Ocean Energy: Position paper for IPCC

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Abstract

This Paper summarise the state of the art for ocean energy used for electricity world wide.

Keywords: Ocean, Wave, Tidal, Thermal, Osmotic, Energy.

Introduction

Ocean Energy (OE) represents one of the largest renewable resources available on the planet. OE is an emerging industry that has a potential to satisfy world-wide demand for electricity, water and fuels, when coupled with secondary energy conversation principles.

OE represents a number of energy conversion principles:

- Wave energy is represented by surface and subsurface motion of the waves;
- Hydrokinetic energy that harvests the energy of ocean currents and tides;
- Ocean thermal energy conversion uses the temperature differential between cold water from the deep ocean and warm surface water;
- Osmotic energy is the pressure differential between salt and fresh water.

The OE generating potential has not been reported by IPCC in prior reports.

1 Energy Potential

The theoretical global resource is estimated to be in the order of:

- 8,000 - 80,000 TWh/year for wave energy;
- 800 TWh/year for tidal current energy;
- 2,000 TWh/year for osmotic energy;
- 10,000 TWh/year for ocean thermal energy

This has to be compared to the Worlds electricity consumption of 16,000 TWh/year

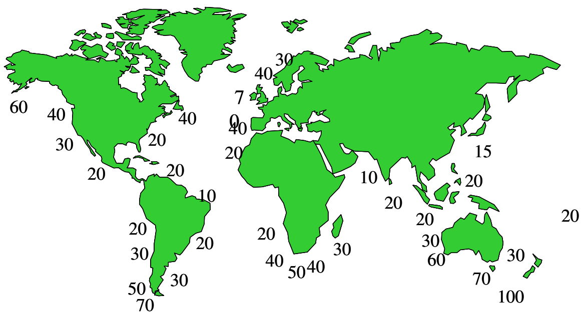

Figure 1: The highest wave activity (kW/m) is found between the latitudes of ~30° and ~60° on both hemispheres.

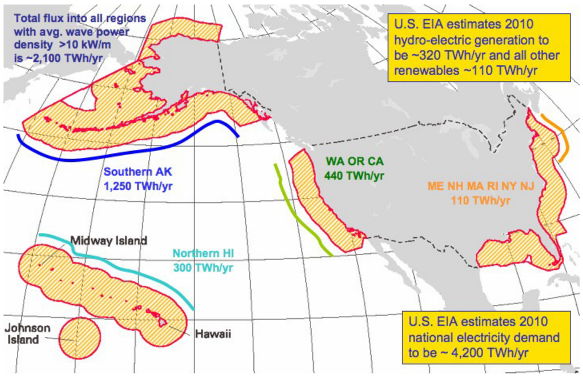

Figure 2: The wave energy potential expressed in potential electricity production (TWh) at the coasts of US.

Figure 3: The tidal range in meters.

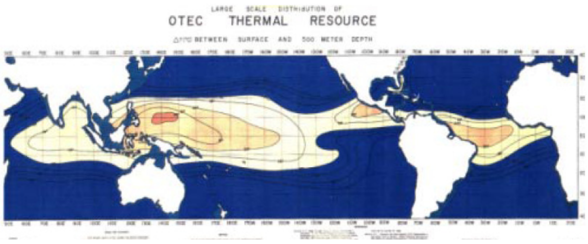

Figure 4: Ocean Thermal world-wide resource.

2 State of the Art

OE is an emerging industry. To date there are few operational OE systems around the world. The primary example of an OE generating facility is the tidal barrage system at La Rance, France that has an installed capacity rating of 240 MW and produces on average 600 GWh/year without any impact on climate change since 1966. Other operational systems are much smaller (5 MW China, 20 MW Canada).

The state of the art of the OE sector has advanced significantly over the last 5 years. A number of large scale test installations are either developed or under development today.

Considering the harsh marine environment, design of OE systems has to address significant technical challenges, those to achieve high reliability, low cost and safety.

At present there is no commercially leading technology amongst ocean energy conversion systems. In contrary to wind it is expected that different principle of energy conversion will be utilised at various locations to take advantage of the variability of ocean energy resource.

Wave Energy Installations:

- 0.4 MW and 0.5 MW Oscillating Water Column plants off the islands of Pico and Islay;
- 0.2 MW AquaBuOY of the coast of Oregon, USA;
- 2.25 MW Pelamis of the coast of Portugal by 2008;
- 7 MW Wave Dragon of Wales coast by 2008-2009;

Tidal:

- Barriers: 240 MW La Range by 1966, 20 MW Canada, 5 MW China
- Current: 1 MW MCT of North Ireland by 2007-2008

Ocean Thermal:

- 0.2 MW Hawaii 1993 -1998

3 Wave Energy

Among different types of ocean energy, wave energy represents the highest density resource. Processes in the ocean concentrate solar and wind energy that in turn create waves as winds blow across the oceans. This energy transfer provides a natural storage of wind energy in the water near the surface. Once created, surface waves travel thousands of kilometres with little energy losses, unless they encounter head winds. Nearer the coastline the wave energy intensity decreases due to interaction with the seabed. Energy dissipation near shore can be compensated by natural phenomena as refraction or reflection, leading to energy concentration ("hot spots").

Ocean waves encompass two forms of energy: the kinetic energy of the water particles, which in general follow circular paths; and the potential energy of elevated water particles. On the average, the kinetic energy in a linear wave equals its potential energy. The energy flux in a wave is proportional to the square of the amplitude and to the period of the motion. The average power in long period, large amplitude waves commonly exceeds 40-50 kW per meter width of oncoming wave.

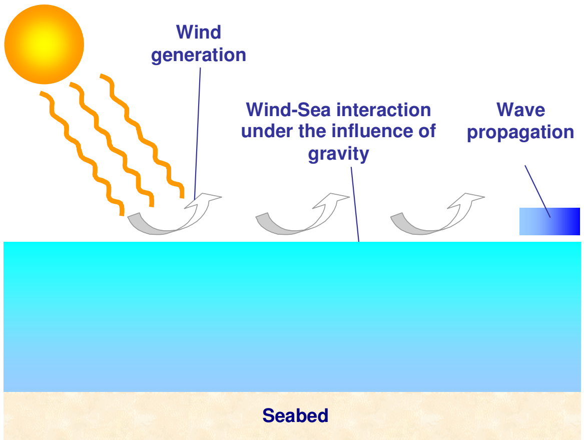

Figure 5: Ocean waves are generated by the wind.

As most forms of renewables energy sources, wave energy is unevenly distributed over the globe. Increased wave activity is found between the latitudes of ~30^o and ~60^o on both hemispheres, induced by the prevailing western winds blowing in these regions. Particularly high resources are located along the Western European coast, off the coasts of Canada and the USA and the south-western coasts of Australia, New Zeeland, South America and South Africa.

Situated at the end of the long fetch of the Atlantic, the wave climate along the western coast of Europe is highly energetic. Higher wave power levels are found only in the southern parts of South America and in the Antipodes. Resource studies assign for the area of the north-eastern Atlantic (including the North Sea) available wave power resource of about 290 GW and for the Mediterranean 30 GW. The similar figure for the west coast of United States is 150 GW.

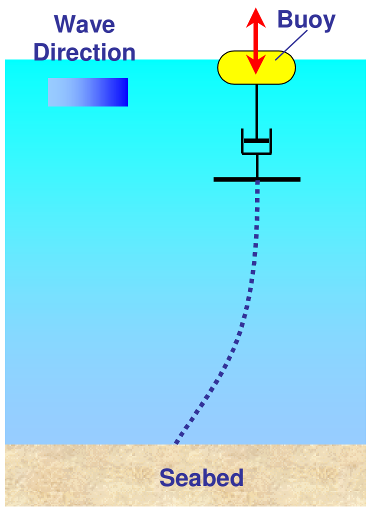

Figure 6: Buoy type of wave device.

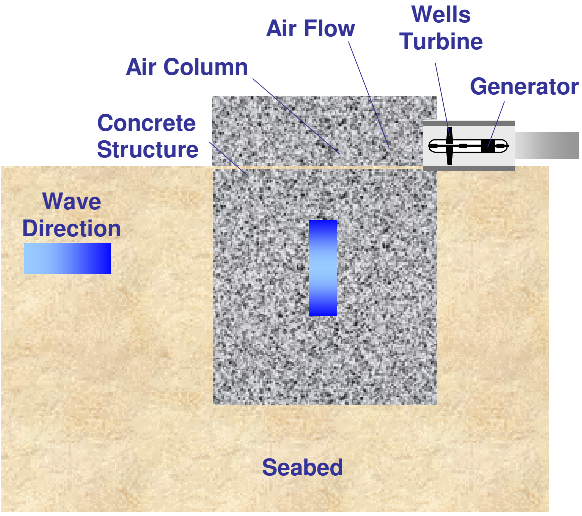

Figure 7: Oscillating water column type of wave device.

Principles and Aspects of Wave Energy Conversion

In contrast to other renewable energy sources the number of concepts for wave energy conversion is very large. Although over 4,000 wave energy conversion techniques have been patented worldwide, the apparent large number of concepts for wave energy converters can be classified by its basic principles of energy conversion:

- Oscillating Water Columns are partially submerged, hollow structures open to the seabed below the water line. The heave motion of the sea surface alternatively pressurizes and depressurises the air inside the structure generating a reciprocating flow through a turbine installed beneath the roof of the device.
- Overtopping devices, floating or fixed to the shore, that collect the water of incident waves in an elevated reservoir to drive one or more low head turbines.
- Heaving devices (floating or submerged) mechanical and/or hydraulic convert up and down motion of the waves into linear or rotational motion to drive electrical generators.
- Pitching devices consist of a number of floating bodies hinged together across their beams. The relative motions between the floating bodies are used to pump high-pressure oil through hydraulic motors, which drive electrical generators.
- Surging devices exploit waves' horizontal particle velocity to drive a deflector or to generate pumping effect of a flexible bag facing the wave front.

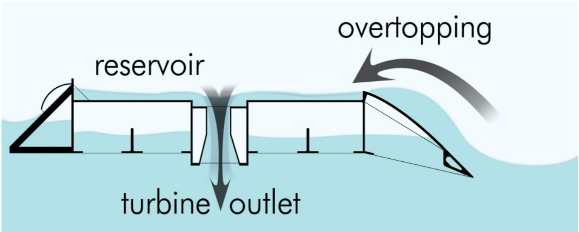

Figure 8: Overtopping type of wave device

It is important to appreciate the challenges facing wave power developments:

- Irregularity in wave amplitude, phase and direction makes it difficult to obtain maximum efficiency over the entire range of excitation frequencies.
- The structural loading in the event of extreme weather conditions, such as hurricanes, may be as high as 100 times the average loading.
- The coupling of the irregular, slow motion (~0.1 Hz) of a wave to electrical generators typically requires a 500 times increase is frequency.

Obviously the design of a wave power converter has to be highly sophisticated to be reliable and safe on the one hand, and economically feasible on the other. The abundant resource and the high-energy fluxes in the waves prescribe economically viable energy production. One of the important advantages of wave energy technologies is their environmental compatibility, as wave energy conversion is generally free of green house emissions. Also, the low visual and acoustic impact, particular of offshore or submerged devices, provides a significant advantage.

The negligible demand of land use is an important aspect. As for most renewable energy sources, the in-situ exploitation of wave energy implies diversification of employment and security of energy supply in remote regions. Furthermore, the large-scale implementation of wave power technologies will stimulate declining industries, e.g. shipyards, and promote job creation in small and medium-sized enterprises.

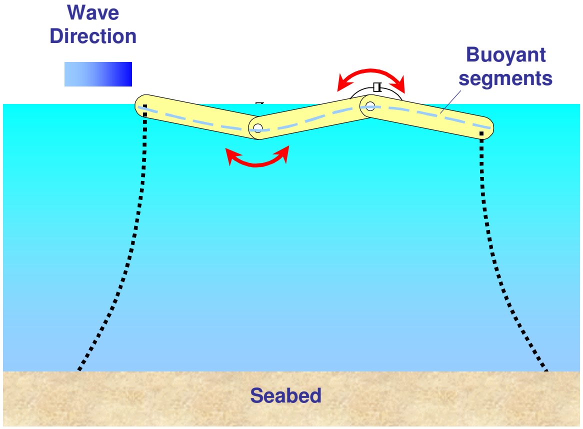

Figure 9: Pitching type of wave device.

Wave Energy Development Status

Wave energy conversion is being investigated in a number of countries, particularly in the member States of the European Union, Canada, China, India, Japan, Russia, the USA and others. Although the first patent on wave energy conversion was issued as early as 1799, the significant research and development of wave energy conversion began after the oil crisis of 1973.

In the last five years there has been a resurgent interest in wave energy, especially in Europe. Nascent wave energy companies have been highly involved in the development of new wave energy converters such as the Pelamis, the Archimedes Wave Swing, AquaBuOY, Oceanlinx or the Wave Dragon.

The predicted electricity generating costs from wave energy converters have improved significantly in the last twenty years. It is projected that energy generated by wave energy installation can reach an average price below 10 c€/kWh by 2020. Compared, e.g., to the average electricity price in the European Union, which is approx. 4 c€/kWh, the electricity price produced from wave energy is still high, but it is forecasted to decrease further with the development of the technologies.

Wave energy installation will consist of farms of wave energy converters, interconnected together to reach the desired farm capacity. Modularity of systems allows for gradual build-out of wave energy farms.

4 Tidal Energy

Tidal energy conversion techniques exploit the natural rise and fall of the level of the oceans caused principally by the interaction of the gravitational fields in the planetary system of the Earth, the Sun and the Moon. The main periods of these tides are diurnal at about 24 h and semidiurnal at about 12 h 25 min. During the year, this motion is being influenced by the positions of the three planets with respect to each other. Spring tides occur when the tide-generating forces of the Sun and the Moon are acting in the same directions. In this situation, the lunar tide is superimposed to the solar tide. Some coastlines, particularly estuaries, accentuate this effect creating tidal ranges of up to ~17 m. Neap tides occur when the tide-generating forces of the sun and the moon are acting at right angles to each other.

The vertical water movements associated with the rise and horizontal water motions termed tidal currents accompany fall of the tides. It has therefore to be distinguished between:

- Tidal range energy, make use of the potential energy from the difference in height (or head) between high and low tides, and
- Tidal current energy, the kinetic energy of the water particles in a tide or in an marine current.

Tidal currents have the same periodicities as the vertical oscillations, being thus predictable, but tend to follow an elliptical path and do not normally involve a simple to-and-fro motion. Where tidal currents are channelled through constraining topography, such as straits between islands, very high water particle velocities can occur. These relatively rapid tidal currents typically have peak velocities during spring tides in the region of 2 to 3 m/s or more.

Currents are also generated by winds, and temperature and salinity differences. The term “marine currents”, often met in literature, encompasses several types of ocean currents. Wind driven currents affect the water at the top of the oceans, down to about 600-800 m. Currents caused by thermal and salinity gradients are normally slow, deep water currents, that begin in the icy waters around the north polar ice. Wind driven currents appear to be less suitable for power generation than marine currents, as they are in general slower. Usually, tidal currents exhibit their maximum speed at fairly shallow waters, making them accessible for large engineering works.

The global tidal range energy potential is estimated to be about 3 TW, about 1 TW being available at comparably shallow waters. Within the European Union, France and the United Kingdom have sufficiently high tidal ranges of over 10 metres. Beyond the European Union, Canada, the CIS, Argentina, Western Australia and Korea have potentially interesting sites, which have been periodically investigated. Some regions with exceptional tidal range are shown on Figure 3 1 (annual average tidal range in meters).

Recent studies indicate that marine currents have the potential to supply a significant portion of future electricity needs. The resource potential of the European marine current is estimated to exceed 12,000 MW of installed capacity. Locations with especially intense currents are found around the British Islands and Ireland, between the Channel Islands and France, in the Straits of Messina between Italy and Sicily, and in various channels between the Greek islands in the Aegean. Other large marine current resources can be found in regions such as South East Asia, both the east and west coasts of Canada and certainly in many other places around the Globe.

Tidal Range Energy

The principle of conversion of tidal range into electricity is very similar to the technology used in traditional hydroelectric power plants. The first requirement is a dam or "barrage" across a tidal bay or estuary. At certain points along the dam, gates and turbines are installed. When there is an adequate difference in the elevation of the water on the different sides of the barrage, the gates are opened. The "hydrostatic head" that is created, causes water to flow through the turbines, turning an electric generator to produce electricity.

Tidal range energy conversion technology is considered mature, but, as with all large civil engineering projects, technical and environmental risks require attention. Some environmental impacts are associated with the changes of water levels that would modify currents, the sediment transport and deposits. However, there are regional development benefits as well, for example the La Rance plant in France, the only commercial sized tidal range conversion scheme so far, includes a road crossing linking two previously isolated communities and has allowed further development of the distribution network for raw materials and developed products.

Tidal Current Energy

Tidal currents can be harnessed using technologies similar to those used for wind energy conversion, i.e. turbines of horizontal or vertical axis (“cross flow” turbine). Some other techniques have either been abandoned or are at an early stage of development.

Several types of tidal current conversion devices, particularly fully submerged devices, are subject to the corrosive effects of seawater. Maintenance requires divers to access submerged machinery. While placing the drive train above water can minimize the need for divers, maintenance costs would remain higher than e.g. in wind turbines.

In contrast to atmospheric airflows the availability of tidal currents can be predicted very accurately, as their motion will be tuned with the local tidal conditions. Because the density of water is some 850 times higher than that of air, the power intensity in water currents is significantly higher than in airflows. Consequently, a water current turbine can be built considerably smaller than an equivalent powered wind turbine.

Tidal current devices are projected to have limited environmental impact. Their installation requires minimal land use, and fully submerged devices will not affect optically or acoustically their surroundings. Their effects on flora or fauna have not been studied extensively yet, but it is unlikely that they will be of significance. Finally, submerged marine current converters are considered to operate in safe environment: disturbances caused by extreme weather conditions are significantly attenuated to the depths of about 20-30 metres where the devices will normally operate.

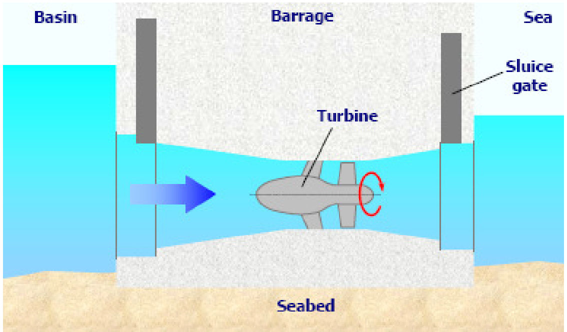

Figure 9: Tidal barrage type of tidal device.

5 Ocean Thermal Energy

A process called Ocean Thermal Energy Conversion (OTEC) uses the heat energy stored in the Earth's oceans to generate electricity.

OTEC works best when the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about 20°C (36°F). These conditions exist in tropical coastal areas, roughly between the Tropic of Capricorn and the Tropic of Cancer. To bring the cold water to the surface, OTEC plants require an expensive, large diameter intake pipe, which is submerged a mile or more into the ocean's depths.

Some energy experts believe that if it could become cost-competitive with conventional power technologies, OTEC could produce billions of watts of electrical power.

History

OTEC technology is not new. In 1881, Jacques Arsene d'Arsonval, a French physicist, proposed tapping the thermal energy of the ocean. But it was d'Arsonval's student, Georges Claude, who in 1930 actually built the first OTEC plant in Cuba. The system produced 22 kilowatts of electricity with a low-pressure turbine. In 1935, Claude constructed another plant aboard a 10,000-ton cargo vessel moored off the coast of Brazil. Weather and waves destroyed both plants before they became net power generators. (Net power is the amount of power generated after subtracting power needed to run the system.)

In 1956, French scientists designed another 3-megawatt OTEC plant for Abidjan, Ivory Coast, West Africa. The plant was never completed, however, because it was too expensive.

The United States became involved in OTEC research in 1974 with the establishment of the Natural Energy Laboratory of Hawaii Authority. The Laboratory has become one of the world's leading test facilities for OTEC technology.

In 2004 Japan moved away from their work in the field of wave energy and directed all their research and development efforts to OTEC. While wave energy resources are marginal, Japan has a good OTEC resource.

The types of OTEC systems include the following:

Closed-Cycle

These systems use fluid with a low-boiling point, such as ammonia, to rotate a turbine to generate electricity. Warm surface seawater is pumped through a heat exchanger where the low-boiling-point fluid is vaporized. The expanding vapor turns the turbo-generator. Cold deep-seawater—pumped through a second heat exchanger—condenses the vapor back into a liquid, which is then recycled through the system.

In 1979, the Natural Energy Laboratory and several private-sector partners developed the mini OTEC experiment, which achieved the first successful at-sea production of net electrical power from closed-cycle OTEC. The mini OTEC vessel was moored 1.5 miles (2.4 km) off the Hawaiian coast and produced enough net electricity to illuminate the ship's light bulbs and run its computers and televisions.

In 1999, the Natural Energy Laboratory tested a 250-kW pilot OTEC closed-cycle plant, the largest such plant ever put into operation.

Open-Cycle

These systems use the tropical oceans' warm surface water to make electricity. When warm seawater is placed in a low-pressure container, it boils. The expanding steam drives a low-pressure turbine attached to an electrical generator. The steam, which has left its salt behind in the low-pressure container, is almost pure fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water.

In 1984, the Solar Energy Research Institute (now the National Renewable Energy Laboratory) developed a vertical-spout evaporator to convert warm seawater into low-pressure steam for open-cycle plants. Energy conversion efficiencies as high as 97% were achieved. In May 1993, an open-cycle OTEC plant at Keahole Point, Hawaii, produced 50,000 watts of electricity during a net power-producing experiment.

Hybrid

These systems combine the features of both the closed-cycle and open-cycle systems. In a hybrid system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, similar to the open-cycle evaporation process. The steam vaporizes a low-boiling-point fluid (in a closed-cycle loop) that drives a turbine to produce electricity.

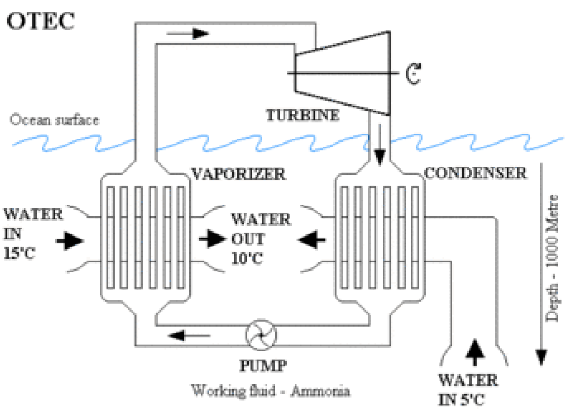

Figure 10: Diagram of a closed cycle Ocean Thermal Energy Conversion plant

6 Ocean Osmotic Energy

Exploiting the pressure difference at the boundary between freshwater and saltwater can capture energy. This is called Osmotic Energy. The difference of potential between freshwater and salt water is called the Salinity Gradient. The potential for osmotic energy exists wherever a stream or river enters the ocean.

Most people are familiar with reverse osmosis where freshwater is obtained from saltwater. Reverse osmosis consumes energy and produces freshwater from seawater. Osmosis consumes freshwater in the presence of seawater and produces energy (the freshwater becomes saltwater).

The principle of salinity gradient energy is the exploitation of the entropy of mixing freshwater with saltwater. The potential energy is large, corresponding to 2.6 MW m3/sec when freshwater is mixed with seawater.

Several methods have been proposed to extract this power. Among them are the difference in vapor pressure above freshwater and saline water and the difference in swelling between fresh and saline waters by organic polymers. However, the most promising method is the use of semi-permeable membranes. The energy can then be extracted as pressurized brackish water by pressure retarded osmosis (PRO) or direct electrical current by reverse electro dialysis (RED).

With the RED method, ion selective membranes are used in alternate chambers with freshwater and seawater, where salt ions migrate by natural diffusion through the membranes and create a low voltage direct current. With the PRO method, another type of membrane, similar to reverse osmosis membranes used for sea water desalination, is used. These PRO method membranes are much more permeable to water than to salt. If fresh and saltwater are separated by such membranes, natural osmosis will force the freshwater through the membrane to the saltwater side where hydrostatic pressure up to 26 bars can be created. The two methods are quite different in their working principles, but it is the same potential energy that is exploited.

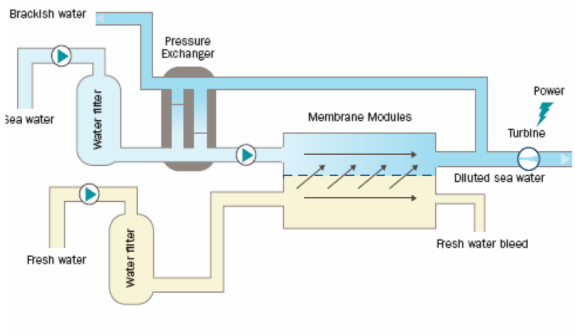

Figure 11: Diagram of pressure retarded osmosis (PSO) process using salinity gradients.

Salinity power represents sufficiently large sources of renewable energy that is yet to be exploited. The resource potential world-wide is estimated to be 2,000 TWh annually. One of the reasons that this renewable source has not drawn more attention is that it is not readily evident to most people. Another reason is that considerable technological development is necessary to fully utilize this resource. Along with the lack of efficient and suitable plant components, some pessimistic cost forecasts have been issued. The potential cost of energy from this source is higher than most traditional hydropower, but is comparable to other forms of renewable energy that are already produced in full-scale plants.

7 Socio Economic and Environment Impact

The creation of an ocean energy industry could lead to a significant increase in jobs that is estimated to be in the range of 10 – 20 jobs/MW in coastal regions.

Like any electrical generating facility, an OE power plant will affect the environment in which it is installed and operates. There is no actual environmental effects data available at this time, however a number of the Environmental Assessment documents have been written to provide a desktop assessment of potential impacts of wave and tidal energy. These assessments, and the follow-on consents for installation of wave and tidal ocean energy conversation devices have provided findings of no significant environmental impacts. These findings support the general opinion that ocean energy represents a fairly benign means of renewable energy generation.

Withdrawal of ocean energy will not present an impervious barrier to the ocean energy resources. Gaps between devices and less than 100% absorption efficiency allow ocean energy to maintain its strength and to pass through a plant. Undiminished ocean energy will spread into the lower-energy zone immediately behind the plant by diffraction.

For devices using close- circuit hydraulics, working fluid spills or leakage may be concern. For devices with equipment mountings on submerged hull surfaces, underwater noise is a concern. For devices with air turbines, atmospheric noise is a concern. These concerns can be mitigated to various extents through system design features.

Ocean energy devices represent low visual impacts as they are either below the surface, or two small to be visible from a distance.

Because of the high level of fishing activity in offshore shelf waters, floating devices will have to be appropriately marked as a navigation hazard. In addition to lights, sound signals, and radar reflectors, highly contrasting day-markers will be required. Day-markers that meet the Coast Guard requirement of being visible within one nautical mile (1.8 km) at sea are expected to have negligible visual impact when viewed from shore.

Potential conflicts for use of space may exist with marine protected areas; shipping, fishing, scientific research areas, and military warning area; telecommunication cable routes and dredge spoil disposal sites. Most of these can be avoided with appropriate research during site selection and early dialogue with groups that might be affected.

Wave energy can have a number of other benefits in both the environmental and social areas. For example, in remote coastal areas, including small islands, it can help reduce the reliance on auxiliary (diesel) power stations. In addition to the resultant reduction of the emission of combustion gases to the atmosphere, the transport of the fuel to the site, often by water, is largely eliminated, which in turn reduces the environmental risks associated with this means of transportation.

8 The Barriers for Ocean Energy

Ocean energy has a tremendous potential to make a significant contribution to the renewable energy generation. While developers work diligently on technology development, their ability to expand commercially may be significantly hindered unless non-technological barriers are addressed in earnest. The following is the list of barriers that would require political, public and financial will to overcome to allow commercial expansion of ocean energy generation.

Electrical Grid Access

Ocean energy is a coastal resource. National grids were designed to accommodate central generation, resulting in weak transmission lines available in coastal areas. Ocean Energy has a potential to generate electrical power in hundreds of megawatts. Except for coastal countries, like Portugal and the SW region of UK that have high voltage transmission lines available close to shore, coastal communities lack sufficient transmission lines capacity to provide grid access for any significant amount of electricity that can be generated from ocean energy.

The barrier to ocean energy commercialization thus lies in the answer to these questions – a) who will finance the grid expansion in coastal areas suitable for ocean energy generation; b) who will determine the energy mix and, hence, the grid access for ocean energy systems.

Regulatory Framework

Initial efforts in securing installation permits in a number of countries demonstrated that permitting is expensive, long, and intensive. Lack of field data to support environmental analysis makes it that much harder to provide permitting authorities with factual information vs. desk analysis. Furthermore, there is lack of coordination between permitting authorities, making it so much more difficult to obtain permits.

Governments can significantly impact licensing of ocean energy systems by creating one-stop permitting structures.

The European Ocean Energy Association will be working with the European governments to streamline permitting processes to facilitate greater number of installations of ocean energy systems.

Availability of Resource Data

Top-level analyses of the available ocean energy resources have been done and are widely available. Now, these top level analyses need to be overlaid with constraints that would prevent harvesting of ocean energy in specific areas, i.e. other uses of the sea, access to transmission lines, populations centres, etc.

Economic Incentives

In the history of new industry creation it is a known fact that artificial market conditions need to be created at the early stage of industry development to create a market pull and to incentivise early adapters. Such market pull can have three elements – incentives for investors (investment tax credits), incentives for end-users (investment and production tax credits) and feed-in tariffs that would make high-cost pre-commercial installations attractive to investors and the end-users.

Public Awareness

Ocean energy is lacking public awareness, as it is a developing industry. A public awareness campaign may provide similar benefits as was enjoyed by the wind industry in its early days.

9 Recommendations

OE can become a major player in the world-wide renewable energy mix in fairly short time, provided that industry players have access to the same level of financial support and incentives as other emerging industries. In particular, governments and private investors have the necessary resources to propel OE from a demonstration stage to the commercial stage in less time that it took the wind industry to mature. The following are some of the recommendations that can stimulate the growth of this emerging industry:

- Permitting, licensing, consenting requirements needs to be simplified and coordinated;
- Market driven incentives drive innovation - let the developer take the technical risk;
- As demonstrated from other industries, long-term, fixed feed-in tariff become a major factor in attracting project financing;
- Infrastructure, like grid access, requires a long-term outlook and planning. Need to start now.
- Accept some unknown environmental impact on the sea in perspective of the positive climate impact; the only way to study is often to deploy
- Support baseline studies and follow up programs related to the environmental impact;
- Establish a better balance between funding of research and demonstration projects
- Ocean energy should be assessed in conjunction with other developing technologies to develop hybrid systems;

10 The EU-OEA

The European Ocean Energy Association was formed as an answer to the expressed need for an ocean energy 'umbrella' organization to draw all ocean energy actors together by providing a forum that facilitates the ongoing development and commercialisation efforts in the field of ocean energy.

The European Ocean Energy Association is officially established in the Renewable Energy House in Brussels beginning of 2007 and is a member of EREC.

Acknowledgements

The authors gratefully acknowledge the financial support of European Union FP6 (contract no. 038571 SSA), the Co-ordinated Action on Ocean Energy (CA-OE) (Contract No. 502701) the Marie Curie Action (Contract no. MRTN-CT-2003-505166 WAVETRAIN) and the NEEDS project (EU FP6 contract No 502687).

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