The *'ins and outs'* of Tides and their use as a renewable energy source

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Ten years ago I remember standing on a beach in the middle of the night. Little did I know that the full Moon above was the cause of the regular tidal flows which I watched drift in and out. In fact, the tides are *such* a predictable and consistent occurrence that often we don't stop to think about how they come about or, indeed, in what ways their energies can be harnessed. Tidal power has taken a backseat behind the expanding utilisation other sources, such as wind, solar and hydroelectric energy. The knowledge of tidal currents and tidal range in different areas is essential to producing a more efficient, cost effective system for harnessing its energy. Therefore to understand tidal energy, we must first understand the physics behind how tides are generated.

Tides occur semi-diurnally, and are the natural rise and fall of sea level caused by a combination of gravitational forces produced by the Moon and Sun, in addition to the Earth's rotation. Isaac Newton was the first to describe this phenomenon as the product of the gravitational attraction of astronomical masses in his publication,

Figure 1

Principia in 1687 (Wikipedia, 2015). Figure 1 shows the most basic explanation of tide formation. The Moon's gravitational attraction causes two tidal bulges, one between the Moon and the Earth (the sub-lunar point) and another on the opposite side of the Earth (the antipodal point). This is due to the difference in the Moon's gravitational field across the planet. At the sub-lunar point, the Moon's gravitational attraction is greater than at the centre of the Earth, therefore the water is pulled more than the Earth creating a bulge; at the antipodal point, it is weaker than at the centre of the Earth, therefore the water is pulled less, producing a second bulge. These two tidal bulges are the resulting high tides and the points in between the low tides (Feynman, 1994).
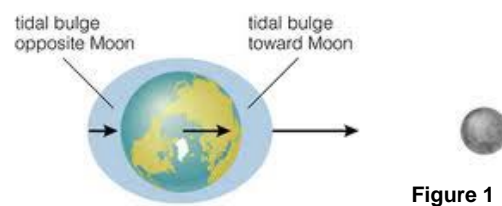
The heights of these tides also vary. This is an important aspect to consider as the tidal power produced from a tidal barrage is based on the loss of gravitational potential energy as the water's height changes. The higher the tide, the more energy can be produced. Tide height is affected by the relative positions of the Moon and Sun. Figure 2 shows what is known as a 'spring tide'[1] where the Sun, Moon and Earth align during new or full Moon. The combined effects of the lunar and solar tides result in a greater tidal bulge, therefore at this time the tides have a larger tidal range. Figure 2 also shows what is known as a 'neap tide' where the Sun, Moon and Earth are not in alignment during 1st quarter and 3rd quarter Moon phases. The lunar and solar tides therefore occur in different places so the overall gravitational effect on the water is less and the tides will have a smaller tidal range.
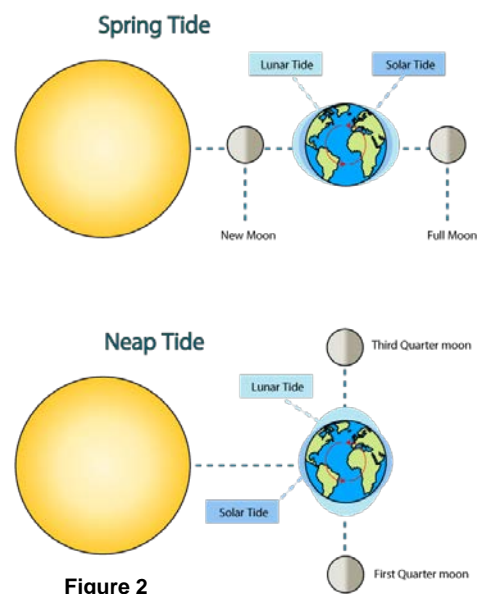

Figure 2

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[1] This is irrelevant to season. Spring originates from its meaning "to jump/burst forward"

In additional, the position of the moon in its elliptical orbit also affects the tides. As shown in figure 3, the Moon has a point of furthest distance from the Earth and a point of closest distance from Earth (these points are known as apsides[2]). At apogee, the Moon has a weaker gravitational attraction, resulting in lower tides; at perigee, the Moon has a stronger gravitational attraction, resulting in higher tides (Rose, 2015). Approximately 3 or 4 times a year the spring tide coincides with perigee, consequently producing a tide with the largest range, known as 'the perigean spring tide'.
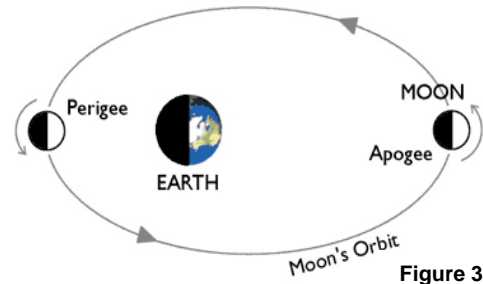

Figure 3

Considering the tides are affected by both the Sun and the Moon, the subsequent question to ask would be which has a greater effect on the tides? Well we know this already, because if you ask anyone in the street *"What causes tides?"* their answer will almost certainly not be the Sun. The trickier question is "Why?" Although the Sun is around 391 times further away from the Earth than the Moon, its force on the Earth is about 175 times larger, but its tidal effect is smaller than that of the Moon's. This is because tides are a result of a difference in gravitational attraction across the planet. As the Earth's diameter is so small in relation to the Sun's there is very little variation in its gravitational attraction across Earth's surface, whereas the Moon's diameter is significantly less, therefore there is a much greater variation in gravitational attraction across the Earth's surface (Nave, 2014). This is an example of *the inverse square law*[3].
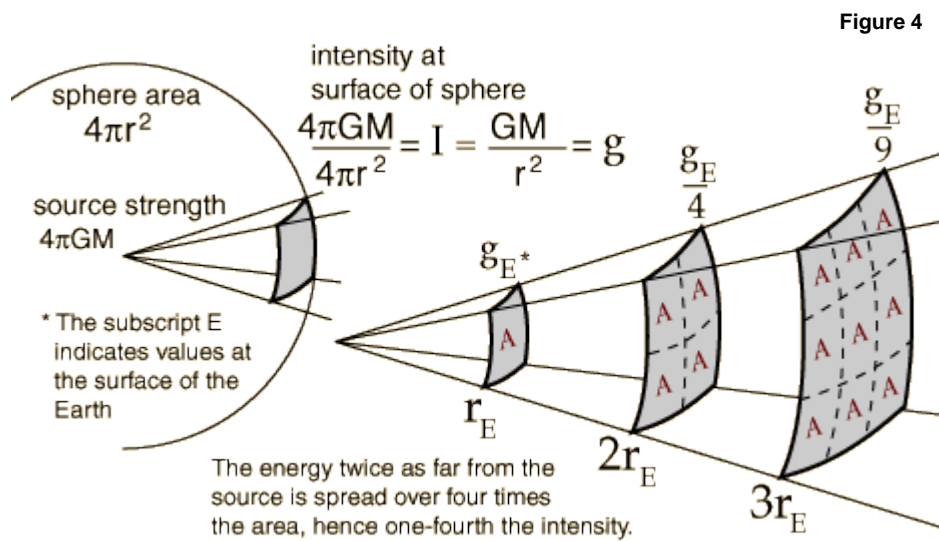
Figure 4

The difference in gravitational attraction of the Sun across the Earth is 0.017%

$$\Delta F_{SUN} = 0.00017 * F_{SUN}$$

Where: ΔF_{SUN} is the change in gravitational attraction across the planet

F_{SUN} is the gravitational attraction of the Sun at its surface

The difference in gravitational attraction of the Moon across the Earth is 6.8%

$$\Delta F_{MOON} = 0.068 * F_{MOON}$$

Where: ΔF_{MOON} is the change in gravitational attraction across the planet

F_{MOON} is the gravitational attraction of the Moon at its surface

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[2] An apsis is a point of least or greatest distance of a body in an elliptic orbit about a larger body.
[3] Gravity varies with the inverse square of the distance between two masses.

When the values are calculated and substituted in, we come to the conclusion:

$$\Delta F_{MOON} > \Delta F_{SUN}$$

Therefore, we know the Moon's tidal effect is greater than the Sun's tidal effect.

Having understood the cause of tides, the variation of tide height during different points in the Moons cycle and solar and lunar tidal effects we can focus on the exploitations of this natural event. With knowledge of how tides work, there are the possibilities of tidal power generators, optimisation of shipping routes, improvement of satellite based sea level measurements and the development of flood defences (Taylor, 2009). Here we shall concentrate on tides as a source of renewable energy.

There are two main methods of harnessing tidal power, either using tidal stream generators or tidal barrages. Tidal stream generators transfer the kinetic energy of tidal currents in electricity using underwater turbines, whereas tidal barrages are large specialised dams which allow the flow of water up stream during high tides, then capture the water's potential energy at low tide as the water moves back out to sea.

As with nearly every method of energy production, tidal power has its advantages and disadvantages. The main argument for its application is that tidal energy is an inexhaustible resource; with fossil fuel predicted to have been depleted as early as 2088, improving other methods for producing energy is crucial, and unlike fossil fuel, there is no contribution to climate change because no greenhouse gases are produced. Furthermore, semi-diurnal tidal flows are much more predictable than solar or wind energy which can be affected by random weather patterns, and it can be much more efficient (up to 80%) much better than most other sources. On the other hand, the construction of the barrages and generators have large upfront costs and long payback times, making projects difficult to fund. There are also a limited number of potential sites, and the habitat of the local wildlife has to be considered as these large constructions can cause ecological harm or damage the environment (Haluzan, 2012).

Although harnessing tidal energy may seem to be less advantageous than solar or wind power, it has been proven to be an effective solution. The world's first tidal power station opened in Brittany, France in 1966. The *Rance Power Station* was the largest tidal power station in the world for 45 years. It is a 750m long barrage which has 24 turbines, with the ability to produce an average annual output of 540GWh; enough to supply the $1/100^{th}$ of France's total power demand. Another successful example is SeaGen which was the world's first commercial tidal stream

Rance Tidal Power Station, Brittany France

generator, located in Strangford Lough, Northern Ireland, and can produce up to 24MW a day.

To summarise, tidal power has the potential to be a very important source of energy in the future. Our knowledge of tides allows us to be able to predict accurately the motion of the sea's tides relative to the Sun and Moon and improvements in technology should hopefully allow us to develop this process into a more efficient, and cost effective method of producing energy.

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