Power and Energy from the Ocean Energy Waves and Tides: A Primer

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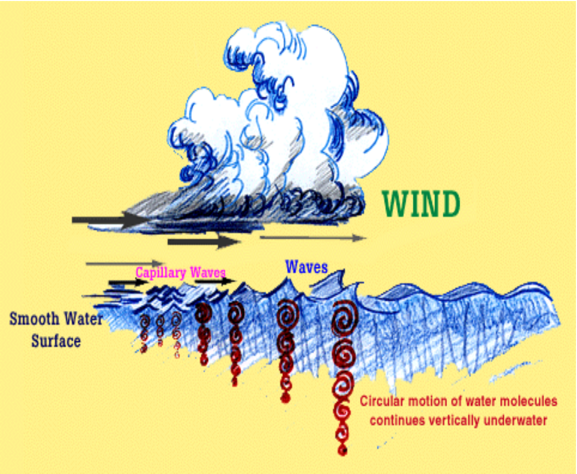
This primer is intended to inform the general public about the possibility of adding ocean wave and tidal power to our portfolio of energy supply options. We have investigated the possibility of many renewables resources; solar, wind, geothermal and biomass. Ocean wave and tidal is probably the last of the large natural resources not yet investigated for producing electricity in the US.

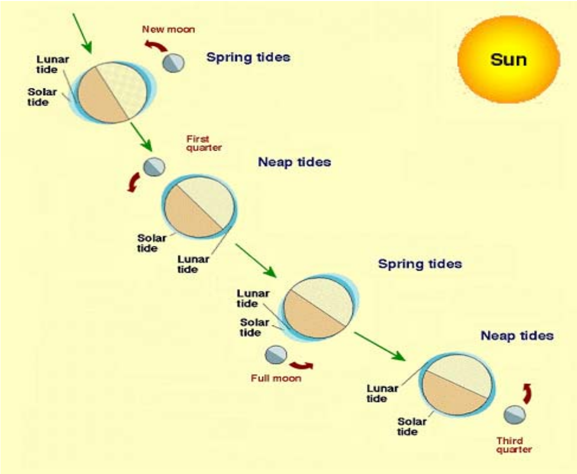
The United States has significant ocean wave and energy resources. The technology to convert those resources to electricity, albeit in its infancy, is here today. This is a renewable resource which can be converted to electricity clean and emission free. Given proper care in design, siiting, deployment, operation and maintenance, ocean wave and tidal power could be one of the most environmentally benign electricity generation technologies yet developed

The natural power of the ocean has inspired awe since the dawn of mankind. Mariners and others who deal with the forces of the sea have learned to understand the potentially destructive powers of ocean waves as well as the regularity and predictability of the tides. Ocean waves and tides contain large amounts of kinetic energy, derived from the winds and gravitational pull of the sun-earth-moon system. Even though early civilizations developed devices to convert waves and tides into mechanical energy, the technology to cost-effectively convert ocean waves and tidal flow into electrical energy is still in its early stages. Waves are created by waves blowing over a fetch of ocean as depicted below. Tidal changes in sea level occur as Earth rotates beneath the elliptical ocean envelope which is produced by solar and lunar gravitational forces as depicted in below. Waves energy, although variable, can be predicted days in advance. Tidal power, also variable, can be predicted into the indefinite future. This predictability is important to electrical grid dispatchers who must balance the changing demand with the supply,

Waves



Tides

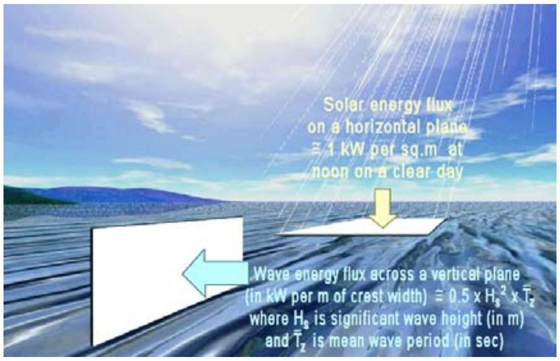


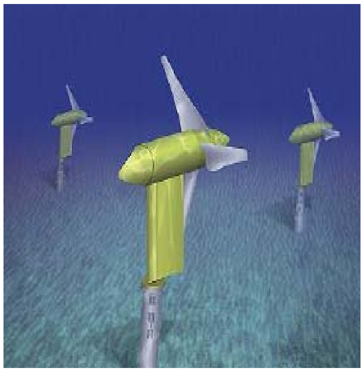
Wave and Tidal Power

The wave power (P_{wave}) in watts per unit wave crest length (L) in meters is a function of the dominant wave period (Tp) in seconds and the square of the significant wave height (Hs) in meters squared as illustrated below.

The tidal current power (P_{flow}) in watts per unit cross-sectoinal area (A) in meters squared is a function of the density of the water (seawater is 1,024 Kg/m3), and the cube of the speed of the water (V) in meter per second as illustrated below.

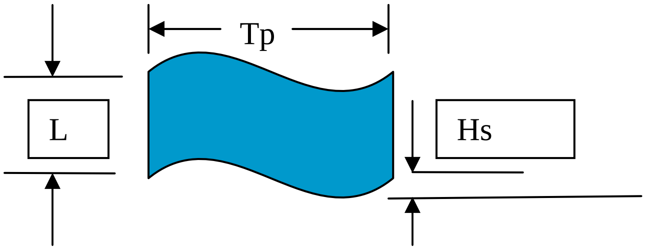
Wave Power **Tidal Current Power**

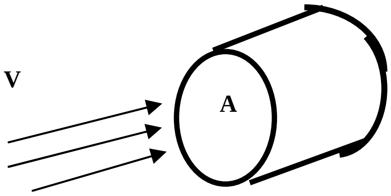




$$(P/L)_{wave} = 0.42\ Hs^2\ Tp$$

$$(P/A)_{flow} = 0.5\ \text{density}\ V^3$$





As an example, the annual average wave power flux in deep water off the coast of Northern California is on the order of 30 kW/m and the annual depth average power density of the tidal flows under the Golden Gate Bridge are on the order of 3 kW/m2.

The Use of the Metric System and K, M, G and T

The metric systems uses the prefixes kilo (K), Mega (M), Giga (G) and Tera (T) to indicate that a quantity is a thousand times (Kilo), a million times (Mega) , a billion (G) times, or a trillion (T) times greater than a watt.. Therefore, a kilowatt is a thousand times greater than a watt, a megawatt is one million times greater than a watt, a gigawatt is one billon times greater than a watt and a terawatt is a trillion times greater than a watt.

The Difference between Watts and Watt hours (Power and Energy)

Power is a rate term; it is the rate at which energy is generated. Energy is a quantity term. Generating or consuming electricity at a rate of 1 watt of power for 1 hour is equal to 1 watt-hour of energy. Using an analogy familiar to us all, the rate of water in gallons per minute coming out of a garden hose is analogous to electrical power in watts. Filling a bucket at 1 gallon per minute for 10 minutes results in a quantity of 10 gallons of water in the bucket. Likewise, for electricity, if we generate 1 watt of power and we do that for 1,000 hours, we have generated 1,000 watt-hours (or 1 kWh) of electrical energy. To keep ten (10) 100 watt light bulb on for 1 hour , for example, consumes 1000 watt hours or 1 kilowatt-hour of electrical energy

Rate in Gallons per Minute
Electrical Analog is Power in Watts

Quantity in Gallons
Electrical Analog is Energy in Watt-Hours

How much electrical power is used by a typical U.S. home?

Since most people cannot relate to watts and watt hours in terms of everyday experiences, we are frequently asked to explain what it means to add new wave or tidal generation in terms of a measure that people understand. We use the number of U.S. homes served by that power source as that measure.

The average US home uses electrical power at the average rate of 1,300 watts (or 1.3 kW). Therefore, for a 30 day month, that average US home consumes 936,000 watt-hours (or 936 kWh). And if that home is paying an average of 6 cents per kWh, their electricity bill for that month is $56.16.

Capacity Factor, Rated Power and Average Power

Notice that the discussion in the previous paragraph was in terms of average power. Average power however, is not the conventional way of describing the size of an electricity generation power plant. The conventional way is in terms of the rated or maximum power. For a wave or tidal power plant, the rated power can only be generated at times of maximum wave height or maximum tidal current velocity. The average power is considerably less that the rated power and it turns out that for wave and tidal plants (and wind plants) that the average power is typically between 30 and 40% of the rated power. The term used to describe this “derating to average” is “capacity factor” and is defined as the actual yearly electrical energy output of a generation plant divided by the electrical energy produced if the plant was operated at rated power continuously during the entire year.

How many Homes are served by a 100 MW (rated power) Wave or Tidal Generation Plant?

If a 100 MW wave or tidal generation power plant were to operate at its rated capacity over an entire year, it would produce 876,000 MWhr, or 876 gigawatt-hours (876 GWh) of energy (100 MW *8760 hours in a year). But as discussed in the previous paragraph, it will produce a lesser amount. If the generation plant operates at a 36% capacity factor, it will produce 135,360 MWh or said another way, it will average 36 MW of power production in a year (100 MW * 36%).

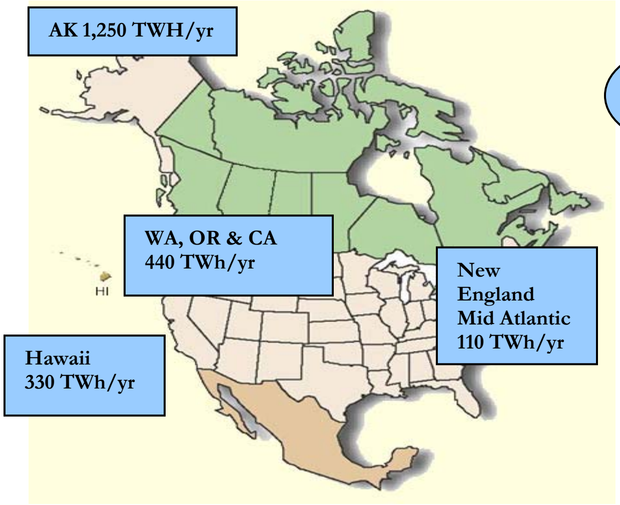
So how many houses would the wave or tidal generation power plant serve? Using the average of 1.3 kW power consumed per US home, it would power 30,000 homes (36,000 kW/1.3 kW pre home). Another way of saying this would be, a 100 MW wave generator operating at 36% capacity factor produces the equivalent amount of energy in a year as 30,000 houses consume in a year.

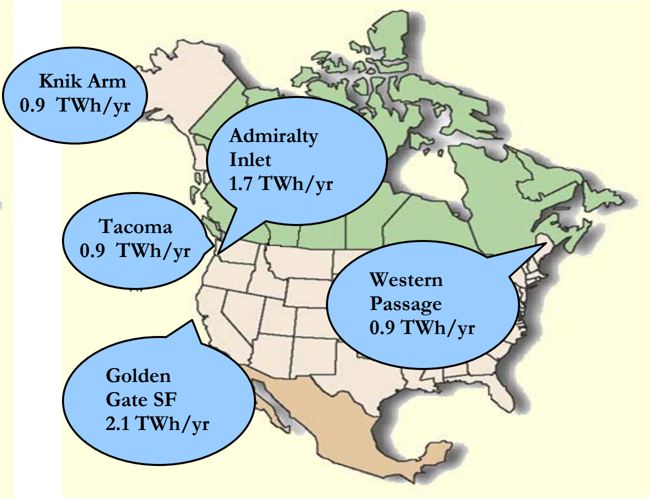
The US Wave and Tidal Resource is Significant

The US wave and current energy resource potential that could be credibly harnessed is about 400 TWh/yr or about 10% of 2004 national energy demand.

EPRI has studied the U.S. wave energy resource and found it to be about 2,100 TWh/yr divided regionally as shown in the figure below. Assuming an extraction of 15% wave to mechanical energy (which is limited by device spacing device absorption and sea space constraints), typical power train efficiencies of 90% and a plant availability of 90%, the electricity produced is about 260 TWh/yr or equal to an average power of 30,000 MW (or a rated capacity of about 90,000 MW). This amount is approximately equal to the total 2004 energy generation from conventional hydro power (which is about 6.5% of total 2004 US electricity supply).

EPRI has studied the North America tidal energy potential at selected sites shown below. The tidal energy resource at those US tidal sites alone is 19.6 TWh/yr. Assuming an extraction of 15% tidal kinetic energy to mechanical energy, typical power train efficiencies of 90% and a plant availability of 90%, the yearly electricity produced at the U.S. sites below is about 270 MW (average power, rated capacity is about 700 MW). EPRI estimates that the total tidal and river in stream potential is on the order of 140 tWh/yr or about 3.5% of 2004 national electricity supply.





How is Ocean Wave Energy Converted to Electricity

Wave energy extraction is complex and many device designs have been proposed. For understanding the device technology, it is helpful to introduce these in terms of their physical arrangements and energy conversion mechanisms, such as:

1. Distance from shore—Wave energy devices may convert wave power at the shoreline, near to the shore (defined as shallow water where the depth is less than one half of the wavelength), or offshore.
2. Bottom mounted or floating—Wave energy devices may be either bottom-mounted or floating.

Wave energy devices can be classified by means of the type of displacement and reaction system employed. Various hydraulic or pneumatic power take-off systems are used and in some cases the mechanical motion of the displacer is converted directly to electrical power (direct-drive).

Four of the best known device concepts are introduced below and the principle of operation is illustrated in the following figures.

Point absorber —A bottom-mounted or floating structure that absorbs energy in all directions. The power take-off system may take a number of forms, depending on the configuration of displacers/reactors. The illustration shows a floating buoy, however, it could be a bottom-standing device as well with an upper floater element. Pressure differences on the top of the float (created by surface wave action) will set the upper floater into motion.

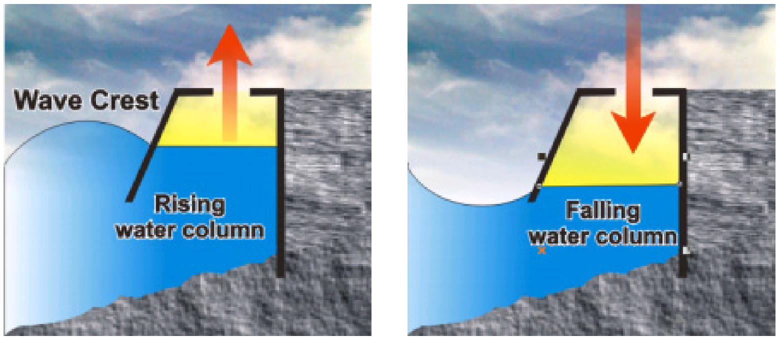
Oscillating Water Column (OWC)—At the shoreline, this could be a cave with a blow-hole and an air turbine/generator in the blow hole. Near or offshore, this is a partially submerged chamber with air trapped above a column of water. As waves enter and exit the chamber, the water column moves up and down and acts like a piston on the air, pushing it back and forth. A column of air, contained above the water level, is compressed and decompressed by this movement to generate an alternating stream of high-velocity air in an exit blowhole. The air is channeled through a turbine/generator to produce electricity.

Overtopping terminator —A floating reservoir structure with a ramp over which the waves topple and hydro turbines/generators through which the water returns to the sea. As shown in Figure 9.3-c, a floating structure moves at or near the water surface, typically with reflecting arms to focus the wave energy. It has both a ramp and a reservoir, so that as waves arrive, they overtop the ramp and are restrained in the reservoir. The head of collected water turns the turbines as it flows back out to sea and the turbines are coupled to generators to produce electricity.

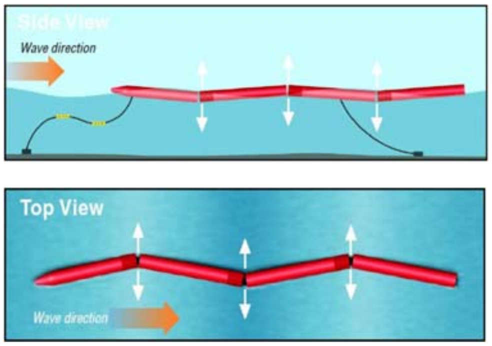
Attenuator —One example of the attenuator principle is a long floating structure that is orientated parallel to the direction of the waves. Sometimes this is called a linear absorber. The structure is composed of multiple sections that rotate in pitch and yaw relative to each other. That motion is used to pressurize a hydraulic piston arrangement and then turn a hydraulic turbine/generator to produce electricity. The figure below illustrates a freely floating hinged contour attenuator device. The four sections move relative to each other and this motion is converted at each hinge point to electricity by a hydraulic power converter system.

Example machines using each of the four types are also shown below.

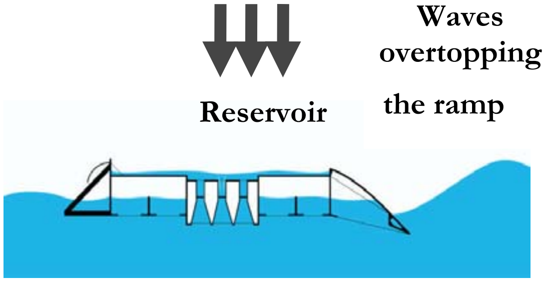
Point Absorber



Oscillating Water Column OWC)



Attentuator

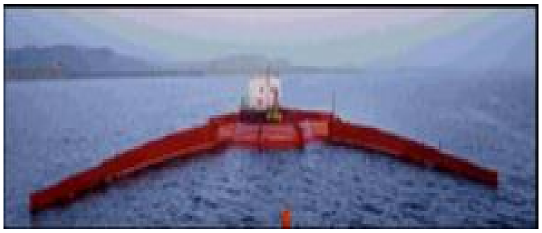


Overtopping

PowerBuoy$^{\text{TM}}$ courtesy Ocean Power Technology

OWC courtesy Energetech

Pelamis courtesy Ocean Power Delivery



WaveDragon courtesy WaveDragon

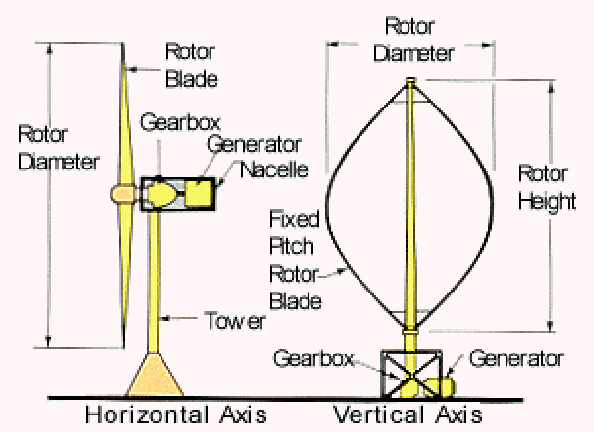
How is Ocean Tidal Energy Converted to Electricity?

Tidal energy extraction is complex and many device designs have been proposed. It is helpful to introduce these designs in terms of their physical arrangements and energy conversion mechanisms. Water turbines, like wind turbines, are generally grouped into two types:

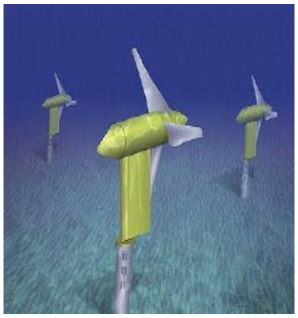
1. Vertical-axis turbines, in which the axis of rotation is vertical with respect to the ground (and roughly perpendicular to the water stream),
2. Horizontal-axis turbines, in which the axis of rotation is horizontal with respect to the ground (and roughly parallel to the water stream.)

The figure illustrates the two types of turbines and typical subsystems for an electricity generation application.

Example machines using each of the two types are shown below.



Turbine Configurations



Horizontal Axis turbine courtesy of Verdant Power

Vertical Axis Turbine courtesy of GCK