MARINE ENERGY

Marine energy refers to the renewable energy carried by ocean waves, tides, currents, salinity and temperature differences.

The constant movement of water in the oceans creates an inexhaustible source of energy with a potential capable of providing a substantial amount of energy to a large part of the world's population. In this regard, Chile is located amongst the five zones of the greatest wave potential in the world, with this potential being the most intense in winter, i.e., the time of occurrence of the greatest energy demand.

It has been estimated that if at least 0.1% of the renewable energy available in the oceans could be converted into electricity, this could satisfy the world's current energy demand by more than five times.

The energy of the oceans presents itself as an effective alternative due to its stable generation cost, reliable supply over long time scales, i.e., with low inter-annual variability.

The objective for the energy sector in Chile is to field prototypes to try out performance in the sea and to move the technology forward to the point of becoming comparable with other renewable energy technologies, such as wind power. This step will make it possible to achieve greater confidence in the use of marine energy as a reliable energy source.

The regulatory framework for incorporating sources of non-conventional renewable energy in Chilean marine waters in 2013 sets out the standards and regulations of Chilean law for the development of adequate conditions for the incorporation of these sources of energy in Chile, and especially tidal power and wave power, which are currently the forms of power generation that have the best technological development proven on international projects.

In addition, the available information indicates that the best energy potential for putting these technologies to good use is located in the near and far south of Chile, which when added to the current coverage of Chilean electrical systems and that forecast over a medium term horizon, would place the coastline of the Pacific Ocean between the Bío Bío Administrative Region and the Los Lagos Administrative Region as being that which affords the best conditions for the siting of power generation projects located in the sea.

1.0 WAVE POWER

Wave power is the most studied form of marine energy, and is therefore that which has the greatest diversity of mechanisms for the extraction of energy. At present, the conversion of the energy of waves is being investigated in various countries of the European Union, with major activity also under way outside of Europe, and principally in Canada, China, India, Japan, Russia and the United States.

Wave power is based on putting to beneficial use the energy generated by the movement of waves. Waves are generated by wind passing over the surface of the sea, which is a consequence in turn of the differences in pressure caused by solar radiation. The sea acts as an accumulator of this energy, transporting it and storing it until reaching the coast, where it is made use of by different existing converters. The intensity of the wave action, and hence the quantity of energy extracted will depend on the intensity of the wind, its duration y and the length over which the wind transmits energy to the waves.

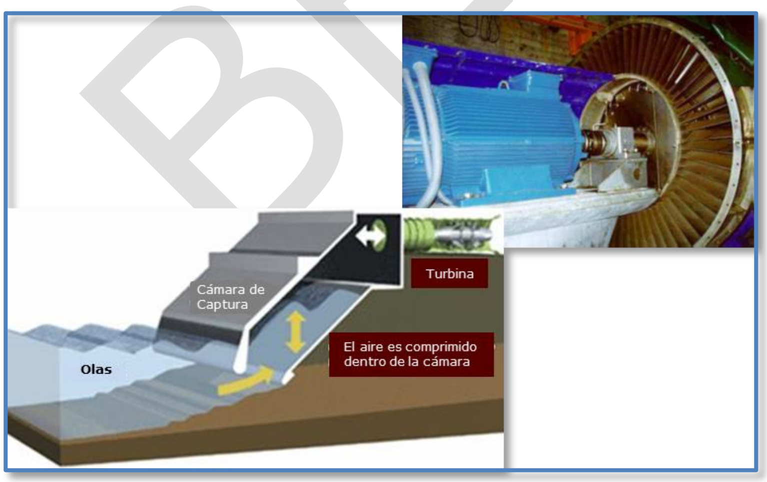
Different energy conversion devices exist- Their classification and principal characteristics are set out below.

Primary Wave Energy Converters: wave energy can be used to move floats vertically and in rotation; in shallow water, wave energy is extracted horizontally by means of floats or fixed structures. A semi-submerged structure can extract energy from the sea by means of mechanical or pneumatic means and, additionally, from the variation in pressure caused by the wave action below the surface of the water. Floating resonators and navigation buoys can combine the effects of resonance in a tube with the vertical movement of the float, yielding as a result a much more efficient energy performance.

On stationary devices, which have a lower opening in the tube oriented in the direction of wave propagation, the energy is harvested by using the total pressure generated by the wave, which is approximately double that of the preceding case in which the static pressure only is beneficially used.

Secondary Wave Energy Converters: pneumatic and hydraulic turbines, mechanical transmission devices and magnetic induction devices; at times, the system designed is intended exclusively for the desalination of water.

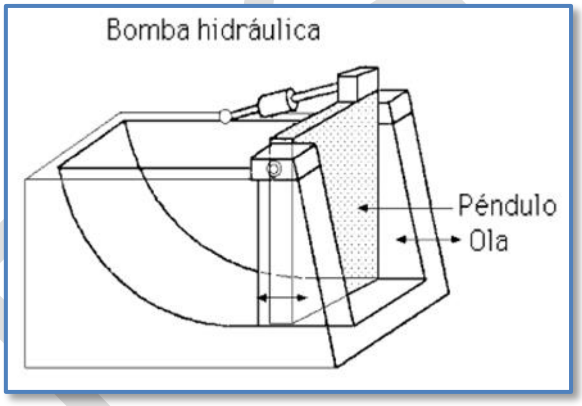
1.1 Shoreline Wave Energy Converters



Land Installed Marine Pneumatic Energy Transformer (**LIMPET –** 500 kW)
LIMPET uses an oscillating water column (OWC) developed by Queen's University of Belfast and Wavegen Ltd in the United Kingdom in the 1990s. It is a shoreline wave energy converter structure that is made up of an in situ concrete collector with the generating unit installed immediately behind the wall

of the rear collector. The system functions such that the movement of the waves pushes an air bag up and down behind a dike; thereafter, the air passes through a Wells turbine.
Finally, when the wave is returned to the sea, an air depression circulates through the turbine in the opposite direction; however, the turbine has a design that allows it to continue spinning regardless of the direction of the air flow. It is currently the latest version of his prototype device.
Approximate power: 75 kW/m.

Further information: www.wavegen.com



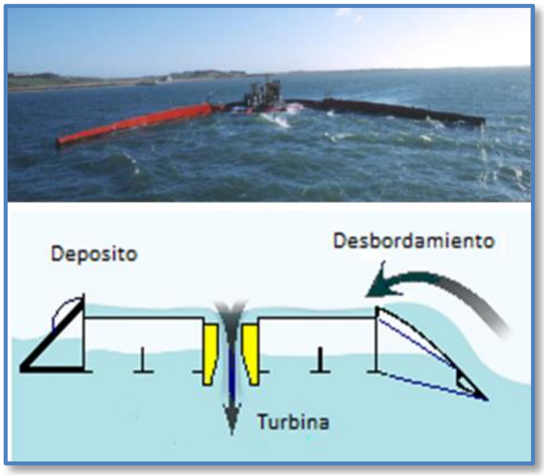
Pendulum System: The pendulum type generator system is a device suitable for installation on a breakwater. This system consists of a rectangular concrete box that is open to the sea on one end. A pendulum fin is articulated on this opening such as to allow the wave action to bring about a back and forth movement; these oscillations are transmitted and absorbed an oil hydraulic device. The pilot plant is located in Muroran (Japan 1984). Currently the model is out of development and exists as a conceptualization only. The maximum power is 15 kW with an average of 5 kW for waves of 1.5 m in a periodo f 4 s.

Further information:
www.engitek.com/ocean-waves-%20energy-pendulum-generators.html

Other Devices:

- Seawave Slot-Cone Generator (SSG)

1.2 Nearshore Wave Energy Converter Devices

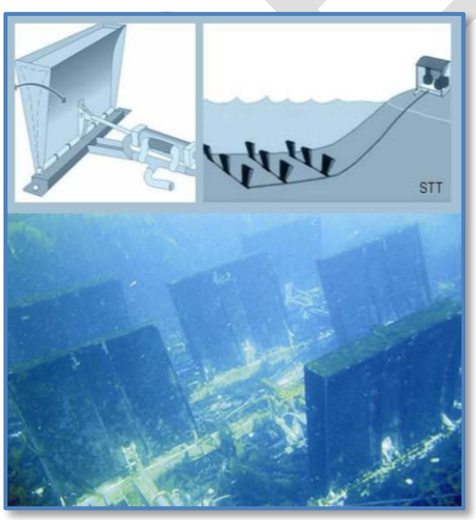


Wave Dragon: Wave Dragon is an overtopping device developed by a group of companies led by *Wave Dragon Aps* in Denmark in the 2003 – 2005 period. This device combines a curved double overtopping ramp and two reflector arms used to focus the energy on the basin in the ramp and fill an upper reservoir. Electricity is produced by a set of Kaplan turbines Kaplan.
The approximate power depends on the model and runs in a range of between 0.4 kW/m and 48 kW/m.

Further information: www.wavedragon.net

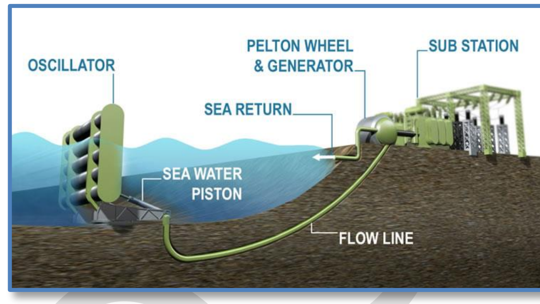
OCEANLINX (GreenWave, BlueWave, OgWave): This company has been active for more than 15 years in Australia renewing their prototypes that functions under the oscillating water column (OWC) principle with the use of a Dennis-Auld turbine. This air passage turbine achieves a greater efficiency than a Wells turbine.
The approximate power is 500 kW. The latest designs are the optimized BlueWave and the GreenWave, with the latter to be ready in late 2013 with a promise to deliver 1MW of power.

Further information: www.energetech.com.au; www.oceanlinx.com



Wave Roller Plate (Sea Bottom): In 2012, an energy module was deployed in Finland and Portugal with three 100kW WaveRoller units each (total of 300kW). The WaveRoller is a plate anchored on the sea bottom that functions as an oscillating conversion device installed in shallow water where the circular movement of the waves is transformed into an elliptical movement until the water particles on the sea bottom take on a back and forth movement only. This movement moves the plate, and the kinetic energy produced is collected in a reciprocating pump to generate hydraulic pressure that is then transformed into electricity by a generator. The approximate power is low and for this reason a set of modules is needed to achieve the required energy.

Further information: www.aw-energy.com



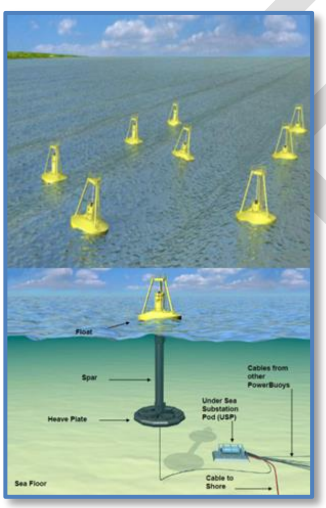
Oyster 800: Oyster 800 is a project in the process of development by Aquamarine Power as the successor to the Oyster 1, but with a greater energy generating capacity. The wave energy converter is an oscillating fin device similar to the WaveRoller and provides sea water under pressure to a, power takeoff unit. It is used in water of around 12 meters depth.
The maximum power is 800 kW.

Further information: www.aquamarinepower.com

Other devices:

- Backward Bend Duct Buoy
- Wave Rider
- Osprey

1.3 Offshore Wave Power Converter Devices



Power Buoy: Power Buoy was developed by Ocean Power Technologies (OPT) at the Hawaii marine base in 2004. It consists of a floating buoy 17 m long by 3 m in diameter anchored to the sea bottom such as to be able to move freely in a vertical direction in response to the waves. The Power Buoy wave energy generation system uses an intelligent open sea buoy to capture and convert waves into mechanical force of controlled rotation that drives an electricity generator. It is designed to be installed in water 40 to 60 m deep at around 8 km offshore. It is one of the wave power devices with the greatest future due to its high power and small size. The approximate power is 40 kW, but plans are in the making for a system of 500 kW using a buoy of greater size.

Further information: www.oceanpowertechnologies.com

Aqua Buoy 2.0: In 2007, the company Finavera Ltd. developed a floating buoy 6 m in diameter and 30 m long based on the conversion of the vertical component of kinetic energy of ocean waves (a point absorber system) by means of pressure through use of hose pumps. The system consists of a hollow acceleration tube rigidly mounted in the body of the buoy. This tube is open at both ends to allow sea water to enter and exit in either direction. Inside the tube is a steel reinforced rubber hose whose internal volume reduces when the hose is extended in such a manner as to act as a pump. The hose pump pumps water at a high pressure level to an accumulator that supplies the water in turn to a turbine that acts as an electricity generator, Approximate power of 800 kW.

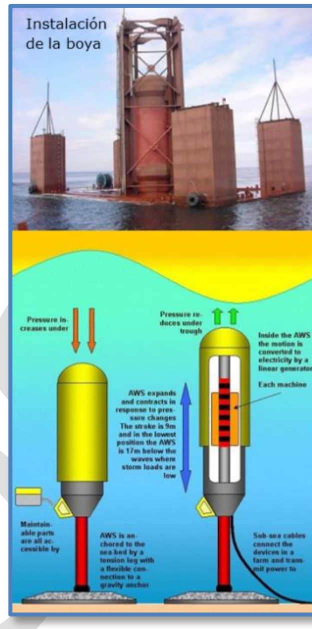
Further information: www.finavera.com

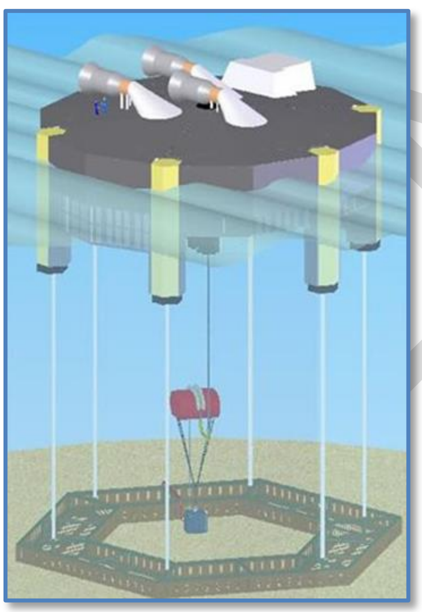
Pelamis: Developed by Ocean Power Delivery and started up in 2004, This device basically consists of a semi-submerged articulated structure made up of 4 cylindrical sections joined by hinges. The device is approximately 120 m de long and 3.5 m in diameter and is moored with slack moorings in water ~50 m deep with an orientation in the same direction as the waves. As the waves pass they induce movement that is resisted by hydraulic cylinders incorporated in the articulations that pump oil at high pressure to drive a hydraulic motor through an attenuated energy system (attenuator); these motors drive generators to produce electricity.
Approximate power of 750 kW.

Further information: www.oceanpd.com; www.pelamiswave.com

Archimedes Wave Swings AWS: Developed by AWS Ocean Energy, the AWS consists of a cylindrical buoy anchored to the sea bottom. As the waves pass by, the mechanism moves an air-filled upper shell against a lower stationary cylinder, imparting a vertical movement that is transformed into electricity. When nearing the crest of the wave, the water pressure increases on the cylinder, and the upper part (or float) compresses the gas that is inside the cylinder to equalize pressures. As the wave passes and the cylinder expands, exactly the opposite occurs. The relative movement between the float and the lower part of the silo is transformed into electricity by means of a hydraulic system and a motor-generator assembly.
Power: A project is currently under development to create an optimized 250-kW system.

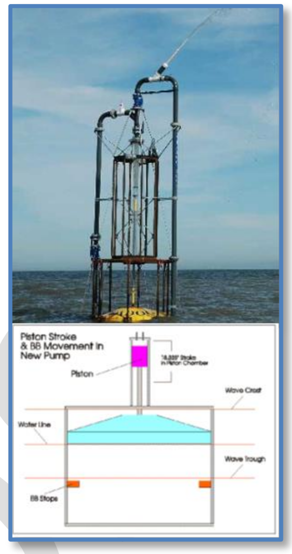
Further information:
www.waveswing.com; www.awsocean.com





Orecon: A device presently in the developmental phase by Electric Power Research Institute (EPRI) that functions under the floating oscillating water column (OWC) concept and uses a configuration of several simultaneous columns and a self-rectifying impulse turbine. Using a la combination of several columns inside the collector component, the device can be tuned to resonate at multiples instead of a single frequency, thus to capture energy over a much wider frequency band. The generation of energy is divided into three stages. First, the air pressure produced by the water column is converted into a rotary movement by means of a turbine. In a second stage, this rotary movement is converted into hydraulic pressure, and finally in the third stage a generator changes this pressure into electricity. The turbine efficiency is estimated at 51%. Approximate power: 1.5 MW.

Further information: www.orecon.com



Sea Dog, absorbent water pump (Independent Naturak Resources): Sea Dog is a point absorber type device that functions as a pump. In a chamber, an ascending block filled with air (shaded in blue in the figure to the left) rises and falls by following the movement of the waves. This block is connected to the piston handle that is moving the piston inside the cylinder. When the block lowers to follow into the trough of the wave, the piston also lowers, which causes water to enter through an entry valve to fill the cylinder. When the crest of the wave arrives, the block and the piston rise, and the water exits under pressure through an outlet valve. Thus, each wave pumps sea water to an onshore tank where the water can return to the sea by passing through conventional hydraulic turbines to generate energy. Power is ~45 kW.

Further information: http://inri.us/index.php

WaveBob: WaveBob is a buoy of point absorbing type that has two bodies, with a lower body of greater inertia that is not subjected to the wave action. By making use of the linear movement of the waves, a device generates 500 [kW] in a constant flow by means of a hydraulic motor that functions with accumulators of oil under pressure. An autonomous control system aids to obtain a good prediction of the energy output. The generation of energy uses standard elements and biodegradable fluids only to prevent environmental impact.
The approximate power is 500 kW.

Further information: www.wavebob.com

Other Devices:

- Salter Duck
- McCabe Wave Pump
- Floating Wave Power Vessel
- Point Absorber Wave Energy Converter
- Wave Rotor (apparently a nearshore device)
- Bristol Cylinder
- Wave energy module
- WavePlane
- Wavemill
- Submerged Matrix
- Oweco (Ocean Wave Energy company)
- Wave energy conversion activator (WECA)
- Danish Point Absorber
- Cylindrical Energy Transfer Oscillator (CETO)
- Wave star

- Mighty Whale (OWC)

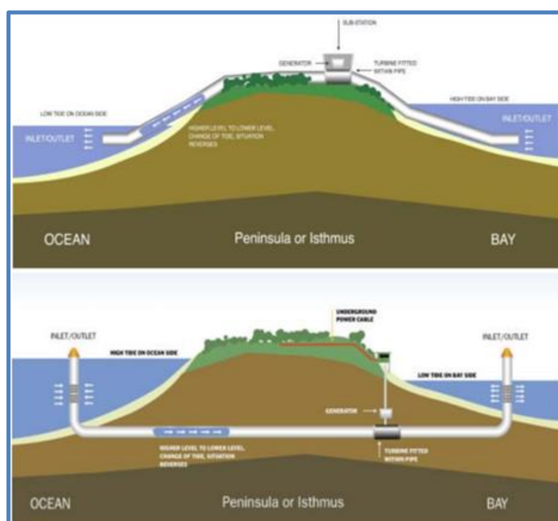
2.0 TIDAL POWER

Tidal power as an energy conversion technique makes use of the natural rise and fall of ocean and sea levels caused mainly by the interaction of the gravitational fields of the sun-earth-moon system. The tide is associated with ascending and descending vertical water movements (tidal range) and horizontal water movements (tidal currents). Accordingly, this resource involves distinguishing between the energy of the tidal range (potential energy of the difference in tidal head) and the energy of tidal current (the kinetic energy of water in a current). Various devices exist that make use of the different tidal energies.

2.1 Tidal Range Tidal Energy Converter Devices

Tidal Barrage Power Plant; The oldest commercial tidal barrage power plant was constructed on the La Rance Estuary in France in the 1960s and is considered at present to be a successful operation, subsisting as the only industrial scale tidal power station in the world. Its 240 MW of power is approximately one fifth of the power of a nuclear reactor. Other smaller tidal power stations have been built in Russia, Canada and China. Approximate power: 240 MW.

Further information: www.wyretidalenergy.com/tidal-barrage/la-rance-barrage



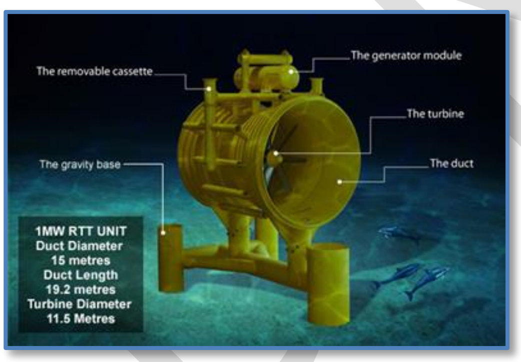
Tidal Delay: As a result of the environmental problems that a damming or impoundment of the tide produces, Wooshed Technologies designed a system termed Tidal Delay in 2002-2004, which is based on the tidal delay of sea water that occurs in places such as peninsulas or isthmuses. These geographic characteristics create a time lag or difference in the phase of the tide between the movement of water driven by the tides on both sides of such coastal relief landforms in a process that can take up to several hours to complete. This delay creates a difference in energy potential. By connecting both points situated at a distance by piping, with each pipe incorporating a standard turbine and generator this makes it possible for the potential energy to be stored in the system and used to produce electricity. The problem that is still in the process is the interruption of the production of energy due to the cycles of the tides. The amount of power depends on the difference of tides, the length of the piping and the internal piping diameter.

Further information: www.woodshedtechnologies.com.au

3.0 CURRENT POWER

The large oceanic surface currents are unexploited energy reservoirs. Their total energy flow has been estimated at between 2.8 and 1014watt-hr. Due to their relation with winds and surface warming processes, marine currents are considered to be indirect sources of solar energy. The concept for harvesting kinetic energy from currents is essentially the same as with tidal currents. The majority of the existing devices are based on the de horizontal or vertical shaft turbine concept. At present, current power is an energy resource that is in the early stage of development.

3.1 Current Power and/or Tidal Current Power Converter Devices



3.1.1 Horizontal Shaft Turbines

Lunar Energy (Rotech Tidal Turbine RTT): The RTT is a totally submerged bidirectional horizontal shaft turbine located in a symmetrical venuri duct. The duct is used to accelerate the tidal flow through the turbine and therefore increase the energy that can be captured by the turbine. The device consists of a totally submerged turbine with a power conversion system inserted in a groove. This makes deployment and maintenance easier. It is probable that the initial standard commercial unit will be of a 1 - 2 MW power rating starting in 2015.

Further information: www.lunarenergy.co.uk

Open Hydro TM: Open Hydro consists basically of a turbine designed to be implemented directly on the sea bottom. In 2007 OpenHydro inaugurated their assembly plant in Europe. The center occupies 2500 m^2 of floor space in the port of Greenore, Ireland. Turbine farms provide a significant, invisible supply of clean, renewable energy. The installation site needs to be selected with all due consideration to the velocity and volume of water that passes through the site and the depth and geology of the marine soil.
Approximate power: 1520 kW at 2.57 m/s.

Further information: www.openhydro.com

Verdant Kinetic Hydro Power System (KHPS): KHPS is a hydroelectric system that uses a three-blade horizontal shaft turbine with an incorporated generator that is deployed under water. It can be implemented in connection with either tidal or river stream currents.

In December 2006, the first set of devices was installed on the East River in New York.

Approximate power: 36 kW with a 5-m diameter rotor.

Further information: www.verdantpower.com

Marine Current Turbines (Sea Gen): Sea Gen is one of the devices that has been in the trial stage for the longest time (their old model was known as SeaFlow 300 kW) with a power of 1.2 MW from two 600 kW turbines installed at Strangford Lough, Northern Ireland in April 2008. It consists of two twin power trains mounted on a crossbeam. This beam can be raised to above sea level for inspection and maintenance. The generation system is connected to the power grid through an onshore electrical substation, for which a Horizontal Directional Drilled (HDD) tunnel was driven 450 meters long on a 300-mm diameter section 20 meters below the sea

bottom to house an 11-kW power cable and take away the power generated by the submerged turbines. The device starts to generate electricity when the current flow runs at greater than 1m/s and the maximum speed of rotation is 14 rpm when resulting from a current speed of 12 m/s. Projects make use of power farms with the intent of reaching the maximum power capacity. The turbine model and size varies from one project to another, and so does its potential.
Approximate power: 1.2 MW.

Further information: www.marineturbines.com/SeaGen-Products

Gulf Stream turbines: This turbine amounts to a unique concept for a self-sufficient submergible electric power station that operates safety near the surface. Surface turbulence is neutralized by the pair of turbines and generators that turn in opposite directions and that are mounted low and on each side of a torpedo shaped flotation tank that extends from stern to bow. Thanks to the float and the weight of the generators, its center of floatability is situated above its center of gravity which additionally prevents the unit from overturning.
Approximate power: between 600 and 1000 kW per rotor depending on the rotor diameter.

Further information: www.gulfstreamturbine.com

Underwater Electric Kite (UEK) (h-axis, shrouded rotor): This company has been developing and evolving its different turbines since 1981. The latest prototype was created in 2005 and consists of a 4-m turbine of high solidity and a 5.18-m nozzle ring to increase velocity, which enables a substantial energy conversion improvement to be achieved.
Approximate power: 400kW at 3.0 m/s

Further information: www.uekus.com

SMD Hydrovision: The SMD Hydrovision system consists or two horizontal shaft rotors that spin in opposite directions joined by a crossbeam and turbines of 500 kW each. The mooring system allows the turbines to be aligned in the direction of the current flow without requiring any external intervention. Each turbine blade is 8 meters long and the rotor is of 18.5-m diameter. These 1-MW units are designed to be mounted in an open sea environment with velocities of 9 knots or more at water depths of more than 30 meters. The approximate power is 1 MW at 2.3 m/s.

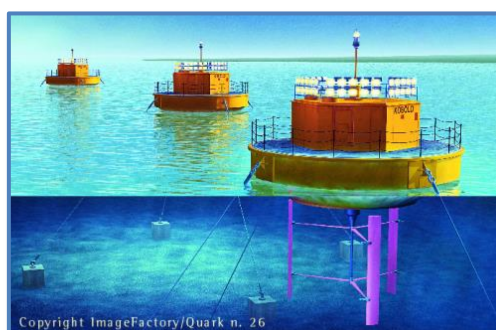
Further information: www.smd.co.uk, www.subsea.org

3.1.2 Vertical Shaft Turbines

Gorlov Helical Turbine (GHT) (vertical-axis): This turbine consists or two or three blades mounted along a vertical shaft to form a rotor. The kinetic movement of the water current creates a thrust on the blades, causing the rotor to turn and drive an electric power generator. This turbine was specifically designed for hydroelectric applications, principally in low flow water streams. The turbine spins at two times the flow velocity of the water current.
Power: ~ 7 kW, which depends on the application - for use on rivers, ocean currents, conventional hydropower outfalls, etc.

Further information:
www.gcktechnology.com/GCK/pg2.html

Ponte di Archimede (Enermar): The Italian company Ponte di Archimede proposed a power generation project that is based on an innovative turbine termed KOBOLD. It consists of a floating structure that has in its inferior a vertical shaft turbine or rotor 6-0 m in diameter with blades 5.0 m long. The power is calculated by multiplying the torque on the turbine shaft by the angular velocity. The pilot plant has been operating since 2001 and has been considered satisfactory up until now.
The design power is 80 kW.
Further information:
www.tidaltoday.com/tidal07/presentations/GuidoCal

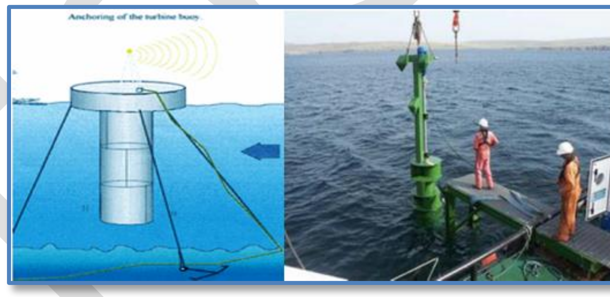


cagnoMoroso.pdf

New Energy Corporation Inc.: This company has developed auxiliary products for the generation of power at the personal consumption level. They have turbines capable of supplying between 2 and 8 homes on the average, in addition to others that are currently in development and capable of reaching 250 kW; their functioning is the same as the GHT. The power varies between 5 and 25 kW, with 125 and 250 kW units now under development.

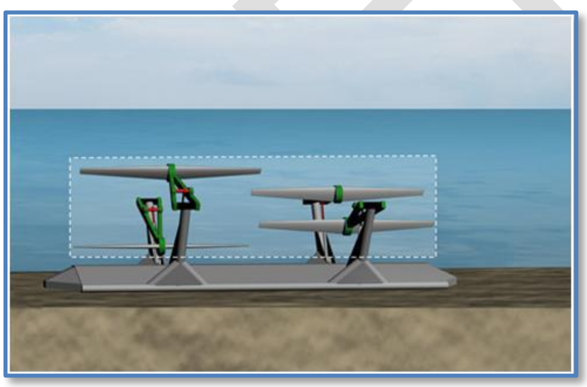
Further information: www.newenergycorp.ca

SeaPower Inc (vertical shaft): The EXIM Tidal Turbine Power Plant (TTPP) by SeaPower is based on the Savonius turbine and was originally designed for the conversion of kinetic energy of oceanic currents into rotary energy. This type of vertical shaft turbine is relatively slow, but generates high torque.
Approximate power: 60 kW.



Further information: www.seapower.se

3.1.3 Oscillating Hydrofoils



Pulse Stream 100: Developed by the company Pulse Tidal with trials run in the UK, this device functions in the manner of an aircraft wing. The control systems change their angle in relation with the water current creating forces of lift and aerodynamic resistance that cause the oscillation of the apparatus. The typical movement of this oscillation drives an energy conversion system. The approximate power is 100 kW.

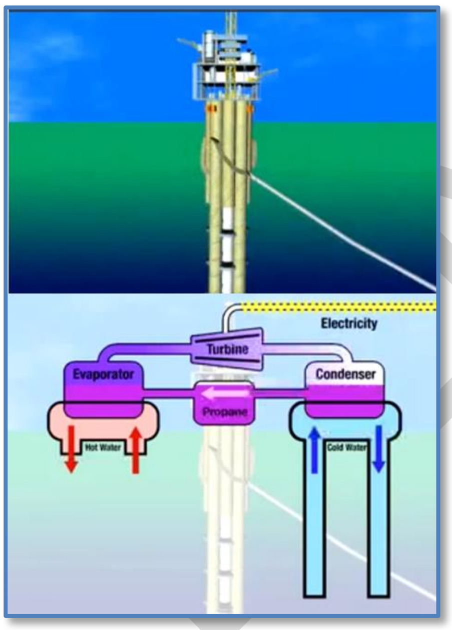
Further information: www.pulsetidal.com

4.0 POWER GENERATION FROM THERMAL GRADIENTS OR OCEAN THERMAL ENERGY CONVERSION

This form of power generation is known as Ocean Thermal Energy Conversion (OTEC). It is marine energy based on the temperature difference between the sea surface and deep waters. This difference is used as a constant source of electricity. The technology is viable in tropical zones where thermal gradients of at least 20° C are found with a sea bottom near onshore facilities. The quantity of energy available in the temperature gradient can be substantially higher than the energy required to pump the cold water from the lower layers of the ocean. To convert this thermal gradient into electric energy, hot water can be used to heat and vaporize a liquid and in some cases distilled water and brine can be used as byproducts to obtain drinking water and salt, respectively.

4.1 Ocean Thermal Energy Conversion Devices

OTEC: Three types of OTEC plants exist: open cycle and closed cycle electric power plants and hybrid systems. The open cycle systems make use of the fact that water boils at temperatures below its boiling point when it is at pressures lower than normal. This system can convert warm surface water into steam in a partial vacuum and then use the steam produced to move a turbine connected to an electric power generator. The cold water sent by piping from well below the surface of the ocean is used to condense the steam and convert it into desalinated water for consumption or irrigation. The closed cycle uses warm surface water that is passed through a heat exchanger to boil a working fluid, such as ammonia or chlorofluorocarbon that has a low boiling point. The cold deep ocean water is used thereafter to condense the working fluid and is returned to the heat exchanger to repeat the cycle. Finally, the hybrid systems use both mechanisms.



OTE PLC anticipates building installations of 5- 10 MW in the Bahamas. The power varies between 500 kW and 10 MW.

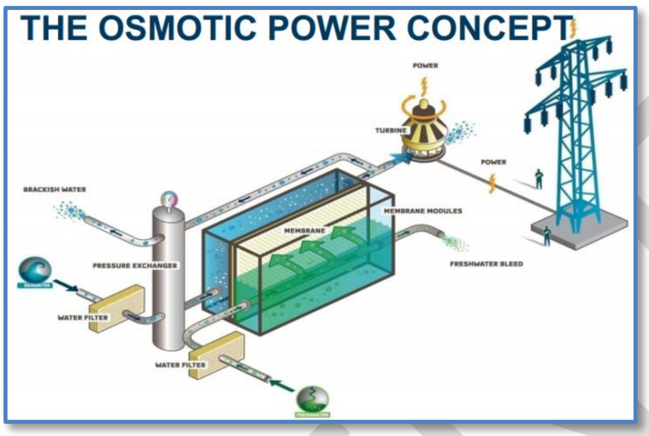
Further information: www.otecnews.org ; www.oteplc.com

5.0 POWER GENERATION FROM SALINITY GRADIENTS: OSMOTIC POWER

Osmotic power, also known as blue energy, is the energy obtained from the difference in the salt concentration between sea water and river water by means of processes of osmosis. Pressure retarded osmosis is based on placing two fluids in contact through a specific membrane that allows water to pass, but not the salts. This generates a difference in pressure that is used by a turbine. This renewable energy is of great potential in regions of rivers with high stream flow volumes.

5.1 Osmotic Power Conversion Devices

Retarded Pressure Osmosis: The world's first osmotic power plant with a capacity of 4 kW was inaugurated by Starkraft in November 2009 at Tofte, Norway. Currently under evaluation is the location of a new 1-2 MW pilot power station.

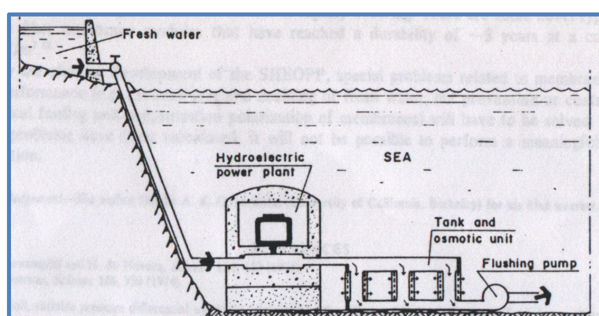


At the osmotic power plant, the fresh water and the salt water are conveyed in separate chambers divided by an artificial membrane. The salt molecules in the sea water pull the fresh water through a membrane, thereby increasing the pressure on the sea water side, and the pressure is used in an electric power generation turbine.

An approximate power reaching 2 MW is intended in the new pilot power station being designed for 2018.

Further information: www.statkraft.com/energy-sources/osmotic-power/

Convertidor SHEOPP (Submarine Hydro Electric Osmosis Power Plant): SHEOPP is a design for a submarine hydroelectric power plant anchored to the sea bottom. The surface fresh water from a river or a water pipeline is conveyed through a head pipe to a hydraulic turbine. Following the generation of electric power, the fresh water is discharged and depressurized in a tank. Finally, the fresh water diffuses out to the sea by osmosis through a semi-permeable barrier. The viability of this plant on an



Simplified schematic diagram of the SHEOPP converter.

industrial scale is doubtful. In addition, another plant design exists termed PRO (Pressure Retarded Osmosis) Underground that uses the same mechanism but, unlike SHEOPP, is located underground. The power output is relatively low.

Further information: www.exergy.se/goran/cng/alten/proj/97/o/index.htm

Reversed Electro-dialysis: This is a second method that is being developed and studied, which consists of the creation of a salt battery. This method was described by Weinstein and Leitz in 1950.

Approximate power: under study. Development is currently in a conceptual phase.

Capacitive Method: A third method is Doriano Brogioli's capacitive method, which is relatively new and until now has been tested on a laboratory scale only. With this method energy can be extracted out of the mixture of saline water and fresh water by means of cyclically charging up electrodes. Approximate power: under study. Development is currently in a conceptual phase.

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