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The potential of wave energy

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1. EXECUTIVE SUMMARY

There is the potential for wave energy to make a contribution to the world’s and Australia’s electricity generation. There are more than 200 different wave energy convertors (WEC) in various stages of development. Research and development of WEC is centred in Europe and North America, with some activity in Australia.

The different types of WEC can be grouped into essentially three classes: point absorbers, attenuators and terminators. Point absorbers are small devices that extract wave energy from all directions. Attenuators are longer than the wavelength and extract wave energy through joints in the WEC. Overtoppers are large WEC that face directly into the wave.

Using actual WEC and Australian resource data the levelised cost of electricity (LCOE) of wave energy in the Australian southern oceans has been calculated to be as low as ~100 $/MWh. There are various ways in which the LCOE of wave energy can be reduced. One of the major components of the cost is operations and maintenance, which does vary depending on the type of technology. Another large cost is anchorage and one of the risks with wave energy is extreme waves. Devices need to be engineered to withstand these waves, whether by being massive or by being inexpensive enough that the financial loss is not too great.

To supply at least 5% of Australia's total grid based electricity demand by 2050 it will be necessary for wave energy to generate 23 TWh. Depending on the technology, this will take up from 100km to 200km of coastline, segmented into a number of regions containing wave farms. This will raise issues, as with any energy technology there are competing-use and environmental concerns that need to be understood and alleviated.

2. INTRODUCTION

Two percent of the world's coastal waters have wave power densities that are great enough for extracting wave energy. This equates to 480 GW of power output or 4200 TWh/yr of electricity generation (Jacobson, 2009). Australia is fortunate to have much of the world's best resource along its Southern coastlines, where for example, the total wave energy crossing the 25 metre depth isobath between Geraldton and the Southern tip of Tasmania is over 1300 TWh/yr which is about five times the total electricity requirements of Australia (Hemer and Griffin, 2010).

The potential to generate large amounts of electricity from wave energy has been known since the 1970's when the first wave energy demonstration devices were deployed. After a long period of stagnation there is renewed interest in wave energy globally due to increasing awareness of climate change and specific country policies focussed on renewables to reduce carbon emissions. Australia's abundant wave energy resource combined with the global effort into wave energy has encouraged CSIRO to investigate the potential for ocean renewable energy in Australia. This report draws in part from a feasibility report that was developed as part of that research in early 2011 (CSIRO, 2011).

There are currently at least 200 different wave energy devices in various stages of development and testing. Of these, about half a dozen have been scaled up and tested at sea with at least some of their test data published. We have used the performance characteristics of three of these, matched to the wave climate along Australia's south coast, as the basis for making assessments of the future market for ocean renewable energy in Australia.

The report was prepared as input to the Garnaut Review Update in a relatively short time frame, and therefore is not intended to be comprehensive.

3. WAVE ENERGY DEVICES

There are a great many techniques for extracting energy from ocean waves and numerous attempts have been made to categorise them. They can be broadly classified as: 'Point Absorbers', Linear Absorbers and Terminators.

3.1 Point Absorbers

The term point absorber refers to devices that incorporate a float that is small compared to the swell wavelength. The float is free to follow the movement of the wave and accept wave energy from any direction. It can be tethered so that it is submerged and moved by the pressure of the wave passing overhead, or it can float on the surface and track or 'heave' with the movement of the sea surface, as shown in Figure 1.

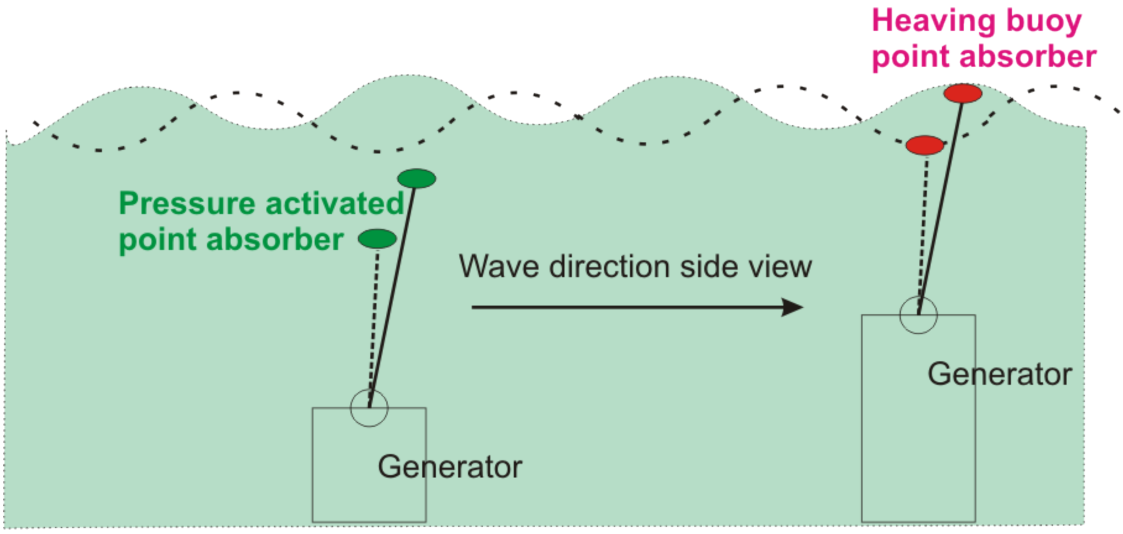

Figure 1: Pressure activated and heaving buoy point absorbers

3.2 Linear absorbers or attenuators

These devices incorporate a float, or a number of floats that are shaped or distributed to be aligned in the direction of wave travel. Their overall length may be large compared to the swell wavelength. However, they are also wavelength dependent. Unlike a point absorber they need to be slack moored so that they can turn to maintain their principal axis normal to the oncoming waves.

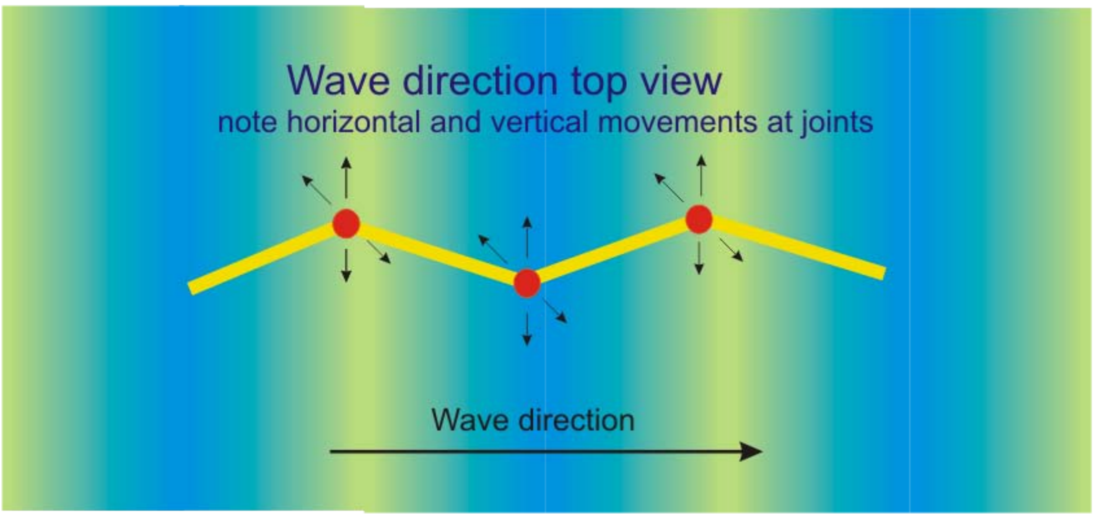

Figure 2: Linear attenuator absorber (adapted from Pelamis schematic (Benson and Orr, 2008))

3.3 Terminators

Terminators are designed to collect energy from waves by directly facing them. They may include passive devices such as a tapered channel to focus energy from a wide section of wave front. Examples of terminators include oscillating water column and overtopping classes of device.

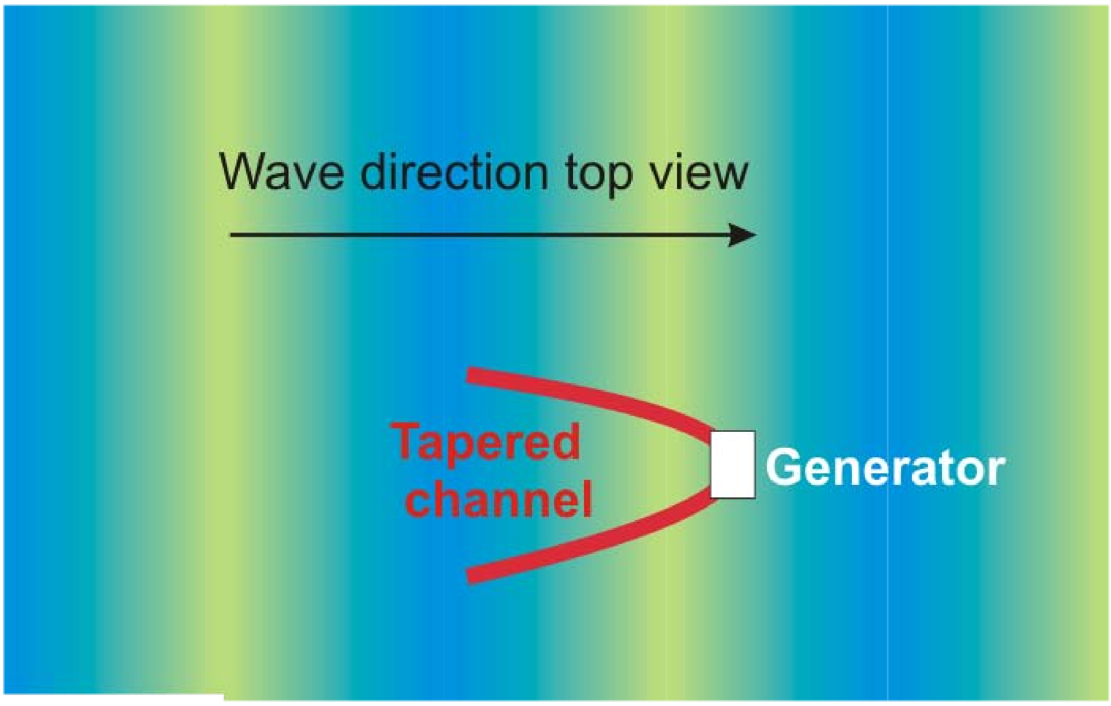

Figure 3: Tapered channel terminator

4. WAVE ENERGY SYSTEMS DEVELOPMENT AND STATUS

The majority of research and development into wave energy systems is in Europe, particularly in the Scandinavian countries and the UK. In addition the UK, Ireland and Portugal are focussed on developing wave energy “hubs” which are sea-placed sites for ocean testing of prototype and commercial scale systems. The hubs are connected to the grid, which allow utilities to become familiar with integrating wave energy systems into the grid. The USA and Canada are also active in research and assessments.

A number of wave farms are under consideration, one of the first was trialled in 2008 in Portugal using three Pelamis devices (attenuator). One of the most recent European wave farm test sites is being constructed off the coast of Sweden which will be powered by Lysekil WEC (point absorbers).

In Australia, research has been ongoing for a decade or more into oscillating water column (OWC) converters. It has accelerated in recent years to include several developed or nearly developed technologies. The two most advanced are the CETO submerged buoy system (point absorber) and the OceanLinx oscillating water column system. The largest ORE project in Australia (recipient of a $66 million grant from the federal government) is the construction of a wave farm off the coast of Victoria by Ocean Power Technologies Australasia Pty Ltd (OPTA), a company with a US-based patent.

There is however a significant lack of experience in public device evaluation and in costing, valuing and managing the power that may be generated by such devices.

5. ECONOMICS OF WAVE ENERGY IN AUSTRALIA

Three devices have publically-available data from trials and they fall into different classifications: terminator, point absorber and linear attenuator. The availability of data on these devices and the Australian resource data has meant that it was possible to determine the current and future projected economics of placing these devices in different locations around Australia. Our calculation of the levelised cost of electricity (LCOE) uses quoted capital costs and operations and maintenance costs for these devices, assumptions and equations from CSIRO's standard electricity plant costing tool (Graham et al., 2009) and other data from CSIRO's Energy Sector Model (ESM) (Hayward et al., 2011).

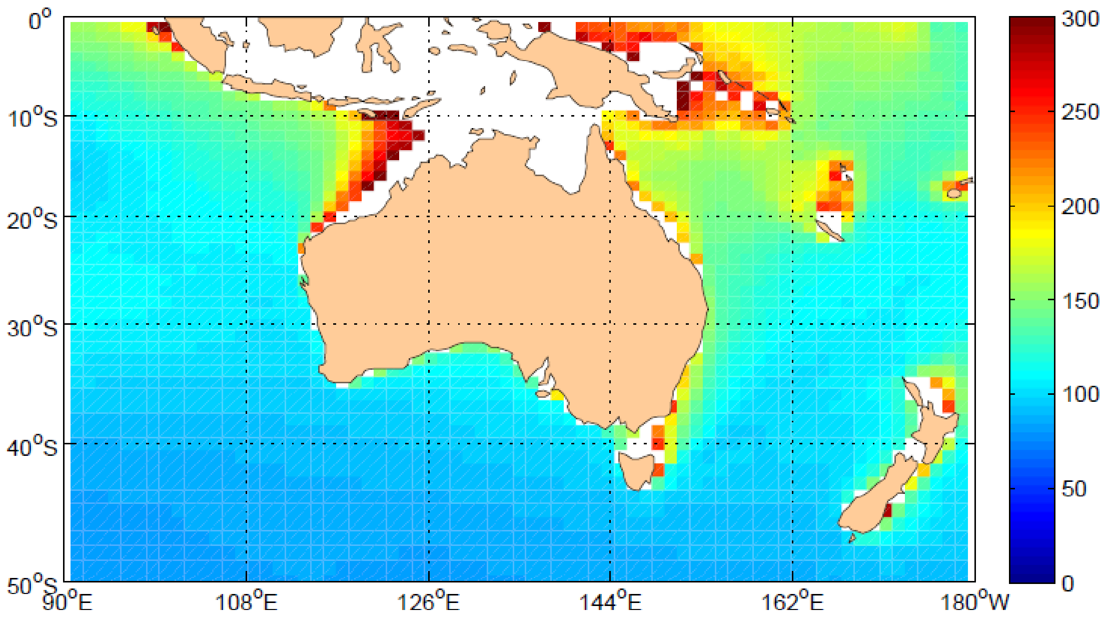

Figure 4: Point absorber levelised cost of electricity (LCOE) per annum map. The units on the scale are $/MWh

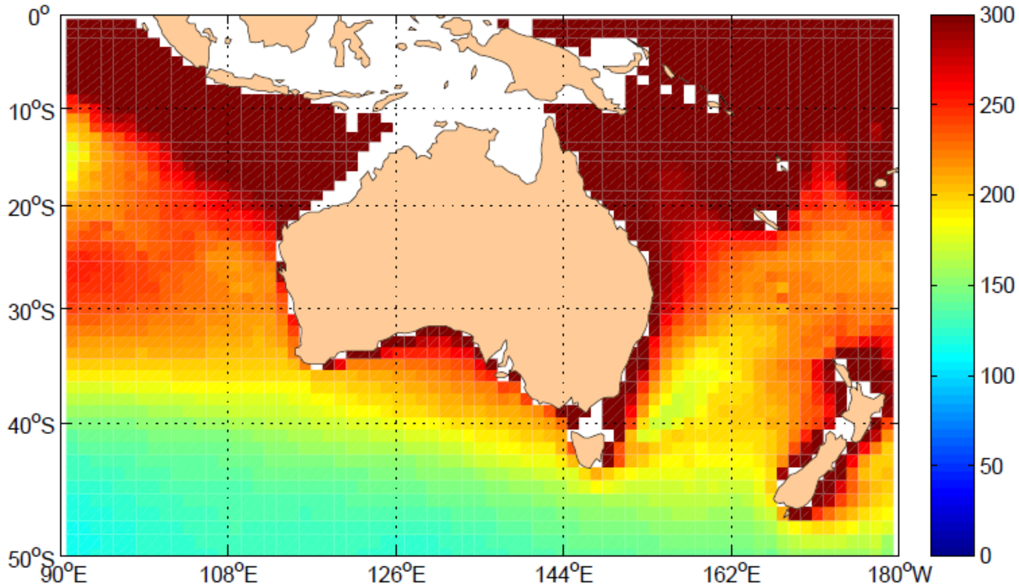

Figure 5: Linear attenuator LCOE per annum map. The units on the scale are $/MWh

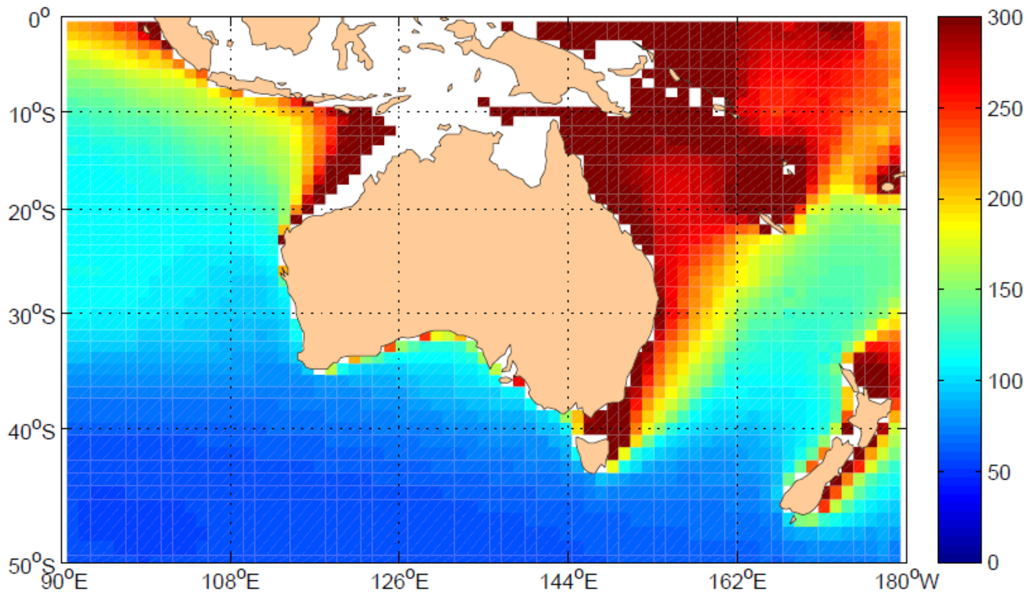

Figure 6: Terminator LCOE per annum map. The units on the scale are $/MWh

The LCOE as shown in Figure 4-Figure 6 reveals that the regions with the lowest LCOE (~100 $/MWh) are indeed along the southern coastline and west coast of Tasmania. However, the linear attenuator has a LCOE higher than this in every region; its lowest is ~200 $/MWh at the southern tip of Tasmania. The linear attenuator data was from a device tuned to European conditions which are quite different to the conditions along the Australian coastline.

The LCOE decreases towards more southern latitudes as the wave power available is much greater. However, the levelised cost offshore reflects electricity generated at that point rather than the cost to transmit it to the coastline. We have included values for the offshore generation of electricity for the case they might supply offshore oil and gas rigs.

6. COMPETING USES AND ENVIRONMENTAL IMPACTS

To supply at least 5% of Australia's total grid based electricity demand by 2050 it will be necessary for wave energy to generate 23 TWh. Depending on the technology, this will take up from 100km to 200km of coastline, segmented into a number of regions. For commercial operation, wave devices will need to be built in “wave farms”; collections of devices in specific areas. The areas can be quite large, for example, a 250MW wave farm designed to extract only 10% of the incoming wave energy could occupy an area of 50km^2. This is an extreme case. Most wave farms will be smaller than this.

Gaining access to these coastal waters for renewable energy development is at least as complex an issue as for land based sites. Considerations include native title and land rights; marine protected areas; fishing, aquaculture and fisheries; oil, gas and mineral development; shipping; national security; and tourism, recreation and visual amenity.

In addition, the environmental impact of wave energy devices and the extraction of wave energy are not well understood. For example, wave calming may have a positive or negative effect by offering protection from coastal erosion and/or changes to local current flows. The devices themselves may provide artificial reefs to the benefit of local marine creatures; on the other hand they may under some circumstances promote the invasion of foreign species.

7. HOW TO REDUCE COST OF WAVE ENERGY?

CSIRO financial analysis found that wave energy becomes economic when capital cost and operations and maintenance (O&M) costs are reduced (CSIRO, 2011), reflecting their high contribution to LCOE. A large part of the capital cost besides the cost of the device itself is anchorage/mooring as shown in Figure 7, which varies by device.

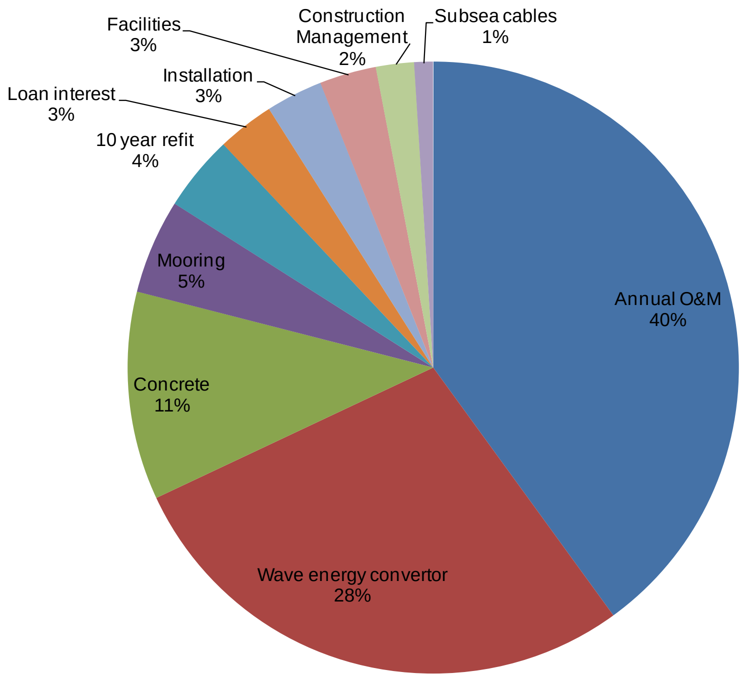

Figure 7: Annual levelised cost of electricity breakdown (Data from R,Bedard (R.Bedard, 2005))

7.1 Anchorage (Mooring and concrete)

The mooring system is a non-trivial key to the wave farm performance and security of investment. It is unlikely that there is any precedent for moorings for a wave farm large enough to deliver hundreds of megawatts. Consider two types of farm; the first in which the number of devices and therefore anchorage points is minimised, the second in which the size of devices is reduced to lower anchorage stresses.

A wave farm capable of delivering 200MW, and using the largest converters available, rated at 7MW to 11MW, would require one hundred or more devices weighing 33,000 tonnes. Terminator devices would be oriented to present a maximum profile to the wave front so as to gather most energy. The stresses on anchorage in a storm may well be unprecedented and require quite new design techniques.

At the other extreme a wave farm capable of delivering 200MW might comprise 5000 point absorber devices typically sized as a 3m diameter wave buoy and rated at 100kW. Such a farm would require innovative system and component design, both to minimise handling during operations and maintenance and to retain the integrity of connection to the seafloor mini-grid.

Linear absorbers, each rated at 750kW, provide a useful compromise between these extremes and they minimise the anchorage stresses by being oriented in the wave direction rather than across the wave front. Further their dimensions are of necessity comparable with wave length being typically three meters diameter by 150 meters length. Devices of this size and capacity would require about a factor of five fewer anchorage points than point absorbers to make up a wave farm of a given capacity.

Figure 8: Wave Dragon (overtopper) prototype with an overtopping wave © Wavedragon (http://www.wavedragon.net, 2010)

7.2 Extreme events

Extreme event protection is another cost impost on wave energy devices that will vary from region to region. Devices need to be protected against “freak waves” which can occur once during the lifetime of the device. Strategies for coping with these events include providing protection mechanisms such as automated lowering of expensive components to the sea floor when extreme conditions are forecast, building the device and farm seaworthy enough to cope, shutting down devices so they are not operating or building expendable devices which are low cost enough to be paid back between these events. There will be issues with anchorage of large, multiple devices, particularly in designing for extreme sea conditions.

7.3 Operations and maintenance

The operations and maintenance costs (O&M) will vary by device type, and there may be a trade-off to make between capital and O&M costs. For instance, for very large and expensive floating platform devices with few parts underwater (such as an overtopper), O&M costs may be lower as the personnel can work directly on the platform and for a MW size farm there will be fewer units to service compared with a farm consisting of lots of smaller, less expensive devices (such as a point absorber).

The location of the wave farms and ease of access will also affect O&M costs and this will vary from region to region. Some of the locations for wave farms in Australia have

Native Title. It may be possible to develop co-investment in wave farms in these areas which are beneficial to the indigenous land-holders (notwithstanding any environmental or competing use issues), resulting in employment opportunities, particularly in operations and maintenance. This could be along the lines of the “Bushlight” program which is promoting solar energy in remote communities (Davison, 2010).

Figure 9: Wave Dragon (overtopper) prototype showing tapered channel and ramp © Wavedragon (http://www.wavedragon.net, 2010)

8. CONCLUSION

Current investigations into the feasibility of wave power suggest that wave energy is a technology which does have the potential to be economically viable in Australia. For wave energy to make this transition will require some improvements in the capital and operations and maintenance costs. There are a wide variety of designs being explored in order to reach this goal. There also appears to be the opportunity to find the right balance between size of equipment, anchorage expenditure and number of units per wave farm.

Achieving technological maturity will also require careful planning to ensure wave farms are located for optimal wave energy conversion, minimal environmental impact and where possible providing useful synergies with environmental management and with other users of ocean resources.

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