M. Ponniah[1], Mr. P.
Mahmood[2], Mr. B.
[1] Student, School of Engineering, Unitec Institute of Technology, Auckland.
[2] Senior ASM / Programme Leader, Engineering Discipline, School of Built Environment, Unitec New Zealand, Auckland. Tel: +64-9-8154321, Fax: +64-9-8156795, Email: mookseyp@wdc.govt.nz, bmahmood@unitec.ac.nz

FEASIBILITY STUDY OF HARNESSING ON-SHORE WAVE ENERGY AT WAIPAPA, NEW ZEALAND: A CASE STUDY

ABSTRACT

The need for renewable energy is becoming more essential in today's energy world market. This is because the world needs a source of energy that will last longer than our limited supply of fossil fuels. Pollution is also an issue; many environmentalist groups are pushing towards more "Earth friendly" sources of energy. The world will have to come up with new ideas and methods for creating energy or civilization will come to a screeching halt around the year 2040.There are three main solutions to the energy crisis by renewable energies such as solar power, wind power, and water power. Climate change and fuel security are two key issues that are beginning to drive the current energy sector.

Wave energy is emerging as a key technology with the potential to make a large contribution, with minimal environmental impact. Oceans cover three quarters of the earth's surface and represent a vast natural energy resource in the form of waves. It has been estimated by the Marine Foresight Panel that if less than 0.1 % of the renewable energy available within the oceans could be converted into electricity it would satisfy the present world demand for energy more than five times over. The main aim of this study was to determine whether Waipapa (New Zealand) has a high potential to harness energy from the onshore sea wave method and to determine the amount of power that can be generated from the Waipapa onshore wave energy model. More research in this area can cut down the cost/kWh produced. This study also reviews the principles and methods currently used to harness onshore sea wave energy and summarises the potential of harnessing onshore wave energy at Waipapa, New Zealand. The data relevant to wave height and wave period at Waipapa and other New Zealand coastlines was collected from NIWA (National Institute of Water and Atmosphere). The amount of power that can be harnessed from an onshore sea wave energy model at Waipapa was determined using the wave power equation. This study showed that if the current existing Wavegen's Company onshore wave technology is installed at Waipapa, then 3,693.4 megawatts (MWh) of power can be generated annually.

1. INTRODUCTION

The two key issues that are beginning to drive the current energy sector are climate change and fuel security. The need for renewable energy is becoming more essential in today's energy world market. Oceans cover three quarters of the earth's surface and represent a vast natural energy resource in the form of waves. The World Energy Council estimates that 2 Terawatt (TW) of energy could be harvested from the world's oceans, the equivalent of twice the world's electricity production (The Resource, 1991).

Ocean waves are created by winds on the surface of the sea and contain both kinetic and potential energy. Energy is transmitted to the ocean from the winds through friction between the air and surface of the seas across which they blow. As winds derive energy from solar gradients, wave energy is an indirect by-product of solar energy. Contrary to popular belief, the water in a wave does not actually travel but merely oscillates while the energy of the wave is translated across the surface of the ocean (EECA, 1996).

The best locations around the world for harnessing wave energy are along the west coasts of Europe, USA, the coasts of New Zealand and the coasts of Japan (Alternative Energy Sources, 1996). New Zealand with its long coastline and large surrounding areas of open sea has a large potential resource. The wave energy around the New Zealand coastline is probably 30kW/m or more in exposed places, which is a good quality resource (EECA, 1996). Wave energy can be harnessed by using two different methods, the onshore method and the offshore method. **Shoreline devices** (onshore type) have the advantage of relatively easier maintenance and installation and do not require deep-water moorings and long underwater electrical cables. The only draw- back is the wave height, which is a key factor in harnessing the energy from the wave. The common shoreline method is the oscillating water column (OWC). The **offshore devices** are situated in deeper water, with typical depths of more than 40m. Several different designs having been deployed worldwide. (Wave Energy-The Technology-Offshore Devices, 2000).

The offshore devices are very expensive to construct and maintain. It is also against New Zealand coastal policy. The policy covers the national priorities for the preservation of the natural character of the Coastal Environment such as the integrity, functioning and resilience of the coastal environment. This will be protected as expressed in terms of dynamic processes, natural movement of biota, water and air, natural biodiversity and the intrinsic value of the ecosystems, which also values the protection of characteristics significant to the tangata whenua (RMA, 1991). It has restrictions to erect, reconstruct, place, alter, extend, remove, or demolish any structure or any part of a structure that is fixed in, on, under or over any foreshore or seabed (RMA, 1991).

"It has been estimated that if less than 0.1% of the renewable energy available within the oceans could be converted into electricity it would satisfy the present world demand for energy more than five times over" (The Resource, 1991). Wave energy, like many other renewable energy technologies, has high capital costs. However, shorelines devices are expected to have low maintenance than those for offshore devices. The high capital costs arise from need to build and deploy large structures to capture significant amounts of energy (Boyle, 1996). Some studies (as reported by EECA, 1996) have been done in the past on the cost comparison between wave energy and other renewable energies. However these studies did not favour the wave energy option in New Zealand due to high costs. Recent developments in the prototype have proven that costs can be reduced significantly, showing that wave energy can be economically viable (Energetech, 2000). During 1996 researchers predicted that the cost involved in producing energy from sea waves prototype is 50cents/kWh (EECA, 1996) but since then many developments in these prototypes have brought the cost down to 15 cents/kWh (Deniss, 1998).

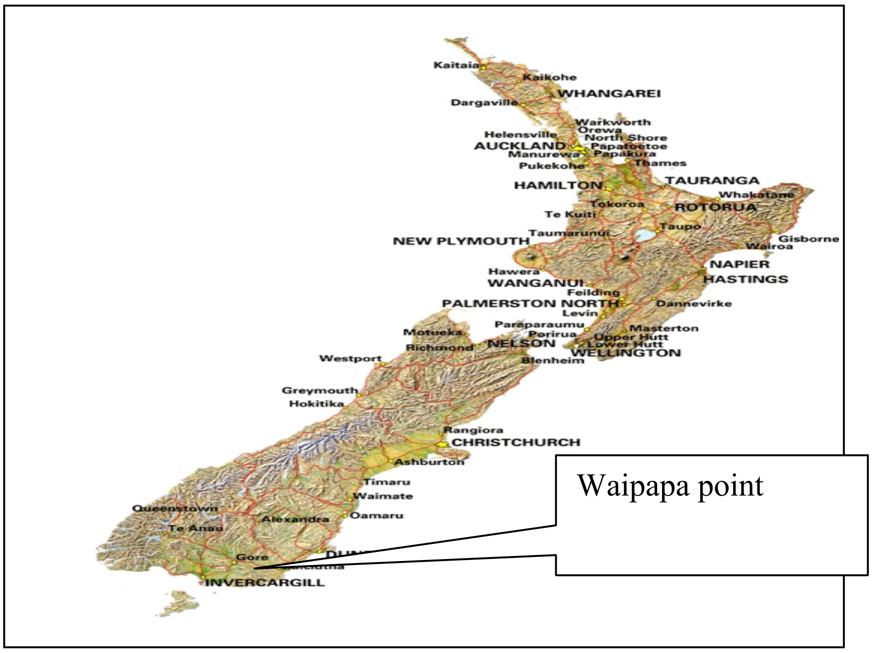


Figure 1. . Map of New Zealand

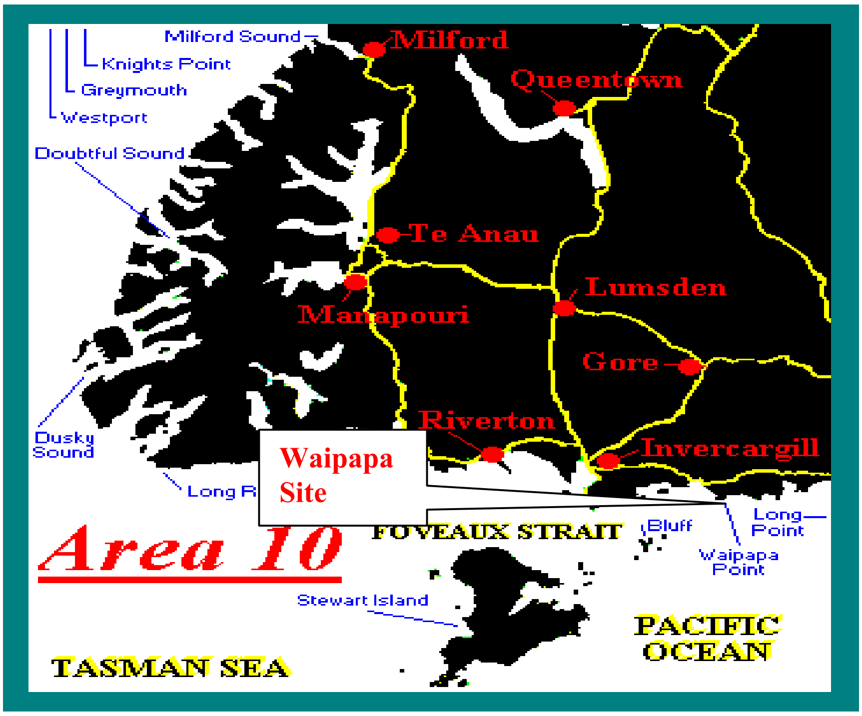


Figure 2. Location of Waipapa in South Island, New Zealand

The main aim of this project was to determine whether Waipapa (New Zealand) has a high potential to harness energy from the onshore sea wave method and also to determine the amount of power that can be generated from the Waipapa onshore wave energy model. The specific objectives of this study were to review the principles and methods currently used to harness onshore sea wave energy and to determine the amount of power that can be harnessed from an onshore sea wave energy model at

Waipapa. In this study, the onshore device method was used to evaluate the feasibility study of harnessing energy from Sea Wave at Waipapa in New Zealand. Waipapa is located along the South Coast of the South Island of New Zealand, which is very close to Stewart Island and near Invercargill (figure 1). It has favourable conditions to harness energy from sea waves along the coast (figure 2).

2. METHODOLOGY

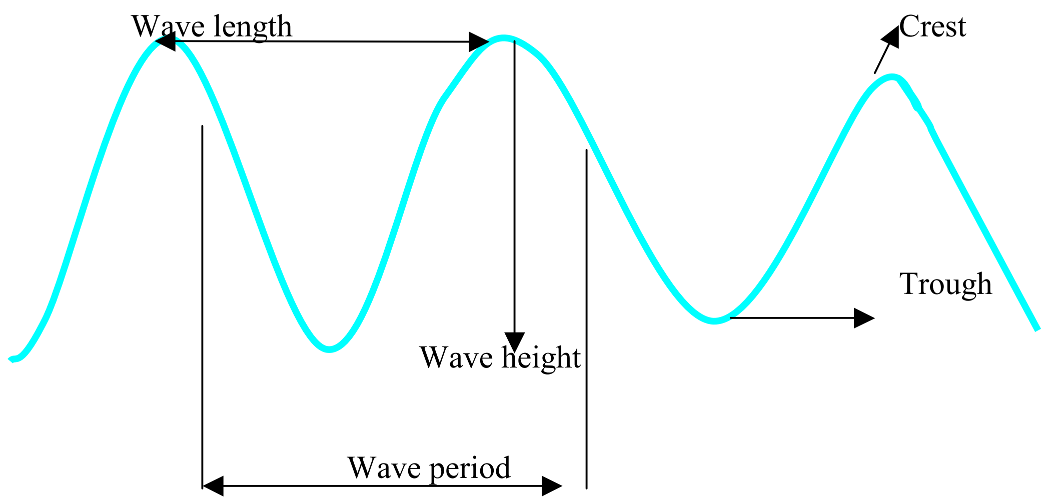
There are different companies around the world producing energy successfully from onshore sea wave energy models (shorelines devices). Companies such as Wavegen (UK based) and Energetech (Australia based) are among the more successful in developing onshore wave energy devices. Wavegen's Limpet model (which is a United Kingdom based) and Energetech (which is Australian based) use the same principle as the "Oscillating column principle (up and down movement of sea waves).

2.1 Principles and Methods of Harnessing Wave Energy On Shore

Based on the wave energy study literature, the two onshore prototypes that were considered for this study are Wavegen's oscillating water column and Energetech's oscillating water column. Wavegen is the current and only onshore wave prototype, which delivers power to the United Kingdom's national Grid. Energetech is still in its construction phase. The Japanese Pendulor uses the wave, push - pull hydraulic system, which is a small onshore wave device (Thorpe, 1999). Evaluation for the most suitable prototype for Waipapa was compared for turbine efficiency, cost, environmental impact and possibility of power to the national grid. The details of the physical principles behind the wave energy and two methods of harnessing wave energy onshore are given below.

2.1.1 Physical principles of wave energy

Ocean waves are generated by wind passing over stretches of water. The interaction between the wind and the surface of the sea involves three main processes.



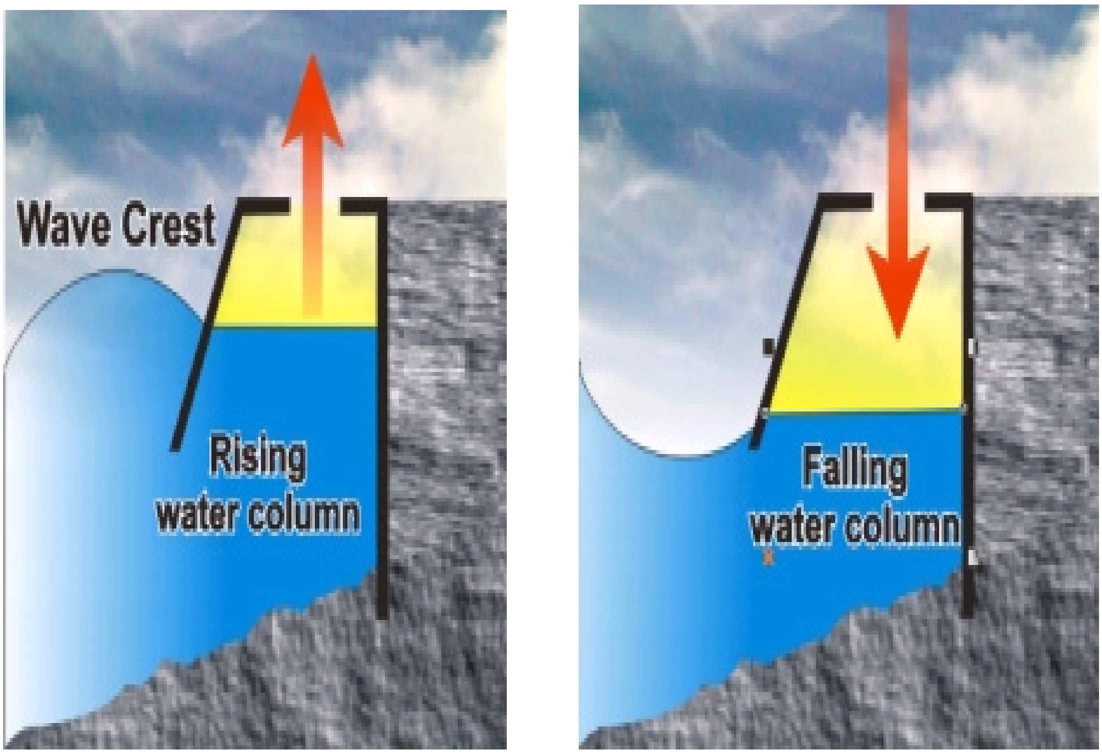
(Source: Boyle, 1996)

Figure 3. Wave principle

These processes include: initially air flowing over the sea exerts a tangential stress on the water surface resulting in the formation and growth of waves; turbulent airflows close to the water surface create rapidly varying shear stresses and pressure fluctuations. Where these oscillations are in phase with existing waves, further wave development occurs; and finally when waves have reached a certain size, the wind exerts a stronger force on the upwind face of the wave, causing additional wave growth (Boyle, 1996).

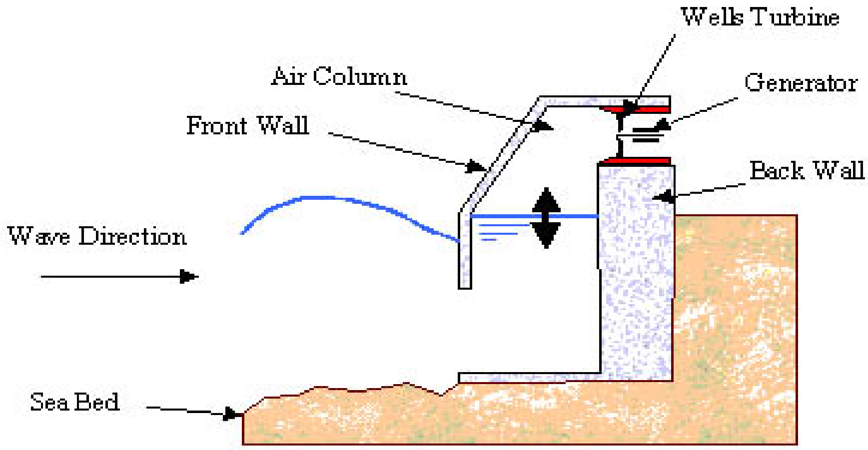
2.1.2 Methods of Harnessing Wave Energy

WAVEGEN - LIMPET (Land Installed Marine Powered Energy Transformer) 500 (0.5MW) MODULE (The Collector and Oscillating Water Column – OWC) - Wavegen's device is comprised of two basic elements: a collector to capture the wave energy and a turbo generator to transform the wave power into electricity (Thorpe, 1996). The wave energy collector, used in Wavegen's Limpet model has the form of a partially submerged shell into which seawater is free to enter and leave. As the water enters or leaves, the level of water in the chamber rises or falls in sympathy. A column of air, contained above the water level, is alternately compressed and decompressed by this movement to generate an alternating stream of high velocity air in an exit blowhole (figure 4). If this air stream is allowed to flow to and from the atmosphere via a pneumatic turbine, energy can be extracted from the system and used to generate electricity (Wavegen.n.d)



(Source: Wavegen.n.d)

Figure 4. Power take off – The Turbo Generator.



(Source: Thorpe, 1999)

Figure 5. OWC Gully Device.

The Limpet is a shoreline- based oscillating water column (OWC) model, which has been developed by the Queen's University of Belfast and Wavegen Company (Wavegen.n.d). An OWC consists of a partially submerged, hollow structure, which opens to the sea below the water line (figure 5). This structure encloses a column of air on top of a column of water. As waves impinge upon the device, they cause the water column to rise and fall, which alternatively compresses and depressurises the air column. If this trapped air is allowed to flow to and from the atmosphere via a turbine, energy can be extracted from the system and used to generate electricity. Energy is usually extracted from the reversing airflow by Wells' turbines, which have the property of rotating in the same direction regardless of the direction to the airflow (Wavegen.n.d). Wells turbines are used to power electricity generators. They have the unique property of turning in the same direction regardless of which way the air is flowing across the turbine blades. Thus, the turbines continue turning on both the rise and fall of wave levels within the collector chamber. The turbine drives the generator, which converts this power into electricity (Wavegen.n.d).

Initial capital cost of the wave energy structure is (1.6 million US) 3.6 million NZ Dollars per MW installed. Civil structure consumes almost half of the capital cost. Cost to produce one kilowatt/hour is between 8 - 16 cents (NZ). The annual operation and maintenance costs were estimated to be approximately 4% of the capital (Thorpe, 1999).

ENERGETECH - Energetech, which is an Australian based wave energy company, uses the same principle (Oscillating Water Column Principle) as the United Kingdom based company - Wavegen. However this device is different. The figure below (figure 6) is a computer-generated image, and shows the Energetech onshore 500 KW wave device. Even though Energetech is more efficient than LIMPET, it has not been used to produce power commercially. The Energetech wave energy system is a shoreline device suitable where there is fairly deep water up the coast, such as on harbour breakwaters and rocky headlands and cliffs (Energetech, 2000).

(Source: Energetech, 2000)

Figure 6. Artistic impression of Energetech onshore wave energy

2.1.3 Power Generation from an Onshore Sea Wave Energy Model at Waipapa

The average wave heights and average wave period were the essential data (as obtained from NIWA) required to evaluate the potential of the Waipapa site to produce power from wave energy. Hence, the monthly averages of wave height and wave period of the past five-years (1989-1993) were used to estimate the potential power at Waipapa.

In nature, waves are irregular and can be described by statistical models. If the wave conditions are measured, over 20 minutes for example, the mean wave height (Hm) and the significant wave height (Hs) can be calculated. The significant wave height is defined as the average of the highest 33% of the waves (*Indian Wave Energy, n.d)*). Equation 1 was used to calculate the wave power.

$$P = 0.5H^2STz$$ *(Equation 1 – Source: Indian Wave Energy, n.d)*

Where (P) is the power (kilowatts per metre width of wave front), (H) is the wave height (m), (S) is the wave period (seconds), and (Tz) is the zero crossing period. The data relevant to monthly average wave height and the corresponding average monthly wave period was used in equation 1 to estimate the total power that can be harnessed per metre of the accesses capture chamber width. The onshore wave device turbine efficiency (i.e. Wavegen's turbine efficiency) was applied here to estimate the total wave power and the accesses capture chamber width which were playing a major role in the final outcome i.e. wave power.

3. RESULTS AND DISCUSSIONS

Oscillating water column - The review of the different methods of harnessing wave energy showed that the Oscillating Water Column (OWC) is the first and only method that has been used to produce power from sea waves at onshore points commercially with the help of Wavegen Company. Hence, OWC principle was chosen in this study.

At this stage the other method such as the push and pull hydraulic system is still at the investigation stage.

Waipapa monthly wave heights (1989-1993) – The results of the study showed that the monthly average wave height at Waipapa varied between 1.8 and 4.2 m. The results also showed that the average wave height during the winter is different to the summer, which could be due to the seasonal changes that cause a change in wind direction towards the coastal area. This was one of the main reasons for the annual changes in the average wave height. Since the average monthly wave height for the months, March to October received a favourable wave height to produce some significant power and hence it could supply power during the winter where significant amount of power are consumed. The graphs of the monthly average wave height (1989-1993) are not presented here for brevity reasons.

It was interesting to note that at Waipapa site there was a mixture of high and low average wave heights due to La Nina (warmer year) and El Nino (strong and more frequent winds from west) affects during 1990 and 1991. Thus, low average wave heights occurred during 1990 and 1991 (i.e. 2.78 and 2.76 m, respectively) as compared to other years.

Power generation from an onshore sea wave energy model at Waipapa –The potential annual power that can be generated from the onshore sea wave prototype at the Waipapa site is shown in figure 8. The results showed that on average per annum, 3286, 3582, 3797, 3726, and 4070 MWh of power can be generated at the Waipapa site during 1989, 1990, 1991, 1992, and 1993, respectively (figure 7). This could be a good source of electricity for the national grid.

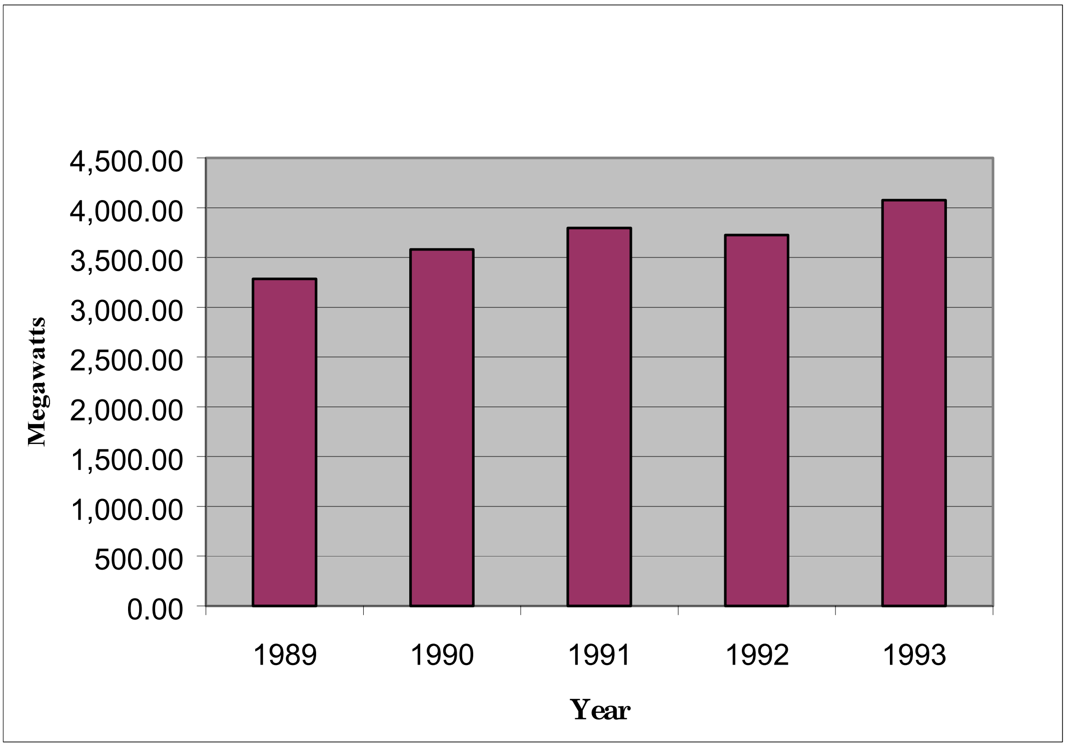


Figure 7. Total annual wave power at Waipapa from 1989 to1993.

Figure 7 showed that 1993 produces more power, which could be due to the high average wave height during winter (due to El Nino which produces more strong southerly winds). It is known that Waipapa tends to experience stronger southerly winds that cause high average wave height, which has more potential to produce power. Results showed that the high average winter wave period heights almost nullifying the low summer average wave height and gave almost on average 3,693 MWh over 5 years. That could have supplied power for 369 houses annually. Hence, this is a significant amount of power that can be harnessed from an onshore sea wave prototype at Waipapa site. Since the power produced by the onshore wave prototype during the winter would be much higher and it can contribute to the high demand of power during this period.

Most suitable prototype for Waipapa - The evaluation of the most suitable prototype, for Waipapa site, was based on the comparison of turbine efficiency, cost benefit and environmental consequence. Based on the findings of the literature review, Wavegen's Limpet prototype was considered for the Waipapa site due to its high turbine efficiency as compared to others (table 1) and because it was the first and only commercial onshore wave energy prototype.

Wave Company	**Wavegen company**	**Energetech company**	**Japanese Pendulor**
1. Turbine efficiency (%)	65%	40%	> 30 %
2. Cost involved to produce one kWh (cents)	10 cents	15 cents	N/A
3. Environmental issues	Very minimum	Not known yet	N/A
4. Current power producer to the national Grid	Yes	NO	NO

Table 1. Comparison of onshore wave prototypes. *(Source: Thorpe, 1999)*

4. GENERAL DISCUSSION

Wave energy is a promising form of renewable energy, and is in the initial phase of establishment in the commercial market. Renewable energy resources are energy sources that can be tapped at a rate that allows them to be replenished, through natural process, so that utilisation is balanced by regeneration. There is always a demand for the future energy opportunities. Wave energy concept hasn't been looked at closely in terms of development, cost, and environmental factors. Unlike wind and solar power, power from the ocean waves continues to be produced around the clock, whereas wind velocity tends to die in the morning and at night, and solar energy is only available during the day in areas with relatively low cloud cover. Among the New Zealand coastlines, Waipapa receives a favourable monthly average wave height; so it can produce a significant amount of power. This wave power can contribute to satisfying the high winter power demand of consumers. The national grid runs very close to Invercargill, which is located near the Waipapa site, therefore the power produced at Waipapa can contribute to the national grid. Results showed that annually Waipapa can produce roughly 3,693.4 MWh, which can supply power to 369 three bedroom houses (in New Zealand), which is very similar to Wavegen's power production. Wavegen supplies power to 400 houses at Hebridean Island of Islay, Scotland (Edie weekly, 2000). Hence Wavegen's Oscillating Water Column Principle was a suitable prototype for the Waipapa site, based on its turbine efficiency, cost and environmental consequences. All forms of electricity generation have an impact upon the environment but it is generally perceived that wave power is **sustainable** and less environmentally degrading than some other forms of power generation, especially in relation to atmospheric emissions. Many of the potential impacts would be site specific and therefore cannot be evaluated until a location for the wave energy scheme is chosen.

Type of Renewable Energy	**Cost to produce one kWh**
Water (small hydro)	5 - 10 c/kWh
Wind farms on best sites	6 - 08 c/kWh
Solar (solar thermal for water heating)	13 – 16 c/kWh
Wave (Onshore wave prototype)	8 – 16 c/kWh

Table 2. Renewable energy cost comparison. *(Source: EECA, 1986)*

There has been huge improvement in the costs of wave power generation. It was predicted by the EECA in 1996 that the cost of wave power was 50 c/kWh, but since then there has been a huge improvement in the onshore wave prototype. The recent cost of wave power shows how it has been improved (table 2). Even when wind energy came on to the market, the price of the wind power was around 14 c/kWh (Thorpe, 1999). Hence, there is a chance to bring down the cost of wave energy by improving the prototype. To support this statement Deniss and Langston quotes are provided here *"Moderately good wave climates should produce power using first generation systems at a cost of around 10 cents US per kWh, and ideal sites at a cost around 5 cents. Over time, on moderately good sites, with capital cost savings from second generation designs, we can see the technology regularly delivering electricity at around 4 cents US kWh"* (Deniss, 2002). *"The price of wave power could come down as the technology improves"* (Langston, 2001).

The following key factors need to be considered while installing the Wavegen onshore model/device to produce electricity:

1. It becomes difficult to generate power, if the wave height is below 0.5 m.
2. The water depth in front of the device should be greater than about 5 m.

3. A device should not be located in a shadow or in shallow water. Ideally, it should be close to road and grid connection.
4. It is possible to attract more power at a site by changing the arrangement around the opening to the capture chamber.
5. Some days it may produce almost nothing, while other days it will be producing at its peak (Personal Communication with Langston, 2000).

Implementation of a project of this nature along the New Zealand coast will require resource consent. In order to achieve the resource consent, cultural, social and environmental issues should be clarified. Implementation of a wave project along the Waipapa coast will bring employment for the local community. It may have an impact on the local people's life style and recreation activities. Consultation with the local iwi will clarify whether it has a cultural impact on them. An Adverse Effect of the Environmental (AEE) will be required to seek resource consent for this type of project.

5. SUMMARY AND CONCLUSIONS

The kinetic energy in waves is large, and New Zealand with its long coastline and large surrounding areas of open sea, has a large potential wave energy resource. Seasonal variations match energy demands well, in the winter when wave generation is producing at maximum output there is a strong winter demand for energy. Oscillating Water Column Principle is the most highly developed and widely recognised principle and is the first to produce successful power commercially. Waipapa can produce annually 3,693 MWh of estimated power from the onshore wave prototype with the help of the Oscillating Water Column Principle. Wavegen's Limpet prototype was the most suitable one for the Waipapa site in terms of turbine efficiency, costs, potential power to the local national grid and environmental benefits. Energetech's prototype is still at the construction phase. It promises to be more efficient in terms of power produced, but at this stage, it was considered premature to pick the model for Waipapa.

At this stage, environmental impacts due to the onshore wave energy device are minimal, but it can have impact on shoreline recreation. The siting of shoreline plants would also need to be on exposed rocky coasts below the high water mark, and such land may be regarded as environmentally, aesthetically and culturally valuable.

The wave energy produced is sustainable (in a sense that maximum use of water recourse and least impact on the environment), clean and non-polluting. Under normal operating conditions, there are no chemical emissions. The cost involved in producing one kilowatt is now around 14 c/kWh. That can be minimised by improving the onshore wave prototype. The power production at the Waipapa site can supply power for nearly 369- three bedroom houses or alternatively it could supply power for 185 small industries.

6. RECOMMENDATIONS

1. The main barriers to wave energy that have emerged from this study are high costs, lack of knowledge and misinformation, hence there should be more study done in the wave energy projects.

2. Misinformation and lack of understanding of wave technology by industry, government and the general public have often slowed the pace of wave energy development. The energy industry seems to be largely indifferent to the potential of wave technology in the generation of electricity due to the low cost options provided by hydro, thermal energy, and other renewable energies. Hence organisation, researchers, and governments should show the initiative towards wave energy options.
3. The costs of possible wave power plants on the New Zealand coast should be more accurately estimated with the help of overseas wave energy companies. A more ambitious project would be to design and build a New Zealand prototype to get an even better idea of New Zealand conditions.
4. There is a need for further detailed research into wave energy in order to study and understand the detailed structure to build one prototype for New Zealand conditions and about the weather pattern, which has been the main factor to produce wave power.

7. REFERENCES

1) "Alternative Energy Sources- Wave Energy", (schwaben.de), Available: http://www.schwaben.de/home/kepi/waves1.html (Accessed: 2000, June 27).

2) Boyle. G, (1996), "Renewable Energy, Power for a Sustainable Future", Oxford University Press, Oxford, United Kingdom

3) Deniss. T, (1998), "Renewable Energy catches more waves", (isr.gov.au), Available: http://www.industry.gov.au/archive/pubs/aen/aen7/7waves.html (Accessed: 2002, May 05).

4) Energetech, 1990, "The Company" Available: http://www.energetech.com.au (Accessed: 2001, November 28)

5) Edie weekly summaries, 2000, World's first commercial wave power station activated in Scotland Available: http://www.edie.net/news/archive/3492.html (Accessed: 2002, November 10)

6) EECA, 1996, "New and Emerging Renewable Energy Opportunities in New Zealand", Energy Efficiency and Conservation Authority and Centre for Advanced Engineering, University of Canterbury, New Zealand

7) Indian Institute of Technology," Indian wave energy", Available: http://www.niot.res.in/m1/mm1.html (Accessed: 2002, April 10)

8) “New Zealand map”
Available: http://www.govt.nz/aboutnz/nzmap.php3
(Accessed: 2002, May 20)

9) Personal Communication, 2000, Information on these issues was obtained through email consultation (20-05-2000) with Mr. D. Langston, Business Development Manager of the Wavegen’s Company, UK.

10) Resource Management Act, 1991 “New Zealand Coastal Policy Statement 1994”

11) “The Resource”n.d, (Wavegen.co.uk),
Available: http://www.wavegen.co.uk/resource.html
(Accessed: 2000, September 12).

12) “Technology”n.d, (Wavegen.co.uk),
Available: http://www.wavegen.co.uk/resource.html
(Accessed: 2000, September 12).

13) T W Thorpe, (1999), “A Brief Review of Wave Energy”
Available: http://www.dti.gov.uk/renewable/pdf/r120w97.pdf
(Accessed: 2002, February 11)

14) “Wave Energy- The technology-Shoreline Devices”, (europa.eu.int),
Available:
http://europa.eu.int/comm/energy_transport/atlas/htmlu/wavint.html
(Accessed: 2000, June 28).

15) “Wave Energy- The technology- Offshore Devices”, (europa.eu.int),
Available:
http://europa.eu.int/comm/energy_transport/atlas/htmlu/waveover.html
(Accessed: 2000, June 28).

16) “Waipapa map”
Available: http://www.marrserv.com/dinza010.htm
(Accessed: 2002, May 20)