Tidal Energy Is Not Renewable

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Abstract

It is a misconception to classify tidal power as a renewable energy source. In reality, large-scale extraction of tidal energy could produce environmental impacts more severe than those associated with fossil fuels. Tides arise from Earth's rotation relative to the gravitational pull of the Moon and the Sun on ocean water. Although tidal patterns appear to move relative to observers on Earth, the tidal bulges remain essentially fixed with respect to these celestial bodies. This decoupling exerts a braking torque on Earth's rotation, dissipating rotational energy and gradually lengthening the day. Over the past 400 million years, this natural process has slowed Earth's rotation from roughly 420 to 365 days per year. Harvesting tidal energy would accelerate this deceleration by removing additional rotational energy from the Earth. This study provides quantitative estimates showing that even modest reliance on tidal power could produce significant environmental disruption on short geological timescales. Based on global energy consumption trends over the past 50 years, meeting only 1% of global energy demand with tidal power could cause Earth to become tidally locked to the Moon in roughly 1,000 years. In such a state, a single day would span an entire lunar month, with one hemisphere experiencing perpetual sunlight and extreme heating, while the other would remain in continuous darkness and severe cooling. These extreme thermal contrasts would render large portions of the planet uninhabitable, potentially leading to widespread ecosystem collapse and the extinction of most life on Earth.

Motivation

Global warming, a consequence of consuming fossil fuels, has brought awareness to the public. As an alternative, tidal energy has attracted more and more attention. Technologies have been developed that make it possible to collect tidal energy for the increasing energy requirements of the world's growing economies. However, it may come as a surprise to many people that tidal energy is **not a renewable energy** source. Using tidal energy will create more severe environmental problems than global warming.

Many individuals believe that tidal energy is a sustainable energy source.[1-4] Imagine talking about global warming a century ago - we'd probably encounter skepticism. When I delivered a presentation on alternative energy resources to a graduate class in 1990, I classified tidal energy as non-renewable. Similarly, the speech sparked a passionate debate and presented many challenges. A recurring question was, "How can harnessing tidal energy harm the environment?" Since that time, I have felt a strong duty to elucidate this matter and convey the message to the broader public.

In 1993, when the first web browser, Mosaic, became available, I created a website on this topic. However, it did not receive much attention until several years later when Google indexed the web pages. Some tidal turbine companies even asked me to take down the pages since they are not good for their businesses. Unfortunately, the website was not well-maintained after I left the school where it was hosted. Nowadays, when searching for "tidal energy," I am unable to find my pages. Instead, I found many web pages that still list tidal energy as renewable energy, alongside other green energies such as wind and solar power.

As more people become aware of global warming, government policies have led industries to search for green alternatives to fossil fuels. Tidal energy has become one of the options, despite being in the wrong direction. Now, more than ever, I feel the necessity and urgency to warn people before it is too late. In the following sections, I will try my best to detail the issues as simply as possible with related physics and mathematical backgrounds.

Collecting Tidal Energy

Tides are the periodic rises and falls of sea levels that are observable almost anywhere along the coasts. Tidal energy is a form of hydropower that converts the energy stored in tides into useful forms of power, mainly electricity. A simple structure to collect tidal energy is to build an artificial reservoir with barrages.[5] Channels are opened for seawater to flow into the reservoir during high tides. Gates in the channels can then be closed to trap the water behind the barrages and create a hydraulic water head between high and low tides. During low tides, the potential energy of the water in the reservoir drives hydraulic turbines to generate electricity.

Other technologies can be used to harness tidal energy. Tidal stream generators make use of the kinetic energy of moving water to drive turbines, similar to wind turbines.[6] Coastal constrictions, such as straits or inlets, can create high-velocity currents at specific sites, which makes it ideal for steam generators. Dynamic tidal power exploits interactions between potential and kinetic energy in tidal flows. A very long dam is built from the coast straight out into the ocean. Tidal phase differences are introduced across the dam, leading to a significant water-level differential in shallow coastal seas, featuring strong coast-parallel oscillating tidal currents such as those found in China and Korea.

The world's first large-scale tidal power plant was the Rance Tidal Power Station in France, which began operations in 1966. The largest tidal power station is Sihwa Lake Tidal Power Station in South Korea, which opened in 2011 and generates 254 megawatts. As fossil fuels become increasingly scarce, large-scale and more effective tidal energy stations are expected to be built to meet the world's growing energy demands. However, as with global warming, without proper regulations, another environmental crisis is inevitable.

How Are Tides Formed?

Tides are caused by the gravitational pull of the Moon and the Sun combined with the Earth's rotation. This interaction generates tidal forces on opposite sides of the Earth, pulling ocean water outward to form tidal bulges, as illustrated in Figure 1. These bulges remain approximately stationary relative to the Moon or Sun as the Earth rotates. As a result, observers on Earth experience periodic rises and falls in sea level.

Now, let us study the physics behind tidal forces. Gravity is the force of attraction between two objects, given by Newton's law of universal gravitation:[7]

(1) $$F_g = \frac{GM_1M_2}{D^2}$$

Here, F_g is the gravitational force, G is the gravitational constant, M_1 and M_2 are the masses of the two objects, and D is the distance between the mass centers of the objects. This force is responsible for pulling the Earth into its orbit around the Sun. The orbital motion of the Earth around the Sun creates a centrifugal force, an inertial force that appears to act on an orbiting object, pushing away from the orbiting center:

(2) $$F_c = mRW^2$$

Here, F_c is the centrifugal force, m is the mass of the object, W is the orbiting angular velocity of the object, and R is the radius of the orbit.

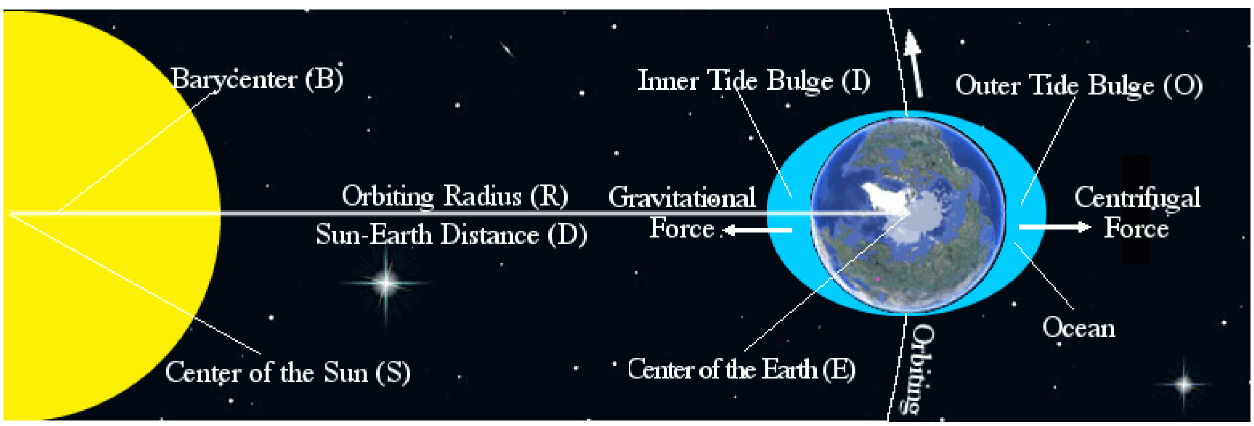

Figure 1: Formation of tides.

Viewing from space above the north pole, Earth indeed orbits around the barycenter B, the mass center of both the Sun and Earth, which is inside the Sun. The radius R is the distance from the center of the Earth E to the barycenter B. D is the distance between the Earth's center E and the Sun's center S, which is slightly longer than R. The Earth can stay in orbit around the Sun because the gravitational force F_g is balanced by the centrifugal force F_c. Specifically, if we consider the Earth as a point mass m at the center, the gravitational force F_{gc} is equal to the centrifugal force F_{cc}. Thus, we have the following equation:

(3) $$mRW^2 = F_{cc} = F_{gc} = \frac{GMm}{D^2}$$

This can be reduced to

(4) $$RW^2 = \frac{GM}{D^2}$$

Now, let us consider a point mass m_i to the inner (or Sun-facing) side of the orbit. The revolving radius is *R-r*, and the gravitational distance is *D-r*, where *r* is the radius of the Earth. The gravitational force F_{gi} is greater than the centrifugal force F_{ci} for the mass m_i, due to the following inequality:

(5) $$F_{ci} = m_i(R - r)W^2 < m_i RW^2 = \frac{GMm_i}{D^2} < \frac{GMm_i}{(D-r)^2} = F_{gi}$$

Here, the middle equation is based on equation (4) above, the first equation is from the centrifugal force equation (2), and the last equation is from the gravitational force equation (1). Thus, the inequality is reduced to

(6) $$F_{ci} < F_{gi}.$$

The difference between the gravitational force and centrifugal force ($F_{gi} - F_{ci}$) is called a tidal force, which is greater than zero ($F_{gi} - F_{ci} > 0$) due to the inequality (6) above. This force pulls the ocean water toward the revolving center *B*, creating the inner tidal bulge shown in Figure 1. Similarly, for a point mass m_o on the outer side of the orbit, the revolving radius is *R* + *r*, and the gravitational distance is *D* + *r*. In this case, the centrifugal force F_{co} is greater than the gravitational force F_{go}, due to the following inequality:

(7) $$F_{co} = m_o(R + r)W^2 < m_o RW^2 = \frac{GMm_o}{D^2} < \frac{GMm_o}{(D+r)^2} = F_{go}$$

or

(8) $$F_{co} < F_{go}.$$

The tidal force ($F_{co} - F_{go} > 0$) pushes the ocean water away from the revolving center *B*, creating the outer tidal bulge. These bulges are stationary to the centerline between Earth and the Sun. As Earth rotates along its axis, the bulges drift relative to the Earth, forming tides for an observer on Earth. This is known as the solar tide.

The Moon also exerts a similar tidal force on the Earth, producing the lunar tides. Because the Moon is closer to Earth than the Sun, the lunar tides are more significant than the solar tides. At the time when Earth, Moon, and Sun are all aligned in a straight line, the solar tide superimposes the lunar tide, creating the largest tidal effect, known as the king tide.

Decelerating Earth

The rotation speed of the Earth is gradually decreasing.[8] To understand the process, let's take a look at how car brakes work. In a car braking system, as shown in Figure 2, there is a rotor disc attached to a wheel and a caliper fixed on the body of the car. During normal operation, the brake pads do not touch the rotor, and the car moves freely on its wheels. When the brake pedal is pressed, the piston causes the calipers to squeeze the rotor disc. The pads inside the caliper create friction that stops the car.

In this analogy, the rotor represents the rotational Earth, while the brake pads are like the stationary tidal bulges. As Earth rotates eastward, the stationary tidal bulges travel to the west. Tidal currents are the motion of ocean water relative to the

Earth, similar to the relative motion between the brake pads and the rotor. The viscosity of ocean water creates a drag between tidal currents and the seafloor, which slows down the rotation of the Earth. In the northern hemisphere, the continental block affects the travel of the tidal bulges, which makes the deceleration of rotation even more pronounced. The direction of tidal currents becomes complicated due to the coastline of land or islands.

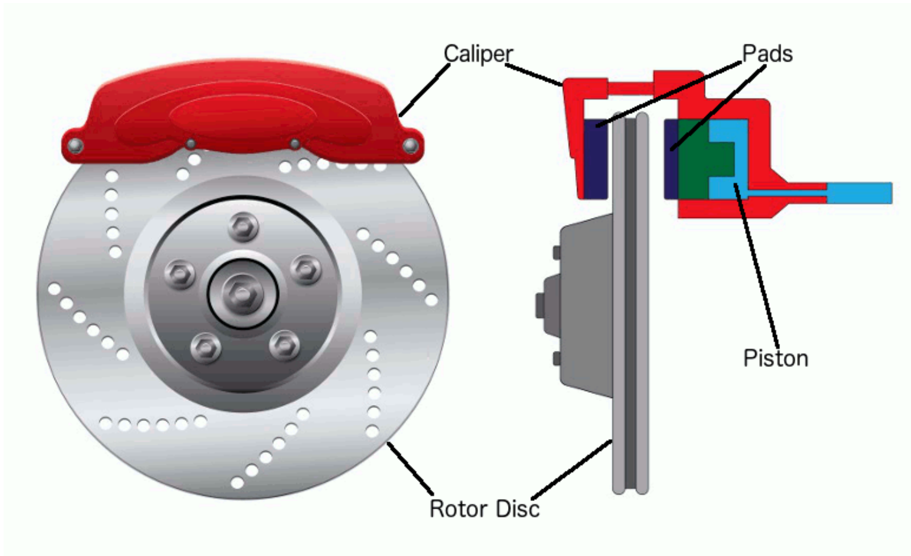

Figure 2: Car brake system.

As a consequence, the rotational energy of the Earth is gradually lost and dissipated by tides. The rotation speed of the Earth has slowly been reduced in these natural processes throughout Earth's history. The number of days in a year has been decreasing, which has been evidenced by the fossil coral.

In addition, there is a tidal acceleration effect that the Earth exerts on the Moon, which transfers the Earth's rotational energy to the Moon and causes it to move away from the Earth. This process also decelerates the rotation of the Earth. However, the effect is much less than that of tides, accounting for only about 4% of the energy loss of Earth's rotation.[9-11]

Tidal Locking

Have you ever seen the other side of the Moon? One side of the Moon is always facing the Earth. This is a phenomenon called tidal locking, which also results from tidal effects.[12-13] Just like the Moon exerts a tidal force on Earth, Earth also applies a tidal force on the Moon. Even though there is no water on the surface of the Moon, the tidal force that Earth exerts on the Moon also results in tidal bulges in the solid body of the Moon, stretching the Moon into a shape like an American football. Scientists call this the solid tide. The effect also decelerates the rotation of the Moon. Eventually, the rotation of the Moon is decreased to once per orbiting cycle. Thus, one end of the "football" is facing the Earth all the time.[14] Since then, the tidal force prevents the rotation from slowing down or speeding up, known as tidal locking or gravitational locking. The rotation is synchronous, also known as captured rotation. Similarly, Earth will gradually decelerate its rotation and eventually lock to the Moon. As a result, both the Moon and Earth will be locked face-to-face, revolving around their common barycenter as a binary system.[15]

Rotational Energy

Just as there is momentum and kinetic energy in a moving object, there is also momentum and kinetic energy in the rotation of an object, called angular momentum and rotational energy. The total rotational energy of the Earth is about **2.138×10^{29} Joules**.

To estimate the rotational energy of the Earth, we need to find out the moment of inertia of the Earth. The moment of inertia *I* for a solid ball can be calculated using this formula:

(9) $$I = \frac{2}{5}MR^2$$

Here, *R* is the radius of the ball. The average radius of the Earth is about 6.371×10^6 meters.[16] *M* is mass. The current best estimate for Earth's mass is 5.9722×10^{24} kilograms.[17] A simple estimate for the moment of inertia using the formula above would give a value of 9.696×10^{37} kgm^2. However, the formula applies to a homogeneous ball. Earth's inner materials are heavier than the outer materials due to gravity and convection inside Earth. The actual Earth's moment of inertia should be less than this estimate. A more accurate estimate for Earth's moment of inertia is 8.04×10^{37} kgm^2. Now, we can compute the total rotational energy for the Earth:

(10) $$K = \frac{1}{2}IW^2$$

Here, *K* is the rotational energy, and *W* is the angular velocity. The rotation period of the Earth is 23.93 hours or an equivalent angular velocity of 7.29×10^{-5} rad/s. With the values for both the moment of inertia and angular velocity, using equation (10), we can estimate the total rotational energy of the Earth, 2.138×10^{29} Joules.

How Much Time Left

When a car brakes, the car's kinetic energy is converted into heat generated by the friction between the rotor disc and the brake pads. Similarly, the rotational energy of the Earth is gradually dissipated and converted to heat due to the friction between tides and the ocean floor. Since there is a finite amount of rotational energy of the Earth, it will be depleted over a **billion years,** as estimated below, and the rotation of the Earth will eventually lock to the Moon naturally.

A simple way to roughly estimate the decreasing rate of Earth's rotational energy is to study the seasonal and daily growing patterns in coral reefs, which are similar to growth rings in trees. Scientists have studied fossil reefs in the early and middle Silurian (444-419 million years ago) and found that there were 420 days in a year. The number of days per year in the early Middle Devonian Period (419-358 million years ago) was 410, and similar research through preserved fossil corals indicates that there were 385 days per year in the early Carboniferous period, 350 million years ago. More paleontological research on this topic can be found in Deines and Williams' publication.

There is no evidence of significant changes in Earth's mass and orbit over the last 400 million years. So, it is reasonable to assume that there has not been much change in Earth's revolving period. Therefore, the decrease in the number of days in a year results primarily from the reduction in the rotation speed of the Earth. Based on the above research, let's assume that there were 420 days around 430 million years ago. So, the angular velocity of the Earth was 8.39×10^{-5} rad/s at that time. Using equation (10), we can estimate that the total rotational energy of the Earth at that time was 2.83×10^{29} Joules.

Using the current estimate for the rotational energy of the Earth (2.138×10^{29} Joules), we can calculate that there was an energy loss of 6.92×10^{28} Joules in the last 430 million years or an average of 1.73×10^{20} Joules per year. If the depletion is linear, the current rotational energy will be depleted in 1.24 billion years. However, this is a rough estimation because friction/viscosity is proportional to the square of the relative motion speed. The depleting rate of rotational energy should decrease as the rotation speed reduces. Therefore, a more accurate estimate should consider the decreasing rotation. Since the relative tidal motion is proportional to the rotation speed of the Earth, the energy-depleting rate should be negatively proportional to the square of the Earth's rotation speed.

(11) $$\frac{dK}{dt} = - aW^2$$

Here, *a* is the depleting coefficient. With equation (10), we establish a derivative equation:

(12) $$\frac{dK}{dt} = - \frac{2a}{I}K$$

or

(13) $$\frac{dK}{dt} = - bK$$

Here, *b = 2a/I*. Solve the equation:

(14) $$ln(K) = c - bt$$

In this solution, c is a constant. Suppose that Earth and the Moon will lock to each other in the future at year t_0. By that time, there are only 12 days in a year because Earth and Moon will rotate together once per month around their barycenter. The angular velocity of the Earth will be 0.24×10^{-5} rad/s by that time, corresponding to a total rotational energy of 2.32×10^{26} Joules. Assume it will take *x* years for Earth to lock to the Moon from now. Equation (14) gives rise to three instances for year t_0 in the future, now, and 430 million years ago, respectively:

(15) $$ln(2.32 \times 10^{26}) = c - bt_0$$

(16) $$ln(2.138 \times 10^{29}) = c - b(t_0 - x)$$

(17) $$ln(2.83 \times 10^{29}) = c - b(t_0 - x - 430,000,000)$$

Solve equations (15), (16), and (17) for *x*:

(18) $$x = 430,000,000 \times \frac{ln(\frac{2.138\times10^{29}}{2.32\times10^{26}})}{ln(\frac{2.83\times10^{29}}{2.138\times10^{29}})} \approx 10,468,000,000$$

Therefore, based on the historical rate of energy dissipation, it will take approximately 10.468 billion years for Earth to become naturally tidally locked to the Moon. This timeline should provide ample opportunity for future generations to develop solutions to withstand or avoid the resulting catastrophe.

Destroy Earth in 1,000 Years

However, history would be significantly different if we were to harness tidal energy. As soon as we tap into tidal energy, the slowdown of the Earth will be accelerated. If we were to take tidal energy just to supplement 1% of the world's energy consumption, the rotation of the Earth would lock to the Moon in about **1000 years**. Here is how I came to this number.

First, let us estimate how fast we can drain the rotational energy from the Earth. The world's energy consumption was about $5.67\text{x}10^{20}$ Joules in 2013.[18] This number has increased by more than 2% per year on average in the last 50 years. The average world economic growth rate in the last 50 years is about 3%, which requires a corresponding increase in the energy supply. Considering the increase in energy usage efficiency in industries, the 2% growth rate for world energy consumption should be a reasonable assumption.

Based on this pace of energy demand, if we were to tap into tidal energy to supply 1% of the world's energy requirements, Earth's rotational energy would be reduced by $5.67\text{x}10^{18}$ Joules per year. Assuming that in the next *N* years, the total energy ($2.138\text{x}10^{29}$ Joules) would be reduced to $2.32\text{x}10^{26}$ Joules when Earth is locked to the Moon, we can use equations (19) and (20) to estimate *N*:

(19) $$2.138 \times 10^{29} - 2.32 \times 10^{26} = 5.67 \times 10^{18} \times (1.02^{1} + 1.02^{2} + ... + 1.02^{N})$$

or

(20) $$2.136 \times 10^{29} = \frac{5.67\times10^{18}\times(1.02^{N+1}-1.02)}{0.02}$$

Solving equation (20) for *N*, we get $N \approx 1031$ years. Hence, at this consumption rate, Earth would lock to the Moon in **1031 years**. Although this is a very rough estimation, it illustrates how fast we could decelerate the rotation of the Earth.

In The End

The result of tidal friction is the disappearance of Earth's self-rotation, similar to the Moon's current situation. Eventually, the Earth and Moon will become tidally locked to each other and will rotate as a binary system around their barycenter once a month. This means that a day on Earth will be the same as a month.

As the Moon moves away from Earth at a rate of 38.247 millimeters per year due to tidal acceleration, it increases the moment of inertia for the Earth-Moon binary system and reduces its rotation speed. As a result, a month will be slightly longer than it is today, which means there will be fewer than 12 months in a year.

After Earth locks to the Moon, a day on Earth will be more than 30 times longer than it is today. One side of the Earth will face the Sun for much longer, resulting in extremely high temperatures, while the other side will experience extreme cold. This vast temperature difference will create a significant pressure gradient, which will drive strong currents and result in massive storms. The severe environment created by these conditions will make it difficult for most life on Earth to survive, and many species may become extinct.

Predictions

One prediction arising from this understanding is that Earth’s inner core rotates faster than the planet as a whole, a phenomenon known as inner core super-rotation. Our knowledge of Earth’s internal structure primarily comes from analyzing seismic waves. When an earthquake occurs, two main types of seismic waves propagate through the Earth: P-waves, which involve ground motion in the direction of wave travel, and S-waves, which involve transverse motion perpendicular to the wave direction. S-waves cannot travel through liquids because they require shear stress, a type of deformation that fluids cannot sustain. Since S-waves do not pass through the outer core, it is inferred that the outer core is liquid.

The existence of the liquid outer core makes it possible for the rotation of the inner core and mantle to be decoupled. As the mantle and crust of Earth are dragged by tides, the inner core may not slow down at the same rate, thus predicting that the inner core may rotate faster than the mantle. Due to the viscosity of the outer core, the inner core will gradually slow down. The speed difference between the inner core and the mantle should decrease along with the rotation of the Earth.

These predictions have been supported by several observations. Xiaodong Song and Paul Richards, scientists at the Lamont–Doherty Earth Observatory, presented seismic evidence for a super-rotation of 0.4 to 1.8 degrees per year,[19] while another study estimated the super-rotation to be 3 degrees per year.[20]

Conclusions

Consuming tidal energy may pose even greater risks than burning fossil fuels. Driven by rapid global economic growth, industries are increasingly developing and deploying high-efficiency machinery and infrastructure that demand ever more energy. If tidal energy were widely exploited to meet this demand, it could deplete Earth’s rotational energy in as little as 1,000 years, much faster than through natural dissipation. A century ago, few believed that fossil fuel consumption could lead to global warming; today, it is a well-established environmental crisis. History may be poised to repeat itself. The pressing issue now is that many people remain unaware of the potential dangers and still mistakenly view tidal energy as a renewable resource. To safeguard our planet, we must avoid harvesting tidal energy and instead give future generations the time and opportunity to develop sustainable solutions that can prevent this looming catastrophe.

Revision History

- 05/30/2019: Initial Post on Stanford Site
- 11/02/2025: Published on Zenodo
- 11/17/2025: Revised Abstract
- 12/17/2025: Adding Links to Summaries of Related Articles

Links to Summaries of Related Articles

- https://cs.stanford.edu/people/zjl/abstract.html, PDF
- https://sites.google.com/view/zjl/abstracts, PDF
- https://xenon.stanford.edu/~zjl/abstract.html, PDF
- https://doi.org/10.5281/zenodo.17967154, PDF

Further Literature

- Misconceptions in Thermodynamics (PDF: DOI) (中文: DOI)
- The Mechanism Driving Crookes Radiometers (PDF: DOI) (中文: DOI)
- The Cause of Brownian Motion (PDF: DOI) (中文: DOI)
- Can Temperature Represent Average Kinetic Energy? (PDF: DOI) (中文: DOI)
- The Nature of Absolute Zero Temperature (PDF: DOI) (中文: DOI)
- The Triangle of Energy Transformation (PDF: DOI) (中文: DOI)
- Is Thermal Expansion Due to Particle Vibration? (PDF: DOI) (中文: DOI)
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- Tidal Energy Is Not Renewable (PDF: DOI) (中文: DOI)
- AI Contamination (PDF) (中文)

- DeepSeek pk ChatGPT (PDF) (中文)

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