

Tidal power

Tidal power or **tidal energy** is a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity

Although not yet widely used, tidal energy has potential for future electricity generation. Tides are more predictable than the wind and the sun. Among sources of renewable energy, tidal energy has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability. However, many recent technological developments and improvements, both in design (e.g. dynamic tidal power, tidal lagoons) and turbine technology (e.g. new axial turbines, cross flow turbines), indicate that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be brought down to competitive levels.

Historically, tide mills have been used both in Europe and on the Atlantic coast of North America. The incoming water was contained in large storage ponds, and as the tide went out, it turned waterwheels that used the mechanical power it produced to mill grain.^[1] The earliest occurrences date from the Middle Ages, or even from Roman times.^{[2][3]} The process of using falling water and spinning turbines to create electricity was introduced in the U.S. and Europe in the 19th century.^[4]

The world's first large-scale tidal power plant was the Rance Tidal Power Station in France, which became operational in 1966. It was the largest tidal power station in terms of output until Sihwa Lake Tidal Power Station opened in South Korea in August 2011. The Sihwa station uses sea wall defense barriers complete with 10 turbines generating 254 MW.^[5]



Sihwa Lake Tidal Power Station, located in Gyeonggi Province, South Korea, is the world's largest tidal power installation, with a total power output capacity of 254 MW

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Generation of tidal energy

Tidal power is taken from the Earth's oceanic tides. Tidal forces are periodic variations in gravitational attraction exerted by celestial bodies. These forces create corresponding motions or currents in the world's oceans. Due to the strong attraction to the oceans, a bulge in the water level is created, causing a temporary increase in sea level. As the Earth rotates, this *bulge* of ocean water meets the shallow water adjacent to the shoreline and creates a tide. This occurrence takes place in an unfailling manner, due to the consistent pattern of the moon's orbit around the earth.^[6] The magnitude and character of this motion reflects the changing positions of the Moon and Sun relative to the Earth, the effects of Earth's rotation, and local geography of the sea floor and coastlines.

Tidal power is the only technology that draws on energy inherent in the orbital characteristics of the Earth–Moon system, and to a lesser extent in the Earth–Sun system. Other natural energies exploited by human technology originate directly or indirectly with the Sun, including fossil fuel, conventional hydroelectric, wind, biofuel, wave and solar energy. Nuclear energy makes use of Earth's mineral deposits of fissionable elements, while geothermal power taps the Earth's internal heat, which comes from a combination of residual heat from planetary accretion (about 20%) and heat produced through radioactive decay (80%).^[7]

A tidal generator converts the energy of tidal flows into electricity. Greater tidal variation and higher tidal current velocities can dramatically increase the potential of a site for tidal electricity generation.

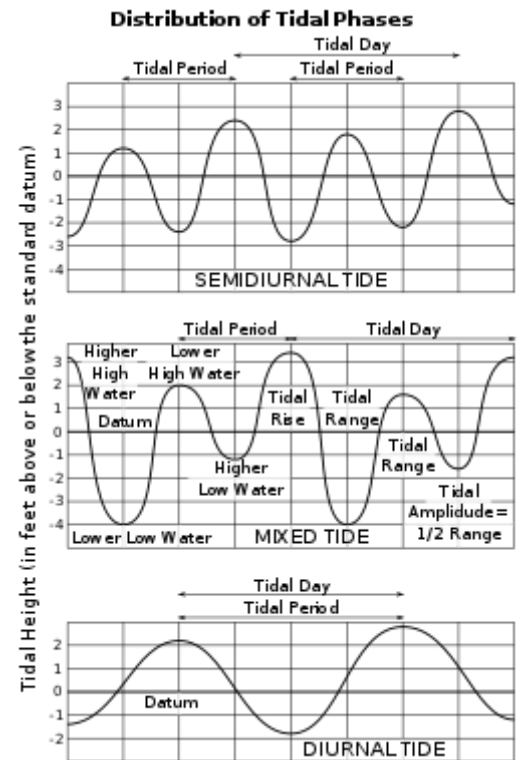
Because the Earth's tides are ultimately due to gravitational interaction with the Moon and Sun and the Earth's rotation, tidal power is practically inexhaustible and classified as a renewable energy resource. Movement of tides causes a loss of mechanical energy in the Earth–Moon system: this is a result of pumping of water through natural restrictions around coastlines and consequent viscous dissipation at the seabed and in turbulence. This loss of energy has caused the rotation of the Earth to slow in the 4.5 billion years since its formation. During the last 620 million years the period of rotation of the earth (length of a day) has increased from 21.9 hours to 24 hours,^[8] in this period the Earth has lost 17% of its rotational energy. While tidal power will take additional energy from the system, the effect is negligible and would only be noticed over millions of years.

Generating methods

Tidal power can be classified into four generating methods:

Tidal stream generator

Tidal stream generators make use of the kinetic energy of moving water to power turbines, in a similar way to wind turbines that use wind to power turbines. Some tidal generators can be built into the structures of existing bridges or are entirely submersed, thus avoiding concerns over impact on the natural landscape. Land constrictions such as straits or inlets can create high velocities at specific sites, which can be captured with the use of turbines. These turbines can be horizontal, vertical, open, or ducted.^[10]



Variation of tides over a day

Tidal barrage

Tidal barrages make use of the potential energy in the difference in height (or hydraulic head) between high and low tides. When using tidal barrages to generate power, the potential energy from a tide is seized through strategic placement of specialized dams. When the sea level rises and the tide begins to come in, the temporary increase in tidal power is channeled into a large basin behind the dam, holding a large amount of potential energy. With the receding tide, this energy is then converted into mechanical energy as the water is released through large turbines that create electrical power through the use of generators.^[11] Barrages are essentially dams across the full width of a tidal estuary

Dynamic tidal power

Dynamic tidal power (or DTP) is an untried but promising technology that would exploit an interaction between potential and kinetic energies in tidal flows. It proposes that very long dams (for example: 30–50 km length) be built from coasts straight out into the sea or ocean, without enclosing an area. 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 found in the UK, China, and Korea.

Tidal lagoon

A new tidal energy design option is to construct circular retaining walls embedded with turbines that can capture the potential energy of tides. The created reservoirs are similar to those of tidal barrages, except that the location is artificial and does not contain a preexisting ecosystem.^[10] The lagoons can also be in double (or triple) format without pumping^[12] or with pumping^[13] that will flatten out the power output. The pumping power could be provided by excess to grid demand renewable energy from for example wind turbines or solar photovoltaic arrays. Excess renewable energy rather than being curtailed could be used and stored for a later period of time. Geographically dispersed tidal lagoons with a time delay between peak production would also flatten out peak production providing near base load production though at a higher cost than some other alternatives such as district heating renewable energy storage. The proposed Tidal Lagoon Swansea Bay in Wales, United Kingdom would be the first tidal power station of this type once built.^[4]

US and Canadian studies in the twentieth century

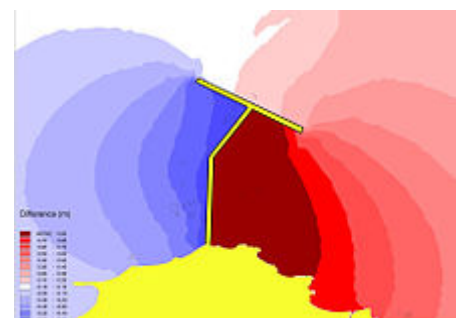
The first study of large scale tidal power plants was by the US Federal Power Commission in 1924 which if built would have been located in the northern border area of the US state of Maine and the south eastern border area of the Canadian province of New Brunswick, with various dams, powerhouses, and ship locks enclosing the Bay of Fundy and Passamaquoddy Bay (note: see map in reference). Nothing came of the study and it is unknown whether Canada had been approached about the study by the US Federal Power Commission.^[15]

In 1956, utility Nova Scotia Light and Power of Halifax commissioned a pair of studies into the feasibility of commercial tidal power development on the Nova Scotia side of the Bay of Fundy. The two studies, by Stone & Webster of Boston and by Montreal Engineering Company of Montreal independently concluded that millions of horsepower could be harnessed from Fundy but that development costs would be commercially prohibitive at that time.^[16]

There was also a report on the international commission in April 1961 entitled "Investigation of the International Passamaquoddy Tidal Power Project" produced by both the US and Canadian Federal Governments. According to benefit to costs ratios, the project was beneficial to the US but not to Canada. A highway system along the top of the dams was envisioned as well.



The world's first commercial-scale and grid-connected tidal stream generator – SeaGen – in Strangford Lough.^[9] The strong wake shows the power in the tidal current



Top-down view of a DTP dam. Blue and dark red colors indicate low and high tides, respectively

A study was commissioned by the Canadian, Nova Scotian and New Brunswick governments (Reassessment of Fundy Tidal Power) to determine the potential for tidal barrages at Chignecto Bay and Minas Basin – at the end of the Fundy Bay estuary. There were three sites determined to be financially feasible: Shepody Bay (1550 MW), Cumberline Basin (1085 MW), and Cobequid Bay (3800 MW). These were never built despite their apparent feasibility in 1974.^[7]

US Studies in the twenty first century

A project to create a tidal power installation was begun in early 2014 by the Snohomish PUD in Washington but was ended in late 2014 due to problems obtaining funding.^[18]

Tidal power development in the UK

The world's first marine energy test facility was established in 2003 to start the development of the wave and tidal energy industry in the UK. Based in Orkney, Scotland, the European Marine Energy Centre (EMEC) has supported the deployment of more wave and tidal energy devices than at any other single site in the world. EMEC provides a variety of test sites in real sea conditions. Its grid connected tidal test site is located at the Fall of Warness, off the island of Eday, in a narrow channel which concentrates the tide as it flows between the Atlantic Ocean and North Sea. This area has a very strong tidal current, which can travel up to 4 m/s (8 knots) in spring tides. Tidal energy developers that have tested at the site include: Alstom (formerly Tidal Generation Ltd); ANDRITZ HYDRO Hammerfest; Atlantis Resources Corporation; Nautricity; OpenHydro; Scotrenewables Tidal Power; Voith.^[19] The resource could be 4 TJ per year.^[20] Elsewhere in the UK, annual energy of 50 TWh can be extracted if 25 GW capacity is installed with pivotable blades.^{[21][22][23]}

Current and future tidal power schemes

- The Rance tidal power plant built over a period of 6 years from 1960 to 1966 at La Rance, France.^[24] It has 240 MW installed capacity
- 254 MW Sihwa Lake Tidal Power Plant in South Korea is the largest tidal power installation in the world. Construction was completed in 2011.^{[25][26]}
- The first tidal power site in North America is the Annapolis Royal Generating Station, Annapolis Royal, Nova Scotia, which opened in 1984 on an inlet of the Bay of Fundy.^[27] It has 20 MW installed capacity
- The Jiangxia Tidal Power Station, south of Hangzhou in China has been operational since 1985, with current installed capacity of 3.2 MW. More tidal power is planned near the mouth of the Yalu River.^[28]
- The first in-stream tidal current generator in North America, Race Rocks Tidal Power Demonstration Project was installed at Race Rocks on southern Vancouver Island in September 2006.^{[29][30]} The next phase in the development of this tidal current generator will be in Nova Scotia (Bay of Fundy).^[31]
- A small project was built by the Soviet Union at Kislaya Guba on the Barents Sea. It has 0.4 MW installed capacity. In 2006 it was upgraded with a 1.2 MW experimental advanced orthogonal turbine.
- Jindo Uldolmok Tidal Power Plant in South Korea is a tidal stream generation scheme planned to be expanded progressively to 90 MW of capacity by 2013. The first 1 MW was installed in May 2009.^[32]
- A 1.2 MW SeaGen system became operational in late 2008 on Strangford Lough in Northern Ireland.^[33]
- The contract for an 812 MW tidal barrage near Ganghwa Island (South Korea) north-west of Incheon has been signed by Daewoo. Completion is planned for 2015.^[25]
- A 1,320 MW barrage built around islands west of Incheon is proposed by the South Korean government, with projected construction starting in 2017.^[34]
- The Scottish Government has approved plans for a 10 MW array of tidal stream generators near Islay, Scotland, costing 40 million pounds, and consisting of 10 turbines – enough to power over 5,000 homes. The first turbine is expected to be in operation by 2013.^[35]
- The Indian state of Gujarat is planning to host South Asia's first commercial-scale tidal power station. The company Atlantis Resources planned to install a 50 MW tidal farm in the Gulf of Kutch on India's west coast, with construction starting early in 2012.^[36]
- Ocean Renewable Power Corporation was the first company to deliver tidal power to the US grid in September 2012 when its pilot TidGen system was successfully deployed in Cobscook Bay, near Eastport.^[37]
- In New York City, 30 tidal turbines will be installed by Verdant Power in the East River by 2015 with a capacity of 1.05 MW.^[38]

- Construction of a 320 MW tidal lagoon power plant outside the city of Swansea in the UK was granted planning permission in June 2015 and work is expected to start in 2016. Once completed, it will generate over 500GWh of electricity per year, enough to power roughly 155,000 homes.^[39]
- A turbine project is being installed in Ramsey Sound in 2014.^{[40][41]}
- The largest tidal energy project entitled MeyGen (398MW) is currently in construction in the Pentland Firth in northern Scotland.^[42]
- A combination of 5 tidal stream turbines from Ørsted are placed in the Oosterscheldekering, the Netherlands, and have been operational since 2015 with a capacity of 1,2 MW.^[43]

Tidal power issues

Environmental concerns

Tidal power can have effects on marine life. The turbines can accidentally kill swimming sea life with the rotating blades, although projects such as the one in Strangford feature a safety mechanism that turns off the turbine when marine animals approach.^[44] Some fish may no longer utilize the area if threatened with a constant rotating or noise-making object. Marine life is a huge factor when placing tidal power energy generators in the water and precautions are made to ensure that as many marine animals as possible will not be affected by it. The Tethys database provides access to scientific literature and general information on the potential environmental effects of tidal energy.^[45]

Tidal turbines

The main environmental concern with tidal energy is associated with blade strike and entanglement of marine organisms as high speed water increases the risk of organisms being pushed near or through these devices. As with all offshore renewable energies, there is also a concern about how the creation of EMF and acoustic outputs may affect marine organisms. Because these devices are in the water, the acoustic output can be greater than those created with offshore wind energy. Depending on the frequency and amplitude of sound generated by the tidal energy devices, this acoustic output can have varying effects on marine mammals (particularly those who echolocate to communicate and navigate in the marine environment, such as dolphins and whales). Tidal energy removal can also cause environmental concerns such as degrading farfield water quality and disrupting sediment processes.^[46] Depending on the size of the project, these effects can range from small traces of sediment building up near the tidal device to severely affecting nearshore ecosystems and processes.^[47]

Tidal barrage

Installing a barrage may change the shoreline within the bay or estuary, affecting a large ecosystem that depends on tidal flats. Inhibiting the flow of water in and out of the bay, there may also be less flushing of the bay or estuary, causing additional turbidity (suspended solids) and less saltwater, which may result in the death of fish that act as a vital food source to birds and mammals. Migrating fish may also be unable to access breeding streams, and may attempt to pass through the turbines. The same acoustic concerns apply to tidal barrages. Decreasing shipping accessibility can become a socio-economic issue, though locks can be added to allow slow passage. However, the barrage may improve the local economy by increasing land access as a bridge. Calmer waters may also allow better recreation in the bay or estuary.^[47] In August 2004, a humpback whale swam through the open sluice gate of the Annapolis Royal Generating Station at slack tide, ending up trapped for several days before eventually finding its way out to the Annapolis Basin.^[48]

Tidal lagoon

Environmentally, the main concerns are blade strike on fish attempting to enter the lagoon, acoustic output from turbines, and changes in sedimentation processes. However, all these effects are localized and do not affect the entire estuary or bay.^[47]

Corrosion

Salt water causes corrosion in metal parts. It can be difficult to maintain tidal stream generators due to their size and depth in the water. The use of corrosion-resistant materials such as stainless steels, high-nickel alloys, copper-nickel alloys, nickel-copper alloys and titanium can greatly reduce, or eliminate, corrosion damage.

Mechanical fluids, such as lubricants, can leak out, which may be harmful to the marine life nearby. Proper maintenance can minimize the amount of harmful chemicals that may enter the environment.

Fouling

The biological events that happen when placing any structure in an area of high tidal currents and high biological productivity in the ocean will ensure that the structure becomes an ideal substrate for the growth of marine organisms. In the references of the Tidal Current Project at Race Rocks in British Columbia this is documented. Also see this page and Several structural materials and coatings were tested by the Lester Pearson College divers to assist Clean Current in reducing fouling on the turbine and other underwater infrastructure.

Structural Health Monitoring

The high load factors resulting from the fact that water is 800 times denser than air and the predictable and reliable nature of tides compared with the wind makes tidal energy particularly attractive for electric power generation. Condition monitoring is the key for exploiting it cost-efficiently.^[49]

See also

- Tidal power in New Zealand
- Tidal power in Scotland
- World energy resources and consumption
- Structural health monitoring
- Marine energy

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External links

- [Enhanced tidal lagoon with pumped storage and constant outputs](#) as proposed by David J.C. MacKay Cavendish Laboratory, University of Cambridge, UK.
- [Marine and Hydrokinetic Technology Database](#) The U.S. Department of Energy's Marine and Hydrokinetic Technology Database provides up-to-date information on marine and hydrokinetic renewable energy both in the U.S. and around the world.
- [Tethys Database](#) A database of information on potential environmental effects of marine and hydrokinetic and offshore wind energy development.
- [Severn Estuary Partnership: Tidal Power Resource Page](#)
- [Location of Potential Tidal Stream Power sites in the UK](#)
- [University of Strathclyde ESRU—Detailed analysis of marine energy resource, current energy capture technology appraisal and environmental impact outline](#)
- [Coastal Research - Foreland Point Tidal Turbine and warnings on proposed Severn Barrage](#)

- Sustainable Development Commission- Report looking at 'Tidal Power in the UK', including proposals for a Severn barrage
 - World Energy Council- Report on Tidal Energy
 - European Marine Energy Centre- Listing of Tidal Energy Developers -retrieved 1 July 2011 (link updated 31 January 2014)
 - Resources on Tidal Energy
 - Structural Health Monitoring of composite tidal energy converters
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