New Zealand's Wave and Tidal Energy Resources and their Timetable for Development

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Abstract

New Zealand is presently in the early stages of realizing its signficant marine energy resources. The potential is impressively large: this paper addresses likely developments to harness this potential. Open-ocean wave and tidal current resource have been modelled using hindcast techniques, resulting in an integrated suite of maps at national regional scales. Specific prospective sites have been assessed by the simulation of 3 generic wave and 2 generic tidal current technologies at these sites. 10-year power generation hindcasts enable assessment of the viability of specific sites and the potential timetable and contribution of marine energy deployments to national energy supply.

1. INTRODUCTION

The study on which this paper is based was intended to assess likely future developments of marine energy in New Zealand [1]. The study reviewed current wave and tidal current technologies and regulatory and financial mechanisms to promote marine energy, before undertaking an integrated modelling of the national open-ocean wave and tidal current resources. Six wave sites were evaluated by modelling three generic wave devices at each site. In the same way six tidal current sites were modelled with two generic device arrays at each site. Annual electricity production was assessed at each site.

2. DEVELOPMENT OF MARINE ENERGY TECHNOLOGIES

2.1. Introduction

Potentially extractable energy from the oceans occurs in a number of forms, although none has yet achieved widespread commercial viability. Only some of these energy sources will be commercially extractable in New Zealand, because resource and environmental considerations will have an impact. There are seven principal marine energy sources, from which energy could be harnessed and at least five different products are under consideration (Table 1).

Table 1: Marine Energy Sources and Products

Energy Source	Conversion Technology	Products
Waves		Electricity Hydrogen Biofuels Heat Potable water (& combinations of above)
Open ocean swells	Point absorbers; Attenuators	
Breaking waves	Oscillating water columns (OWCs); Overtopping devices	
Tides		
Tidal rise and fall	Barrages; Impoundments	
Tidal/ocean currents	Turbines; Reciprocating devices	
Heat	Ocean Thermal Energy Conversion (OTEC)	
Osmotic power	Reverse osmosis	
Marine biomass	Farming and harvesting	
Offshore winds	Offshore wind turbines	

A generic classification of marine energy devices was developed. Heat, osmotic power and marine biomass were not considered in this study because either the technologies to extract energy from the sources is currently very immature, the resource is limited or it is difficult to access. Offshore wind farms may be developed, particularly if floating wind turbines become viable. However, the most likely marine sources to be developed are wave and tidal current energy.

Power Projects Limited (PPL) has identified at least 70 tidal current devices under development and at least 53 wave devices but these are probably under-estimates. The numbers are a function of the different ways in which energy can be extracted from waves and tidal currents and the levels of disparate effort going into device development. In due course, convergence on economically viable designs is likely to occur, as happened with wind technologies.

2.2. Wave Technologies

Wave energy can be separated into two extractable forms: open ocean swells and breaking waves. Open ocean swells result from the aggregated effects of wind currents blowing across the surface of the ocean, the swells arising from constructive interference of waves resolving into larger waves with bigger amplitudes and longer wavelengths. Generic devices, which can extract energy from swells, are called 'attenuator' or 'point absorber' devices. There are also other generic devices, which extract energy from the surge component of waves or from pressure transients, associated with passing waves.

Breaking waves result from the incidence of these ocean swells on the seabed, initially as they approach the coast and eventually on the beach or cliffs. The generic class of devices, which extract energy from breaking waves are called 'terminator' devices, of which two common sub-classes are 'oscillating water column' devices and 'overtopping' devices.

2.3. Tidal/ Current Technologies

Tidal current energy devices can be classified by the source of tidal energy to be harnessed and the physical form of the device, i.e., how its active surfaces present to the current. Two basic methods of energy extraction are from tidal rise and fall or from tidal currents, which accommodates this rise and fall. New Zealand's tidal range is relatively small: 2.5 – 3.5 m.

Barrages are the only currently operating utility-scale marine energy technology (excepting offshore wind). More barrages are under construction or consideration internationally but environmental, cultural and access issues are likely to be major constraints on development of barrages or impoundments in New Zealand. Constriction projects have some potential but may face special cultural problems. Tidal fence technologies have been proposed but face access issues. Indeed all surface-piercing technologies that seek to utilize natural harbours, estuaries and channels face problems of access and competing uses, as well as environmental issues.

Tidal currents present an opportunity in New Zealand partly because, as we shall see, they can be harnessed in open ocean situations and also because the resource is potentially more widely available.

Tidal current devices have a diverse range of forms at present – horizontal axis turbines, shrouded turbines, open-ring turbines, vertical axis turbines, oscillating hydrofoils and pressure devices.

2.4. Likely Deployments in New Zealand

Table 2 summarizes generic wave and tidal current devices, with those in red being the most likely to be deployed in New Zealand in the next decade.

Table 2: Potential Marine Energy Technologies

Energy Source	Conversion Technology	Comment
Waves		
Breaking Waves	Onshore Oscillating Water Column	Likely in new breakwater designs
	Nearshore Oscillating Water Column	Possible but difficult to consent
	Overtopping Devices	Possible but difficult to consent
	Surge Devices	Possible but limited by steeply shelving coastline
Open Ocean Swells	Attenuators	Possible but navigation problems for large arrays
	Point Absorbers	Probable widespread deployment of arrays
Tidal/Ocean Currents		
Tidal Rise and Fall	Barrages	Prohibitively expensive; potentially impossible to consent
	Impoundments	Very unlikely due to steep shelving coastline
	Fences	Unlikely due to competing uses; very difficult to consent
Current Devices	Horizontal Axis Turbines (including shrouded & open-centred turbines)	Probable widespread deployment of arrays
	Vertical Axis Turbines	Possible, subject to successful design
	Pressure Devices	Possible
	Oscillating Hydrofoils	Technology problematic

There is unlikely to be a single convergent design for wave energy or tidal current energy extraction. OTEC could be applied in special circumstances in New Zealand but technology developments are probably some way off. Osmotic power and marine biomass may have some future potential but energy extraction technologies are presently very immature.

In conclusion few generic wave and tidal current technologies could potentially be deployed in New Zealand in coming years, i.e., to 2030. The most likely technologies were then modelled to determine their likely electricity production (see Sections 5.2.1. and 6.2.1.).

3. NON-TECHNICAL DEVELOPMENTS IN NEW ZEALAND

3.1. Incentives and Barriers to Development

Uptake of marine energy in New Zealand will depend on the incentives and barriers to its development. New Zealand is blessed with abundant renewable energy resources – hydro, geothermal, wind – all of which can be harnessed with mature technologies at lower unit costs (in NZ$/kWh) than currently immature marine energy technologies. Government policies in support of marine energy have been reviewed elsewhere [2] and the following section is an update on that paper.

3.1.1. Targets and Forecasts

Approximately 65% of New Zealand's electricity is generated from renewable sources and the Government has set a target of achieving a figure of 90% renewable electricity generation by 2025, with strategies to support the achievement of this target [3 & 4]. Although there is some debate about the figures, this sustainable growth requires the installation of 240 MW per annum of new renewable generation capacity from now until 2025.

Modelling by the Ministry of Economic Development has included scenarios, in which 200 MW of wave energy generation is included by 2030, ~2% of NZ's present electricity generation capacity [5]. However, the government has not set any formal target for the future contribution of marine energy. Whilst New Zealand's renewable electricity proportion is high relatively to other countries, the absence of a marine energy target, compared with other countries, reflects the abundance of renewable alternatives in New Zealand.

3.1.2. Funding Mechanisms

Although New Zealand has come lately to recognize the potential for marine energy, the Government has moved quickly to provide some funding support. The Government has provided R & D funding for three projects since 2004 and recently announced funding for two more projects, plus continuing funding for one of the original projects. Total Government R & D funding will exceed NZ$ 1.4 million per annum for the next 3 years at least. Private sector funding is more difficult to assess but may match this sum.

The Government also implemented a capital grant programme for the deployment of prototypes. The Marine Energy Deployment Fund (MEDF) will provide NZ$ 8 million over four years, i.e., NZ$ 2 million maximum per annum, to project developers, who can provide at least 60% of their project funding [6]. The first award was made in May 2008 to Crest Energy to support the deployment in Kaipara Harbour of its first 1-3 tidal current turbines, subject to securing resource consents and matching funding [7]. The second round is in progress as this paper is being written (round closes on 24 November 2008) and two further rounds are expected. During the development of the Government's Energy Strategy [3 & 4], it considered various other funding mechanisms, including renewables obligations and feed-in tariffs and considered the latter as potentially applicable to marine energy [8]. However, the Strategy did not implement any of these mechanisms and none is forecast for implementation in the immediate future.

3.1.3. Regulatory Mechanisms

Apart from funding mechanisms to promote research and development and marine energy deployments, there are other regulatory mechanisms that the Government could employ to promote uptake of marine energy. The NZ Energy Efficiency and Conservation Strategy [4] introduced three initiatives in addition the MEDF funding. These were:

1. A commitment to a marine energy atlas by end-2009
2. Development of marine energy standards (end-2011)
3. Ongoing funding for the industry association, the Aotearoa Wave and Tidal Energy Association (AWATEA).

A growing number of countries, most recently the United States, have committed to development of marine energy testing centres [9]. At least two sites have been considered for such a testing centre in New Zealand but none has been selected for development as yet. Nonetheless development of a marine energy testing centre in New Zealand is under consideration and is likely to stimulate deployments.

There is no specific permitting regime for marine energy projects. The standard processes of the Resource Management Act 1991 (RMA) apply in the offshore out to 12 nautical miles. Consenting authorities currently suffer a lack of familiarity with environmental issues in relation to marine energy deployments, due to lack of deployments and consent awards. Encouragingly, consenting authorities have so far taken an 'adaptive management' approach, enabling projects to proceed whilst dealing with unforeseen environmental issues as they arise.

However, the RMA process is an environmental planning process. Consents are allocated on a 'first come, first served' basis: the RMA does not allocate space or resources. There have been calls for a space/resource allocation regime to complement the RMA and for some 'fast-track' permitting regulations for prototype deployments (cf. US federal and UK regulations). However, none is currently in development.

New Zealand has just become the first sovereign nation to enact an emissions trading regime. The NZ Emissions Trading Scheme (ETS) into law on 26 September 2008. The legislation is in two parts:

1. A bill establishing a trading scheme, introduced progressively but eventually involving all sectors of the economy by 2013 and all greenhouse gases,
2. A bill establishing a preference for renewable electricity generation, which introduces a 10-year moratorium on building new baseload thermal generation plant, subject to maintenance of security of supply [10].

Stationary energy must join the ETS on 1 January 2010 and this will favour investment in renewable energy generation technologies over thermal generation.

3.2. Industry Development

PPL has identified at least domestic 26 marine energy projects. Most of the projects under development are run by single entrepreneurs or partnerships without the depth of investors, suppliers and supporters-in-kind, which are common in larger overseas projects and which will be required to make deployments possible. There is also an absence of investors of scale. Major domestic electricity generators have demonstrated interest in marine energy but none has yet committed to any project development. They, or overseas investors or developers, are likely to be the source of capital for the first utility-scale deployments, whilst smaller projects may be locally financed.

The marine energy supply chain in New Zealand is similarly immature. The Aotearoa Wave and Tidal Energy Association (AWATEA) has compiled and distributed (nationally and internationally) a Supply Chain Directory [11] but the supply chain will only mature, once a significant number of projects are in deployment. There may be some gaps in the supply chain, notably in the deployment capabilities and in engineering capacity.

4. WAVE AND TIDAL CURRENT RESOURCE MAPPING

4.1. Marine Energy Resources and Potential Electricity Production

Wave energy potential is often expressed in kW/m of wavefront and tidal current potential as the mean current speed (in m/seconds) at a potential site. These are measures of the resource potential but ultimately electricity generation potential is a more useful measure for assessing potential project developments. Sometimes the potential resource of a site or a region is quoted in megawatts (MWs), which can lead to confusion with proposed nameplate capacity for potential projects. There is often a wide difference between these two sets of figures and new industry practice and standards are needed to provide clarity. Continuing confusion about marine energy resources and generation potential is damaging, as it leads to accusations of 'over-selling' and uncertainty (and thus discounting) by the potential investment community.

For the purposes of this paper, we discriminate between potential resources (wave or tidal currents), expressed for a region or area, and the potential reserves (i.e., potential electricity generation) from an array deployment at a specific site. Both may be measured in MWs but there is no intent to suggest that the two are directly related. Potential electricity production from a specific project is a function of the wave or tidal current resource, the number and location of the deployment sites and generation efficiency of the (array of) devices at the sites. For clarity the figures cited in the remainder of this report are reserves (not resources) and relate to either single generic devices or notional 50-unit arrays at specific sites.

4.2. Wave Modelling

Wave hindcasts were undertaken over an NZ-wide domain, utilizing a longitude/latitude grid with a 0.05° resolution (4.5 x 5.4 km).

The SWAN (Simulating WAves Nearshore) program was used for all wave modelling [12, in 1]. The model incorporates the growth, refraction and decay of each component of a complete sea state, each with its own frequency and direction, giving a realistic description of the changing wave field. The model simulates the generation of waves by surface wind, dissipation by white-capping, resonant non-linear interaction between wave components, bottom friction and depth-limited breaking. More details can be found in [13].

Boundary conditions were defined by construction of the Ochi-Hubble spectra from the NOAA WAVEWATCH III (NWW3) historical global nowcast of primary spectral parameters. Regional wind fields are important for local wave generation. A blended global wind product developed by MetOcean Solutions Limited (MSL) that combines Seawinds [14] and satellite data with historical GFS wind fields was used for the spatially varying wind field. These data were 10 m wind velocity vectors at 3-hourly resolution gridded at 0.25° resolution..

4.2.1. Validation

The hindcasting methodology was developed to meet offshore oil industry engineering design specifications and has been extensively peer-reviewed and validated. It is used for offshore field developments, harbour design and under-keel clearance applications. In this work hindcast wave model outputs have been validated against wave buoy data from 11 locations (with water depths from 10 – 110 m). As an example, the wave hindcast matches well with wave rider buoy data collected at the Kupe gas field (Figure 1).

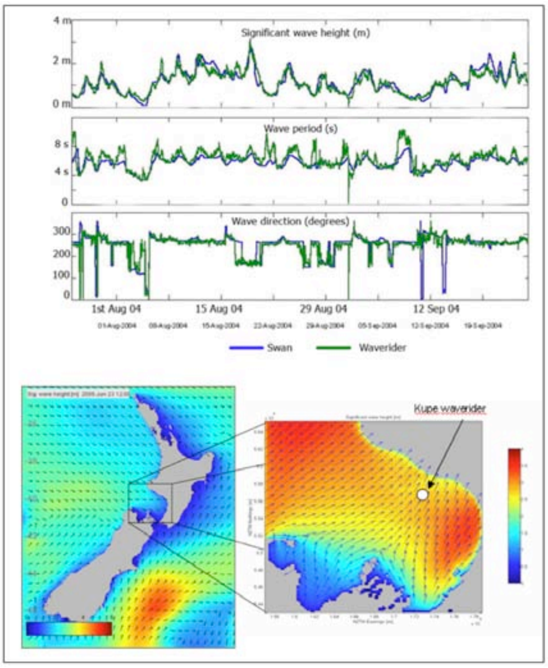

Figure 1: Validation of MSL wave hindcast with wave rider buoy data at Kupe gas field.

Since the relationship between wave height and wave power is non-linear, small errors in hindcast wave heights can lead to significant errors in mean wave power assessments. To further validate the wave power data, the wave power flux was estimated from both measured and modelled primary wave parameters at seven sites with a range of wave conditions. Modelled results were all within 20% of measured power values and no systematic errors occurred. Finally, validation of a full spectral integration of energy flux was undertaken, using data from two sites (Maari oil field and Southland). The measured spectral wave power corresponded very closely with the modelled spectral wave power at these locations [12, in 1].

In summary, the hindcast techniques reported here have been audited by international experts and used extensively in real world applications for New Zealand's oil and gas industry. Multiple validation methods have been used. The validations demonstrate that the modelled wave power results from hindcast data are a reliable representation of the actual wave resource as measured.

4.2.2. Spectral Parameters

Ten years of hindcast data were available for the present study (1998-2007) and directional wave spectra were output at hourly intervals over the hindcast run. The following key spectral wave parameters were derived: significant wave height (total, sea and swell – using an arbitrary cut-off of 10 seconds), peak period, mean frequency mean wavelength and mean spectral wave power.

4.3. Tidal Current Modelling

Tidal current modelling was conducted on an NZ-wide grid with a 0.06° resolution (5.6 x 6.6 km). Two nested high-resolution domains over Cook Strait (0.002°; 170 x 230 m) and Foveaux Strait (0.004°; 340 x 450 m) were also simulated.

4.3.1. Current Model

The Princeton Ocean Model (POM) was used to hindcast the tidal current around New Zealand [15]. Only open ocean sites were modelled: harbours, estuaries and channels were not included. For the tidal current simulations, POM was used in a vertically integrated two-dimensional mode with boundaries provided from the global TPX07.1 solution [16].

4.3.2. Model Outputs

The 2D hydrodynamic model was allowed to spin up and then run for a period of 40 days. The elevation and flow fields were then post-processed to derive the nine primary tidal constituents (M2, S2, N2, K2, K1, O1, P1, Q1 and M4) for each node in the domain. The modelled open ocean tidal current flows have been validated at several sites in the offshore Taranaki region as part of the engineering design studies for oil and gas projects. The constituents of the tidal elevations within the regional and high-resolution domains (i.e., Cook Strait and Foveaux Strait) were also validated against the published tidal constituents at discrete locations.

5. WAVE MAPPING

5.1. National and Site-specific Wave Mapping

A suite of maps was derived from modelling of the national wave resource, describing a range of wave and wave spectral characteristics, such as the mean spectral wave power (Figure 2). From these maps, six sites were chosen for more detailed statistical analysis, undertaken to evaluate the annual electricity generation production for an array of wave devices at each site.

The mean spectral wave power is a measure of the wave power potential. It is cited in kW/m of wave front and represents the potentially extractable unit energy experienced by a wave device at any point on the map.

5.1.1. National Distribution

A range of wave power maps was produced to demonstrate facets of the national distribution of wave power around New Zealand's extensive coast.

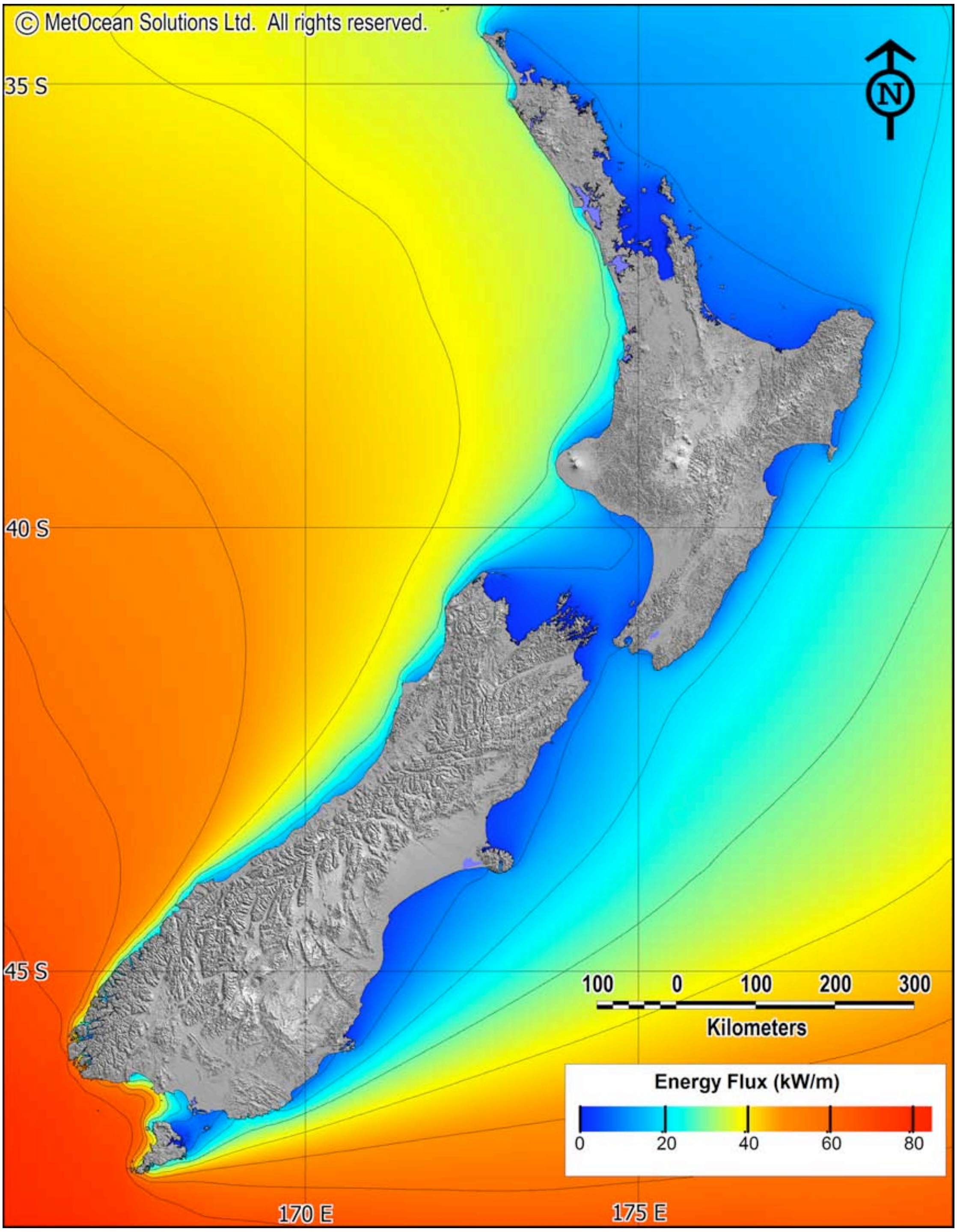

Figure 2: National Mean Spectral Wave Power in kW/m (1998 – 2007)

The key observation from all of these maps is a gradient from southwest to northeast, resulting from the predominantly southwesterly weather direction (the Roaring Forties). The two main islands act as barriers to the advancing southwesterly flows and nearshore (<12 nautical miles) wave energy on north- and east-facing coasts is substantially less than on south- and west-facing coasts.

5.1.2. Specific Sites

Six sites were analyzed in detail to assess the potential electricity generation output from a 50-unit array of three different generic device types. The open-ocean sites were chosen to represent the range of wave climates around New Zealand's coast on the following criteria:

1. All sites were 6 km from the coast (to minimize submarine export cable length and reduce the likelihood of competing uses),
2. Sites had a range of water depths from 23 to 65 m,
3. Sites were selected for their proximity to onshore transmission grid/distribution network access and markets (Figure 3).

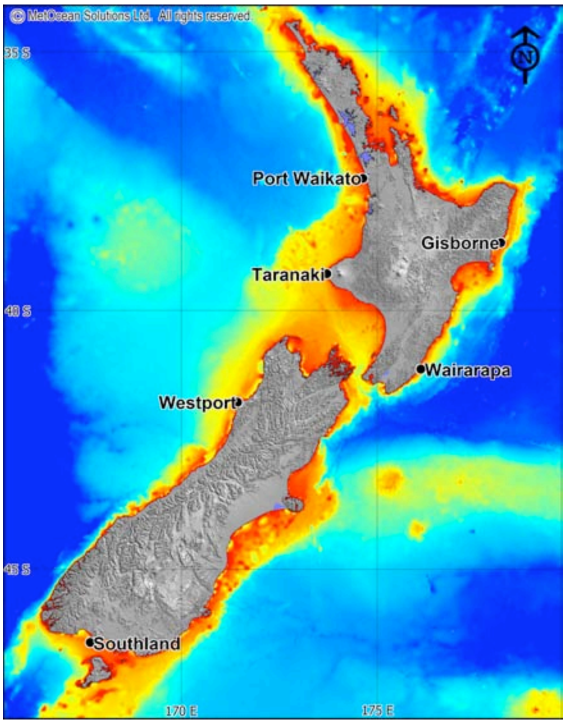

Figure 3: Locations for Site-Specific Wave Power Evaluation

5.2. Modelling of Electricity Production

A three-stage approach was taken to establish electricity production outputs at the chosen wave sites:

1. Time series of wave parameters were extracted from hindcast data at each of the chosen wave sites.
2. Power matrices, relating wave parameters to power generation were developed for three notional wave devices, based upon data for existing or generic devices [Appendix B in 1]. The power matrices were applied to derive time series of power output.
3. Mean annual electricity production was calculated at each of the six sites.

More details on calculating the annual electricity production from each device array can be found in [1]. The detailed modelling of wave and tidal current arrays requires different inputs and considerations.

5.2.1. Wave Device Arrays

Power generation time series at each of the six sites were used to calculate the annual electricity output from an array of 50 units of three different generic devices – a 750 kW attenuator device, a 1.5 MW attenuator device and a 750 kW point absorber device. Eighteen potential outputs were thus calculated. The arrays were nominal 50-unit arrays: no attempt was made to site the individual devices at the locations to maximize output. The parameters used for input to the electricity production calculations are given in Table 3:

Table 3: 50-unit Wave Device Array Parameters

Device	Capacity	Sea Area	Packing	Gen. Density
	MW	Km^2	Devices/ km^2	MW/km^2
750 kW Attenuator	37.5	3.33	15.0	11.25
1.5 MW Attenuator	75.0	4.00	12.5	18.75
750 kW Point Absorber	37.5	2.00	25.0	18.75

A power loss of 5 % due to array effects was included, although this may be unduly pessimistic [17]. The capacity factor – annual mean yield/nameplate capacity - was calculated in each case. No transmission losses were included.

5.2.2. Results from Specific Wave Sites

Modelled electricity production from a single 750 kW point absorber device and a 50-unit array varies considerably at each site (Table 4). South- and west-facing coastal locations produce substantially greater electrical output than east-facing coastal locations (Wairarapa and Gisborne). Since the Southland location produces 73% more power than the Gisborne location for the same equipment (and thus capital cost), it is likely that west- and south-facing coastal locations will be developed in preference. The rank order of the sites is consistent, regardless of the generic device selected. The high capacity factors mean that the underlying power spectrum needs further evaluation or that the devices are undersized for the specific locations. The results from the other two generic wave devices are available in [1].

Table 4: Electricity Generation by Unit and 50-unit Array at Six Wave Sites

Location	Unit Power	Annual Mean Yield	Capacity Factor	Annual Product
	kW/unit	MW/unit	%	GWh/year
Port Waikato	551	26.2	70	229.3
Taranaki	572	27.2	72	238.0
Gisborne	371	17.6	47	154.4
Wairarapa	441	21.0	56	183.5
Westport	592	28.1	75	246.3
Southland	643	30.5	81	267.6

6. TIDAL CURRENT MAPPING

6.1. National and Site-specific Tidal Current Mapping

6.1.1. National Distribution

The national distribution of utilizable open ocean tidal currents is very limited, compared with the wide distribution of potential wave resources. Most areas have very low mean current speeds (<1 m/second) and only four areas have mean current speeds that exceed this value (Figure 4). From north to south these are Cape Reinga, Cook Strait, Foveaux Strait and south of Stewart Island. It is important to note that modelling at the present scale does not identify local bathymetric features that may create conditions at specific sites with greater current speeds. More detailed modelling at specific sites may identify other opportunities.

Cape Reinga and the south of Stewart Island were not considered further, since both areas are significant distances from existing electricity infrastructure and potential markets, both of which would considerably increase the cost of potential projects in these areas.

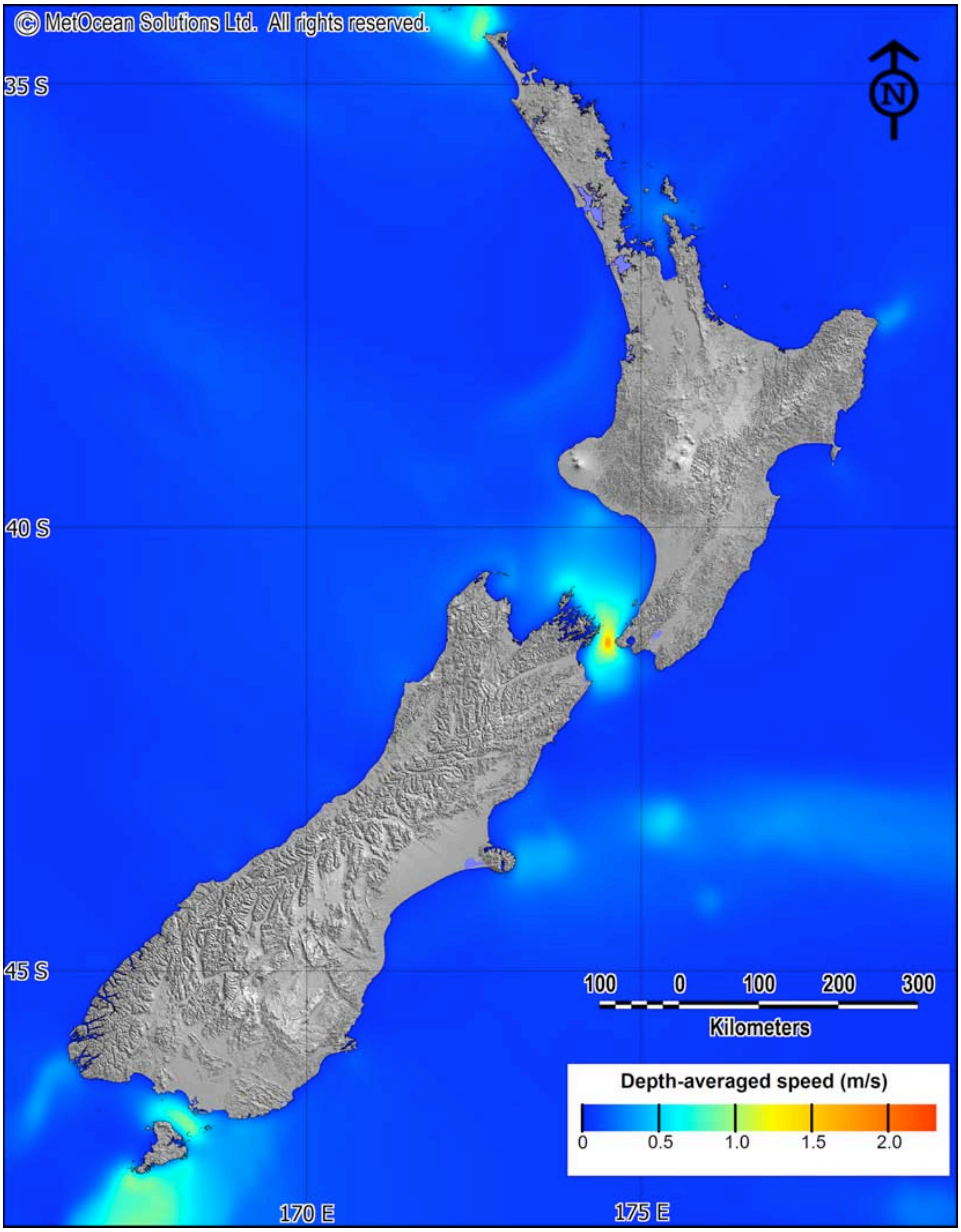

Figure 4: National Depth-averaged Tidal Current Speeds for Mean Spring Flows (in m/second)

6.1.2. Specific Sites

Detailed maps were made of the Cook Strait and Foveaux Strait/Stewart Island areas, utilizing the high-resolution sub-model. The Cook Strait area has a sizeable area off the south Wellington coast, where depth-averaged tidal currents exceed 1 m/second and, in some areas, 3 m/second. Six sites were selected – five in Cook Strait and one in Foveaux Strait (Figures 5 & 6).

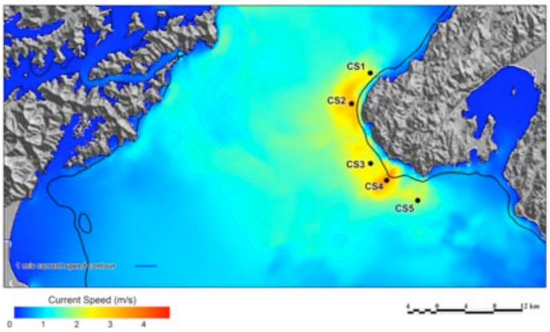

Figure 5: Five Tidal Current Evaluation Sites (CS1-5) in Cook Strait

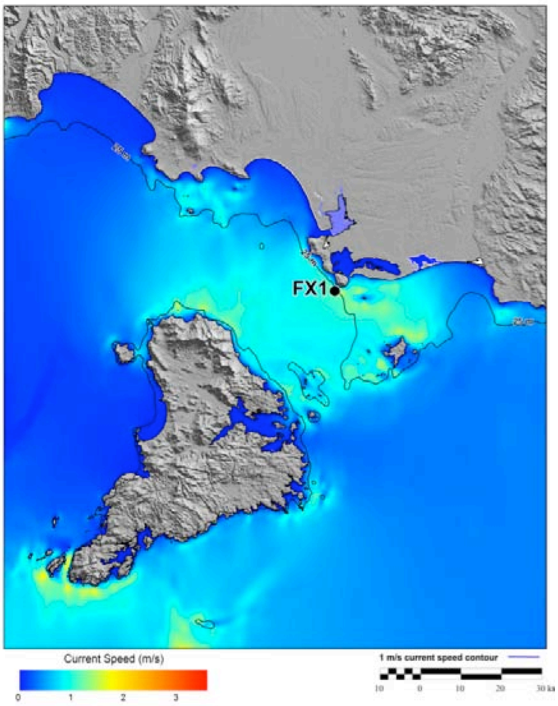

Figure 6: Tidal Current Evaluation Site (FX1) in Foveaux Strait

6.2. Modelling of Electricity Production

Modelling of tidal current arrays is quite different from modelling wave devices, as the time components of each resource are quite different. The extractable electrical power is limited by:

1. The tidal current passing the site
2. The characteristics of the site
3. Environmental conditions at the site

From these characteristics the instantaneous power that can be extracted from the current incident on a device (or an array of devices) can be determined, taking into account various losses in converting the kinetic energy in the water to electrical power, including:

1. Coupling device active surfaces with current flow
2. Mechanical inefficiencies in the turbine, drive train, generator and power conditioning equipment.

Every loss is additive so total efficiencies may be relatively low. During slack water current flow velocities are likely to be too low to turn turbine blades (the 'cut-in' speed) and periods when current flow exceeds the rated power of the device, so the device produces at its rated capacity.

Two generic horizontal axis tidal turbines were modelled at each of the tidal current sites: a single 10 m diameter bladed turbine (300 kW) and a twin-turbine device with 16 m diameter blades (1.2 MW).

6.2.1. Tidal Current Arrays

As with the wave devices, 50-unit arrays of each of these devices were notionally located at each of the six modelled sites. No attempt was made to site individual turbines and no transmission losses were included. The packing density of tidal current arrays is an area of active research, for which there is as yet little practical experience. Packing density, individual device siting and downstream wake effects may be critical factors in maximizing electrical production. For the purposes of this study a conservative packing density of 15 units/km^2 was selected, although figures between 12 and 48 units/km^2 have been proposed [18]. Power losses of 5% due to wake effects were also included in the output calculations [17]. The input parameters for the electricity production calculations are given in Table 5:

Table 5: Tidal Current Device Array Parameters

Device	Capacity	Sea Area	Packing	Gen. Density
	MW	Km^2	Devices/ km^2	MW/km^2
300 kW HA turbine	15.0	3.33	15.0	4.5
1.2 MW HA turbine	60.0	3.33	15.0	18.0

6.2.2. Results from Specific Tidal Current Sites

Modelled electricity production from a single 1.2 MW HA twin-turbine device and a 50-unit array varies considerably at each site (Table 6). There is a huge difference between the most energetic site (CS4) and the least (FX1). Since the nominal devices and arrays are identical, the critical factor in determining electrical output is the mean current velocity at each site (compare Figures 5 & 6).

Table 6: Electricity Generation by Unit and 50-unit Array at Six Tidal Current Sites

Location	Water Depth	Unit Power	Annual Mean Yield	Annual Product
	M	kW/unit	MW/year	GWh/year
CS1	42	210.0	9.98	87.4
CS2	50	400.0	19.00	166.4
CS3	69	211.0	10.02	87.6
CS4	31	458.6	21.78	190.8
CS5	86	143.0	6.79	59.5
FX1	31	38.8	1.84	16.1

7. DEVELOPMENT OF MARINE ENERGY IN NEW ZEALAND

7.1. Current Status of Marine Energy

A model for the growth of marine energy in New Zealand is important because it will enable Government, regional councils, the electricity industry, R & D funders, investors, device developers and deployment project developers guidance on the likely issues that this growth will face in coming years. Comparison with the development of marine energy internationally and the growth of the wind industry are also instructive.

7.1.1. International Developments

Assessments of the international uptake of marine energy made even five years ago have proven unduly optimistic [19 & 20]. At the end of 2007 there were only 8 MW of marine energy generation technologies installed [21]. However, this figure is likely to rise steeply once device developments become a commercial reality. This is because most project developers have multiple international projects in progress. This parallel development should reduce the stress on supply chains in certain countries and enable developers to deploy projects quit rapidly. Increasingly planned projects are tending towards multi-unit arrays of greater nameplate capacity. Testing centres, such as EMEC and Wave Hub, are also attracting developers to make early commitments to deployment.

7.1.2. Domestic Projects

Consensus on the pace of development and ultimate contribution of marine energy to national electricity supply is absent. Marine energy is considered to be somewhere between 5 and 30 years behind wind developments with potential capacity ranging widely up to 30,000 MW (for wave only) [22]. Government forecasts are quite conservative: 200 MW by 2030 but some business groups are even more pessimistic – 'early commercial use' by 2050.

PPL has identified 26 marine energy projects of which 20 are device/deployment projects in New Zealand. Most are immature, self-financed but ambitious, developing their own devices or seeking to import overseas devices. A slight majority are tidal current projects. There is an absence of utility-scale investors. The most advanced projects are publicly known and at least three have completed or begun the process of securing consents for specific sites (Table 7). To date, only the WET-NZ project has deployed an experimental prototype.

7.2. Forecast Growth

As noted above, forecasting the growth of marine energy is difficult and historically been over-optimistic. The development of international and New Zealand wind energy capacity may provide a useful comparison. Within the New Zealand context, there are likely to be constraints on the marine energy supply chain, which could eventually act as a brake on the rapid deployment of marine energy. International supply chain issues and commodity prices (e.g., the price of steel) may be significant influences on the pace of marine energy developments.

Table 7: Domestic Marine Energy Deployment Projects

Name	Device/*Site*	Funding	Comment
Crest Energy	Open Hydro; formerly Lunar Energy device *Kaipara Harbour*	Self-funded at present with MEDF funding to come	Consent applications submitted in July 2006 and July 2007. Consents recommended in August 2008 but four appeals now lodged
Neptune Power	TidEL device originally; new device with TNEI *Cook Strait*	Self-funded at present	Resource consent granted on 10 April 2008; believed to be importing UK device;
Power Generation Projects	Pelamis importation & domestic fabrication	Self-funded; HERA contributed to UK visit in 2007	Project dormant since UK visit in June 2007; current status unknown
WET-NZ	WET-NZ's own device; *Pegasus Bay & Wellington*	Further six years R & D funding granted July 2008	Device deployed periodically since Dec 2006
Tidal Flow Seamills	Own vertical axis tidal turbine; *Karori Rip*	Unknown	Prototype deployment planned for 2008
Natural Systems Limited	HydroVenturi; *Canterbury irrigation canals*	Self-funded	Project on hold pending further progress in UK device trials; current status unknown
Energy Pacifica	Device not yet selected; *Tory Channel*	Self-funded	Resource consent applications submitted in August 2008

7.2.1. Comparison with Wind

The wind industry developed slowly in the 1980s and 1990s but has undergone exponential growth since 1997, such that installed wind capacity now exceeded 100 GW in 2007 [23]. The growth in New Zealand has followed the same trend. The first wind turbine was erected in 1993, reaching a cumulative total of 160 MW by end-2007, which doubled in 2007 to more than 320 MW. For the foreseeable future growth is forecast to be approximately 150 MW per annum (Figure 7).

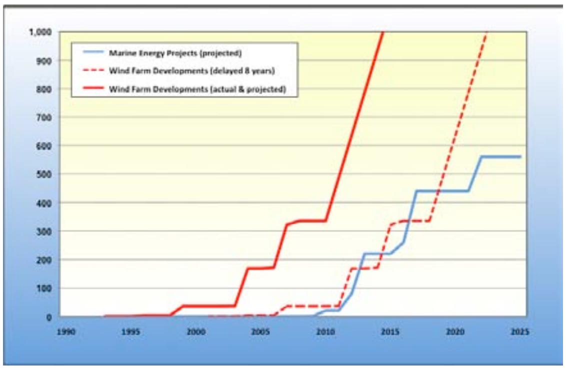

Figure 7: Comparison of Growth of Wind with Project Plans of Two Tidal Projects

Marine energy may undergo the same exponential growth in New Zealand – mirroring the pace of potential international developments. Figure 7 shows the proposed growth of two tidal current projects: the Neptune Power [24] and Crest Energy projects [25 & 26]. The growth curve for wind has been shifted (by 8 years) to overlay the marine growth curve and the proposed pace of development is clearly similar to the growth rate of the domestic wind industry. The latter has only been achieved with significant strain on the supply chain. Whether the two marine projects can deliver to their proposed timetables remains to be seen; other marine energy projects are likely to contribute. However, it seems unlikely that the combined marine energy industry will be easily able to exceed the demonstrated growth of the wind industry, partly because of the capacity of NZ's industrial supply chain to meet a greater demand, particularly whilst wind farm developments continue apace.

8. MARINE ENERGY IN NEW ZEALAND - SUMMARY

8.1. Summary

PPL has conducted a review of the range of marine energy technologies, the incentives and barriers to uptake of marine energy in New Zealand. Together with MSL it has produced an integrated suite of new maps of the open-ocean wave and tidal current resources around New Zealand. PPL and MSL are planning to make these maps available as a web-enabled marine energy atlas.

Three generic wave and two generic tidal current devices have been modelled at six wave and six tidal current sites identified from the mapping. Annual electricity production has been calculated for all of these sites. The modelled electricity production demonstrates that there are large regions off New Zealand's coastline, where wave energy projects could be located. The tidal current potential is more restricted but there are very attractive sites. More detailed mapping, analysis and evaluation will be required to defined wave and tidal current sites with economic potential. PPL and MSL have established a database of generic marine energy technologies power matrices, which can be applied to investigate the potential of specific sites for project deployments.

The first demonstration projects are likely to occur in the next 3-5 years and the first commercial installation may occur in the next 3-7 years, assuming that Government support remains at its present levels.

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9. REFERENCES

[1] Power Projects Limited, 2008. Development of Marine Energy in New Zealand. Client report, 30 June 2008. http://www.eeca.govt.nz/eeca-library/renewable-energy/marine/report/marine-energy-in-nz-jun-08.pdf

[2] Huckerby, J.A., 2007. Regulatory Interventions in Support of Marine Energy in New Zealand. European Wave and Tidal Energy Conference, Porto, Portugal, 14 September 2007.

[3] New Zealand Government, 2007. New Zealand Energy Strategy: Powering Our Future. Wellington, 11 October 2007.

[4] New Zealand Government, 2007. New Zealand Energy Efficiency and Conservation Strategy: Making It Happen. Wellington, 11 October 2007.

[5] Ministry of Economic Development, 2006. Energy Outlook to 2030. MED, Wellington, August 2006.

[6] Energy Efficiency and Conservation Authority, 2008. New Zealand Marine Energy Deployment Fund: Fund Definition Document. http://www.eeca.govt.nz/eeca-library/renewable-energy/marine/report/defintion-document-jul-08.pdf

[7] Minister of Energy, 2008. Marine Energy in New Zealand and the Marine Energy Deployment Fund. Ministerial address to AWATEA conference, Wellington, 29 May 2008.http://www.beehive.govt.nz/speech/marine+energy+new+zealand+and+marine+energy+deployment+fund

[8] Ministry of Economic Development & Ministry for the Environment, 2007. Transitional Measures: a discussion paper. MED and MfE, Wellington, 2007.

[9] US Department of Energy, 2008. DOE Selects Projects for Up to $7.3 Million for R&D Clean Technology Water Power Projects. DOE press release, Washington 18 September 2008. http://www.energy.gov/news/6554.htm

[10] Ministry for the Environment, 2008. NZ Emissions Trading Scheme. http://www.climatechange.govt.nz/emissions-trading-scheme/index.html

[11] AWATEA, 2008. Marine Energy Supply Chain Directory. AWATEA, Wellington, 29 May 2008.

[12] MetOcean Solutions Limited, 2008. Marine Energy Resources: Ocean wave and tidal current resources in New Zealand. MSL, New Plymouth, May 2008.

[13] Holthuijsen, L.H., Booij, N., Ris, R.C., Haagsma, I.J.G., Kieftenburg, A.T.M.M, Kriezi, E.E., Zijlema, M. and van der Westhuysen, A.J., 2007. SWAN Cycle III version 40.51 User manual. http://fluidmechanics.tudelft.nl/swan/index.htm

[14] Zhang, H.M., Bates, J.J. and R.W. Reynolds, (2006) Assessment of composite global sampling: Sea surface wind speed. Geophysical Research Letters, 33, L17714, doi:10.1029/2006GL027086.

[15] Mellor, G.L., 2004. User guide for "A three-dimensional, primitive equation, numerical ocean model". Princeton University, Princeton, NJ. http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/

[16] Egbert, G. and Erofeeva, L. (2002). Efficient inverse modelling of barotropic ocean tides. Journal of Atmospheric and Oceanic Technology, 19, N2.

[17] Scottish Executive, 2006. Matching Renewable Electricity Generation with Demand. University of Edinburgh report, February 2006.

[18] Strathclyde University, 2008. Technology Considerations: packing density. http://www.esru.strath.ac.uk/EandE/Web_sites/03-04/marine/tech_consider.htm

[19] Scottish Executive, 2005. Marine Renewable (Wave and Tidal) Opportunity Review. Introduction to the Marine Renewable Sector. December 2005.

[20] British Wind Energy Association, 2006. Path to Power: delivering confidence in Britain's wave and tidal stream energy industry. BWEA and npower juice, London, July 2006.

[21] IEA: Ocean Energy Systems Executive Committee, 2008. Annual Report, 2007.

[22] Allan, G., 2008. Capitalizing on the Demand for Clean Energy. Presentation to AWATEA 2nd Annual Conference, Wellington, 29 May 2008.

[23] World Wind Energy Association, 2008. Wind turbines generate more than 1% of global electricity. WWEA press release, Bonn, 21 February 2008.

[24] Neptune Power. Present Status. Presentation to the Electricity Commission, Wellington, 17 December 2008. http://www.electricitycommission.govt.nz/pdfs/opdev/transmis/renewables/presentations/Neptune.pdf

[25] Crest Energy Limited (2006). Kaipara Harbour Marine Turbine Electricity Generation Project: Application for Resource Consents and Assessment of Environmental Effects. Auckland, July 2006.

[26] Crest Energy Limited (2007). Kaipara Harbour Marine Turbine Power Generation Project: Project Update and Further Information Pursuant to Section 92 RMA. Auckland, July 2007.