydro Turbine and Control Equipment for Wave Energy Converters (Wave Dragon)	Denmark	Lowenmark Consulting Engineers	445
FP5	Wave Energy Thematic Network	UK	ETSU	592
FP5	Power Production from Osmotic Pressure Difference Between Fresh Water and Sea Water	Norway	Statkraft SF	1,808
FP5	Economically Efficient Floating Device for Wave Power Conversion into Electricity – Phase 1: Mathematical & Physical Model Testing	Greece	CRS	540
FP5	Sea Testing and Optimisation of Power Production on a Scale 1:4.5 Test Rig of the Offshore Wave Energy Converter Wave Dragon	Denmark	Spok Aps	1,532

Table 5.3 Wave and Marine Current Energy Projects Supported by the EC

The Sixth Framework call (FP6) specifically targeted wave and current developments under the general heading of Ocean Energy Technologies. The call included *"Ocean energy technologies, including wave, ocean current and tidal technologies which are* *ready for demonstration at full scale with a view to commercial exploitation".* Under the March 2003 call a Co-ordinated Action on Ocean Energy was funded. In response to the call closing in December 2004, one Integrated Project was submitted.

5.3.3 National Programmes

R&D in wave energy is underway in several countries around the world. There follows a brief overview of activities in several of these.

The **Australian** Greenhouse Gas Office (AGO), under its Renewable Energy Commercialisation Programme (RECP) has funded work on two wave energy devices (from Energetech and Ocean Power Technologies). It has no national R&D programme in these areas.

Canada has little in the way of a national R&D programme on wave or current. One of its main utilities has initiated a pre-feasibility assessment of the potential for developing wave energy resources in 2000. Two specific sites (Ucluelet and Winter Harbour) have been 23 identified, each with over 200 MW of potential wave power capacity. In 2001, BC Hydro selected Ucluelet site as the initial site for the wave demonstration projects in Vancouver Island. BC Hydro has signed memorandum of understanding with Energetech (Australia) and Ocean Power Delivery (UK), to build two demonstration plants in 2004. However, a decision by the Canadian Government has stopped these activities. A series of performance trials of a Wavemill device were conducted in 1998, at the hydraulic laboratory of the National Research Council of Canada. The Blue Energy Canada company is soliciting financing for a marine current demonstration project using their technology particularly for their 'tidal fence' concept.

In **China** the main funding comes from the State Science and Technology Committee which is aiming to develop offshore wave power stations. Fundamental research on wave power is continually supported by the Nature Science Fund of China and the Chinese Academy of Sciences. No details of the funds involved could be obtained.

Various projects include:

- A shoreline OWC. This is being undertaken by Gunagzhou Institute of Energy Conversion of the Chinese Academy of Sciences. After problems encountered in considering the device for Nanao Island, the latest plans are for it to be built at Shanwei city in Guangdong province and will be a two chambered device with total width of 20 m and rated at 100 kW. 24
- A shoreline pivoting flap device (Pendulor) being developed by Tianjin Institute of Ocean Technology of the State Oceanic Administration
- Developing a new turbine for oscillating airflows
- Evaluating safety factors for the design of wave energy devices
- Time domain modelling and control
- Non-linear hydrodynamic simulation
- Providing an information system for wave energy resources

The **Danish** Wave Energy Programme started in 1996 and spent € 5,300,000 between 1998 and 2002. As noted above, several Danish developers have received funding from the European Commission. Recent changes in the Government in Denmark have significantly cut R&D budgets for renewable energy, particularly on ocean energy systems

The funds have been spent mainly on:

- Formation of the Danish Wave Energy Association to disseminate information and arrange meetings for its members and those interested in wave energy
- Evaluation of over 40 new ideas by model testing in wave tanks
- Testing large-scale versions of a Point Absorber and the Wave Dragon at an outdoor site in Nissum Bredning

A few activities have been funded by the **French** Government and the European Commission through universities. Little information is available on the level of Government funding. Most projects were carried out by the Centre Nationale pour l'Exploitation de Oceans (now stopped) and the École Nationale Superieure de Mechanique (ENSM) Nantes has been following a programme of fundamental research.

Despite its low wave power levels, **Greece** has seen some activities on wave energy, including:

- Sea trials of a 5 kW converter in Sweden for desalination processes.
- Deploying a prototype power and desalination plant consisting of about 10 wave energy converters rated at 30 kW each, producing up to 200 kW plus 10 m^3/h of desalinated sea water
- Installing a demonstration plant at Amorgos, which will include high basin energy storage (a mixture of the Hosepump and TAPCHAN devices.
- Developing the European wave energy atlas

Nearly all these activities were funded by the Greek Government and the EC – amount unknown.

India and the UN Development Fund have supported a wave energy programme in India since 1983 at the Institute of Technology, Madras. It has concentrated almost exclusively on the OWC concept, with a 150 kW prototype OWC with harbour walls having been built onto the breakwater of the Vizhinjam Fisheries Harbour, near Trivandrum in India in 1991. Following the successful testing of this, it is proposed to build a commercial scheme of 10 caissons, each 21 m wide, at Thangassery, on the west coast of India. However, little progress has been made on this for a number of years.

In **Indonesia** a feasibility study has been carried out by Groner AS of Norway on deploying a TAPCHAN scheme at Baron on the island of Java. However, nothing has happened for over a decade.

The Marine Institute was established by the **Irish** Government in 1991 with a mandate to quantify and develop Ireland's marine resources. The Marine Institute provided some funding for wave energy research during the period 1994-1999. In

1997, as part of its third Alternative Energy Requirement the Irish Government sought tenders for wave power projects in Irish waters that could have qualified for EC grant aid capped at €1.2 million, together with a premium price for power delivered. Unfortunately, it was found that the scheme did not meet relevant EU spending criteria at the time and as no grant aid was available no award could be made.

The Marine Research, Development and Demonstration programme was launched late in 2002 and the Sustainable Energy Ireland published its € 16 million Research, Development and Demonstration Programme Strategy (including wave) consultation document. A call for proposals was made in June 2002 and the programme will run for four years with specific priorities for wave energy research.

Despite the relative lack of locally generated funds, considerable wave energy research has been carried out in Ireland, primarily as a result of EC supported international collaboration but also through commercial developments. There is also a fledgling Irish wave power industry and a number of companies have been established to develop wave power devices. These include:

- Hydam Technology which is developing the McCabe wave pump, primarily to extract fresh water from sea water via high pressure reverse osmosis, for use on arid coastlines
- Harland &Wolff in a joint venture with du Quesne Environmental and the Marine Institute to develop the Wave Bob deepwater offshore converter
- Ocean Energy, a commercial venture to develop an OWC system for electricity production

Research and development of wave energy utilization (and other renewables) has been undertaken in **Japan** since the early 1970’s. The deployment of these ‘new energy’ technologies has been promoted by subsidies through various organisations including the New Energy Foundation (NEF) and the New Energy and Industrial Technology Development Organization (NEDO).

- In the late 1970’s and early 1980’s, R&D focused on the floating wave generating device ‘Kaimei’ and a shoreline wave energy device had been carried out in Japan Marine Science and Technology Center
- During the 1980’s and 1990’s other shore-line wave devices were are researched and developed in another organisations such as the Ministry of Transport, the Tohoku Electric Power Co. and the Muroran Institute of Technology. These research programmes had ended by 2000
- The latest device is the offshore ‘Mighty Whale’ which has been tested in open sea

Baek Jae Engineering of **Japan** has designed a prototype wind-wave energy scheme, with a floating, lattice structure fabricated from plastics and composites to reduce wave loading on the device and utilise a cheaper construction material. This has been developed totally with private financing by the inventor of the scheme.

Teamwork Technology and a consortium of **Dutch** companies have been working to develop the Archimedes Wave Swing over the last four years. There has been no Government funding for this device.

Norwegian Government funding for wave energy (and other renewables) has been small, given the large offshore fossil fuel reserves and extant hydro capacity. It has supported wave energy research since 1973 at the Department of Physics in the Norwegian University of Science and Technology. The only devices built have been funded by commercial companies:

- The 500 kW Multi-Resonant Oscillating OWC, built by Kvaerner Brug in 1985
- The 350 kW Tapered Channel (TAPCHAN) built by Norwave A/S in the late 1980's

The Norwegian Research Council also sponsored R&D on the Controlled Wave Energy Converter (ConWec) with an industrial company (Brodrene Langset AS) joining in 1994. The leading marine current device is being developed by Hammerfest Strom, with funds provided by a range of companies and little government funding.

The **Portuguese** Ministry of Science and Technology provides funding for R&D and company-led Demonstration projects through different programmes. Most Government funding is provided by the Ministry of Economy and the European Commission. Wave energy research started in 1978 at IST in Lisbon, who were joined in 1983 by the Instituto Nacional de Engenharia e Tecnologia Industrial (INETI) primarily on OWCs. The OWC in Pico was sponsored to promote wave energy research and development, and also to provide the island with electricity by being connected to the grid. However, it has hardly worked. INETI and a pan-European team developed and published the first European Wave Energy Atlas WERAtlas, which covers an extensive area from the Mediterranean to the Baltic Sea. The north coast of Portugal (Viana do Castello) was the location chosen by a Dutch company (Teamwork Technology BV) as the location for their Archimedes Wave Swing (AWS, 2001).

The Portuguese Government has started to take effective measures to establish wave energy within Portugal, primarily through its announcement that wave energy projects will receive enhanced prices for electricity delivered to the grid, with an initial tranche of 30 MW receiving a premium price of 0.25 €/kWh. Portuguese industry and academia have set up a Wave Energy Centre, whose chief objective is to provide dissemination, promotion and support to the implementation of wave energy technology and commercialisation of devices, which is best achieved by promoting collaboration between companies, research centres, inventors and developing teams

Two of the main devices developed in **Sweden** (the Hosepump and the Floating Wave Power Vessel) were funded primarily by industry with some help from Government-funded academia. The other (the IPS buoy) was initially an academic initiative. A new company (Eurowave Energy AB) was formed in early 1998 to promote commercial schemes based on the Hosepump and IPS buoy. More recently, commercial application of this technology has been sought by AquaEnergy in the USA.

There has been little governmental support for wave energy in the **USA**. However, several industrial companies have tested a range of prototype devices. In recent years, wave energy activities in the US have been confined to regional studies by coastal utilities and State Government Agencies, with relatively little technology development. More recently, the Electricity Innovation Institute and the Electrical Power Research Institute were funded to assess potential wave energy sites and conversion devices. They have identified several viable candidate sites in Oregon, Washington, Hawaii and Maine for possible demonstration plants and assessed a wide range of wave energy devices. The NREL web site states specifically that it is not undertaking research in the mechanical ocean energies. This position may be subject to change in the near future.

5.3.4 Device Specific Investment

Much of the wave and current developments in the last 10 years have been driven by the private sector – particularly a number of SMEs with innovative device concepts and an ambition to get their product to market first. Several such developers have been successful in leveraging a combination of private/personal, institutional and public sector financing. Table 5.4 summarises the scale of some of these enterprises.

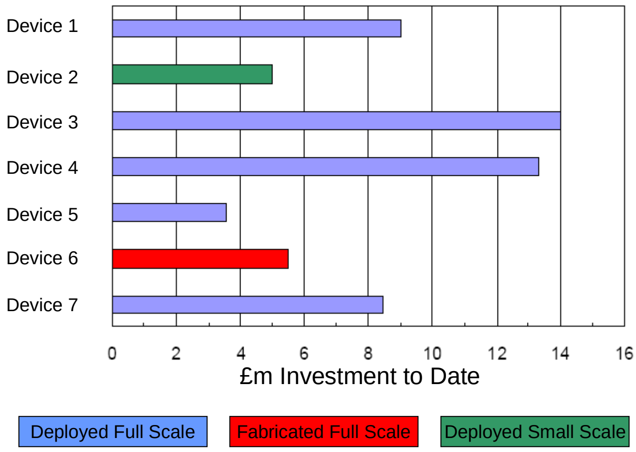
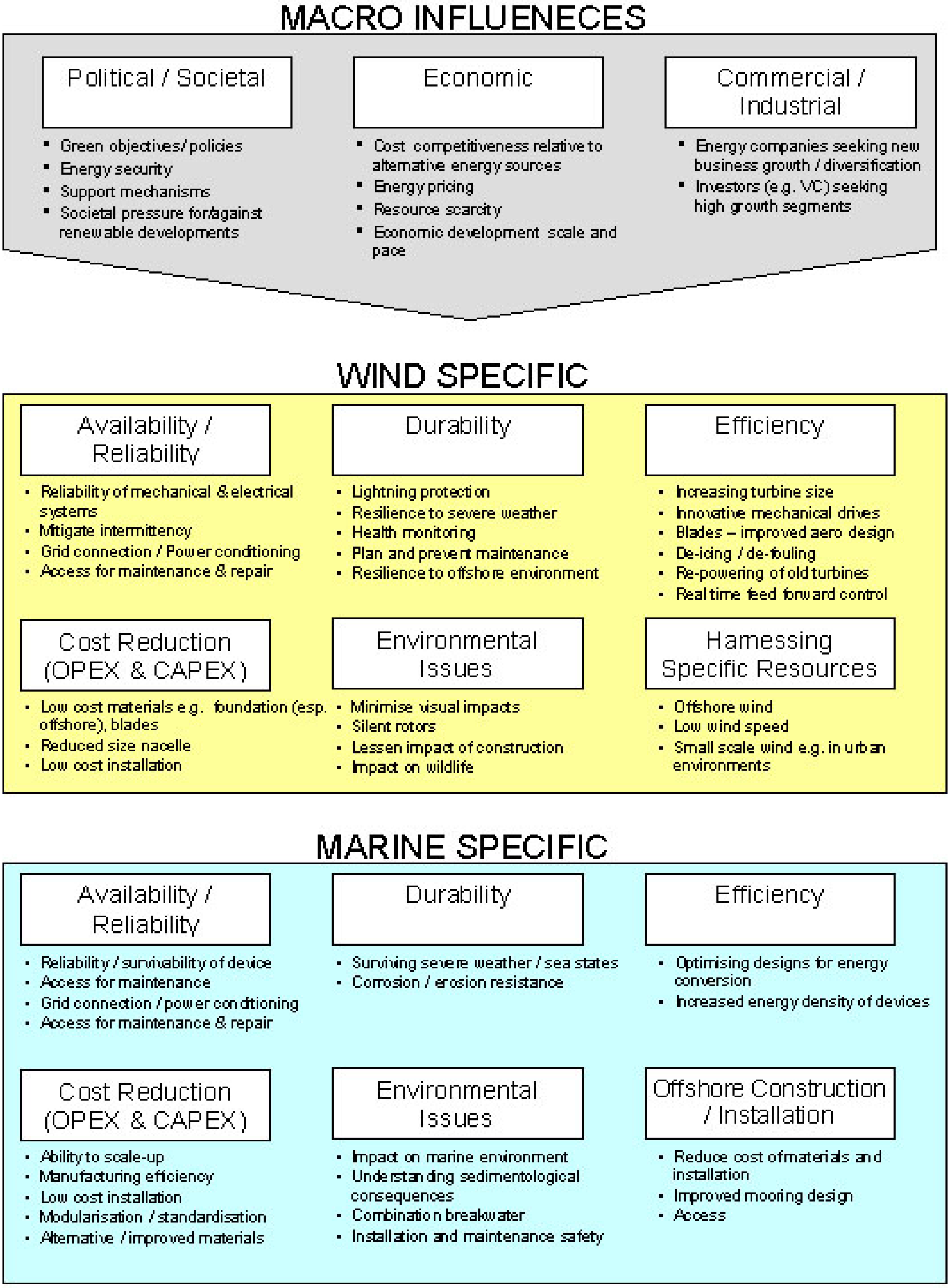


Table 5.4 Investment to Date in Various Devices
(at different stages of development)

6 SUMMMARY OF TECHNOLOGY INFLUENCES

The preceding three sections of this report explored a range of factors likely to be major influences in shaping market and technology developments in the coming years. The following figure summarises these considerations:



MACRO INFLUENECES

Political / Societal
- Green objectives/ policies
- Energy security
- Support mechanisms
- Societal pressure for/against renewable developments

Economic
- Cost competitiveness relative to alternative energy sources
- Energy pricing
- Resource scarcity
- Economic development scale and pace

Commercial / Industrial
- Energy companies seeking new business growth / diversification
- Investors (e.g. VC) seeking high growth segments

WIND SPECIFIC

Availability / Reliability
- Reliability of mechanical & electrical systems
- Mitigate intermittency
- Grid connection / Power conditioning
- Access for maintenance & repair

Durability
- Lightning protection
- Resilience to severe weather
- Health monitoring
- Plan and prevent maintenance
- Resilience to offshore environment

Efficiency
- Increasing turbine size
- Innovative mechanical drives
- Blades – improved aero design
- De-icing / de-fouling
- Re-powering of old turbines
- Real time feed forward control

Cost Reduction (OPEX & CAPEX)
- Low cost materials e.g. foundation (esp. offshore), blades
- Reduced size nacelle
- Low cost installation

Environmental Issues
- Minimise visual impacts
- Silent rotors
- Lessen impact of construction
- Impact on wildlife

Harnessing Specific Resources
- Offshore wind
- Low wind speed
- Small scale wind e.g. in urban environments

MARINE SPECIFIC

Availability / Reliability
- Reliability / survivability of device
- Access for maintenance
- Grid connection / power conditioning
- Access for maintenance & repair

Durability
- Surviving severe weather / sea states
- Corrosion / erosion resistance

Efficiency
- Optimising designs for energy conversion
- Increased energy density of devices

Cost Reduction (OPEX & CAPEX)
- Ability to scale-up
- Manufacturing efficiency
- Low cost installation
- Modularisation / standardisation
- Alternative / improved materials

Environmental Issues
- Impact on marine environment
- Understanding sedimentological consequences
- Combination breakwater
- Installation and maintenance safety

Offshore Construction / Installation
- Reduce cost of materials and installation
- Improved mooring design
- Access

7 TECHNOLOGY OPPORTUNITIES

The remainder of this report focuses on the development of a long-list of technology opportunities and the subsequent screening and prioritisation.

The foresighting process, as discussed in Section (1), included a combination of desk-top and consultative activities. This formed the basis for generating an extensive list of technology development opportunities harnessing a breadth and depth of industrial and research expertise / experience.

The following section provides a summary of this "long-listing" exercise and is structured as follows:

- Process of "Long-listing" the Opportunities
- Discussion of Opportunities and Provisional Assessment: Wind, Wave and Current
- Conclusions

7.1 Opportunities Long-listing

Outputs from all of the foresighting activities were synthesised into a long list of circa 350 potential investment opportunities which are available in Appendix A. All opportunities were clustered into one of 23 categories listed in Table 7.1 to consider the applicability of each opportunity to each of onshore wind (On-W), offshore wind (Off-W), wave and current energy. The summary of this analysis, in Table 7.1, confirms that the foresighting has achieved a reasonable balance across all four areas of interest as well as identifying technologies with potential cross cutting applications.

As well as the numerous investment opportunities, consultations with industry also revealed a number of areas of consensus on research priorities, and some common general observations.

Category	**On-W**	**Off-W**	**Wave**	**Current**	**Description**
Wind Turbine Concepts	✓	✓			Variation on, and departure from, 3-bladed horizontal axis machines
Rotor and Aerofoil Concepts	✓	✓			Alternative rotor / aerofoil geometry and operation
Lightning Protection	✓	✓			Especially for conductive carbon-content composites
Wind Turbine Environment Adaptations	✓	✓			Design features for low / high wind speeds, hot / cold climates, severe terrain
Wind Turbine Adaptations	✓	✓			Integration of wind energy with human activities e.g. aviation.
Environmental Protection		✓	✓	✓	Protection of machines against harsh (e.g. corrosive) environmental conditions
Materials	✓	✓	✓	✓	Development of new materials for components and structures
Offshore Wind Turbine Foundations		✓			Novel foundation designs
Offshore Construction		✓	✓	✓	Lower cost construction through more efficient installation methods
Offshore Access		✓	✓	✓	Enhanced access through the year through new, safe, access methods
Onshore Construction	✓	✓	✓	✓	Measures to reduce cost and improve feasibility of large machine construction
Transmission / Drive	✓	✓	✓	✓	Alternatives and improvements to the traditional gearbox / generator configuration
Monitoring / Control	✓	✓	✓	✓	New and lower cost sensors; sophisticated and data analysis
Electrical Generators	✓	✓	✓	✓	New generator concepts
Power Converters	✓	✓	✓	✓	Optimised power quality via power conversion
MV/HV Collection System	✓	✓	✓	✓	Optimised inputs to and infrastructure of the collection system
Grid Issues	✓	✓	✓	✓	Turbine, grid and operational improvements for better grid integration
Offshore cable issues		✓	✓	✓	Cost reduction in cable topologies and installation
Energy Storage	✓	✓	✓	✓	Storage to complement intermittent renewables
Wind / diesel	✓	✓			Increased deployment of wind / diesel
Supporting Tools	✓	✓	✓	✓	Ancillary tools for the industry e.g. improved resource assessment
Small Wind Turbines	✓	✓			Development of designs and supporting infrastructure for better market penetration

Category	On-W	Off-W	Wave	Current	Description
Wave and Marine Devices			✓	✓	Development of device concepts

Table 7.1 Categories of investment opportunity

Each of the following four sub-sections provides a scene setting and context for each of the four areas (onshore and offshore wind, wave and current technology) followed by more detail on the range of opportunities in each.

7.2 Wind - Opportunities & Provisional Assessment

7.2.1 Context

Onshore

In the onshore market, the design consensus of a three-bladed, horizontal axis, pitch controlled, variable speed machine, promoted by a handful of market-dominant manufacturers, is expected to prevail. "Niche" opportunities for other manufacturers may exist, but it is unlikely that they will compete in terms of volume.

Market opportunities for any organisation other than the main manufacturers are broadly:

- *Adoption by the manufacturers of a new concept or practice:* The industry is relatively conservative - a limiting factor in any step changes in design is the significant role that non-recourse Project Finance plays in the development of projects. Most financial institutions prefer to invest funds in proven technology with a demonstrable track record. This means that turbine manufacturers have an interest in producing turbine designs that have a direct relation with earlier designs in order that the track record of these earlier designs may be relied upon. Furthermore, manufacturers tend to favour in-house research as this allows strict quality control. Thus market penetration is a major barrier, but if overcome the rewards are significant. Opportunities which fall into this category include improvements to the drive train, rotor and generator, and the use of new materials in wind turbines.
- *Ancillary technologies:* new products which do not impinge on fundamental wind turbine design. Potential customers are various. Opportunities which fall into this category include small wind turbines (where there is no one dominant manufacturer, and where there remains a large, untapped market), supporting tools, power converters and grid issues.

Onshore wind turbines may be considered a mature technology. Significant cost reduction has been achieved as designs have converged and, crucially, as volume has increased. Although step changes in cost of energy (through technology evolution) are unlikely there are still considerable opportunities for incremental improvements.

Offshore

Offshore wind, however, is less mature than onshore and carries with it a much wider scope for cost reduction. To-date, offshore wind turbines have been marinised onshore turbines, but this approach is unlikely to remain the case as turbines move further offshore and into harsher environments. With different design drivers, and being less constrained by noise and visual considerations, there is significant scope for departure from the onshore design consensus.

Offshore issues, in particular the need to reduce costs and uncertainty in offshore operations, represent perhaps the most obvious and often-voiced market opportunity. This is because offshore wind has presented an immediate demand for improved access and for more efficient installation. It is also clear that the other emerging offshore renewables will present similar needs and particular challenges. Access to offshore wind farms has a direct impact on turbine availability and on revenue. A reliable means of access under hostile weather conditions is thus very valuable and will command a high price.

In short, there is a growing market, an industry which will have to adopt novel solutions and no long standing industry leaders. Not surprisingly, the resulting opportunities have been recognised – a proliferation of concepts is known to be under investigation, and it is reasonable to assume that further confidential work is underway. This may legitimately be described as a “hot topic”.

7.2.2 Fundamentals of Cost of Energy Reduction

Innovation in wind energy offers an attractive opportunity if it achieves:

- Further reductions in Cost of Energy (“CoE”) through a reduction in cost and / or an improvement in energy production.
- Enhancement of deployment range by addressing limitations listed in Table 3.1.
- Increase in availability for offshore turbines.

It is sensible to undertake a CoE check using the following equation:

CoE = (Total capital cost + lifetime maintenance cost)/ Life time energy)

If lower capital cost is achieved through the sacrifice of energy production then it is very unlikely to be attractive. This observation is fundamental and failure to recognise it is often the reason for potential innovations not bearing fruit. Cost reduction with no reduction in energy remains attractive.

The rotor gathers the energy and the rest of the structure simply supports and converts it from one form to another. The rest of the structure therefore provides losses and costs but no income. Scope for further significant cost reductions in onshore wind turbine design are thought to be rather limited:

- *Less than 5% energy gain is realistically possible in the power train.* There is no power source, only losses to be minimised. With present technology, most methods of significantly improving efficiency (e.g. more copper for reduced losses in generator windings or electric cables) add to cost, so that a CoE gain of 5% is impossible from technology that only addresses power conversion efficiency.

- *The only source of energy is the aerodynamic rotor and the major prospect for CoE benefit is in improving energy capture.* Although technical advances may significantly reduce the cost of wind turbine components, large concurrent savings in major components are needed to have much impact on CoE – not, for example, just an isolated breakthrough in generator technology.

- *Only a few percent of energy can be gained from improvements in rotor aerodynamics.* Tip loss and rotor wake swirl loss of a three bladed rotor at tip speeds acceptable for acoustic emission, and aerofoil drag loss cannot be eliminated.

- *Cost reduction will be achieved most markedly through volume and size.* The history of the wind energy industry has shown that volume is the most powerful means of driving down cost and this trend is likely to continue. The growth of the physical size of turbines has also been a significant contributor.

Scope for cost reduction in offshore wind is, however, more significant.

7.2.3 Opportunities Specific to Offshore Wind

The efficiency of the turbine when operating is a major interest – low loss drive train and high efficiency blades - but the availability is also of significant importance. A highly efficient turbine is of little benefit if it is not available for use. The availability of onshore turbines is now consistently high at 97-98% but this good behaviour is achieved through careful and efficient maintenance – prompt response to faults by on-site maintenance teams. It has not been achieved through the provision of highly reliable turbines. The luxury of easy access will not extend to offshore devices and hence, offshore, considerable attention must be paid to increasing reliability in the absence of constant human presence. More reliable components, more self sufficient control, more remote intelligence and good access will all play their part in maximising the numerator in the CoE equation. These themes emerged very clearly from the various workshops.

7.2.4 General Development Requirements

Market growth itself will be limited by the ability of the industry to install sufficient turbines, limited, for example by planning constraints and public resistance. Onshore this constraint means that there is significant benefit in making a wind turbine a better neighbour – reducing its environmental impact – through careful consideration of acoustic noise, electromagnetic noise, interference with radar and other aircraft and defence systems. There are opportunities in this area which have no direct effect on CoE but which do affect the market.

7.2.5 Project Finance

A further limitation on the rate at which the offshore industry can grow is the ability to secure finance. Project finance will eventually be used for the funding of offshore wind farms. This finance will be conditional upon a thorough and accurate investigation of the project and, in particular, on the accurate estimation of the energy output and construction cost as well as proven access as mentioned above. To undertake investigations offshore is a great deal more expensive than onshore and hence developments in remote sensing of the environmental characteristics of a site will be very valuable: wind speed, wave height and water currents, and geotechnical and geological conditions. The gathering of these site data offshore are very expensive at present and add significantly to the cost of the project. Reduction in the cost of these background tasks can therefore be very valuable.

7.2.6 CoE Reductions - Relative Priorities

The analysis of major manufacturers R&D interests (discussed previously in section 6.2) provides a reasonable indication of the main potential technology development opportunities, summarised below:

- Blade Materials and Process Development
- Aerofoil, Aerodynamic Design and related developments
- Intelligent Control of Loads
- Direct Drive Transmission Systems
- Grid Compatibility

The following qualitative analysis, summarised in Table 7.2, takes this a step further to illustrate which areas might have most significant effect on the cost of energy, across: onshore, offshore and small scale segments. This table is not intended to provide evaluation of specific ideas but rather to show in which areas effort might be concentrated. The “long list” of opportunities (appendix A) was evaluated in the light of this general guidance.

	Equipment Capital cost	Installation/ Construction cost	Energy capture		O and M costs
			Efficiency	Availability	
Onshore wind	Control design Integrated design		Rotor design		
	New materials. Grid friendliness		New generators Aerofoil design and surface treatment	Gearbox Design Control system reliability	Condition monitoring
	Low speed generators	Self erection		Lighting protection NDT	SCADA
Offshore wind	Foundation and tower design. New turbine concepts Economies of Scale Project Experience	Installation techniques New vessels Economies of Scale Project Experience		Access systems High reliability turbines	Remote interrogation and correction Project Experience
	Cable system and Topology Grid Connection. Component Supply (turbine, transformer, tower)	Remote sensing of wind, waves and sub sea conditions			Condition monitoring Short term weather forecasts
		Offshore electrical supply			
Small scale wind	Grid connection systems	Net metering	Low speed aerofoils		
	Safety systems			General purpose control	
	Low cost blades				

🟩 Large effect 🟨 Moderate effect 🟥 Small effect

Table 7.2 Assessment of different characteristics of wind farms on Cost of Energy

7.3 Wave / Current - Opportunities & Provisional Assessment

7.3.1 Context

The preoccupation for wave and current devices at present is to design and demonstrate a working, cost-effective machine. This achievement would be significant in itself. There is a multitude of known design concepts, and almost certainly many more unknown designs, under development. Some are clearly more mature than others. There are no winners as yet but there are some clear front runners.

In the form of device developers and academia, Scotland undoubtedly has some world-class expertise. It also hosts a huge potential resource. This “fit” has already been recognised through provision of funds and a test centre at EMEC in Orkney.

There is broad consensus on generic issues which, while not the current preoccupation, will need to be solved. These include bio-fouling, access and installation, low cost materials, mooring and underwater hydraulics.

The most obvious investment opportunities in this field are the devices themselves. They are in need of additional financing to take them from their present immature state to commercial reality.

7.3.2 Wave Energy

Wave energy is at an early phase of its development, with few prototypes having been built and no clear idea of which will be the successful technologies. Hence, considerable R&D remains to be done. Because of the wide differences between one wave energy technology and another, most of the present R&D is device-specific.

There are several areas where more generic research could be undertaken that would benefit wave energy as a whole. These are described below and outlined in Table 7.3. Some of these areas could also benefit current technologies.

Accessibility: how to gain access to devices in sea states of at least 2m H_s (significant wave height) and, preferably higher exactly as for offshore wind. Gaining access and *in situ* repair is proving difficult for some offshore wind farms and they are situated in less energetic wave climates that would be chosen for wave energy devices. Simple probabilistic modelling shows that if wave energy devices cannot be accessed for repair in waves of at least 2m, then the availability of the device will probably be unacceptably low. Investment in this technology will have benefits across all offshore renewables.

Controls: integrating monitoring of device/sea state and controlling of key features (e.g. hydraulic pressure, pitch of turbine) to ‘tune’ the device. In order to obtain the maximum output from wave energy devices, it is necessary to adjust the damping in order to tune the system to the period of the incoming wave. This can be achieved either through altering hydraulic pressure (in moving body devices) or the pitch of the turbine blade (in OWCs). Several companies are each developing their own specialist software, at considerable expense. There is an opportunity for the development and manufacture of control systems that can be adjusted by the developer for their own device, especially if it is combined with add-ons such as computer modelling of non-linear behaviour of wave measurement/prediction or moorings. Adaptation of wind energy technology should be possible in this area.

Condition monitoring: techniques of measuring parameters that give advance warning of failure. Mobilising access to offshore wave energy devices is likely to be an expensive operation. Therefore, preventative maintenance must be kept as low as possible. It would be beneficial to have some means of predicting incipient failure (such as measurement of vibration or device response) in order to minimise both unnecessary mobilisation and device down time.

Subsea ‘connectability’: the ability to detach/attach underwater components from the sea surface. Several devices (including marine current devices) have subset components that can be repaired and maintained only by their removal from the device. This will require the development of capability for rapid detachment and attachment of mechanical and electrical plant. Such capability exists in the offshore oil and gas industry for sea bed plant but more flexible and cheaper methods will be required for a range of wave energy devices.

Power conditioning: energy storage and other ways to smooth the electrical output so that it is acceptable to the local utility. The power delivered by the waves to a device varies on a number of timescales: on a wave-by-wave basis of ~ 10 s, on a wave packet basis of several minutes and on a day to day basis between storm and calm. In order for the electricity from a wave device to be acceptable for a local utility, at least some of this variability will have to be removed. There are several methods for doing this including smoothing of the electrical output using power electronics and storage of energy from the waves (e.g. accumulators for hydraulic power takes off systems and flywheels for OWCs). These add to the cost of the device (significantly in terms of the power electronics) mainly because the systems are ‘one-offs’. There is an opportunity to develop and mass produce systems such as these tailored for wave energy (in terms of rating and storage time), which would also benefit some current devices.

Construction materials: cheaper alternative construction materials to steel or concrete. The cost breakdown figures indicate that typically over 50% of the costs for OWCs are incurred in civil construction, whilst for offshore devices this falls to about 33%. Hence this represents a significant cost centre that needs to be reduced if wave energy is to become economic. All structures are manufactured from either welded steel or reinforced concrete. Most wave energy and marine current devices consist of regular forms, which lend themselves to replication and the use of different construction techniques (e.g. re-useable formwork for concrete, robotic welding for steel) and materials. Several developers are looking at alternative materials or new combinations of materials. This is also undertaken by manufacturers of structures for marine use such as marinas, lighthouses and breakwaters. This is an area for investment which could benefit several developers and (because it relates to the biggest device cost centre) be of particular importance to Scottish industry. Areas for investigation include: impermeable foam concrete with density sufficient to be buoyant and with an impermeable skin; techniques for pouring concrete in water so that it is never necessary to support any weight, reusable shuttering panels and new materials for reinforcement which can be sprayed along with the concrete, steel-concrete sandwich structure such as Corus’ Bi-Steel.

Moorings: cheaper or easy connect moorings. Moorings are a significant cost centre, because they again are ‘one-offs’ that have often been developed from the offshore oil and gas industry, where costs are much higher than can be tolerated in wave energy. Some companies (e.g. OPD) have developed proprietary systems at considerable expense but most have gone with a modification of existing techniques. R&D into mooring for wave energy devices is an area that has been overlooked and which could produce benefits for a number of developers. This R&D would range from modelling of moorings (few existing programs can accommodate the different behaviour of wave energy devices, especially in shallower water), development of materials and methods of connecting/disconnecting. The last point is particularly important for those devices which will be returned to shore for repair.

Hydraulics in seawater: all measures leading to high reliability and efficiency for hydraulic power take-offs in marine conditions. Theoretically, hydraulics make an ideal power take-off, because they are a good match for the low speed-high force movements of wave energy devices and offers the possibility of short term energy storage. However, there are several problems that must be solved before they can be optimised for wave energy (and possibly current and wind energy too). Hydraulics quickly break down if the hydraulic fluid becomes contaminated, which requires high reliability seals or materials that can operate in sea water. Much has been made of the Ceremax hydraulic cylinder; however this has functions well in seawater only in use as operating lock gates – which in terms of the cyclic frequency and forces involved is far removed from wave energy. Hydraulics can have high efficiency but usually only when they are working near their nominal rating – systems that have high part load efficiencies and capable of being digitally controlled are an area of potential benefit to a number of devices[9]. However, the long term reliability of such systems in a seawater environment is paramount.

Oscillating air flow turbines: high efficiency, low-cost and reliable turbines for OWCs. The Wells Turbine has been the turbine of choice to deal with the oscillating air flows in OWCs. However, it has the drawback of low or even negative torque at low flow rates and a sharp drop) in power output at flow rates exceeding the stall-free critical value. Attempts have been made to overcome this by using variable pitch blades[10]. Other types of turbine have been developed, such as a symmetrical impulse turbine with guide vanes[11], whilst Energetech have constructed a variable pitch, impulse turbine. The OWC technology is the only wave energy technology that has been proven to work reliably over a prolonged period of time (albeit uneconomically). The development of a reliable, high efficiency turbine capable of dealing with reciprocating air flows would have a marked effect on the economic performance of such systems.

Low head turbines: reliable, high efficiency, low cost seawater turbines for use with overtopping devices and low-head hydro schemes. A few devices generate energy by allowing waves to overtop into a raised lagoon and then release the potential energy by allowing the water to return to the sea via a low head turbine. High efficiency, low cost turbines would benefit these technologies (however the economic attractiveness is in some doubt) and low head hydroelectric schemes, which have a world-wide application.

Electrical connectors: design and manufacture of standardised subsea electrical connectors and cheaper subsea cabling/connection to the grid. “Wet electrical connectors” are currently available up to 33 kV, which limits the size of scheme that can be connected. Subsea cabling and grid connection are large cost centres that are outside the control of device developers (including offshore wind). There may be opportunities for working with utilities and cable manufacturers to reduce these costs.

Computer models for simulating non-linear effects. Many wave energy devices show non-linear behaviour and this is poorly modelled by current software packages. After development, such software could be licensed to all developers to allow more accurate predictions of their device’s behaviour in real seas as a means of improving device performance.

Short term wave measurement & prediction: being able to measure or predict incoming waves. Knowledge of the incoming wave allows several devices to

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[9] Such as the work being carried out at Edinburgh University by Artemis (see http://www.artemisip.com/)

[10] Some work is currently underway at Wavegen and a turbine was built by Edinburgh University – see *Design and Construction of the Variable-Pitch Air Turbine for the Azores Wave Energy Plan*, Third European Wave Energy Conference, Patras, Greece, October 1998.

[11] A review of impulse turbines for wave energy conversion, Renewable Energy, Elsevier, Vol: 23, Issue: 2, June, 2001

optimise the energy extraction by ‘tuning’ the device to the wave. However, it has proved difficult to measure wave height and period accurately over long interludes (the devices tend to ‘drift’ or even, in the case of wave rider buoys, break their moorings. Development of schemes to address this area would benefit many developers. Being able to predict the incoming waves (through mathematical algorithms) would be an even bigger boost to performance.

There are other areas of generic benefit, although some of these are unlikely to provide the right combination of IP generation and market opportunity to be prime areas of interest for ITI Energy:

Wave loading:
- Accurate wave data for the site,
- Predicting wave loading more accurately (especially wave slam)
- Developing software to model the non-linear effects of waves in shallow waters

Energy connection to shore:
- Affordable grid integration
- Isolating device during grid faults
- Power transmission to shore using fluids

Regulatory:
- Easier permitting/licensing
- Design codes and regulations tailored to unmanned devices

Accurate costs:
- Predictability of construction & deployment costs to promote investor confidence

Standardised methods:
- Predicting energy production to promote investor costs

Reliability database:
- Components in various environments (air, hydraulic fluid, seawater, spray)

In Table 7.3 below the relevance to the individual wave devices of the various R&D topics has been summarised.

	Accessibility**	Control	Condition monitoring	Subsea connectability for O&M	Power conditioning	Construction Materials	Moorings	Hydraulics in Seawater	Oscillating air flow turbines	Low head water turbines	Electrical connectors	Short term wave measuren prediction
Device 1	✓		✓		✓	✓	✓				✓	✓
Device 2		✓	✓	✓	✓	✓	✓				✓	✓
Device 3	✓		✓	✓		✓					✓	✓
Device 4	✓		✓		✓	✓			✓		✓	✓
Device 5	✓	✓	✓		✓	✓	✓	✓			✓	✓
Device 6		✓	✓			✓	✓	✓			✓	✓
Device 7		✓	✓	✓	✓	✓		✓			✓	✓
Device 8	✓		✓		✓	✓	✓		✓		✓	✓
Device 9			✓								✓	✓
Device 10			✓								✓	✓
Device 11			✓								✓	✓
Device 12	✓	✓	✓		✓	✓	✓			✓	✓	✓
Device 13	✓	✓	✓			✓	✓			✓	✓	✓
Device 14			✓		✓	✓			✓		✓	✓
Device 15	✓	✓	✓		✓	✓	✓		✓		✓	✓

Table 7.3 Generic wave device research and development

7.3.3 Current Energy

Current energy is at an early phase of its development, with few prototypes having been built. In the same way as for wave energy the present R&D is device-specific, although there is more similarity between marine current devices and, hence, some generic R&D is more feasible.

Areas potentially suitable for generic R&D are described below and outlined in Table 7.4.

Installation: Installation is a significant cost centre for current plant (and offshore wind turbines), especially if initial numbers are small. Different approaches have been developed, each of which has its own pros and cons. Development of novel installation methods is an area of R&D that would generate IP and bring benefits to a range of offshore renewable energy technologies.

Access: Personnel access to offshore structures from small boats for maintenance and repair is proving problematic for offshore wind and has prevented access to the UK's only full size current device for several months. Developing novel access methods will be a key development enabling cost effective installation operation and maintenance and of marine renewable devices.

Bio-fouling. Nearly all marine current turbines use blades whose performance is dependent on having the correct profile and a smooth surface. However, in seawater these blades will be subject to bio-fouling, which will have a detrimental effect on performance. Some of the anti-fouling treatments such as tri-butyl tin or cupro-nickel are toxic even in very small concentrations and their use has exterminated marine life in some yacht harbours. This would be quite unacceptable in many places that are suitable for marine current devices. Therefore, the development of a new anti-fouling coating or process would be an area of generic R&D that would benefit offshore renewables (and other industries such as shipping).

Sealing. Sealing has proved to be a problem in some current energy devices (it is also relevant to some wave energy devices), having to remain intact against pressure, grit and bio-fouling. Static seals are well developed but dynamic seals still need R&D. Seal manufacturers can produce seal that operate in conditions similar to that of current devices (e.g. the stern tube of a ship propeller shaft) but development of seals for offshore renewable energy applications is an area where R&D could accrue significant benefits.

Power conversion. The rotation speeds of current rotors will be one-third or less than those of wind turbines of equivalent power and so the input torques will be proportionally higher. Hence, they will face a similar problem to wind turbines, namely how to convert such slow rotational speeds to the higher speeds required for electric generators. Wind energy (and some current devices) use large gearboxes, which have proved expensive and unreliable. Enhancement of gearbox design to address the specific needs of current devices is an R&D topic of generic benefit. There are also interesting developments in using hydraulics for power take-off for marine current and wave energy devices. Producing controllable, reliable, high efficiency hydraulic power system would benefit not only most marine current schemes but could also be used in wave and wind devices.

Cavitation. Cavitation occurs in many hydraulic mechanisms, where fast-streaming fluid causes a drop in fluid pressure that in turn results in the formation of gas-bubbles. These may subsequently violently collapse causing high increases in local pressure and possibly mechanical damage. It is often possible to redesign parts in order to avoid cavitation. The problem will be less serious for deeply submerged plant because of the lower velocities near the seabed and the higher standing pressure. The cavitation problem has been closely studied by Rolls Royce Marine (formerly Brown Brothers) for its effect on the hydrofoils used by ship stabilisers, which are very close to the needs of marine current hydrofoils. R&D directed more at current turbines (e.g. cavitation resistant hydrofoil sections) could benefit several designs and would provide IP in the form of blade design or material selection.

Pitch Change Mechanisms: Changing the pitch of turbine blades is one mechanism by which horizontal axis turbines can accommodate bi-directional flow (e.g. MCT's Seaflow). Vertical-axis rotors in good sites will experience a large range of angle of incidence and consequently will risk the high drag losses associated with stall unless they too have a pitch adjustment mechanism. However, some companies have little confidence in the long-term reliability of pitch control and prefer other approaches. Having a reliable pitching mechanism is undoubtedly more economic than other solutions but such systems have yet to be demonstrated. Producing this technology (enhancing bearings that work in seawater) would benefit nearly all current developers. This is an area in which it should be possible to “borrow” technology from the wind energy industry.

Moorings and Umbilicals: similar considerations to that of wave energy. There are several designs of floating current turbines, all of which require low cost, detachable moorings and umbilicals for electrical power off-take. Moorings for bottom standing devices are also an expensive cost item. Development of novel, low cost systems where retrieval and installation are rapid would have significant benefits for such devices.

Device Modelling: Software exists for the modelling of offshore oil and gas structures but few (if any) software suites can cope with modelling moving marine energy devices. Development of such software is crucial to the optimisation of these devices in the longer term.

As for the wave devices Table 7.4 summarises the relevance of the R&D activities to the individual marine current devices.

	Installation	Access	Biofouling	Sealing	Power Conversion	Cavitation	Pitch mechanism	Moorings umbilicals	Device modelling	Regulatory	Resource
Device 1		✓	✓	✓	✓			✓	✓	✓	✓
Device 2								✓	✓	✓	✓
Device 3	✓	✓	✓			✓		✓	✓	✓	✓
Device 4								✓	✓	✓	✓
Device 5									✓	✓	✓
Device 6									✓	✓	✓

Table 7.4 Marine current generic R&D

7.4 Concluding remarks

This section has provided a broad discussion of opportunities for innovation across the wind and marine technology markets. Many opportunities in wave and current energy are device specific, whereas in general the wind industry has a much tighter convergence of device types. However, a number of cross-cutting (or enabling) technologies have emerged which have broad applicability to both offshore wind, wave and current technologies.

8 SHORT-LISTED OPPORTUNITIES

The final phase of this study focused on developing a prioritised list of technologies which represent particular promise for ITI Energy investment. Clearly, screening of such a long list (~350 ideas) required a systematic approach but must ultimately rely heavily on qualitative analysis. The following summarises the key criteria used through the screening process:

- Market value and scale of opportunity
- Technical feasibility
- Opportunity for IP creation / capture
- ITI Energy fit

The assessment also looked at the spread of opportunities addressing each of four critical business drivers:

- Equipment Capital / Installation Cost Reduction
- Operational & Maintenance (O&M) Cost Reduction
- Increased Energy capture – Improve Efficiency
- Increased Energy capture – Improve Availability / Reliability

The particular nature of the market for each technology – existing activities, key players and potential for collaboration – were considered as important as the viability of an innovation in itself.

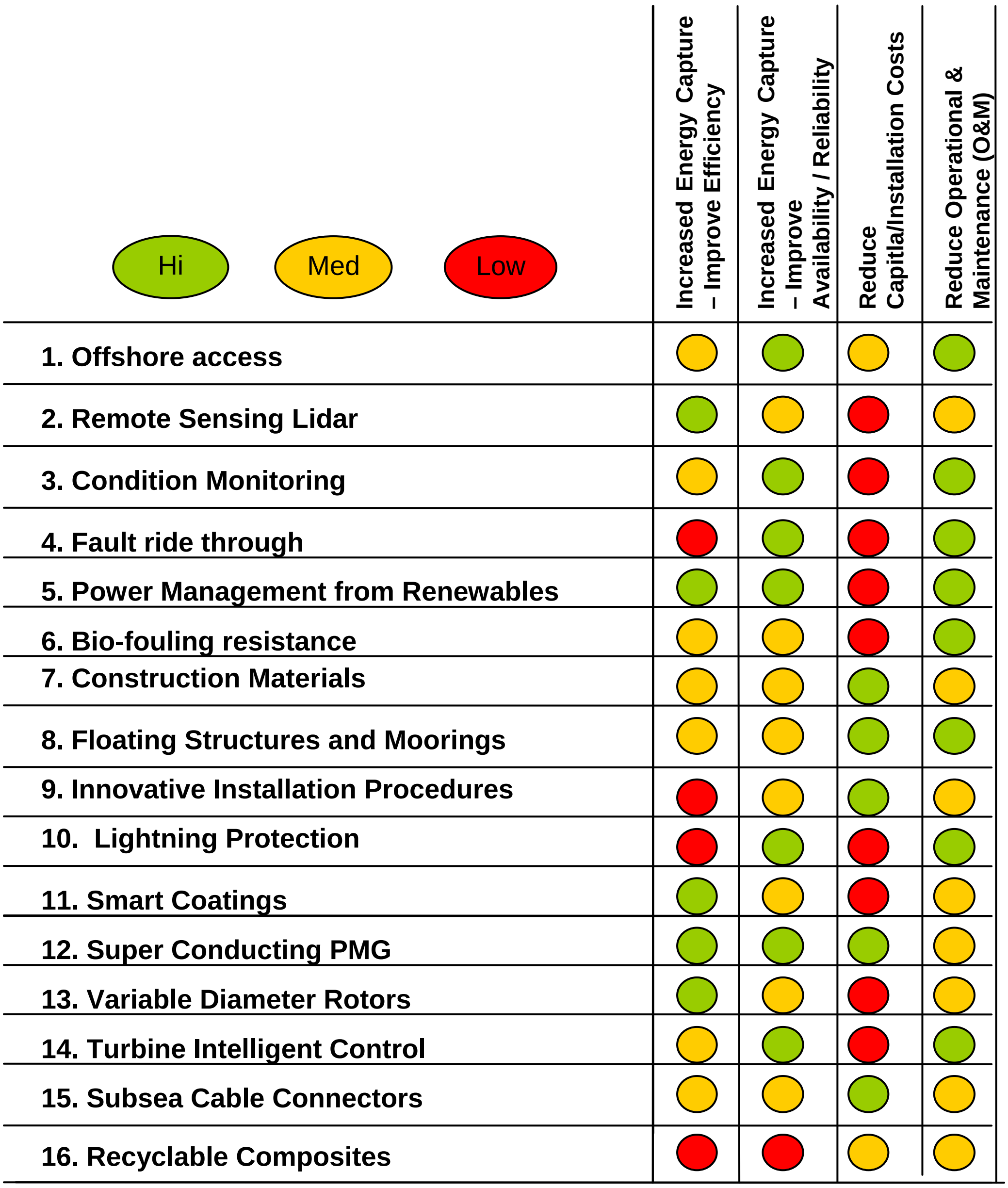
The 350 opportunities were collated and categorised, with each cross referenced as to their applicability to onshore wind, offshore wind, wave and marine current. Some opportunities were rather vague or generic – a statement of the obvious such as “component cost reduction.” Thus only those that could be sensibly evaluated were then scored against each of the criteria. Each had to possess potential in all areas, but significant variations were allowed, such that a scrape “pass” in one area could be compensated by an exceptionally high score in another.

The following Table 8.1 summarises the areas of technology that emerged as highest priority. These 16 projects represent those which have been short-listed from the 356 ideas identified through this investigation and hence they are only a very small sub-set of potential projects. This process has inevitably been very subjective. Hence, these priorities are not meant to infer that other areas of opportunity are not of interest. Indeed it is entirely possible for a strong project proposal, not short-listed here, to receive support from ITI Energy, providing the proposal represents a strong case across the criteria discussed above. However, ideas which fall outside the prioritised areas are more reliant upon a third party making a direct approach to ITI Energy and acting as the champion for their particular proposal.

	Opportunity	Description
1	Offshore new access solutions	Increased availability through safe access to machines for a higher proportion of the year thereby reducing weather dependence – benefits can justify substantial expenditure
2	Remote sensing lidar	New, cost-effective, portable wind measurement system based on laser technology which will allow measurement at larger height without tower.
3	Condition monitoring	New and cost-effective sensors widely deployed through the system, on-line data interpretation for predictive maintenance and asset management will increase availability
4	Fault ride through	Rather than automatic disconnection, wind/wave/marine current devices maintain generation in the event of a grid fault. Will be needed for any areas of large scale renewable penetration.
5	Power Management from renewable sources	Introduction of integrated control system and drive for use on renewable devices allowing increased adaptability to different grid types and there applications.
6	Bio-fouling resistance	Preventing formation of artificial reefs on hydrofoils, thereby preventing reduction in performance which is very sensitive to surface roughness.
7	Construction materials	Alternatives to the use of steel as construction material offers potentially lower costs.
8	Floating structures and moorings	Floating wind turbine solutions for deep water deployment, and reliable, cost-effective moorings for marine renewables
9	Innovative installation procedures	Faster, cheaper installation methods for offshore structures to reduce installation costs and weather risk
10	Lightning protection	Improved lightning protection, especially for more conductive carbon-content blades. Lightning is the biggest insurance cost
11	Smart coatings	Novel surface coatings which allow embedding of condition monitoring and control infrastructure and also “self-cleaning”. A highlighted opportunity is that of a smart blade tip for noise reduction.
12	Super-conducting PMG	Permanent magnet generators can be adopted as part of a “gearless” direct drive system or a geared system. Lighter and smaller than wound rotors. With superconductors could reduce weight by factor of 10.
13	Variable diameter rotor	Increase diameter for low wind speed conditions and reduce for high winds – avoiding loads and increasing energy capture respectively
14	Turbine intelligent control	Sophisticated control functions which, via structural load management, extend design boundaries and reduce weight and cost. Reliability risk increases.
15	Subsea cable connectors	Development of offshore cable connectors which will permit cost effective connection to offshore grid systems
16	Re-cycling composites	Improve the environmental foot print of wind turbines by increasing proportion of material which can be re-cycled – present composite material is not suitable for this purpose

Table 8.1 Short-listed opportunities

The following Figure 8.1 illustrates how these priorities play across the four key business drivers:



🟢 Hi
🟡 Med
🔴 Low

	Increased Energy Capture – Improve Efficiency	Increased Energy Capture – Improve Availability / Reliability	Reduce Capital/Installation Costs	Reduce Operational & Maintenance (O&M)
1. Offshore access	🟡	🟢	🟡	🟢
2. Remote Sensing Lidar	🟢	🟡	🔴	🟡
3. Condition Monitoring	🟡	🟢	🔴	🟢
4. Fault ride through	🔴	🟢	🔴	🟢
5. Power Management from Renewables	🟢	🟢	🔴	🟢
6. Bio-fouling resistance	🟡	🟡	🔴	🟢
7. Construction Materials	🟡	🟡	🟢	🟡
8. Floating Structures and Moorings	🟡	🟡	🟢	🟢
9. Innovative Installation Procedures	🔴	🟡	🟢	🟡
10. Lightning Protection	🔴	🟢	🔴	🟢
11. Smart Coatings	🟢	🟡	🔴	🟡
12. Super Conducting PMG	🟢	🟢	🟢	🟡
13. Variable Diameter Rotors	🟢	🟡	🔴	🟡
14. Turbine Intelligent Control	🟡	🟢	🔴	🟢
15. Subsea Cable Connectors	🟡	🟡	🟢	🟡
16. Recyclable Composites	🔴	🔴	🟡	🟡

Figure 8.1 Evaluation of shortlist (2)

Having developed this short-list, a more rigorous evaluation was completed to develop a further level of prioritisation. Short summaries of each technology were prepared addressing the following considerations:

- Description of opportunity
- Benefits
- Technology Assessment e.g. viability, feasibility and risk
- IP Issues / competitive Landscape e.g. likely defensible IP position
- Market Assessment e.g. growth rate, ultimate scale and risks

- Strategic Fit e.g. potential economic benefit to Scotland

From this more in-depth analysis of the 16 areas, the following prioritisation was developed as in Figure 8.2:

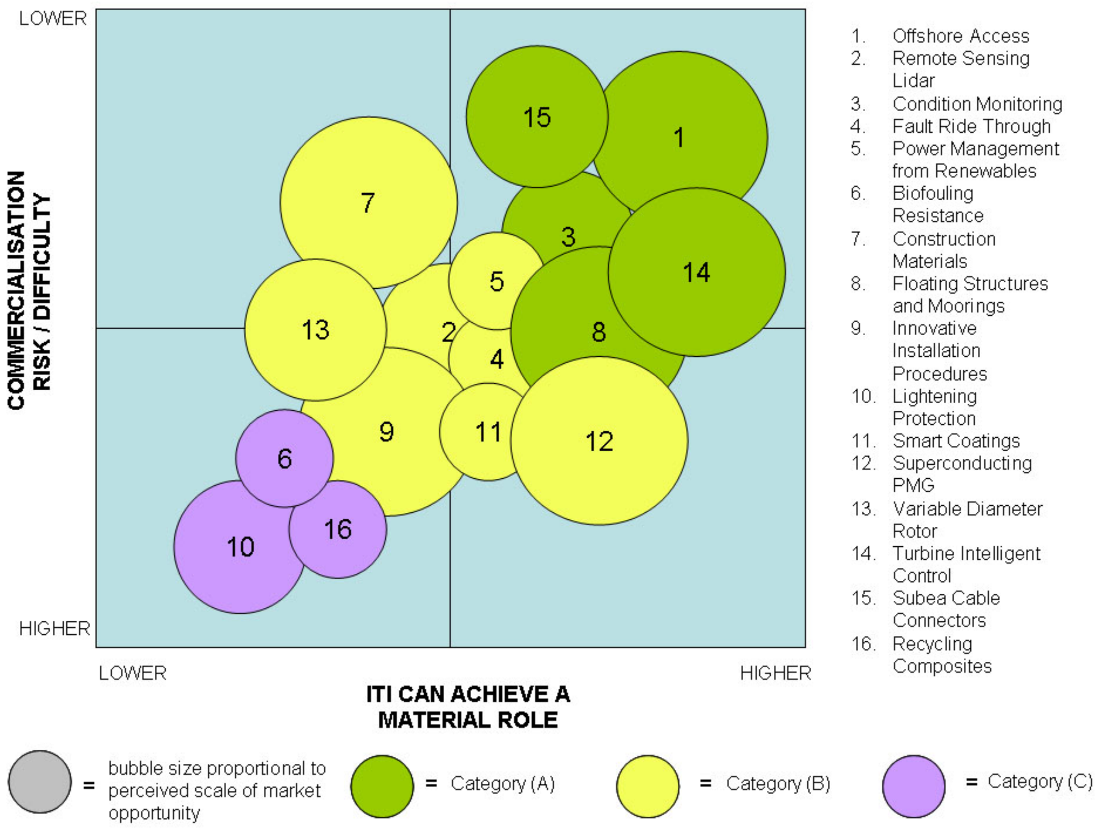


Figure 8.2 Evaluation of the Short-list

The top right quadrant of this diagram represents technologies which are perceived as offering stronger possibility of projects where ITI Energy can play a key role and where there is a reasonable potential to achieve commercial success. The 16 technology areas have been, as indicated in the above diagram, allocated a prioritisation / categorisation as follows:

Category (A): ITI Energy will look to develop specific program or project proposals using it's own resources (e.g. conduct initial scoping / feasibility study to define specific technology gaps, estimate the scale of market opportunity for technologies to fill these gaps and assess the potential for successful capture of related IP and scope the feasibility of onward licensing and commercialisation of the technology beyond the ITI research project)

Category (B): ITI Energy will seek to engage with a targeted set of companies and researchers to explore in more depth the potential technology opportunities in this area (e.g. exploratory discussions with other parties and networking to bring interested parties together to build a clearer case for initiating more resource intensive project scoping / feasibility studies)

Category (C): ITI Energy will adopt a more passive approach looking to other parties to bring forward specific project proposals - of course 3rd parties are also open to bring forward technology proposals relating to any of the 16 technology areas.

The prioritisation of these 16 areas – as discussed above – is only for the purpose of allocating ITI Energy's own resources (i.e. staff time) in proactively developing project proposals i.e. categories A and B. These technology areas have all been selected from the long-list as having significant potential for new technology development. However, project proposals in any of these areas will go through the same project screening and selection process i.e. the categorisation does not imply a pre-allocation of R&D project funding biased toward areas categorised as A or B.

To move forward on these areas, consistent with the above prioritisation, ITI Energy is initiating a range of activities, including;

- Further one-to-one discussions with companies and research organisations to encourage project proposals
- Workshops or other forums to stimulate proposals of potential R&D projects
- Scoping / feasibility studies to develop specific proposals

However, ITI Energy remains open to 3rd parties bringing forward proposals in other areas outside the list of 16 – the prioritisation simply highlights where most of ITI Energy's time and resource will be focused in the near to medium term.

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APPENDIX A - ITI Energy – Long List of Opportunities

Wind Turbine Concepts
Flexible, downwind machines
Diffuser augmented turbines
Different blade numbers
Two-bladed machines
Optimised medium-scale onshore turbines
Variable diameter rotor
Flexible blades and hubs
Coned rotor
Variable speed machines

Rotor and Aerofoil Concepts
Rimmed rotor
Single rotor bearing
Soft mounted rotor
Twist flap coupling (to regulate loads)
Blade vortex generators
Active vortex generators
Air jet vortex generators
Circulation control
BERP-like blade tip shape
High lift aerofoils
Reduction of aerodynamic losses at blade / nacelle interface
Low noise tip shapes
Higher tip speeds
Serrated trailing edge for low noise
Alternative erosion protection on blade leading edge
2-part blades

Lightning protection
Lightning protection of carbon blades

Wind Turbine Mass reduction

Magnetic attachment of sundries
Light-weight tower

Wind Turbine Environmental Adaptations
Cold climate adaptations
Icing blade adaptations
Aerofoils for cold climates
Hot climate adaptations
Low wind speed adaptations
High wind speed adaptations
Severe terrain adaptations

Wind Turbine Social Adaptations
Radar mitigation

Reduction of radar cross section
Turbine aesthetics

Wind Turbine Offshore design concepts
Big stall-regulated machines
Multi-MW machines
40 MW vertical axis
RE Power 5 MW design
Reduce complexity of wind turbines
No pitch
No rotating
No yaw
Electrical drives onshore
Reduced maintenance
More complexity onshore
Design for deep water deployment
Replace bolted flange connections – use pull-in joints
Ratchet joint (under offshore installation)

Environmental Protection
Corrosion protection
Cathodic protection
Epoxy paints
Thermal spray coatings at splash zone
Sacrificial coating protection
Positive air pressure in tower
Reducing common corrosion protection costs – cylinder role?
V. high IP box enclosure or resin encapsulation
Liquefaction scar
Scour protection
Design it out
Remote scour monitoring
Synthetic fronds
Industrial textiles
Seaweed – biological fouling
Anti-fouling paints

Offshore Wind Turbine Foundations
Floating structures
Buoyancy
Hydraulic control of inclination
Easier decommissioning
Thrusters – DP
Hybrid between floating / fixed
Suspension between turbines
New foundation designs
Suction caissons
Concrete tripods
Tension leg structures
Transfer technology

Gravity base – partial coupled and tower
Light weight material for structure
Decommissioning of foundations
Tripod tower
Guyed tower

Offshore Construction
Installation a design driver
Complete onshore wtg construction
Self-erection
Telescoping tower
Clever upending system
Modularisation for onshore construction
De-couple installation equipment from turbine size
Redesign wtgs to installation loads etc
Standardisation of foundation / tower
Plug-and-play solution
New barge and handling system
Purpose-built vessels for sequence installation
Systems for whole turbine installation
Dynamic positioning required
Flotation of complete wtgs
Floating complete upright – overturning
Dumb vessel + upender
Dumb barges - + lifting
Docking dumb vessels - manipulation
Airships
Jacks good vs. sea states – slow
Single crane
Installation and access of wave/tidal
Jack-up barges that can operate in deep water high current environments
Mobilisation of wave / tidal components
Oil rigs - use as installation vessel

Offshore New access solutions
Helipad at base of turbine
Platforms on towers
Davit launching-type system
Fabricom Offshore Access System
Deep water access vessels
Jacks sinking (repairs)
Dedicated vessel for major intervention
Different vessels for access and egress
Canon and net
Floating bouncy castle - velcro
Underwater access
Floating jetty
Zip line
Breeches buoy
Escape pod – to water

Escape area mid way
Catenary between turbines – could also be power cables
DP gangway
Forestry tree gripper – lift boat
Artificial beach
Subsea tunnels
Universal access system for all wind farms
Gyroscopes
Heave compensated cranes
Access easier higher up tower – bigger vessel = more stable: access turbine at mid-tower height

Offshore O&M innovations
Temporary living quarters on towers
Repair space and kit in towers
Personnel lift up the outside of tower
Removable nacelle – to ship for maintenance
Larger modular assembly
Readily removable components in gearbox – internal jacks
Design for reliability – learn from offshore oil and gas
Oil rigs - decommissioned

Transmission / Drive train
Direct drive machines
Direct drive, wound field rotor
Direct drive PMG
Light weight PMG – (Zephyros 1.8 MW)
Permanent magnet air core
Super-conducting PMG
Alternative transmission
Planetary gear – multi-generation
Hybrid transmissions (Multi-brid etc.)
Hydraulic drive train
Hydraulic torque converter
CVT Torotrak
Geared transmission
Gearbox for multi-MW (Renk & Re Power)
Maag multi-pinion lightweight gearbox
Re-evaluated gearbox configuration
Gearbox, shaft-mounted pumps

Monitoring / control
Turbine intelligent control
Individual pitch control
Rotor control
Intelligent rotor blades?
Optielectronics (fibres?) in blades
Active aerodynamic control devices?
Intelligent blade tips
Smart material

Self-learning
Vibration software (helicopter-inspired)
Condition monitoring
Condition monitoring better for mechanical structures
Condition monitoring for corrosion
Predictive maintenance
Fault tolerant turbines – from aircraft industry, health monitoring, amend design
Cooling to improve reliability
Keep it simple, over-sensitive control
Graceful failure, modular power system with by pass
Sensors specific to wind components
Sensors for fatigue, long range ultrasonics
Remote monitoring
Monitoring oil (gearbox)
Telemetry
Onshore to read faults offshore
Laser sensing – hums
Structural testing of blades during manufacture, arrival or after assembly?
Replacement controller market
Automated lubrication
Wave/tidal Device control
Dynamic ballasting of wave devices
Wind Farm Intelligent control
Use information
Gearbox, vibration, heatspot
Complementary generators seen as "unit" by grid - conventional control for unit

Electrical - Generators
Superconductivity (super-cooled)
MV generation at turbine – eliminate turbine transformers
Permanent magnets
DC/ Variable voltage, variable f, common speed
Direct drive – eliminate gearbox
Ultra-high speed generation
Multi-generator concepts
Switched reluctance machines
Narec Snapper
Permananet magnet induction generator
Free piston engine concepts
Oscillatory generators
Low speed generators
Linear generators

Electrical - Power converters
Inverter-connected turbines
New inverter technology
Control of inverters
LV to MV converters

New topologies
New high power semi-conductors
New materials with high band width
New low loss materials
Silicon Carbide
Multi-level converters
Fault tolerant converters
Modular constructions
Fault current control
Harmonic filtering - passive
Harmonic filtering – active
Higher frequency converters
Eliminate DC link in conversion
Low power frequency converters

MV/HV Collection System

- Novel collection systems
  - DC generation offshore
  - DC/ Variable voltage, variable f, common speed Offshore
  - HV transmission issues
  - Transients and dynamics of offshore electrical systems
  - Superconductivity
- Switchgear, protection and control
  - Standard grid connection hardware
  - Standard grid connection software
  - Modular switchgear and protection
  - New protection within wind farms – eliminate fuses or other switchgear
  - New distance or directional protection
  - Link protection to WFarm SCADA
- New earthing software to reduce uncertainty and costs
- Grid loss survivability – back-up generation

Grid issues

- Grid-friendly features
  - power factor control
  - power output control
  - fault ride through
  - better power quality
  - Synching of signal (switch in/out)
  - What kind of power electronics?
- Grid simulation and testing
  - Test facility for grid compliance
  - Proper turbine models
  - Grid simulation
- Management and Control
  - Active management at distribution level
  - Forecasting generation
  - Direct control by grid operator
  - Energy storage tied in to the grid
  - Real-time monitoring of constraints

- Real-time temperature monitoring for increased asset use (thermal ratings)
  - Real-time monitoring of voltage – power factor and voltage control
  - Power line carrier communications
- Devices
  - Electrical fault limiting devices
  - Fault limiting power converters
  - Is limiters
  - Reactive power devices

Offshore Cable issues

- Bringing into turbine & terminating
  - J-tube design to be integrated into tower/foundation design
  - Avoid use of J tube
  - Pre-install cable inside pile
  - More efficient cable pulling
  - Plug in above or below mean sea level
  - Cut cables according to installed wtg position
  - J-tube vs subsea connector
  - Wet mate subsea connections
  - Plug mounted on transition piece
- Installation in seabed
  - Innovative cable laying
  - Reduce cable wastage
  - Cables infield – not buried
  - Cables – above sea (OH lines)
  - To floating turbines
  - Attach to submarine walkways
  - Bury but not plough – ROV
  - Redundancy in cabling
  - Cables in pipes or conduits
  - Microwave transmission
  - Cables through cables
- Sand waves – unbury
- Cable design
  - Dynamic cables
  - Floating cables
  - Better armour – not buried
  - Cable minimum bend radius –careful or produce more flexible cables

Energy Storage

- Compressed air
- Hydrogen production
  - Electrolyser direct production of hydrogen
  - Hydrogen generators from intermittent power sources
- Pumped electrolyte batteries
  - Non-toxic electrolyte
- Oxygen generation
- Hydrogen wind systems fresh water
- Hydrogen and waste heat

Local storage
Fly wheel blocker = vacuum

Wind / Diesel

Materials
New blade materials – for strength, pliability
    High quality composite development (resin infusion)
    Carbon blades
    Thermoplastic blades
    Alternative to wood or glass – polyester in crystalline form?
    GLARE (new material – Airbus)
Blade materials - for reduced energy loss
    Self-cleaning blades
    roughness insensitive aerofoils
Smart materials
    Smart coatings
Blade technology GRTP
Recyclable blade materials
Decommissioning glass fibre blades
New tower materials
Novel component materials
Nanotubules – available?
Non-concrete foundations
Recycling civil materials, electronics
Alternative construction materials for wave devices
Concrete
Compliant, elastic, salt-resistant materials

Supporting tools
Dynamic PS model
Wind characterisation
Resource assessment
    satellite
    sodar
    Lidar
    Wind modelling improvements
    Doppler wind / wave surveys
Forecasting
Correlations of measured data to provide better forecasting
Private met service using wind farm data
Lidar solar kites
Short term forecasting of sea states
Custom made CFD
Sea bed characterisation
Offshore soil investigation
    Sonar for soil investigation
    How to deal with rocks
O&M simulation
Management systems for reliability

Aerodynamic modelling techniques
Wave loads on large towers
Combined wind & wave loading

Small Wind Turbines
Low noise, low speed – elephant ear blades
ADSL and intelligent meter solution
Net metering
General purpose small and micro process control board
Inverter with reactive power control
4 x Lobe system/inverter: turbine, grid, local load
Must be low maintenance
Pultrusions in blade manufacture
Aerodynamic design for low reynolds number
Innovative safety systems

Onshore works – access, mobilisation
Commissioning onshore
  Simulate conditions onshore and test onshore
  Install turbines in one piece – commission onshore before building offshore
Portable blade plant / on-site blade manufacture
Improved onshore installation
Transport of multi-MW components
Self-erecting turbines
Ballooned vehicles for site access

Wave and Tidal devices
New devices – mechanical
New devices – exploiting salinity gradient
OWC – avoid extreme loads

Wave and Tidal other generic issues
Sealing
Mooring
Try to avoid moorings – seabed fix
Umbilicals
Hydraulics
Energy storage (accumulators)
Alternative turbine design
Reduction of load ratio
Improvements in manufacturability
Improved power take-off

APPENDIX B - Foresighting Sources/References

(1) Companies / Organisations Involved in Foresighting

- Energetech
- Ocean Power Delivery
- ANZ
- Babcock & Brown
- Caley Ocean Systems
- Marine Current Turbines
- Ocean Prospect
- Royal Bank of Scotland
- Renewable Energy Systems
- Willis
- NSure
- TU Delft
- ECN
- DNV
- Riso
- LM
- Bonus
- NOI Scotland
- Bently Nevada
- Seebyte
- Garrad Hassan
- EA Technology
- Edinburgh University
- Evolving Generation
- ECEBS
- Sun
- TUV NEL
- AEA Rail
- Agilent
- Freescale
- SLDI
- Thales Ess
- Insensys
- BT
- AREG
- Boreas
- Connect Scotland
- Oreada
- Qinetiq
- Scottish Hydrogen and Fuel Cells Association
- BG Group
- AEA Technology
- Ocean Power Delivery
- SMD Hydrovision
- Talisman Energy
- Sgurr Energy
- Scottish Renewables Forum

- Airtricity
- Allen Gears
- Artemis Intelligent Power
- EPSRC
- Howden Group
- Imperial Innovations
- Imperial University
- MG Bennett & Associates
- Mitsui Babcock
- Proven Engineering
- Repower UK Ltd
- Sinclair Knight Merz (Europe) Ltd
- University of Edinburgh
- University of Glasgow
- University of Strathclyde
- Paisley University
- Nordic Windpower
- Boreas
- CEASA
- Howden Group
- Reflex Marine
- Robert Gordon University
- Ross Deeptech
- Scottish Enterprise
- Sparrow Offshore
- Vestas
- Gamesa
- Wavegen
- EWEA
- Clipper Windpower
- Craig Group
- Durham University
- Highlands and Island Enterprise
- MIT
- Norsk Hydro Technology Ventures
- NREL Deepwater Wind Conference
- EWEA 2004 Wind Conference
- PSAG
- Scottish and Southern Energy
- Scottish Power
- SEEF
- Shell Renewables
- SIGEN
- SMD Hydrovision
- Engineering Business
- TWI

(2) Summary of Desk-top Research Sources

General

- Active Implementing Agreements of the IEA
- Wind Energy R&D Network
- Concerted Actions of Offshore Wind Energy
- European Framework Programmes 5 and 6
- UK Foresight Program
- Carbon Trust
- DTI
- Scottish Executive
- FREDS (Forum on Renewable Energy Development in Scotland)
- Parliaments Science and Technology Select Committee
- Regional Development Agencies
- NREL
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