Earth’s Gravitational Attraction to the Moon and the Resulting Tides

The revolution and rotation of the Moon are well understood and there is little debate as to their mechanisms in the present day. However, it is generally unknown to the public that the Moon is responsible for the current length of our day. Research in the early part of the 20th century found that the Moon was much closer in the past and is getting farther everyday (Street, 1917). More current investigations found the Moon to have a drag effect on the Earth, causing our days to go from 18 hours long to the current 24 hours. While the Moon orbits the Earth, it will continue to lengthen our days (Brosche, 1984). There is also evidence that if it were not for the Moon, the Earth’s tilt would be much more variable (one model suggests it would change from eleven to forty degrees) (Peterson, 1993). This would have had a tremendous impact for life on Earth. With the Earth’s tilt varying, the Earth’s climate would be much more erratic, making it difficult for more complex life forms to develop.

The biggest influence that the Moon has on the Earth on a daily basis is the tides. This interaction has been understood on a gross scale according to Newton’s laws for a very long time (Schneider, 1880). The Sun also plays a role in the Earth’s tides. Although the Sun is much larger than the Moon, it is also much further away. The importance of distance becomes obvious when you examine Newton’s law of universal gravitation. The strength of gravity decreases with the square of the distance proportional to the product of the two masses. A more sophisticated description of how the Moon influences the tides involves a gravitational gradient. (Trujillo, Thurman, Essentials of Oceanography, Pearson Prentice Hall, 2005) Because the Moon is much closer the gravitational gradient between the far and near side of the moon is more significant than the gradient between the near and far side of the sun. This results in the lunar force being inversely proportional to the cube of the distance, thereby causing the Moon to have a greater influence on the tides on Earth. The Sun’s influence is felt as constructive or destructive to the Moon’s influence based on the geometrical relationship between the forces of the Earth, Moon, Sun system. When the geometrical relationship is parallel, as in the Full Moon and New Moon, the forces are additive and the Earth has the highest tides. When
The geographical relationship is at right angles between the Sun and the Moon. The Sun’s influence mitigates the Moon’s influence and the tides are at their lowest. (Trujillo, Thurman, *Essentials of Oceanography*, Pearson Prentice Hall, 2005)

The Moon pulls on Earth’s ocean nearest the Moon and causes a bulge. On the opposite side of the Earth, the bulge is caused by the moon pulling on the Earth’s center of mass more than it pulls the ocean on the opposite side of the Earth, essentially resulting in the Earth being pulled out from under the water and creating a second high tide each day. Some of the other factors that influence the tides are the shapes of the coastline, depth of the water, and the deformation of the ocean basin (Farrel, 1973). These effects are demonstrated by the unusually large tidal range in the Bay of Fundy. The effects of the Moon on the tides is not only on seas and oceans, but on groundwater as well; studies on groundwater over the course of months show that the average groundwater levels also fluctuate with the tides (Schureman, 1926).

**How is tidal energy harnessed?**

There are two different approaches to the exploitation of tidal energy. The first is to harness the cyclic rise and fall of the sea level through entrainment and the second is to harness local tidal currents in a manner somewhat analogous to wind power.
Tidal Barrage Methods

There are many places in the world in which local geography results in particularly large tidal ranges. Sites of particular interest include the Bay of Fundy in Canada, which has a mean tidal range of 10 m, the Severn Estuary between England and Wales, with a mean tidal range of 8 m and Northern France with a mean range of 7 m. A tidal-barrage power plant has been operating at La Rance in Brittany since 1966 (Banal and Bichon, 1981). This plant, which is capable of generating 240 MW, incorporates a road crossing of the estuary. It has recently undergone a major ten-year refurbishment program
Photos and diagrams from: http://www.reuk.co.uk/Severn-Barrage-Tidal-Power.htm

Other operational barrage sites are at Annapolis Royal in Nova Scotia (18 MW), the Bay of Kislaya, near Murmansk (400 kW) and at Jangxia Creek in the East China Sea (500 kW) (Boyle, 1996). Schemes have been proposed for the Bay of Fundy and for the Severn Estuary but have never been built.

**Principles of Operation.**

On a fundamental level, the principles of operation are always the same. An estuary or bay with a large natural tidal range is identified and then artificially enclosed with a barrier. This would typically also provide a road or rail crossing of the gap in order to maximise the economic benefit. The electrical energy is produced by allowing water to flow from one side of the barrage, through low-head turbines, to generate electricity.

There are a variety of suggested modes of operation. These can be broken down initially into single-basin schemes and multiple-basin schemes. The simplest of these are the single-basin schemes.

*Single-Basin Tidal Barrage Schemes*

These schemes require a single barrage across the estuary. There are three different methods of generating electricity with a single basin. All of the options involve a
combination of sluices which, when open, can allow water to flow relatively freely through the barrage, and gated turbines, the gates of which can be opened to allow water to flow through the turbines to generate electricity. (Survey of Energy Resources, World Energy Council, *Harnessing the Energy in Tides*, 2007)

_Ebb Generation Mode_

During the flood tide, incoming water is allowed to flow freely through sluices in the barrage. At high tide, the sluices are closed and water retained behind the barrage. When the water outside the barrage has fallen sufficiently to establish a substantial head between the basin and the open water, the basin water is allowed to flow out through low-head turbines and to generate electricity.

The system can be considered as a series of phases. Typically the water will only be allowed to flow through the turbines once the head is approximately half the tidal range. This method will generate electricity for, at most, 40% of the tidal range. (Survey of Energy Resources, World Energy Council, *Harnessing the Energy in Tides*, 2007)

_Flood Generation Mode_

The sluices and turbine gates are kept closed during the flood tide to allow the water level to build up outside the barrage. As with ebb generation, once a sufficient head has been established the turbine gates are opened and water can flow into the basin, generating electricity. This approach is generally viewed as less favourable than the ebb method, as keeping a tidal basin at low tide for extended periods could have detrimental effects on the environment and on shipping. In addition, the energy produced would be less, as the surface area of a basin would be larger at high tide than at low tide, which would result in rapid reductions in the head during the early stages in the generating cycle. (Survey of Energy Resources, World Energy Council, *Harnessing the Energy in Tides*, 2007)

_Two-Way Generation_
It is possible, in principle, to generate electricity during both ebb and flood currents. Computer models do not indicate that there would be a major increase in the energy production. In addition, there would be additional expenses associated in having a requirement for either two-way turbines or a double set to handle the two-way flow. Advantages include, however, a reduced period with no generation and the peak power would be lower, allowing a reduction in the cost of the generators. (Survey of Energy Resources, World Energy Council, *Harnessing the Energy in Tides*, 2007)

*Double-Basin Systems*

All single-basin systems suffer from the disadvantage that they only deliver energy during part of the tidal cycle and cannot adjust their delivery period to match the requirements of consumers. Double-basin systems have been proposed to allow an element of storage and to give time control over power output levels. The main basin would behave essentially like an ebb generation single-basin system. A proportion of the electricity generated during the ebb phase would be used to pump water to and from the second basin to ensure that there would always be a generation capability.

It is anticipated that multiple-basin systems are unlikely to become popular, as the efficiency of low-head turbines is likely to be too low to enable effective economic storage of energy. The overall efficiency of such low-head storage, in terms of energy out and energy in, is unlikely to exceed 30%. It is more likely that conventional pumped-storage systems will be utilized. The overall efficiency of these systems can exceed 70% which is likely to prove more financially attractive. (Survey of Energy Resources, World Energy Council, *Harnessing the Energy in Tides*, 2007)

*Tidal lagoons*

Tidal barrage systems are likely to cause substantial environmental change; ebb
generation results in estuarial tidal flats being covered longer than in a natural estuary. Electricity would be generated using sluices and gated turbines in the same manner as conventional barrage schemes. The principal advantage of a tidal lagoon is that the coastline, including the intertidal zone, would be largely unaffected. Careful design of the lagoon could also ensure that shipping routes would be unaffected. A much longer barrage would, however, be required for the same surface area of entrainment. Some preliminary studies do suggest that in suitable locations, the costs might be competitive with other sources of renewable energy. There has not yet been any in-depth, peer-reviewed assessment of the tidal lagoon concept, so estimates of economics, energy potential and environmental impact should be treated with caution.

In 2000 a large vertical-axis floating device (the Enermar project [www.pontediarchimede.com]) was tested in the Strait of Messina between Sicily and the Italian mainland. Marine Current Turbines Ltd (www.marineturbines.com) of Bristol, England, has been demonstrating a large pillar-mounted prototype system called Seaflow in the Bristol Channel between England and Wales. It is intended that the same company will install a further large prototype system, SeaGen, in Strangford Narrows in Northern Ireland, probably in late-summer 2007. Although conceptually similar to Seaflow, it would be equipped with two rotors and have a rated capacity of 1.2MW.

In Norway, the Hammerfest Strøm system (www.tidevannsenergi.com) demonstrated that pillar-mounted horizontal-axis systems can operate in a fjord environment. In the USA the first of an array of tidal turbines were installed in December 2006 in New York's East River (www.verdantpower.com ). Once fully operational this should be the world's first installed array of tidal devices.

In 2007, The European Marine Energy Centre (EMEC) (www.emec.org.uk), which was established in 2004 to allow the testing of full-scale marine energy technology in a robust and transparent manner, became fully equipped for the testing of tidal, as well as wave energy, technology. The tidal test berths are located off the south-western tip of the island of Eday, in an area known as the Fall of Warness.
The facility offers five tidal test berths at depths ranging from 25 m to 50 m in an area 2 km across and approximately 3.5 km in length. Each berth has a dedicated cable connecting back to the local grid. The first tidal device (www.openhydro.com) was installed at the end of 2006. This is operated by the OpenHydro Group and is a novel annular-turbine system held by twin vertical pillars.

**Tidal power is like wind power**

The physics of the conversion of energy from tidal currents is superficially very similar to the conversion of kinetic energy in the wind. Many of the proposed devices have therefore an inevitable resemblance to wind turbines. There is no total agreement on the form and geometry of the conversion technology itself. Wind-power systems are almost entirely horizontal-axis rotating turbines. In these systems the axis of rotation is parallel to the direction of the current flow. Many developers favour this geometry for tidal conversion. Vertical-axis systems, in which the axis of rotation is perpendicular to the direction of current flow, have not been rejected. It is of interest to note that Enermar used a novel Kobold vertical-axis turbine.

The environmental drag forces on any tidal-current energy-conversion system are very large, when compared with wind turbines of the same capacity. This poses additional challenges to the designer. Designs exist for devices which are rigidly attached to the seabed or are suspended from floating barges, such as the early Loch Linnhe device. It is generally accepted that fixed systems will be most applicable to shallow-water sites and moored systems for deep water.

Although prototype tidal-current devices are now available and have mostly proved successful in their operation, there are still issues requiring resolution before the resource can be fully exploited. With the exception of the New York East River development, knowledge of the performance of devices in arrays is somewhat limited, although theoretical models are at last becoming available. It is also becoming obvious that turbulence levels in high-energy tidal flows can be considerable. Turbulent amplitudes
exceeding 30% of the time-averaged flows have been measured and this will prove challenging to systems designers. There is an ongoing need for enhanced understanding of the behaviour of tidal-current devices in the presence of incident waves. These gaps in understanding should not prevent ongoing deployment of pre-commercial, or even early-stage commercial technology, provided that technology developers are aware of the design constraints that knowledge gaps impose and recognise that they themselves are part of the research process. This will ultimately allow efficient technology development and hence allow cost-effective exploitation of the tidal-current resource.