science made simple®

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Teacher Notes

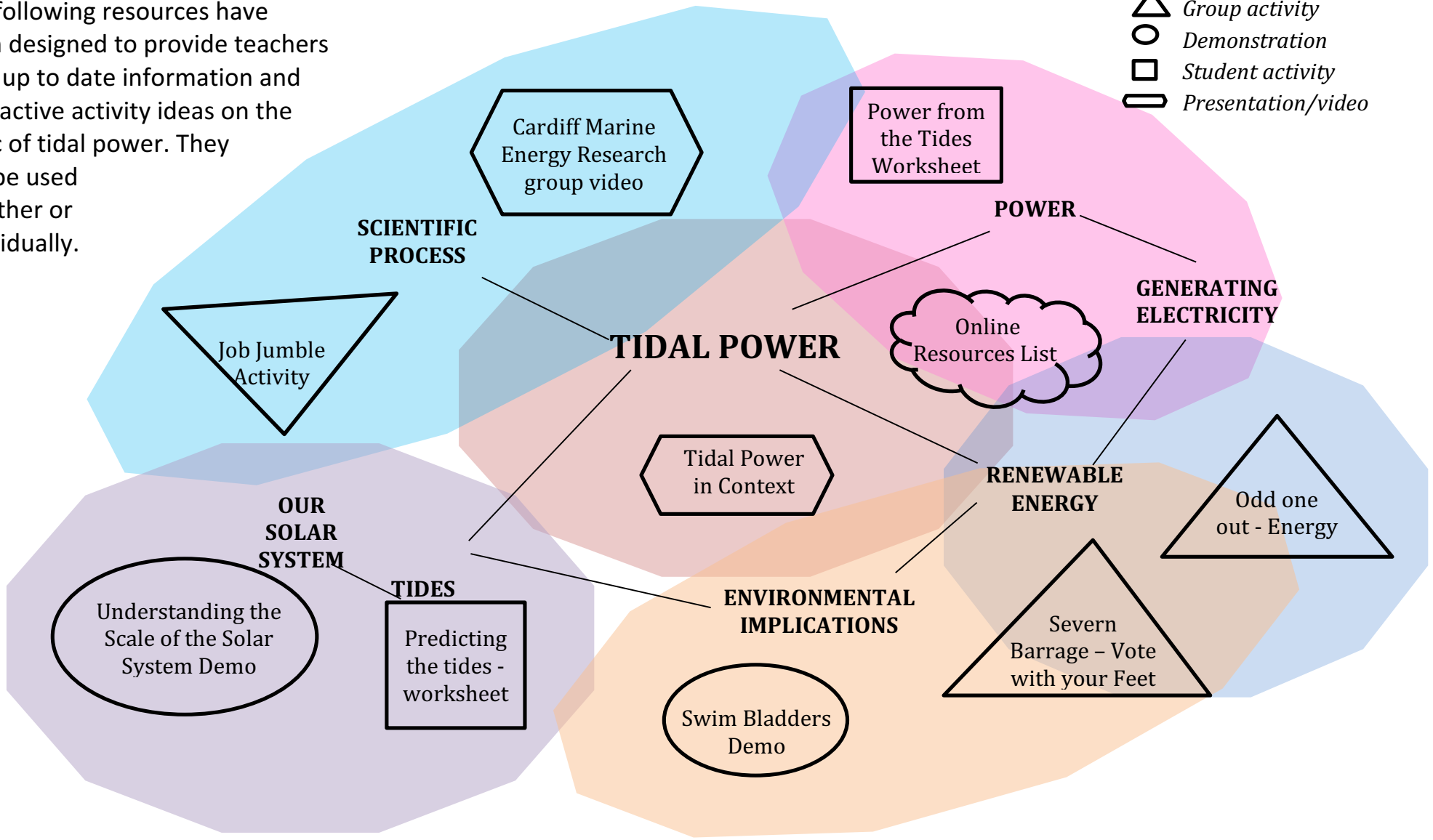
Tidal Power

This resource provides students with the opportunity to explore science, engineering and mathematics related to research into tidal power

Table of Contents

Outline of Tidal Power Resources

The following resources have been designed to provide teachers with up to date information and interactive activity ideas on the topic of tidal power. They can be used together or individually.

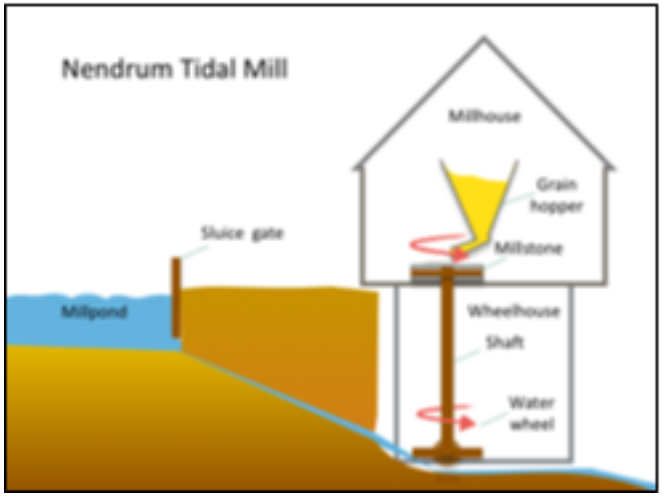


1. Tidal Power in Context

These notes accompany the powerpoint file - TidalPowerinContext.pptx. They are designed to provide context for the topic of tidal power and a brief discussion of some of the new technologies currently being researched and their implications for the UK.

SLIDE 1

SLIDE 2



Harnessing the power of the tides has been ongoing in the British Isles, probably since Roman times, but definitely since at least the 7th century, as excavations at the medieval monastery, Nendrum, at Strangford Lough in Northern Ireland have shown. The monks had built a tidal mill here around 619- 621 CE, which would have helped them conform to the rules of Western Monasticism as drawn up by St. Benedict (c.480 – c.547). He stressed moderation in all things, including diet, which resulted in the rule that monks only eat two meals a day, and that these meals should principally consist of bread, with a daily allowance of 1lb of bread per monk. https://www.archaeology.co.uk/articles/features/harnessing-the-tides-excavating-the-earliest-mills- in-ireland.htm

Milling their flour would have been very important to their adherence to these rules, and their creation of a tidal pond, which filled up with the tides and then was released through a narrow chute, called a penstock, gave them sufficient power to turn a horizontal paddle wheel directly attached to the millstone.

Other tidal mills became common and were particularly important in Anglesey, which was known as the breadbasket of Wales, during the 16th and 17th centuries owing to the lack of usable rivers for milling locally. Holy Island (Ynys Gybi) off the Anglesey coast had 3 such mills in a 2Km radius.

SLIDE 3

Other tidal mills became common and were particularly important in Anglesey, which was known as the breadbasket of Wales, during the 16th and 17th centuries owing to the lack of usable rivers for milling locally. Holy Island (Ynys Gybi) off the Anglesey coast had 3 such mills in a 2Km radius.
In Pembrokeshire, the Carew tidal mill (shown in picture) associated with Carew Castle is the only intact mill of this type in Wales. Built in the 19th century to mill corn, but on the site of an earlier mill, it uses two undershot water wheels.

One of the principal requirements for siting a tidal mill is an indented coastline with sheltered bays, estuaries or inlets, across which a causeway or sea wall can be constructed to impound water. A reasonable tidal range is necessary to give an adequate head of water, and a large area for storing water is also required to provide a continuous flow for the mill to operate between tides. One or more channels are cut through the causeway to allow sea water to fill the pond as the tide rises. In these channels are set floodgates, which may be hand operated sluices or automatic gates, that are pushed open by the rising tide and shut by the water pressure in the pond as it starts to fall.

The tidal range in Milford Haven is up to 7.9 metres, one of the largest in the world and, when the tide swells the remote inlets of the Cleddau River, no part of Pembrokeshire is more than seven miles (11 km) from salt water. It is small wonder that tidal power should have been harnessed to drive two mills, first at Carew and later at Pembroke. A further eight tidal mills are known to have existed in Wales, mainly around Holy Island (Ynys Gybi) on Anglesey (Ynys Môn) and on the banks of the Menai Strait (Afon Menai). Anglesey, which was known as the breadbasket of Wales, has a lack of usable rivers for powering mills, and therefore the tidal range around the island was put to good use.

SLIDE 4

Tidal mills are an example of using tidal range.

“Tidal range technologies exploit the difference in height between high and low tides by holding back water at high tide and releasing it through turbines at low tide. Tidal barrages and tidal lagoons are tidal range schemes; barrages span an estuary or embayment, whereas tidal lagoons enclose a discrete area of water in shallow coastal locations.

Tidal stream technologies generate electricity using the flow of water created by the tides and accelerated by coastal topography. There are many different types of tidal stream devices, although they all work on the principle of the tidal stream causing a part of the device to move, and this movement being used to generate electricity.“

Source: http://www.sd-commission.org.uk/data/files/publications/TidalPowerUK2- Tidal_technologies_overview.pdf

The first map shows the estimated resource for energy from tidal range devices and the second map shows the estimated resource for energy from tidal stream devices.

Prior to incorporation into the Department for Business, Energy and Industrial Strategy in July 2016, the Department of Energy and Climate Change estimated that wave & tidal stream energy combined has the potential to deliver around 20 per cent of the UK's current electricity needs which equates to an installed capacity of around 30 – 50GW. In addition, tidal lagoons could deliver up to 8 per cent of our energy needs according to a 2014 report by The Centre for Economics and Business Research.

https://www.cebr.com/reports/tidal_lagoons-2/

The UK has around 50% of Europe's useable tidal resources, and yet the development of tidal turbines is in its infancy, relative to the development of wind power generation. Cutting edge research is being undertaken into the design and development of such turbines.

SLIDE 5

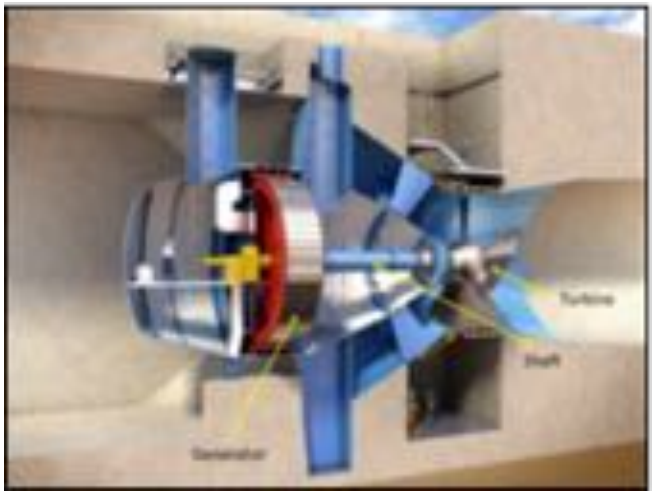
This is an artist's impression of the proposed tidal lagoon in Swansea Bay.

"A tidal lagoon is a 'U' shaped breakwater, built out from the coast which has a bank of hydro turbines in it. Water fills up and empties the man-made lagoon as the tides rise and fall. We generate electricity on both the incoming and outgoing tides, four times a day, every day." Source: http://www.tidallagoonpower.com/projects/swansea-bay/

Video - http://www.tidallagoonpower.com/projects/swansea-bay/3d-model/

The proposed tidal wall will be 9.5km long and the electricity generated could power 155,000 homes each year.

SLIDE 6



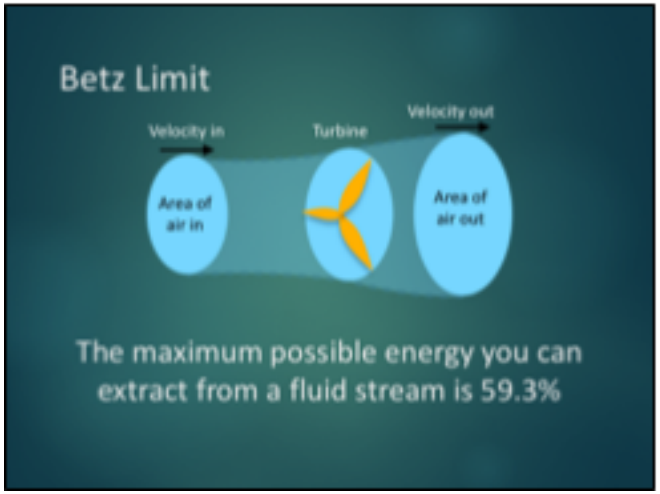
This is one of the 60-90 turbines that will be installed in the Swansea tidal lagoon. It is bi-directional and can generate electricity when the tide comes in and when it goes out.

SLIDE 7

There are also lots of tidal stream projects in development. In 2008, following extensive environmental studies, a project was awarded a five year licence by the Northern Ireland government. The *SeaGen S* device, developed by Marine Current Turbines Ltd (MCT), is a twin axial-flow turbine supported on a structure with the ability to raise the moving components out of the water for maintenance. It is only in 2017 that the device will be decommissioned.

Where was this power generating device installed? Strangford Lough in Northern Ireland. Harnessing the same tidal power as the Nendrum monks 1,400 years earlier. And around Holy Island (Ynys Gybi) three separate seabed sites have been identified for tidal stream power generating systems.

SLIDE 8



Tidal stream turbines cannot convert all of the kinetic energy from the water flow. If they did the water would stop dead and prevent further water from passing through the turbine. In 1919, the German physicist Albert Betz, published what became to be known as Betz's Law. He calculated, derived from the principles of conservation of mass and momentum, that for a fluid stream (he was working on wind turbines, but the principle is the same) flowing through an idealised 'actuator disc' that extracts energy from the stream, the maximum possible capture of kinetic energy is 16/27, or 59.3%. See https://en.wikipedia.org/wiki/Betz%27s_law for further information.

Betz limit is based on a number of assumptions

- No hub (the component that the blades slot into)
- Infinite number of blades
- No drag
- Uniform flow/thrust over disk
- No swirl in wake
- Unconstrained Flow

Why is this important? If you calculate the efficiency of a tidal stream turbine based on the energy it converts from the total kinetic energy in the water it would not be a realistic figure. Efficiency is calculated as the energy converted from the total energy ***available*** from the flow instead i.e. 59.3% of the total energy. **Turbine Power Coefficient (C_p)** Most working turbines operate at an efficiency of 75% to 80%, however this is 75% to 80% of the Betz limit ($C_{p\ max}$) of 16/27.

Worked example If a tidal stream turbine is operating at an efficiency of 80%, and has a power output of 2MW, calculate the actual power of the water flow.

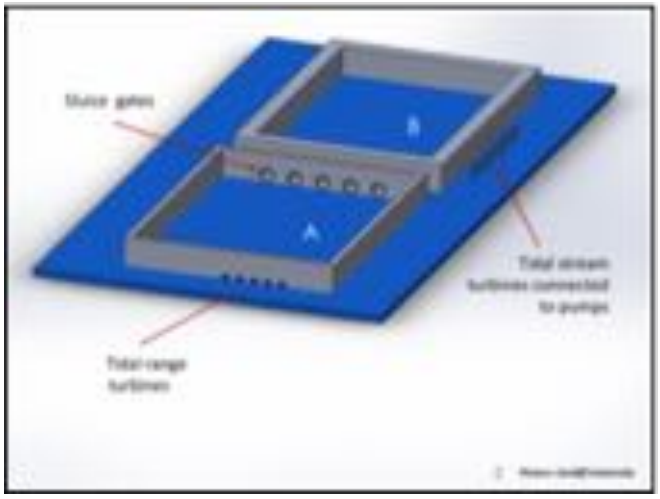
Water power x 80/100 x 16/27 = 2000
Water power = 2000 x 100/80 x 27/16 = 4218.75 watts = ~ 4.2MW

Power generation by wind or tidal stream turbines can be defined as follows:

$P = 1/2\rho AV^{)}C_{+}$

where P = the power generated in watts
ρ = the density of the fluid
A = the sweep area of the turbine ($m^{\cdot}$)
V = the velocity of the flow (m/s)
C_{+} = the turbine power coefficient

SLIDE 9

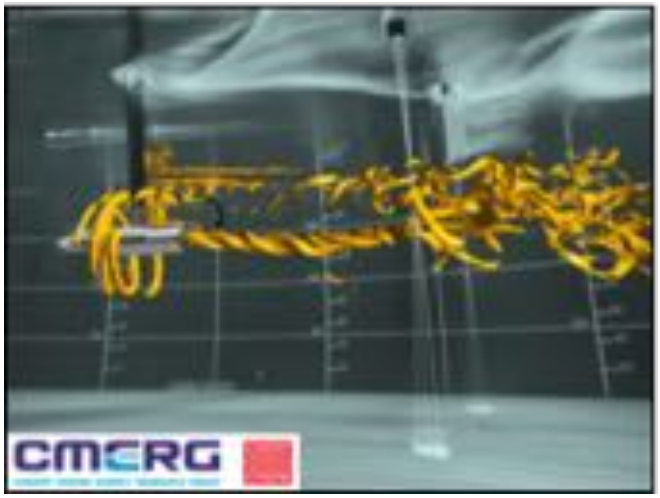


This is an example of a research project from Cardiff University that combines both tidal range and tidal stream turbines.

The water is separated into two enclosures. Enclosure A acts like a normal tidal range enclosure and has bi-directional turbines that generate power when there is a significant difference in water levels.

There are also tidal stream turbines that operate pumps on the side of enclosure B. They pump extra water into enclosure B so that the extra kinetic energy in the flow is converted into further potential energy. This extra water can be used when difference in water level is not enough to drive the tidal range turbines and more power is required. The gates are opened and the water flows from B to A and increases the water height.

SLIDE 10

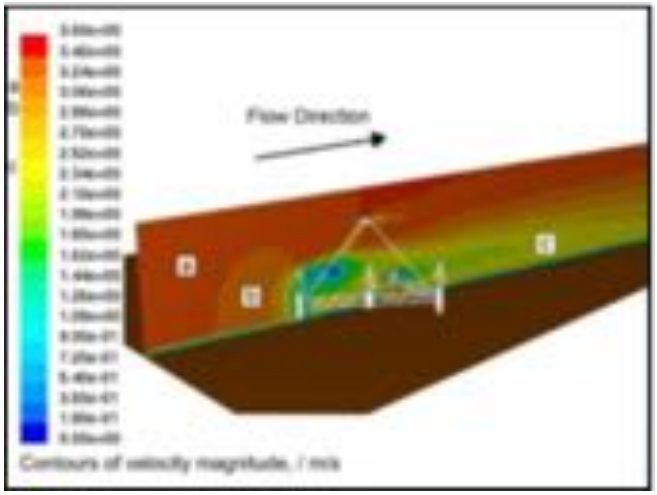


Modelling the turbulence (or wake) caused by tidal stream turbines is also a big area of research. In order to create ‘arrays’ or ‘farms’ of turbines, we need to know how long it takes the water to settle down after passing through the turbine, so that we can work out how close the turbines can be arranged. We also need to ensure that the wake created from won’t have any negative effects on passing boats or marine life.

This picture shows the results from a numerical model of the water flow superimposed on a picture from a test done in a flow tank in the laboratory. The laser beams are part of a system scans the water and calculates its velocity.

Laser Doppler Anemometry https://www.dantecdynamics.com/measurement-principles-of-lda

SLIDE 11



At the moment, tidal stream turbines are being designed to work in fast flowing waters with a velocity of around 3m/s. This means there is lots of kinetic energy, which could be converted. However it also means that the turbines experience very high forces and the design challenge is much greater.

If we were able to design turbines that work efficiently at lower speeds, such as 1.5m/s, more places in the world would be able to use tidal power.

SLIDE 12

Many designs rely on having a very heavy base that keeps the turbine anchored to the seabed. This makes installation, maintenance and recovery expensive, as large specialist boats from the oil industry must be hired.

Some designs, therefore, use lots of smaller turbines to generate power. This picture shows *Minesto Deep Green* tidal stream kite, an array of which is also in planning for installation off the coast of Anglesey. The turbines are tethered to the seabed and can swoop though the water increasing the relative velocity.

http://minesto.com/ Video https://www.youtube.com/watch?v=wdOvS-3e0MQ

Engineers try to find simpler solutions as fewer parts means less things that can go wrong. As in aircraft design, engineers design for planned maintenance, so that breakdowns do not occur. Since tidal power is not yet an established industry many external factors are still being studied to find out where the weaknesses lie. The aim is to create turbines that can be left in the sea for 20 years without needing any intervention.

There are many different designs and technologies being researched and they all have their own advantages and disadvantages.

2. Odd-one-out Energy Activity - Teacher Notes - suggested time 10 minutes

This activity is designed to be a mental starter/warm up exercise. It gets the students discussing different sources of energy and their respective advantages/disadvantages. It also helps develop scientific thinking and provides context for other tidal power classroom activities.

What you need?
Oddoneout_energy.pptx file

What to do
Display one of the Powerpoint slides and tell the class here are four different sources of energy.
Ask which one is the odd one out and why?

You can either use this to facilitate a class discussion, or ask the students to discuss in small groups or pairs for a few minutes before feeding back.

There are no correct answers. What is important is that students develop their reasoning skills and can give clear arguments to support their ideas. The powerpoint includes a number of different slide options, which can also be cut and pasted to create your own version.

Encouragement/facilitation ideas
Do you agree with this person/group? Do you disagree? Why?
Who had a different answer?
What about this type of energy – can anyone think of a reason that this might be the odd one out?

This activity can be used as a way to introduce further activities relating to Tidal Power. Whilst it is still in its infancy compared to other energy sources, a large amount of research is currently being carried out in this area.

Tidal Power Advantages

- Very reliable and predictable source of energy
- High energy densities – can use smaller turbines than wind

- Combining stream and range devices is possible, and placing around the UK coastline would take advantage of differing tide times to provide 24hr power
- Large predicted resource in the UK – provides security for long term energy supply
- Tidal stream turbines can be placed underwater and won't spoil the view
- Renewable and low carbon

Tidal Power Disadvantages

- Underwater Installation is more complicated
- Current technology ten years behind wind turbines.
- Maintenance is expensive so turbines need to be very reliable and built to last for years
- Harsh environment – large forces, corrosive environment, sediment build up and organic growth may occur on static surfaces.
- Other sea users – ships, divers, marine animals and fish may be affected

3. Job Jumble Activity – Teacher notes – suggested time 15-20mins

This is a classroom activity to get students thinking about the sorts of skills that studying science and maths helps develop. It is also an opportunity to practise scientific thinking.

What you need

Printout of Jobs Jumble Activity pdf (1 set per group)

Instructions

Split the class into smaller groups of 6-12 and give each a set of profiles and job information relating to people working in tidal power research and related industries in South Wales. Ask them to try and match the people to their role. Get groups to feedback on their process and solutions before revealing the correct answers.

Facilitation Notes

Ask for evidence – ask them to back up their choices with reasoned argument and discuss the different strategies they used to analyse the information, e.g. process of elimination, looking for commonalities, patterns of speech etc.

Encourage debate - Ask if others agree/disagree and why?

If there is disagreement, point out that often in science there isn't one solution that fits and scientists may disagree over which evidence is the most relevant. As new evidence comes to light scientists may change their opinions. Part of the excitement of science is that what we don't know about the world is much greater than what we do, so it is always possible to make new discoveries.

Emphasise the skills developed by studying STEM subjects. This exercise is not designed to be straightforward. Many of the researchers and jobs could be matched together. Studying science and maths is often thought to limit career options but in reality, it provides many transferable skills that can be useful in any roles. This activity is designed to encourage students to engage with careers information, and challenge their ideas about STEM careers and the kinds of people that do them.

Challenge attitudes

If students express views that indicate gender stereotyping, this is a good opportunity to challenge unconscious balance:

- To address the challenge of energy supply, we need all kinds of people who can think in different ways and bring different experiences with them.
- Male:Female ratios in engineering are worse in the UK than in other European countries so it must be a cultural problem rather than a problem with women.
- Male:Female ratios in engineering are much better in many developing countries that place more emphasise on hard work rather than innate talent – so if we believe the idea that boys have innate talent and girls do not – it is a self-fulfilling prophecy.
- Engineering is one of the only industries where women currently earn more than men. (This could be due to the lack of women entering at a lower level and using engineering apprenticeships as a career route.)

Links to further resources that tackle gender balance in school.
http://www.iop.org/education/teacher/support/girls_physics/resources/page_63821.html
http://www.expecteverything.eu/hypatia/toolkit/

Answers: A) Tattiana B) Stephen C) Jo D) Cath E) Sarika F) Tim
G) Alex H) Filipa J) Ceri K) Jon L) Matt M) Tamsin

4. Severn Barrage Vote with your Feet Activity – Teacher Notes – suggested time 25 minutes

This exercise has been developed to involve students in a discussion of the ethical elements to a large engineering project. The project we have chosen was the recently shelved Hafren Power Severn Barrage scheme. The 'vote with your feet' concept acts as a means of ensuring that every student has to make a choice and take a physical position, which can then be examined through questioning. It should be understood and communicated that there are no 'right' answers, and that this discussion process will involve them in a similar way to the actual discussions that took place. Tidal Power is still a fairly new industry and a lot of the work that scientists and engineers carry out is concerned with the implications for society and comparing different options.

What you need
Severn barrage – vote with your feet powerpoint
Clear space suitable for students to move around
'YES', 'NOT SURE or MAYBE' and 'NO' signs on wall (Placed so that students can spread out between them)

What to do
Here is a suggested script that takes the students through the accompanying powerpoint.

Introduction

In order to give you a feel for some of the ethical issues faced by scientists and engineers I have developed this section, which we call 'vote with your feet'.

SLIDE 1 – title slide

The subject that I want to discuss with you is the most recent proposal for a Severn Barrage. Has anyone heard of this project?

OK good - if you look at the rear of the classroom you will see that I have stuck 3 signs to the wall: YES on the left, NO on the right, and NOT SURE or MAYBE in the centre between the 2. I am going to discuss with you the problems, or things that engineers need to take into account, of the

proposed barrage scheme and we want to know what you think, and whether any evidence we present will change your mind one way or the other. So what I want you to do is as follows: if I ask a question and the answer you think is YES then I want you to go and stand near the YES sign. Now if you think that the answer is NO then go to the NO sign. If you are unsure then aim for the centre, but if you think that the answer is probably YES then stand somewhere in between the two. Likewise if you think probably NO. And so on. You'll soon get the hang of it, and what I want you to do is if I later mention something that changes your mind in any way, then please feel free to move position. At the end of the question session you should be in about the right position and then we will record your answer.
I will stress that there are no right answers here – your answers are as good as anyone else's, and so don't be shy of saying what you feel. I really do want to know what you think, as it will be you and the engineers of the future who will have to deal with the consequences of our choices today.

Before you stand up, let me give you a small bit of history and background.

The River Severn, or Afon Hafren in Welsh, is the longest river in the UK.

SLIDE - map

It runs for over 210 miles from Pumlumon (pronounced pimlimmon), in the Cambrian Mountains of Mid-Wales, through Wales and England, and forms the border between the two countries for a large part of its length. Where it enters the sea, known as the Severn Estuary, it has the second largest tidal range (which means the size of its rise and fall at high and low tides) in the world!

SLIDE – Severn Estuary

This means that it has a massive potential for us to harness tidal power by some means. One such idea, and the most recent proposal, was to have a barrage running from near Cardiff to Weston Super Mare.

SLIDE – Proposed site
SLIDE – artist impression of barrage

But putting a barrage across the Severn is not a new idea. In fact this was first proposed in 1849 by Thomas Fulljames, a civil engineer, who wanted to create a large shipping harbour, road and rail transport and flood protection for the area. There was no electricity generation in the scheme as this was before commercial electricity production.

SLIDE – old barrage pic.

In the UK we have said that by 2020 we need to cut emissions of Carbon Dioxide by 35% from our 1990 total.
(Have you all heard about CO2 being a greenhouse gas caused by burning what are called fossil fuels – coal, oil, gas? Yes? – good)
If No then a brief explanation.
The likely average Wales temperature is predicted to increase by 4C by 2050 (how old will you all be then?) This is likely to mean increased frequency and severity of extreme weather events.

So we need to start investing in large-scale 'clean' energy production from renewable sources such as wind, solar, wave and tidal.

It is estimated that this particular barrage plan could produce 5% of the UK's energy needs.

So let's have you standing up for our first question:

SLIDE: Should we build this barrage across the River Severn?

Question them as to why they are standing where they are.

Ranged against the barrage proposal are various environmental groups, such as the RSPB (Royal Society for the Protection of Birds). They say that there are over 75,000 waterbirds that live in the Severn Estuary, many of which depend on the inter-tidal areas, such as mudflats at low tide, for their food and habitat.

SLIDE: Should we build the barrage if it means that we displace many of these birds and change their habitats so much that they are unable to survive.

Sub-questions

- Are natural ecosystems more important to maintain than 'clean' power generation?
- Where would you stand if say only half of the birds were disrupted? Quarter? Three quarters?
- The company stated that the proposed method would preserve 60% of intertidal habitat, so not as much compensatory habitat (new places for the birds to live) would be needed.
- The company also stated that as the barrage decreases the current speed of the estuary, so the sea bed would be more stable and could increase the biological productivity
- Fish could also be strongly affected. Although the company claimed that their turbines would be fish-friendly this is as yet unproven either way – does this change your mind? Would you risk it?

Nuclear power

Nuclear power is currently a significant part of the UK's energy production methods. But our nuclear power stations are all old and they have begun shutting them down. As you know, nuclear waste is a particular problem for safe disposal because it stays dangerously radioactive for hundreds and hundreds of years. The proposed barrage scheme would generate the power of 3 nuclear power stations.

SLIDE: If building the barrage means that we need to build fewer nuclear power stations, do you think that we should build it?

Floods.

Recently flooding has been a major problem in the UK with many houses and businesses finding themselves under water due to storm surges. As climate change increases it is predicted that such storms and extreme weather patterns will increase.

SLIDE: If the barrage protected 500 square Km of floodplain, and so protected an estimated 90,000 properties from flooding should we build it?

Jobs.

As you all know employment for people is very important. The company that proposed this barrage predicted that building the barrage would have created 20,000 jobs, with 1,000 jobs remaining permanently in order to run and maintain it. Turbines would be assembled in Bristol and Port Talbot.

SLIDE: Should we build the barrage in order to create so many new jobs?

Other schemes

There are other tidal and wave generating proposed schemes that have been suggested for the Severn Estuary. Many of them have less environmental impact, but would also produce less energy. But everything we do will have some effect on either people or wildlife.

SLIDE: Should we investigate other means of harnessing the tidal power of the Severn Estuary?

- Even if they produce less power?

OK so we've now discussed a lot of the problems and possible consequences of this barrage plan. I'd like to ask you the first question again:

SLIDE: Should we build this barrage across the River Severn?

The company responsible for this proposal was dissolved after the government ruled against the scheme. A tidal lagoon project in Swansea Bay is currently under discussion, with similar, though not as extreme, environmental ethical issues.

SLIDE: Artists impression of the Swansea tidal lagoon project

NOTES:

- Government voted against, so it's not currently going to happen.

RSPB

- Tidal lagoon, tidal reef, tidal stream are all for consideration, subject to satisfactory Environmental Impact Assessment.
- Public funding to support development of new technologies?
- Need for engineers and environmentalists to work together.

HABITATS DIRECTIVE - COMPLIANCE

- Appropriate assessment to determine whether there might be adverse environmental impacts.
- IROPI – Imperative Reasons of Overriding Public Interest.
- Compensatory habitat; where, ratio to habitat lost, cost? 'Serious questions remain – effectiveness and feasibility'.
- 'The requirements of the EU Habitats Directive are a significant challenge.'

ECC COMMITTEE INQUIRY REPORT

- 'We conclude that the environmental impacts of the Hafren Power barrage...are very considerable and that there is a high risk of unintended and possibly damaging consequences.'
- La Rance (French barrage cited by Hafren Power as evidence): re potential for improved biodiversity, assessment of environmental impacts is hampered by lack of baseline data.
- Compliance with EU legislation, including Birds and Habitats Directives – SPA and SAC designations – and Ramsar Convention sites.

5. Environmental Impacts

Swim bladders - Classroom Demonstration – 5-10mins

This demonstration illustrates a potential environmental impact of tidal turbines. It is also an opportunity to observe Boyle law's in practice.

What you need

2L clear plastic bottle with lid
Water
Straw
Blutack and scissors

What to do

Watch instructional video at http://www.physics.org/interact/physics-to-go/cartesian-diver/

What's happening?

Apart from the risk of being hit by the spinning blades of the turbine, the other major threat for the fish is rapid pressure change. Bony fish have a gas-filled internal organ, called a swim bladder, which, amongst other functions, contributes to their ability to maintain and control buoyancy.

With tidal turbines there is a pressure increase in the water immediately in front of the turbine, which is followed by a sudden pressure drop directly behind, after which the pressure gradually increases again to match the ambient pressure. It is this rapid pressure change that causes the damage. A pressure drop such as this causes the swim bladder to swell so significantly that it pushes on other internal organs causing damage, and often mortality.

Boyle's Law accurately describes this phenomenon. It states that at constant temperature for a fixed mass, the absolute pressure and the volume of a gas are inversely proportional.

$$P \propto \frac{1}{V}$$

Thus a rapid pressure drop will be associated with a rapid increase in volume of the swim bladder.

The straw diver contains an air bubble sealed inside. Without squeezing the bottle the overall density of the diver is slightly lower than that of the water, so it floats. When you squeeze the sides of the bottle you increase the pressure on the air bubble, compressing it into a smaller space.

This decrease in volume of the bubble causes an increase in the overall density of the straw diver. When it becomes greater than that of the surrounding water it sinks. Releasing the pressure (by releasing the bottle from your grip) allows the air bubble to expand back to its normal size, and the straw diver floats again.

Bony fish can adjust the gas pressure in the swim bladder by using a gas gland. Thus the fish can obtain neutral buoyancy and ascend and descend to a large range of depths.

Implications for tidal turbines

- Environmental impact is an important aspect of the research into tidal stream turbines. Any new technology must be fully tested to find out what effects it might have on the local habitat.
- Turbines are likely to be placed in the fastest flowing parts of the channel. These tend to be areas that the fish avoid since it is tiring to swim in fast currents.
- Since the fish avoid these areas it is thought that mammals that feed on the fish such as seals and dolphins are also likely to avoid these areas.
- Larger turbines are able to rotate at slower speeds making them potentially safer.
- As we do not yet have enough evidence current testing has been very cautious. Turbines are constantly monitored and sonar is used to monitor the local area. If groups of animals are detected the turbines are switched off.
- At one site, several decapitated seals washed up on the shore. After an investigation it was found that the seals had suffocated after becoming trapped in lobster pots. On discovering the dead seals, the fishermen had cut their heads off to release them from the pots and thrown the bodies back into the sea. This highlights the value of fully testing and monitoring new technology so that we know what it is (and isn't doing).
- Another potential outcome is that wildlife that do not like living near the turbines move to other areas. This may have implications for the fishing industry.
- Tidal range installations often include fish gates to enable fish to pass through the barriers without having to pass through the turbines.

Additional notes

- Cartilaginous fish, such as sharks, do not have a swim bladder.
- Human divers use weights to increase their density when diving, but submarines have tanks of compressed air on board to help control their buoyancy. Surrounding the submarine are a number of ballast tanks which, when filled with water, increase the overall density of the submarine and it dives. But when the submarine needs to rise to the surface, the water in these large ballast tanks is replaced with air from the compressed air tanks.

6. Power from the Tides - Teacher Notes

The Tidal Power Review worksheet is designed to review student knowledge of tidal power, particularly energy transfer and design constraints. Some extra information for teachers including real-life applications is below.

What you need: Printouts of "Power from the Tides Worksheet" (pdf).

Notes

Q1) Having a horizontal waterwheel means that the axis, or shaft, can be directly connected to the millstones, with no need for gears or complicated mechanisms.

The horizontal water wheel needs a small volume of water, but needs a high velocity to turn it. It is not very efficient, and derives its motion from the impact of the water hitting its blades. The horizontal wheel is only 15 to 30% efficient at converting the energy of the water in to usable energy transferred through the axle as torque.

The turbines in Dinorwig Hydroelectric Power Station in LLanberis , North Wales are in the horizontal plane.

Many modern designs also find ways to avoid the need for a gearbox. Maintenance is expensive and many locations will be difficult to access. Therefore engineers aim to design systems that will survive for twenty years without breaking. The fewer parts a system has – the fewer things can go wrong. This is one of the reasons that engineers are always trying to find the simplest solution.

Q2) The passage of water, when released from the millpond by opening the sluice gate, causes the water wheel to turn.

Q3) This energy change is Potential Energy (mass x height x g) to Kinetic Energy (mass x velocity^2/2)
Students may also mention mechanical energy, rotational kinetic energy, torque etc. Discussions around these points should be encouraged.

Q4) Wind is a variable resource with speeds changing constantly, and often ceasing altogether. Tides are completely predictable, and, although the size of the tidal rise and fall may change, will still offer approximately twice-daily milling opportunities.

Q5) Sea water is held back by a tidal barrage, or lagoon, and then allowed to flow through the turbines, which spin and generate the electricity.

Q6) Potential Energy to Kinetic Energy to Electrical Energy.

Q7) Things to consider:

- Tides predictable
- UK has immense tidal power generating opportunity
- After construction of barrage or lagoon wall the electricity production is carbon neutral, although there will be small amounts due to maintenance etc.
- Possible dangers to aquatic life, for example swim bladders in bony fish (see swim bladders demo doc.)
- Possible removal of intertidal habitats, for example wading birds
- Could be considered as devaluing the natural environment for tourism and leisure activities, such as sea views, sailing and fishing. Conversely they may also increase the possibility of such activities.

Q8) 0.7MW

Q9) The *Seagen S* has a much bigger turbine, and is sited in, and needs, faster water flow to operate than the *Minesto* type.

Q10) Possible answers:

- Can be installed in slower tidal streams, which means easier installation and more potential sites.
- Can operate at greater depths, and without the above water tower that the *Seagen S* has. This means that they are less obstructive to shipping (although it should also be noted that the ability of the *Seagen S* to be raised up its shaft structure for maintenance are a positive as far as this design is concerned).
- Smaller size and less expensive installation means more turbines can be installed. So if one fails it has less effect on the overall power output.
- Kite design means that the *Minesto* can change it's angle to suit the flow of water – other designs need more complicated mechanisms and sensors to do this.

Further information can be found at

http://www.seageneration.co.uk/
Video https://www.youtube.com/watch?v=OIoHgTQ4LlA

http://minesto.com/
Video https://www.youtube.com/watch?v=wdOvS-3e0MQ

7. Predicting the Tides – Teacher Notes

The apparently simple phenomenon of the ebb and flow of the sea is often plagued by misunderstanding and errors - even in mainstream textbooks and websites. We have therefore written these notes to provide teachers with extensive background information and suggested classroom activities.

Predicting the Tides worksheet – 30mins

The included worksheet encourages students to analyse data from www.tidetimes.org.uk/tide-tables

What you need

Copies of the 'Predicting the tides' worksheet for students (p.5-6)

Student access to tide-times or similar website. (Please note if looking at tides in other geographical locations they may not follow a clear semi-diurnal pattern as in the UK.)

If students are unable to access the internet during class, you can compile tide data from the last month for a given location for them to analyse from a printout.

Notes

Q1-3. Most locations around the UK have a clear semi-diurnal pattern of tides. In some places however local factors create bumps and flats in the tide patterns and it may be more difficult to assess the data for the purposes of this exercise.

Q4. The time between the first high tides of the day should be around 24 hours and 50.4 minutes.

Q5. The lunar day is longer than the earth day. This is why the tide times will be slightly later tomorrow, and later again the next day.

Q6. If the moon orbited the earth in the opposite direction we would expect to pass it before we had completed one rotation of the earth. Therefore it must be travelling in the same direction.

Q7. Encourage students to understand that in science being able to learn from mistakes is a very important skill.

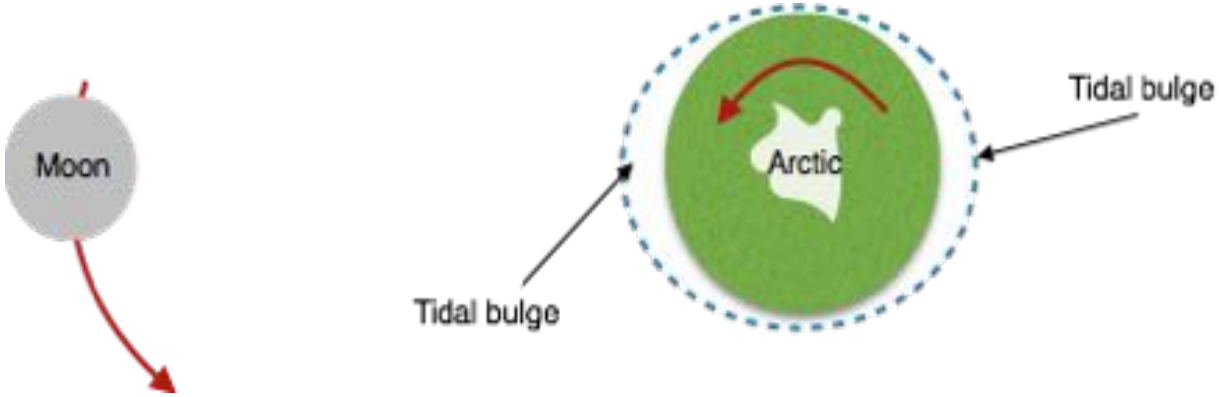
Q8. There should be a noticeable trend in the tidal range over the course of the week. It is possible that the cycle of tides may peak in the middle of the week and the tidal may be similar at the start and end of the week.

Q9. The moon takes about 29.5 days to orbit the earth. During this time there will be two occasions when the earth, moon and sun will be aligned. Therefore we experience spring tides every two weeks.

Why do we have tides?

The gravity of the moon affects the earth's oceans, causing an increase in depth either side of the earth, and is known as the 'tidal bulge'.

Figure 1 - Earth-Moon system (Not to scale)



The earth spins around its own axis once a day, so our continents pass each tidal bulge and we experience two tides a day. (Or at least we would do if the oceans were an even layer of liquid covering a smooth sphere. In reality, a large number of other factors affect the arrival time and size of tides experienced at a particular location.)

Not to Scale

The actual tidal bulge only represents a less than 1 metre increase in the depth of the ocean and the diameter of the earth at the equator is 12,756,000 metres. Therefore, diagrams showing the tidal bulge always exaggerate the effect otherwise it wouldn't be visible. (Also the moon is about 385,000,000m away and definitely wouldn't fit on the page.)

Suggested Activity

Check out the 'Understanding the Scale of the Solar System Demo' sheet from this resource pack for a way to illustrate the relative size of the earth, moon and sun.

This raises an interesting question: if the tidal bulge is less than a metre, why do we get tides much greater than this? For example, in the Bristol Channel between South Wales and South West England, the tidal range (i.e. the difference between high and low tide) can be as much as 14m.

This local variation is due to many different factors, including the shape of the seabed, the coastline and the way that the oceans 'slosh about', causing constructive and destructive interference.

The UK is in a location where these factors come together to create a large tidal resource – high tidal range and fast flowing tides. This is partly due to the continental shelf, which extends into the Atlantic Ocean and 'trips up' the tide as it approaches, and the way the water is forced through small gaps. If we locate tidal generators at different points around the coastline, we could take advantage of the different tide times experienced around the country enabling us to generate power 24hrs a day.

What about places that don't have two tides a day?

The way the oceans flow around, and reflect off the coastline, also helps to explain why, despite two tidal bulges, some places only have one tide a day (Diurnal tide), whereas others have uneven tides (Mixed tides).

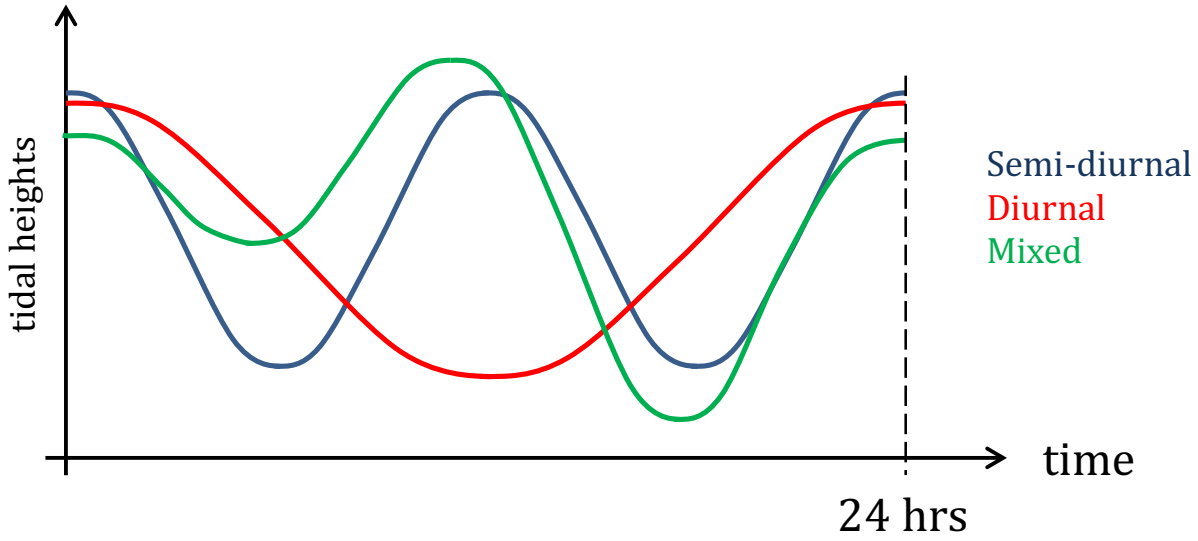


Figure 2 – graph showing tide types

Some places end up without any discernible tide – many places around the Mediterranean have a tidal range of only a few centimeters.

Why does the size of the tides vary throughout the year?

So far we've only considered tides due to the moon (lunar tides). The sun also affects the oceans (solar tides). It is much bigger than the moon but it is also much further away. This means the 'tidal force' caused by the sun is about half that of the moon (45%).

Look at the animation on this website to see the interaction between the tidal raising forces caused by the moon and those caused by the sun.
http://scienceprimer.com/lunar-and-solar-tides

Suggested Activity
The Exploratorium's Tide-O-Matic activity is a simple way for students to make a visual model of the movement of the sun-earth-moon. It provides a talking point about the predictability of tidal power.
www.exploratorium.edu/snacks/tide-o-matic

"If the moon is pulling the oceans around, why isn't it pulling on everything else?"
Actually it is. How much gravitational force a mass exerts on you depends on the size of the mass and its distance away from you. The moon has a smaller mass than the earth and it is much further away from us. The gravitational pull from the moon we experience on the earth's surface is therefore very, very small. It is much smaller than the earth's gravity, which keeps us from floating away.

We are talking about tiny forces but it's not the absolute force that's important, it's the difference across a wide area and the change in direction.

Tides are a differential force, that is, they are a result of the difference in the force of gravity between two points. Therefore, they are only significant for objects that cover a very large area of the earth.
Since water is more flexible than rock, we can see the tidal effect in the oceans of the earth more easily. However, the planet also deforms, by as much as 30 centimeters up and down twice a day.

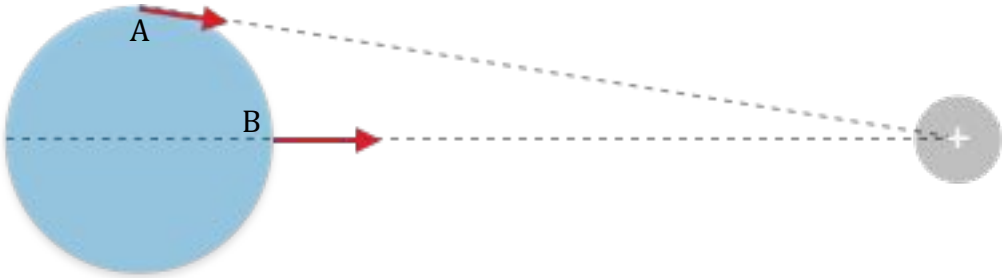


Figure 3 – showing force directions - even though the red forces are tiny the overall effect is that water at A moves towards B.

Note: In diagrams we illustrate the bulge exactly lining up with the moon, however in reality the tidal bulge is pushed slightly in front due to the earth spinning around.

"What causes the second bulge on the far side?"

One of the most common areas of confusion is why the moon/sun creates a tidal bulge on the far side of the earth. It is commonly blamed on centrifugal forces caused by the earth's rotation. This is incorrect and you should avoid any reference to it. The rotation of the earth does affect the position of the bulge but it does not create it.

To explain the bulge on the far side - this is a simple demo which may be useful: www.youtube.com/watch?v=CTQ6ciHENgI

If you think about the moon's gravitational force at different points across the earth you can see it's smallest at the side furthest from the moon.

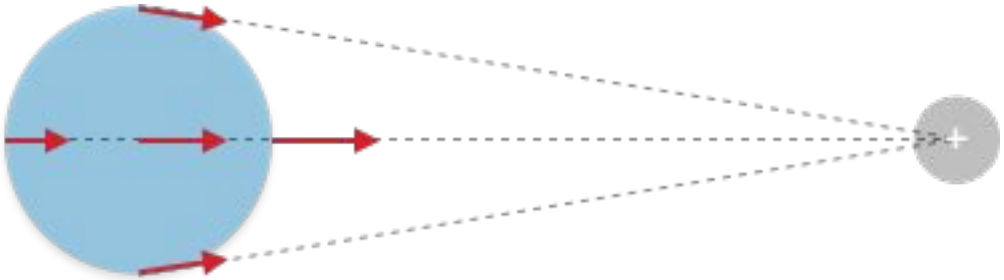


Figure 4 – showing gravitational forces at different points on the earth

This is in respect to the moon. If we change our point of reference and make the centre of the earth our zero point instead, we need to take away the force at that point from all the other forces. The resulting 'tidal raising' forces look like this.

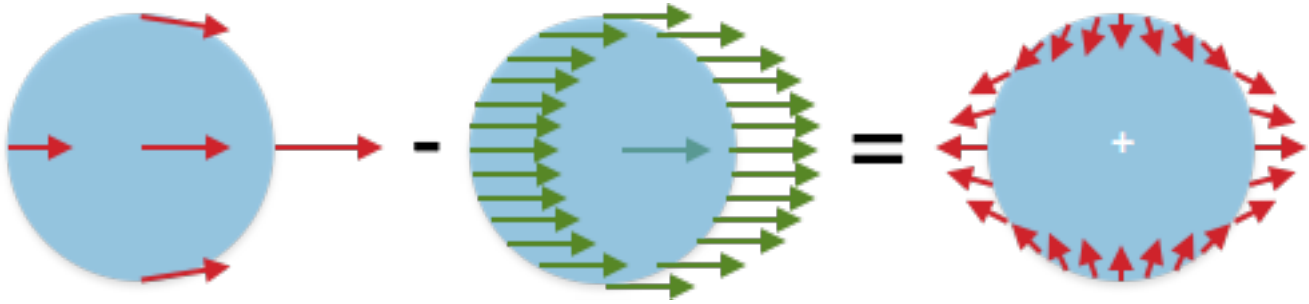


Figure 5 – showing resultant forces

For a more in-depth understanding including the aspect of 'squeezing' rather than pulling see www.youtube.com/watch?v=pwChk4S99i4

This website examines some of the common misconceptions about tides:
www.math.nus.edu.sg/aslaksen/teaching/tides.html

This document shows the estimated wave, tidal stream and tidal range energy around the UK:
https://www.thecrownestate.co.uk/media/502058/ei-uk-wave-and-tidal-key-resource-areas-project-distribution-map.pdf

8. Understanding the Scale of the Solar System - Classroom Demonstration - 5 mins

What you need
A tennis ball
A basketball
Measuring tape/metre rule/string cut to length

What to do
Tell the students that the basketball represents the earth and the tennis ball represents our moon.

Ask 'The relative sizes are about right- how far apart should the two balls be?'

Ask one or two students to help hold the balls at the distances suggested. See if there is a consensus. If there is disagreement, ask students to try and justify their answers.

At this scale the distance between the two is around 7.3m. Get the students holding the balls to move to this distance so that everyone can see this visually.
(You can either have them measure it out, or you could have previously worked out spots in the classroom that are roughly this distance apart, or you can have a prepared piece of string or ribbon at this length.)

Invite students to suggest how big the sun would be. How far away would it be?

Reveal that it would be about 26.5 m in diameter (about the same as the length of 3 buses) and it would be 2.8km away (a 30min walk).

Notes

Use Google maps to try and find a familiar place that is approx. 2.8km from your classroom to use as an example for the students. It is much easier for students to grasp a distance they may have travelled than a number alone.

It is not possible for us to draw diagrams of our solar system to scale as they would not fit on the page/screen. This means that we often have the wrong idea about the scale of space. It is much more vast than we imagine.

The sun is much bigger than the moon, however it is also much further away. This means that from our perspective they are a similar size. If this were not the case, the moon would not be able to block the sun during a total eclipse.

With respect to the tides, the moon plays a much more significant role.

Useful websites and online resources

Tidal power introduction

http://www.sd-commission.org.uk/data/files/publications/welshenglish_onstream_booklet.pdf
http://www.sd-commission.org.uk/data/files/publications/TidalPowerUK2-Tidal_technologies_overview.pdf
https://www.thecrownestate.co.uk/energy-minerals-and-infrastructure/wave-and-tidal/the-resources-and-technologies/
https://www.thecrownestate.co.uk/media/502058/ei-uk-wave-and-tidal-key-resource-areas-project-distribution-map.pdf
https://www.teachengineering.org/lessons/view/cub_energy_lesson02

Historic tidal mills

https://www.archaeology.co.uk/articles/features/harnessing-the-tides-excavating-the-earliest-mills-in-ireland.htm
http://www.buildinghistory.org/buildings/mills.shtml
https://en.wikipedia.org/wiki/Carew_Tidal_Mill
http://www.pembrokeshirecoast.org.uk/default.asp?PID=301
https://en.wikipedia.org/wiki/Tide_mill
http://ffden-2.phys.uaf.edu/211_fall2010.web.dir/Brooks/types-of-water-wheels.html

Tides

www.tidetimes.co.uk
http://www.ntslf.org/
http://scienceprimer.com/lunar-and-solar-tides
www.youtube.com/watch?v=CTQ6ciHENgI
www.youtube.com/watch?v=pwChk4S99i4
www.math.nus.edu.sg/aslaksen/teaching/tides.html

Electricity Distribution

http://www.nationalgrideducation.com/resources/

www.rareloop.com/project/gridmania/

Renewable Energy Sources and Comparisons

https://www.youtube.com/playlist?list=PLFjdi9STI26NseXKKYB7228HojuWPp7TC

http://news.bbc.co.uk/1/shared/spl/hi/guides/456900/456932/html/nn5page1.stm

https://blog.education.nationalgeographic.com/2015/03/24/costa-rica-goes-renewable/

Laser Doppler Anemometry

https://www.dantecdynamics.com/measurement-principles-of-lda

Betz's Law

https://en.wikipedia.org/wiki/Betz's_law

Wind turbine technical specifications

http://www.hitachi.com/products/power/wind-turbine/specification/

http://www.aweo.org/windmodels.html

Swim Bladders

https://ww2.kqed.org/quest/2015/03/12/science-spotlight-fish-swim-bladders-and-boyles-law/

Tidal power generation companies

http://www.seageneration.co.uk/index.php

http://www.nautricity.com/

http://minesto.com/
http://www.openhydro.com/Environment/Tidal-Energy
http://www.energy.ox.ac.uk/marine/

Severn Barrage

http://blueandgreentomorrow.com/features/severn-estuary-the-tidal-barrage-debate-continues/
https://en.wikipedia.org/wiki/Severn_Barrage
http://www.bbc.co.uk/news/uk-wales-18066981

Anglesey tidal stream projects news reports

http://www.dailypost.co.uk/business/business-news/70m-anglesey-tidal-project-shelved-11078552
http://www.walesonline.co.uk/business/business-news/70m-skerries-tidal-project-gets-9160142
http://www.dailypost.co.uk/news/north-wales-news/plans-tidal-energy-scheme-anglesey-11113659
http://www.walesonline.co.uk/business/business-news/tidal-energy-kite-maker-minesto-9286295

Design and Make/ Workshop activities

http://www.re-energy.ca/hydro-generator
https://www.exploratorium.edu/snacks/tide-o-matic
https://www.ewb-uk.org/our-initiatives/inspiring-change-in-engineering-education/outreach-programme/power-for-everyone-everywhere/
https://www.exploratorium.edu/snacks/earth-moon
https://www.exploratorium.edu/snacks/stripped-down-generator
https://sciencebob.com/make-a-cartesian-diver/
http://www.physics.org/tricks/cartesian-diver/