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BREAKWATER – WAVE ENERGY CONVERTER

Coastal defence and cheap evergreen energy production

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Coastal defence and cheap evergreen energy production

This paper deals with breakwaters for coastal defence against tsunami and storms, creation of habitable space and wave energy conversion into sustainable electricity. The study was undertaken as DRR (disaster risk reduction) to the adverse effects of climate change and see level rise caused by the warming up of the planet, on top of existing natural disasters like earth quakes generating tsunami. In many parts of the world increasingly deteriorating weather caused catastrophes to the affected regions. During the last decade we witnessed major disasters, like the devastating 2004 Sumatra tsunami, the 2011 Japan tsunami, hurricane Katrina in 2005 and Sandy in 2012 in the USA and typhoon Haiyan in 2013 in the Philippines. Those catastrophes had demonstrated that the breakwaters for coastal defence, constructed during many decades according to standard engineering practice, did not work properly. Even the world largest breakwater at Kamaishi in Japan, which took 31 years to build, was smashed down in few minutes by the 2011 tsunami.

To understand the situation and appreciate the difficulty of standard breakwater technology, the author studied the nature of tsunami as treated in the literature on non-linear wave dynamics of incompressible fluids, and proposed, for coastal defence: Breakwaters against tsunami and storm waves, patent document NL 1039528 published 2013-01-31 (EMID, 2013), for creation of habitable space: Return and annihilation stormbreakers on habitable spaces, patent document NL 1040026 published 2014-01-14 (EMID-1, 2014) and for cheap evergreen energy production: Breakwater as wave energy converter, patent document NL 1040193 published 2014-01-20 (EMID-2, 2014). The essentials of each document will now be described briefly. For more detailed information the reader is referred to the full documents and relevant references therein. The author focuses the discussion upon his own work and does not elaborate on existing literature, neither on breakwaters, nor on wave energy conversion methods for which since the oil crisis in the 1970s there are more than a thousand patents in the USA, Europe and Japan.

Breakwaters against tsunami and storm waves

The dynamics of tsunami, generated by underwater earth quake at the subduction zone of two continental plates, are well understood from the fundamental wave equation of incompressible fluids. The essential aspects are discussed in NL 1039528 (EMID, 2013), where it is argued that the existing breakwaters are inadequate against tsunami, because the strengths of materials are insufficient for a head on clash with major tsunami. A global tsunami is usually generated by a major underwater earth quake of magnitude ≥ 9 on the Richter scale, which is an indication of a large scale rupture along the subduction zone leading to a tsunami wave length L > 200 km, which in turn means shallow water condition: L/20 > D, where D is the depth of the ocean. Under these circumstances the (phase) velocity v of the wave disturbance is given by: $v = \sqrt{(gD)}$, with $g = 9.8\ m/s^2$. For ocean depth of 5000 m, v = 221 m/s = 800 km/h, the speed of a jetliner. The amplitude of the tsunami wave is initially small, of the order of 1 m, the up shift of the rupture. However, when the tsunami wave approaches the coast, D at the front becomes smaller, say 50 m, so the front slows down, whereas the tail of the tsunami some 200 km away has still a high velocity, so that the tsunami wave length become shorter, say ten times, and the amplitude correspondingly higher. This effect is called shoaling and this is why the tsunami becomes deadly near the coast as it can become 10 m high and still 20 km long, rushing ashore at a speed of 50 – 100 km/h, carrying ships on shore as in the 2011 Japan tsunami.

Return and annihilation type breakwaters are proposed against tsunami and heavy storm waves. The return type returns the tsunami to travel back, opposite to the incoming direction. The annihilation type arranges the tsunami to annihilate among itself. The arrangement is depicted in Figure 1: as the vertical cross section of the return type, or as the horizontal cross section of the annihilation type. (1) is the cross section of a half-cylinder, (2) is the cross section of a cylinder, concentric with the half-cylinder. For the return type breakwater the openings between (1) and (2) serve as a vertical U-turn for the water waves coming from the right, entering through the lower opening and return to the right on top of the incoming waves. For the annihilation type the water waves enter in equal amounts into

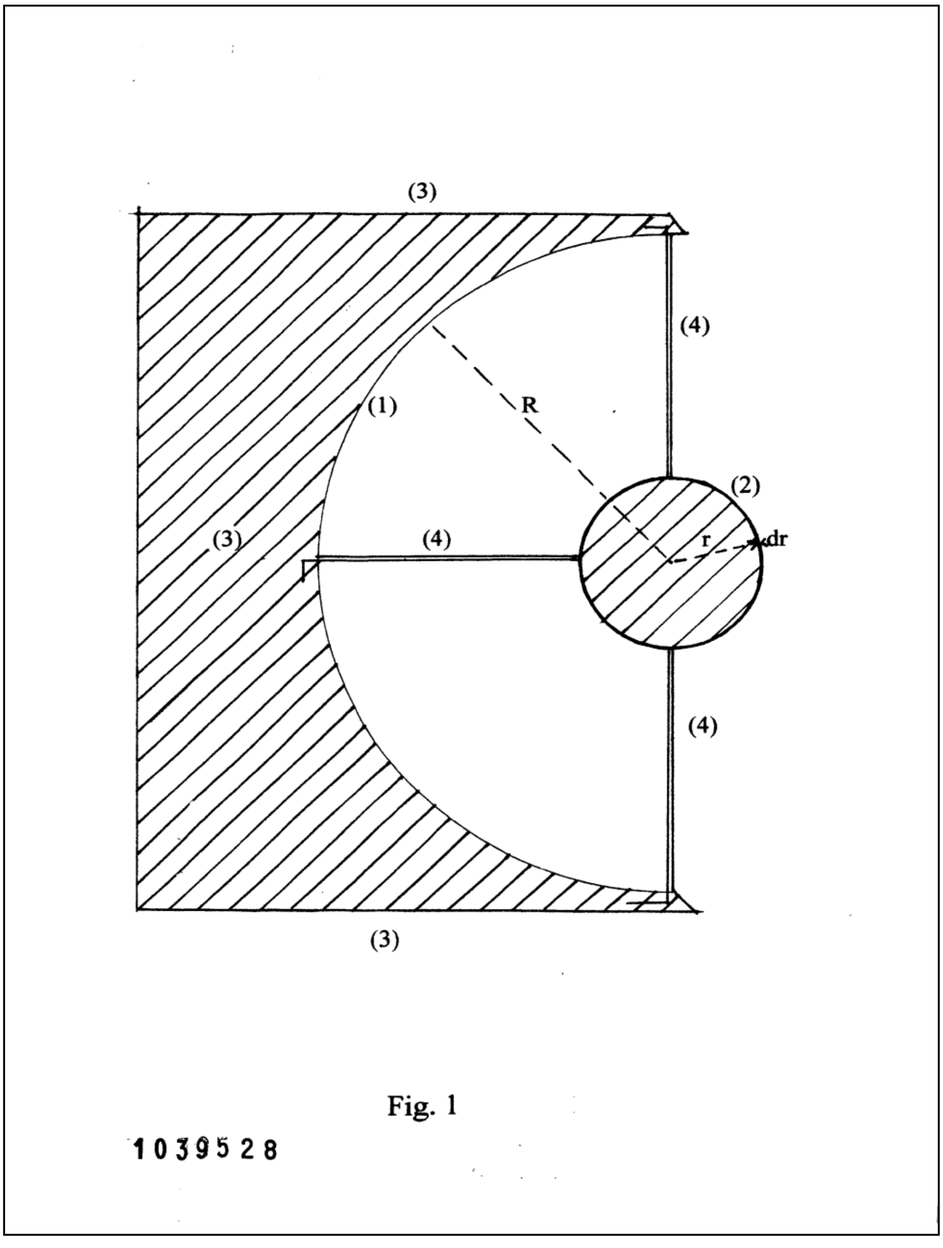

Figure 1: Vertical cross section of the return type breakwater or as horizontal cross section of the annihilation type breakwater, from patent NL 1039528 (EMID, 2013)

the right and left openings between (1) and (2) and mutually annihilate their impulse moments and kinetic energies midway in the breakwater. In case of oblique incoming waves only the normal components need to be considered in the way just mentioned; the tangential components pass along the breakwaters and along the coast.

The breakwaters can be installed either onshore or offshore. The offshore installations are preferred for the following reasons: Not affected by earth quakes, especially those generating the tsunami, which might cause structural damage to the breakwaters even before the arrival of the tsunami; not subject to hydrostatic pressure as they float up and down with the waves; keeping the sea surge off the coast and so prevent flooding on coastal homes and assets; convenient arrangement of shifted double array for free passage of ships and sea life; creation of still water between the breakwaters and the coast, which offers the possibility of territorial expansion towards the sea, thus creating living space for the growing global population.

With regard to the material for the construction of the breakwaters, HDPE (high density poly ethylene) is the material of choice as it has low resistance to water flow, black HDPE is resistant to UV light, non-corrosive, resistant to sea water and unsinkable, specific weight 0.95 kg/l (compared to 1.02 kg/l of sea water), affordable, durable (life time > 50 yrs.) and recyclable. All those aspects are crucial for a large scale application of the technology, especially when it comes to get a competitive kWh price of generated electricity as will be described in the section on the economics of wave energy conversion.

Breakwater as stormbreaker on habitable spaces.

The return and annihilation type breakwaters of the previous section can be used for several situations of coastal defence: protection of sinking coastal (mega) cities, harbours, sinking islands as well as creation of artificial lands and islands. They can also be used as windbreakers forming integral parts of buildings, e.g. the annihilation type breakwater as balcony with the semi-cylinder of curved glass for sea sight. As breakwater is typically associated with water waves and windbreaker with wind waves, the term stormbreaker is also used for both kinds of waves. Many megacities like New York, Miami, New Orleans, Tokyo, Jakarta which is sinking, many harbours, power stations on the east and west coasts of the USA are located on the coasts, most of them at only few meters above high tide sea level, many islands in the Pacific and the Caribbean belonging the SIDS (small island developing states) are already sinking, because of sea level rise and frequently have problems already with storm waves or local tsunami of 3 m high. Figure 2 depicts an example of using a double array of return or annihilation type of breakwaters (5) against tsunami and storm waves, surrounding an island (1) protected by a ring dyke (2) against sea level rise; the radials (3) are floating piers/pontoons serving as access roads to the breakwaters and for structural developments of the still water region between the breakwaters and the island, which region can be used as floating space for living; (4) depicts a floating single family home, with garden, with fresh water from the rain and sustainable electricity from wave energy conversion which will be described in the next section.

It should be clear that (4) can be any construction, like administrative building, a university, a refugee camp, a UN building on international water. Floating homes and other floating constructions are rather common nowadays and in south-east Asia known for long as a need for survival, actually a lot safer than floating on hot magma as we are used to.

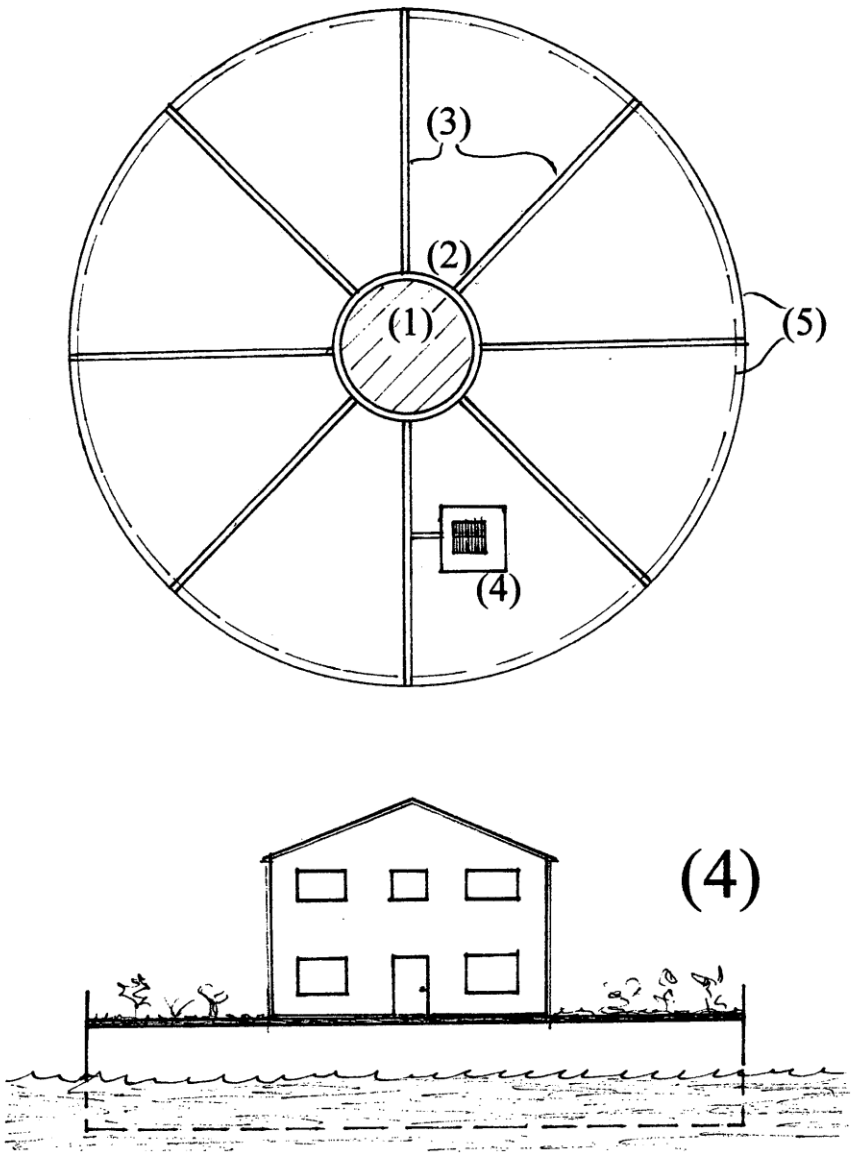

Fig. 2

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Figure 2. Shifted double array return or annihilation breakwaters (5) around sinking island (1), ring dyke (2), piers or pontoons (3), floating living space (4), from NL 1040026 (EMID-1, 2014)

Breakwater as wave energy converter into sustainable electricity

Harnessing wave energy is the dream of mankind, a saying in the literature. Indeed, as the wave power along the coasts varies between 10 – 100 kW per meter wave crest and the world coastline length amounts to 356.000 km, there is therefore a capacity > 3.560.000 MW along the coasts. This means an electricity production per year at 90% load of > 28.067 million MWh (> 28.067 TWh), comparable to the world electricity production of 20.181 TWh in 2008. Table 1 with the column numbers increasing from left to right illustrates this for some coastal and island states more specifically. The production is calculated for 90% running time, 10% is for maintenance, repair and shut down during extremely bad weather like heavy storms or tsunami. Furthermore, there is much more wave energy offshore, for electricity farming. So it would be gratifying to make the dream comes true.

Indonesia	54.716	20	1.094.000	8.625
Japan	29.751	15	446.000	3.516
USA	19.924	20	398.000	3.064
Brazil	7.491	20	150.000	1.183

Table 1: 1. Country, 2. coastline length in km, 3. wave power in kW/m crest, 4. capacity in MW, 5. production in TWh/year

However, up till now there are only a few MW capacity installed, whereas since the oil crisis in the 1970s there were many (> 1000) ideas for wave energy conversion in research and pilots projects with wave energy converters in all sizes and shapes. The main problem is the price per kWh generated electricity, which is > 1 USD, much more than the 0.05 USD for land hydro electricity or nuclear energy. Another problem is that the wave energy converters are not resistant to heavy storms as they are not meant as breakwaters.

A review of the situation is given in NL 1040193 (EMID-2, 2014). In this document the author proposed a dual purpose breakwater-wave energy converter (BWEC), which acts as breakwater during tsunami, which might occur once or twice in a century, or storms, which may occur once or several times a year, and under normal weather conditions as wave energy conversion to electricity. The annihilation type breakwater is taken as a starting point for the modification to wave energy converter. The layout is depicted in Figure 3, a vertical cross section through the middle of the breakwater, where (1) is the semi-cylinder of radius R, wall thickness dR, (2) is the small cylinder with radius r and wall thickness dr, (3) and (4) are fixing and floating provisions, (5) are upper and lower covers of the upper and lower openings of the breakwater, closed in the WEC-mode and open in the B-mode. In the latter case the inlet to the WEC is closed to protect the installation. In the WEC-mode the water entering the breakwater is guided via the tube T with a one-way valve (6) to the conductor (7) with adjustable radius s to be collected in a collector (8) at height H, called head, from where the water goes through the penstock (9), driving the turbine-generator (10), leaving through the outlet (11) to the ocean. A reservoir as in land hydro is not needed here as the ocean is the reservoir. With regard to the choice of materials, as already mentioned in the breakwater section, HDPE is the best choice. The BWEC can be prefabricated and the dimensions adjusted to the available wave power of the desired location. Moreover, the scalability is linear, i.e. just adding up standard modules, which makes construction easy.

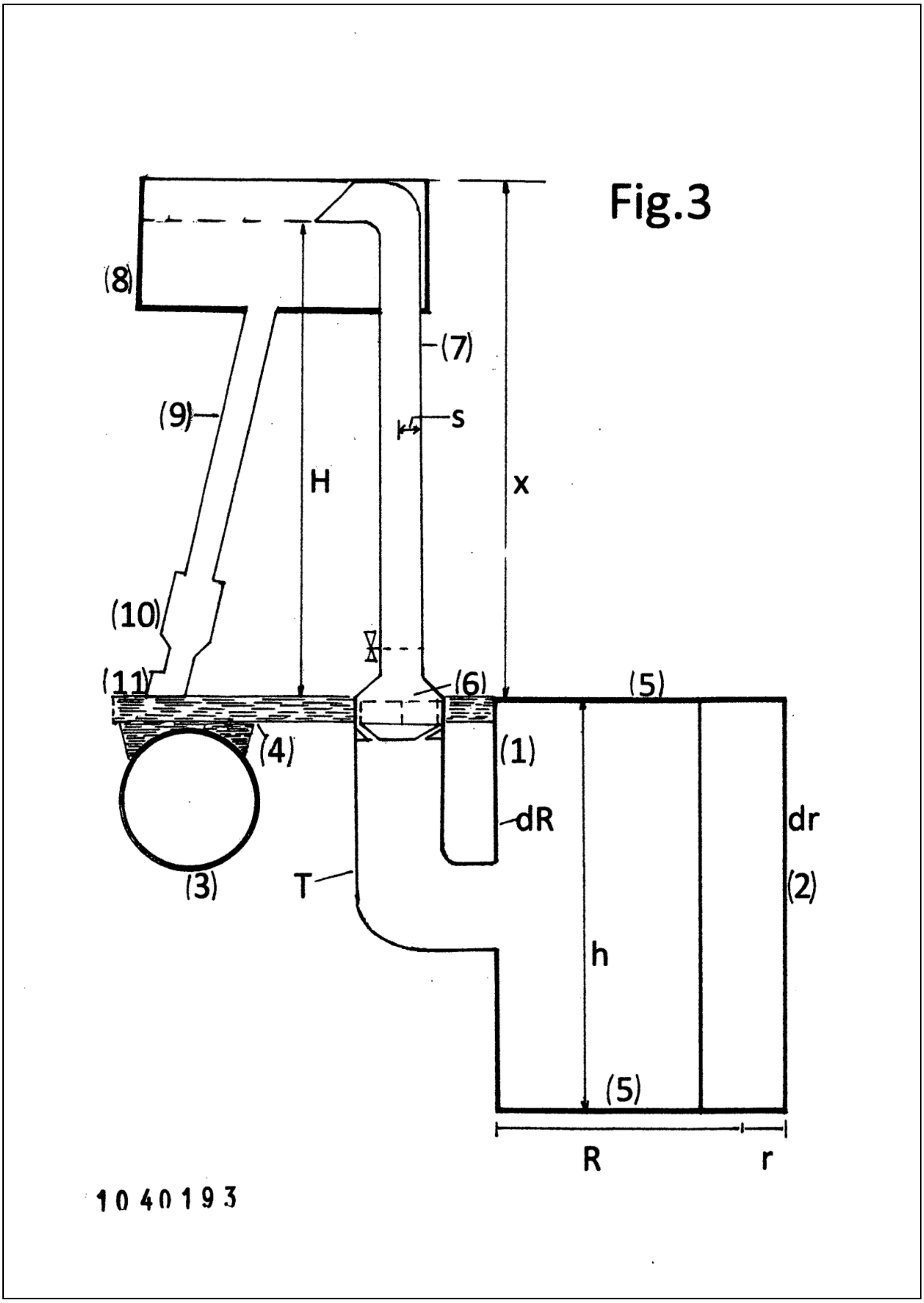

Figure 3. Breakwater – wave energy converter, from NL 1040193 (EMID-2, 2014)

Compliance to DRR and the economics of BWEC

From the above discussions one concludes that it is indeed possible to reverse the climate change, to prevent that disasters inflict casualties upon coastal communities, by taking proper measures like offshore BWECs, during tsunami or storm to prevent the sea surge coming onshore, saving lives and repair costs on coastal infrastructures (e.g. for the 2011 Japan tsunami: repair costs were 110 billion USD, plus persistent hazards of crippled nuclear power station, for hurricane Sandy the damage was 65 billion USD); in idle the system is producing sustainable electricity. The capacity is enormous and is sufficient for the world need.

For the wave energy conversion the kWh price of the electricity is crucial. The calculation, done with the usual assumptions as for other energy sources, is given in NL 1040193 (EMID-2, 2014). As an example, even for a rather low wave power of 10 kW/m crest as at the coast of Suriname (where the author was born) the kWh price is 0.01 USD, very competitive indeed, compared to 0.05 USD of present day gold standard. With 386 km length of the coastline the coast has a capacity of 3860 MW, that is 20 times the present day need (≤ 200 MW) of that country, so it is enough for the near future and there is more offshore when needed. This is a better alternative than the long discussed and meanwhile abandoned idea of amplifying the existing land hydro with 100 MW running capacity. For each coastal country one can calculate the capacity from the coastline length and the wave power at that coast.

Creation of living space on still water is another important aspect of the technology, to relieve the pressure on the natural resources of our planet due to the growth of the world population. Implementation of the technology can be done simultaneously at any scale in all parts of the world, with some urgency on locations under tsunami threat, like on the ring of fire around the Pacific, especially east of Japan and the Philippines, south of Indonesia and the west coasts of north and south America where the subduction zone is very close to the coast. Application is urgently needed for the sinking SIDS in the Pacific and the Caribbean.

To conclude, it is indeed possible by nuts and bolts technology to fulfil the dream of mankind in harnessing the wave energy of the ocean, at the same time protecting the community against disasters and creating save havens for the displaced persons and victims of conflicts and abuses. The technology might be helpful for organizations, national and UN institutions, to resolve the problems of slums around megacities and poverty by providing ample living space on floating structures on national and international waters.

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