WAVE ENERGY

TECHNOLOGY DESCRIPTION

Wave energy is a concentrated form of solar energy. Winds generated by the differential heating of the earth pass over open bodies of water, transferring some of their energy to the water in the form of waves. This energy transfer involves concentration of the energy involved: the initial solar power level of about 100W/m^2 is concentrated to an average wave power level of 70kW per metre of crest length. This figure rises to an average of 170kW/metre of crest length during the winter, and to more than 1MW/metre of crest length during storms.

Wave energy converters extract and convert this energy into a useful form. The conversion usually makes use of either mechanical motion or fluid pressure, and there are numerous techniques for achieving it, eg oscillating water/air columns, hinged rafts, gyroscopic/hydraulic devices. The mechanical energy is then converted to electrical power using a generator. Direct drive generators, in which the motion of the wave is converted directly to electrical power, are now being considered.

Wave energy converters can be deployed either on the shoreline or in the deeper waters offshore. The shoreline resource potential is much smaller than the offshore potential. This is because there are few specific sites that meet the requirements for useful energy capture. East-facing sites in the UK are unsuitable because of the limited energy associated with easterly winds, while bottom friction reduces power levels where the water depth is less than 80 metres. As a result, the inshore resource is only one-quarter or less of the deep-water resource, although this reduction can be offset in some locations, where wave refraction focuses and concentrates wave energy, creating locally attractive shoreline sites.

There are significant differences between the engineering challenges of offshore and shoreline sites. Offshore, although transmission costs and losses will be higher, cost-effectiveness should be greater because the power component rises with the square of the amplitude, whereas the stresses (and therefore structural costs) rise a little less than the first power. Furthermore, in deeper water, there is also more of a chance to yield to extreme loads. Onshore sites, however, are inaccessible in bad weather: they also have much higher construction costs than factories or shipyards. Despite this, obstacles to the early deployment of offshore wave energy converter prototypes are greater than for those in onshore or near-shore locations.

MARKET

The primary market for wave energy is electricity generation. Connection could be at National Grid level, or into the regional or local distribution systems. This market opens up a range of secondary products and services, including equipment manufacture, installation, operation and maintenance.

There are also opportunities for using those wave energy converters designed to produce mechanical energy for the desalination of, or mineral extraction from, sea water. These markets exist both in the UK and overseas (where the opportunities are potentially much greater).

The renewable nature of wave energy means that it could ultimately be attractive as one component in a possible hydrogen economy.

BENEFITS

- A developed wave energy conversion technology could be expected to produce electricity at a competitive commercial cost and with no gaseous emissions (greenhouse or polluting) or waste products.

- Shoreline plant could provide electrical energy for local (island or remote) or national electricity grids.

- Successful exploitation of the estimated offshore UK wave energy resource could make a substantial contribution to the national electricity supply, providing diversity of supply and sustainability in our use of energy.

- UK industrial competitiveness could be strengthened by a domestic wave energy conversion industry.

TECHNOLOGY STATUS

Many wave energy devices have been, and continue to be, proposed, and there is no consensus on the best approach or any certainty that this has yet been identified. In practice a number of alternative approaches may prove to be equally attractive.

While it is clear that wave power devices can be made to work, it has not yet been demonstrated that they can be made to work cost-effectively, with economically attractive prices for the energy generated.

The UK has one of the best wave power resources available, and three projects have been awarded contracts under the Third Scottish Renewables Order (SRO), the first Renewables Order to be open to wave power. Although the prices to be paid for the electricity from these three projects are commercially confidential, they are higher than the cap price under the new Renewables Obligation, though not substantially so. However, these prices are well below the bid prices for UK wind power in the first tranche of the Non Fossil Fuel Obligation (NFFO) for England and Wales, and the first GW of wind energy capacity in California. They are also comparable with predicted electricity costs from the first offshore wind farms although, admittedly, the UK has a much greater experience of wind turbines, derived from their widespread use onshore.

The first of the SRO projects is now operational. This is the LIMPET device, a 500kW shoreline oscillating water column (OWC) deployed by Wavegen (Inverness) on the Scottish island of Islay in November 2000.

In the second project, Ocean Power Delivery of Edinburgh is developing Pelamis, a floating offshore device. Towards the end of 2001, the company evaluated a 1/7th scale model in the sea. It plans to deploy a 750kW device in 2002, and it is currently undertaking research and development initiatives to reduce the risk and to tackle remaining areas of uncertainty, thereby maximising the opportunity for project success.

The third SRO contract is for a Swedish wave power concept.

These three projects will generate a lot of valuable information: this will improve the industry's understanding of the commercial prospects for these particular devices in the UK, and of the key development issues facing wave power. It will be important to publish as many of the technical and economic performance results for these devices as possible: this will help to develop a wider understanding of the overall prospects for wave energy.

A number of other projects are also under way in various parts of the world:

- Wavegen is proceeding with an R&D project to demonstrate its floating offshore concept at the 2MW scale. The company will be constructing the demonstration device during 2002.

- In Australia, a shoreline device is being deployed by Energetech, and a power purchase agreement with the local utility in Australia is already in place.

- In Ireland, a 400kW floating device (the McCabe Wave Pump) has been tested as a pilot scheme, and a commercially sized device is nearing completion.

- In the Netherlands, another floating wave device (the Archimedes Wave Swing) has been developed.

- In Romania, the construction of a 2MW device is nearing completion: this will be deployed near Portugal.

- A floating wave energy device, developed by Ocean Power Technology in the USA, has been tested at a large scale in the Eastern Atlantic: the first commercial schemes are being built in Australia and the Pacific.

In general, shoreline wave energy conversion is technically developed but not fully commercially proven. It is still some way from being fully competitive commercially. Furthermore, there is, at present, insufficient operating experience, and schemes need to demonstrate long-term performance and reliability. The DTI Programme is currently supporting monitoring of the LIMPET device.

Offshore wave energy is still mainly at the research and development stage. Much work is needed to tackle key development issues, reduce uncertainty and verify the concepts, although the leading developers are now beginning to progress to large-scale demonstrations of their technologies.

Although the development of wave energy technology is reducing predicted energy costs, studies have shown that these costs are still not fully competitive with electricity supplied from the grid at today's costs. Further innovation is needed to overcome the technical challenges that hinder this competitiveness.

On the other hand, there may be opportunities to supply wave-generated electricity to isolated or island communities where the competition is only from diesel generation.

TARGETS FOR COMMERCIAL COMPETITIVENESS

The Renewables Obligation, a market incentive measure developed by the Government, ensures a price of up to a maximum of ~5p/kWh for electricity from renewable energy sources. It achieves this by placing an obligation on electricity suppliers to provide 10% of their electricity from renewable sources by 2010.

The Climate Change Levy, a tax on business energy use, and the exemption from it for electricity purchased from renewable sources is worth a further 0.43p/kWh. The Government is also proposing a Capital Grants Scheme to help biomass and offshore wind projects make the transition from research through demonstration to competitiveness within the market created by the Obligation.

The initial target for wave power is for it to produce energy at the cost expected for the early offshore wind and biomass projects.

The ultimate, longer-term target is for wave power to be commercially competitive without the need for market support measures: to achieve this, the technology would need to be generating electricity at a price that is competitive with other sources of energy. It is difficult to know what this price might be at some point in the future. In today's electricity markets and at today's prices, the value is in the region of 2.5p/kWh, assuming real commercial rates, although this price is expected to change over time.

RESEARCH AND DEVELOPMENT ISSUES

Wave energy devices

An early priority is to develop and apply a methodology for systematically identifying and evaluating the most promising wave energy devices, and to base this on the good understanding of fundamental hydrodynamics that already exists. This approach should ensure that:

- the most attractive and promising devices are identified and included in the Programme
- a deeper insight is acquired into the overall prospects for wave energy.

There are already a number of device concepts at different stages in their development and evaluation. Most use proven engineering concepts, but their long-term reliability and effectiveness have not yet been verified in appropriate environments and applications.

Priorities for the more developed concepts are:

- to reduce uncertainty in the key components
- to make as rapid progress as possible towards meaningful scale prototypes

- to do this in a way that manages the technical risk and allows performance to be evaluated in realistic operating environments.

This approach would require long-term reliability and performance monitoring.

In addition, there is a need for studies that focus on the continued improvement of design concepts so that their potential for further development towards commercial competitiveness can be understood.

There are several new concepts where initial exploratory work is required to understand their potential for energy capture, to evaluate the likely cost of energy and to undertake initial wave-tank testing. The more promising of these concepts would then need to undergo realistic prototype testing, having first been evaluated at a smaller scale in realistic, though benign, sea environments.

Generic issues

At the generic level, a recent review of wave energy R&D requirements by Ove Arup concluded that there were no fundamental technical barriers to the development of this technology. The review noted that many issues relating to design, construction, deployment and operation could be addressed by technology from other industries, notably the offshore industry. However, it did identify some technology gaps, notably in the areas of mooring, cable connections, hydraulic machines, grid connection and energy storage.

The following key generic technical R&D requirements were identified:

- Studies of mooring technology for specific types of wave energy device. Studies of generic mooring issues, including long-term fatigue of lines and connection points, standard connector designs for the quick release and re-attachment of mooring systems, and sub-sea cables.

- A standardised, flexible electrical connector. Cheaper cable and connector fabrication and cable laying.

- Modelling of systems involving multiple devices.

- Modelling device performance quickly and cheaply using linear assumptions.

- The extension of numerical modelling techniques to the non-linear regime.

- Research into real-time forecasting of detailed wave behaviour.

- Development of hydraulic systems using water or other environmentally acceptable fluids. Development of hydraulic machines (motors with low part-load losses, high-torque pumps).

- Mechanical shaft seals with a long life in sea water.

- Low friction bearings with high-load capability, long life and high tolerance of poor geometry.

- The development and evaluation of direct-drive generators.

- The development of electronic filters giving an arbitrary variation of damping coefficient but with no change in phase. This might then be extended to full complex conjugate control.

- Cheaper, more efficient energy storage for power smoothing.

There are also a number of issues associated with embedded generation (fault detection, safety when operating in island mode) but these are common to most renewable energy generation systems and to combined heat and power. These issues are dealt with separately.

NON-TECHNICAL ISSUES

As a result of the planned deployment of offshore wind farms, the general issues associated with the deployment of specific offshore renewable energy schemes (planning, the consents process, the role of the Crown Estates) are being simplified.

General studies have been carried out on the potential impact of offshore energy devices, as well as Environmental Impact Assessments (EIAs) for specific schemes. These studies indicate that, as long as schemes are deployed with some care, they will not have any significant adverse effect on the environment. Furthermore, simple steps can be taken to ensure that such schemes are not a navigation hazard.

As UK experience of offshore renewable energy technologies increases, and as more EIAs are completed for specific schemes, it may be possible to identify a range of generic issues that are common to all wave power devices. It would be appropriate for the Programme to commission some work of this type to ensure that impartial and objective information is available to project developers and to those involved in the consents process.

UK INDUSTRY STRENGTHS

The UK has substantial industry and academic strengths that are relevant to the development of wave energy. These include:

- world-class experience in the development and evaluation of wave energy conversion devices

- strong offshore and marine engineering capabilities, mature turbine manufacturing companies, and civil engineering and hydraulic engineering industries.

Furthermore, the offshore industry is looking to diversify from its traditional business, and many within that industry see offshore renewables as an area of opportunity in which they can exploit their existing skills and experience.

RATIONALE FOR A DTI PROGRAMME

The UK has a very significant wave energy resource available to it. However, the commercial exploitation of even a fraction of this resource requires substantial technical and economic challenges to be overcome.

Potential benefits

Wave energy is unlikely, by 2010, to make a significant contribution to UK targets for energy from renewable sources or greenhouse gas emissions reduction. However, it could be an important option should more demanding targets be set after that date.

The successful exploitation of wave energy would improve the diversity of UK energy supply and improve energy security. It would increase the sustainability of energy use and could make a significant contribution to greenhouse gas emissions reduction.

There could also be a significant export potential.

Barriers to commercial deployment

Prospects for commercially exploiting this resource remain uncertain: the time-scale for any potential commercial return is long, and this is likely to limit industry investment as industry is used to much shorter investment return periods.

How a DTI programme could help

A DTI programme, in collaboration with industry and with the cost shared by industry, could enable technology development to the point where major uncertainties have been addressed. Business can then make informed decisions about the commercial prospects for wave energy.

A DTI programme would also act as a focal point for UK activities. It would facilitate co-operation and information dissemination between UK industry and universities, and it would encourage international links with European Commission and International Energy Agency initiatives.

A strategy for a DTI programme could be:

- To move existing well developed device concepts forward to the prototype scale where their performance could be evaluated and verified. This would include tackling areas of outstanding technical uncertainty to reduce the technical and commercial risk.

- To support the initial evaluation of less well developed device concepts through initial design studies and, perhaps, wave tank testing. The aim would be to verify the concepts, estimate their energy capture potential and evaluate predicted energy costs.

- To support industry in the development and evaluation of individual innovative components, where these seem likely both to improve prospects for the successful commercial exploitation of wave energy in the UK and to stimulate export opportunities for UK companies.

- To co-operate closely with the Engineering and Physical Sciences Research Council in order to encourage fundamental research in areas where innovation is required, and to encourage co-operation between industry and academia.

- To co-operate with European Commission and International Energy Agency programmes, where this will complement UK activities, strengths and business interests, and help to ensure the best value for money for the UK.

- At the appropriate time, to encourage the demonstration and deployment of proven design concepts.

TECHNOLOGY ROUTE MAP FOR THE DTI PROGRAMME

Because there are several device concepts, each at a different stage of development, the Route Map proposed below should be regarded as a generic development pathway that can be applied, perhaps with different dates, to each concept.

It is implicit within the Route Map that progression to the next stage for any particular device concept is subject to the prospects for that device continuing to be good. In other words, estimates for the eventual energy cost must continue to appear attractive, uncertainties in the estimates must be acceptable, and any development issues identified must have good prospects of being tackled successfully. Furthermore industrial investment is expected to increase with time as risks and uncertainties are reduced.

Individual research needs are very dependent on the specific device concept and its configuration. However, they are likely to be in the areas already identified under Research & Development Issues – moorings, power capture, power take-off, survivability, long-term performance.

The dates given in the Route Map are indicative only and will not be used to disqualify sensible projects. Furthermore, the Route Map and the dates included within it will be reviewed at regular intervals as experience is gained.

Existing, well established device concepts

Activity	Target date
Further reduce the risk and uncertainty associated with the key components of initial projects. This could be laboratory-based or use a real sea environment (only if this is a sensible way of reducing risks and uncertainty.	End 2002
Commence small (typically 1/10 scale, but larger if justified) prototype testing in real, meaningful sea environments. Primary aims: • To confirm energy capture • To further improve confidence in mechanical design, survivability • To improve confidence in cost estimates and energy costs. Such projects are unlikely to include all the electrical aspects of the system.	End 2002
Support design studies that will evaluate the potential of these concepts for further development.	End 2003
Evaluate the results of the above. Consider if there is sufficient justification for the design, construction and deployment of meaningfully sized prototypes (perhaps 1/3 or ½ scale) for testing offshore in realistic marine environments. Such projects are likely to include electrical aspects of the system and long-term performance evaluation.	End 2004
Take forward additional projects on components where innovation is necessary and a case has been made for the work.	End 2004
Report on the performance of prototypes. Identify their prospects for subsequent commercial development. Identify the next steps, which could include commercial-scale demonstrations (probably post-2010, but earlier if justified).	2010

New design concepts

Activity	Target date
Completion of initial feasibility studies and design evaluations. The studies should improve confidence in estimates of energy capture, capital and operational costs, and eventual energy costs. They should also identify key development issues and areas of risk and uncertainty.	2003
Further evaluation and development of new device concepts; initial evaluation of models in wave tanks (typically at scales of 1/50 to 1/20); more detailed design, engineering and costing studies. Projects should further improve confidence in estimates of energy capture, costs and energy costs. They should also identify areas of uncertainty and risk.	2004
Take forward attractive concepts to small-scale or model prototype tests (typically 1/10 scale) in an accessible but real sea or loch environment.	2006

Development of methodology

The programme team, with support from independent consultants and hydrodynamicists, is currently developing a methodology that it hopes will be able to systematically identify and evaluate the most promising devices to ensure they are included in the Programme. The methodology will be used to model existing device concepts and assess/validate their predictions. Details of the methodology, and the results of the validation exercise, will be published and open to review by the wave community. If the methodology is accepted as a valid tool for identifying and evaluating the most promising device concepts, it will be used to select projects for support under the Programme.