

Ocean Energy

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1. Introduction

The oceans, covering more than 70 % of the Earth, have long been appreciated as a vast renewable energy source. The energy is stored in the oceans partly as thermal energy, partly as kinetic energy (waves and currents) and also in chemical and biological products. Numerous techniques for extracting energy from the sea have been suggested, most of which can be included in one of the following categories:

- Marine and tidal current energy
- Wave energy
- Ocean thermal energy (OTEC)
- Energy from salinity gradients (osmosis)
- Cultivation of marine biomass

The kinetic energy present in marine and tidal currents can be converted to electricity using relatively conventional turbine technology. Harnessing the kinetic energy in waves presents a different set of technical challenges and a wide variety of designs have been suggested. Ocean thermal energy conversion is possible in locations with large temperature differences, extracting energy using a heat engine. Salinity gradients can be exploited for energy extraction through the osmotic process. The cultivation of marine biomass can yield many useful products, including renewable fuels for electricity generation.

Only a fraction of the global ocean energy resource can be found in sites economically feasible to explore with available technology. However, this fraction could still make a considerable contribution to the European electricity supply and the marine renewable sector is currently the focus of much industrial and academic research around the world.

Sites with attractive wave climate and intense tidal currents are abundant in the vicinity of the European coastline. Thus, research and development activities in the European marine renewable energy sector have mainly concentrated on wave and tidal energy. Therefore wave and tidal energy are reviewed in the following sections.

2. Marine and Tidal Current Energy

Ocean energy, including wave and tidal current energy, has the potential of playing a major role in the electricity market, providing reliable and sustainable energy. Some of the most attractive features of tidal currents include its highly predictable nature and the sizeable resource along the European coastline (1). It is technically possible to extract energy from tidal currents with no pollution during operation and presumed low environmental impact (2).

There are basically two ways of generating electricity from marine and tidal currents: by extracting energy from free flowing water, or by building a tidal barrage across an estuary or a bay in high tide areas. A tidal barrage harnesses the energy in a similar way as run-of-river hydro power plants and was the first ocean energy technology to be used in a large scale project. The 240 MW tidal barrage La Rance was constructed during the 1960s in France and it is still operational today. Since then, the focus has been on capturing the energy in free flowing water, meaning much less civil engineering work and less environmental impact at the site.

A great deal of attention was drawn to marine and tidal currents as a possible source of energy during the oil crisis in the 1970s, but all in all the abundant resources of tidal energy have remained untapped. However, recent developments in power electronics, in the offshore industry and in wind power technology have brought tidal energy much closer to an introduction on the electricity market. At present, there are a number of promising and more or less innovative concepts for Marine Current Energy Converters (MCECs).

The tidal energy potential is substantial, but not all of the resource can be extracted using the available technology. One might choose to call the extension of present prototypes **first generation** devices, using conventional engineering components and reaching a depth of 20 to 30 meters. Early devices might be rated in the range of 200 to 700 kWh (1), but for reaching economical viability the effort to increase operational lifetime and minimize maintenance is likely to be more important than an increase in rated power.

Second generation devices are expected to follow within 10 years (3), introducing specialized components, and more importantly, exploring sites of depths below 40 meters where more of the tidal current potential can be extracted.

The MCEC industry is still in its early days and no full-scale commercial MCEC farm has yet been tested and proven. Hence, it is still too early to foresee a winner in the tidal race. It is likely that the best option will depend on site specific conditions and what follows can be considered as a snapshot of ideas and designs that are evolving continually.

A selection of MCEC resembling wind turbines will be reviewed in chapter 1.3.1. The oscillating hydrofoil technique will be further discussed in chapter 1.3.2. Finally, the concept of constructing tidal barrages will be discussed in chapter 1.3.3.

2.1 General issues on Marine and Tidal Current energy

This chapter presents the basic characteristics and potential of marine and tidal currents. The nature of the source also has implications for environmental and economical aspects of extracting tidal current energy.

2.1.1 Peculiarities of Marine and Tidal Currents

Marine and tidal currents are generally slow moving, but as water is roughly 800 times the density of air a current of only 2 m/s would correspond to the energy density at a wind speed of 18 m/s. Thus, as many as 106 sites of interest for electricity generation have been identified along the European coastline (1). Strong currents are usually found in straits and other shallow or narrow passages. Some of the locations with extremely intense currents include the Pentland Firth, Alderney Race and Severn Estuary in the UK. Particularly promising sites can also be found in the Messina Strait (between Italy and Sicily) and between the Greek islands in the Aegean Sea.

The tide is caused by the gravitational attraction between the moon and the sun with the Earth's oceans. Tidal currents change with the tide in a highly predictable pattern, dominated by semidiurnal, diurnal and mixed tidal streams. This predictable behaviour makes it easier to plan base production power contributions to ensure a firm supply capacity. There are also marine currents of more constant nature, albeit with seasonal change, driven by the Coriolis force and variations in salinity and temperature. A predictable energy source and possible long utilization time are desirable features for achieving economical solutions for renewable energy conversion.

The degree of utilization (the ratio of yearly produced energy to the rated power of the device) is of importance when evaluating the economic potential of renewable energy production (4). This can be seen as the investment cost is driven by the installed power, whereas the income is

dependent on the produced energy. The degree of utilization does not only consider the technical aspect of device *availability*, but also includes the *natural variation* of the energy source. For instance, cloudiness or calm weather could affect the degree of utilization for solar photovoltaic and wind turbines respectively. Marine currents offer a degree of utilization in the order of 80%, which allows for comparatively high investment costs per unit installed power while still achieving economic viability. Even tidal currents show a relatively high degree of utilization, in the range of 40 to 50%, compared to the 20 to 30% that is common for land-based wind turbines (1).

Several resource assessments of the available tidal current potential have been conducted, though it can be difficult to compare the estimates at first sight. Different variables and factors in the assessments include expected average efficiency, device availability, significant impact factor (extractable, or available, percentage of the total resource), spacing of MCEC arrays, lower limit of stream velocity for electricity generation, ratio between first and second tide to name only a few. The JOULE 1996 study (1) included all sites with a mean spring velocity above 1.5 m/s, and considered sites with lower velocities on a site by site basis. Other reports (5, 6) concentrate on locations with mean flow speed greater than 2 m/s.

The extractable potential in the UK has been reported to be 22 TWh per year and 17 TWh per year for the rest of Europe (5). Other reports give estimates of 48 TWh per year for Europe (1) and as high as 58 TWh per year in the UK alone (6) (note that these are estimates for tidal current potential only). One aspect of the available potential is that it is not really 'available' with first generation MCECs operating at depths of 20 to 30 m. Much of the extractable energy is to be found in sites of depths below 40 m (5).

In general, marine and tidal current energy, as well as many other renewables, is characterized by high capital cost and low operational costs. Some of the most advantageous characteristics of tidal currents include its predictable nature, high degree of utilization, lack of pollution during operation and little or no visual impact. However, it is a fluctuating source and difficult conditions can be expected during installation and maintenance.

Some parameters affecting design and operation of MCECs include:

- Fouling by unwanted marine growth, or bio-fouling, would eventually increase the drag and lower the efficiency of the turbine. Antifouling

paint can be used effectively, but may be toxic even in small concentrations (7).

- Reliable sealing of the device is important, but this should not pose a problem as sealing technology is well developed within other industries. Cable junctions, entry and exit points are all potential leak paths and some uncertainties remain where large seals with high rubbing rate has to be used (7).
- Finding a suitable array configuration for a MCEC farm might not be as straight forward as to use existing models from the wind power industry. Wind turbines only use the bottom layers of the atmosphere and are usually placed in open areas. Therefore the kinetic flux can be expected to recover within a relatively short distance behind the turbine (8). MCECs, on the other hand, are likely to be placed in channels or narrow passages where the flow will be constrained. Hence it is not improbable that a tidal current farm might affect the underlying flow to a greater extent than a wind farm would. The amount of energy that can be extracted without any significant impact on the underlying flow has been estimated at 10 to 20% (5, 9) and slightly higher where the flow is less constrained.
- Cavitation occurs when the partial pressure locally falls below the vapor pressure of water. This will be an important and limiting design parameter for MCECs as it could lead to surface damage on the turbine and a subsequent decrease in efficiency. To avoid cavitation, a limited rotor tip-speed of around 7 m/s relative to the oncoming water is recommended for first generation devices (1).
- Turbulence and vibration will also be important design issues. Different load over the structure can give rise to vibration and eventually fatigue in the material.

2.1.1.1 Grid connection

The integration of large amount of renewable energy will become an increasingly important issue for the management and stability of electric grids. While moving from centralized generation towards distributed (or embedded) generation, the intermittency of most renewables is driving additional system requirements and corresponding costs.

When discussing the effect of intermittency on grid stability, it is important to recall the different time scales of natural variation for renewable energy sources. Direct sunshine can show variation within seconds and wind within minutes, whereas tidal currents have a predominant semidiurnal cycle of 12.4 hours and marine currents only experience seasonal change. Short term fluctuations in the total output power can be

reduced by geographically distributed production. Furthermore, the requirements for backup capacity can be significantly reduced if the electricity is generated by a well-balanced mix of renewables rather than by one intermittent source only (10).

Preferred voltage for grid connection for wave and tidal energy devices ranges from 10 kV to 380 kV (11). Grid connection costs will depend on distance to shore. In comparison the grid connection would be in the order of 20% of the total investments for a 150 MW offshore wind farm located 40 km from the nearest grid connection point (12).

2.1.2 Environmental aspects

Little is known about the environmental impact of large scale energy extraction from marine and tidal currents. It is likely though that the environmental impact will be low if appropriate care is shown during site selection and deployment (2). However, energy extraction will not be without environmental detriment, and adequate research is required to increase the understanding of the environmental footprint of MCECs and mitigate any impacts (13).

There are no direct emissions of green house gases (GHG) or other atmospheric pollutants during normal operation of a MCEC. Furthermore, there are no indirect emissions from fuel transports. Most of the life-cycle emissions, including a mere 12 g/kWh of CO₂ (see table 1), are released during manufacturing of the device and to a lesser extent during construction and decommissioning (2).

Pollutant	Tidal Current (g/kWh)	Wave Energy (g/kWh)	Wind energy (g/kWh)	Average UK mix (g/kWh) (1993)
CO ₂	12	14 - 22	12	654
SO ₂	0.08	0.12 – 0.19	0.09	7.8
NO _x	0.03	0.05 – 0.08	0.03	2.2

Table 1: Life-cycle emissions from offshore renewables [2]

Very little intrusion on the public is to be expected during operation of MCECs, but local shipping and fishing industry might be affected though. Thus, care should be taken during site selection and choice of technology to avoid conflict with other users. Potential environmental impact on the benthic ecology, seabirds, pinnipeds and cetaceans is presumed to be insignificant, although, further research is required before any conclusions as to their magnitude can be drawn. Other factors to be regarded include sediment dynamics and acoustic emissions. These factors, together with recommended research areas, are thoroughly discussed in (14).

The long term benefits of MCEC, such as the avoidance of GHG emissions and preservation of oil and coal, are assumed to far outweigh the negative impacts. Good environmental impact assessment could also be crucial for public support.

2.1.3 Economical aspects

More research and development is to be expected before MCECs will find their way to full commercialization. A clear picture of the costs will not be available until a full scale MCEC has been in operation for some time. The economy of a farm would also be highly dependent on site specific conditions, as can be seen in a case study (15) of two sites in British Columbia, Canada. The cost of developing the resource at the two different sites was predicted to 7.7 and 17.5 c /kWh respectively¹.

Electricity cost of below 12 c /kWh have been set as an achievable goal for first generation MCECs (1)². Several more recent reports (3, 16, 17) on potential future energy cost fall within the range of 3.8-9.5 c /kWh as presented in the World Energy Assessment report (18)³.

Other electricity generation technologies, such as wind and nuclear, also started off with what would now be regarded as an uncompetitive price. The key issue here is that the physics behind marine and tidal currents is very promising for energy conversion and grid connection. With a comparatively high possible degree of utilization, the price of electricity produced by MCECs can only be expected to decrease when the technology is developed to better suit the nature of the energy source.

2.2 Description of Marine Current Energy Converter technologies

The concepts of MCECs described in this chapter are a selection of some of the more successful projects including a general review of the technology used.

2.2.1 Marine Current Turbines

Generally, most applied research on MCECs so far has adopted the same basic ideas as behind a wind power system: a turbine in order to convert the linear movement of the current into a rotational movement, and a

¹ Average 2002 exchange rate used, 1 € = 1.4835 CAD and 2 % inflation rate per year added. The indicative cost analysis assumes 8 % discount rate combined with a 30 year facility life of the tidal current farm and a capacity factor (mean power/rated power) of 20%. The calculations are based on cost analysis of MCT technology as presented in [16].

² Presented in [3] as 0,1 €/kWh in 1996, 2 % inflation rate per year added.

³ Average 2001 exchange rate used, 1 € = 0.8968 USD, and 2 % inflation rate per year added.

generator to produce electricity out of the rotational movement. What follows will be a short survey of the different design issues for the main parts of a marine current turbine.

2.2.1.1 Turbine concepts

2.2.1.1.1 Rotor types

There are basically two different rotor concepts, axial flow (propeller type) rotors and cross flow rotors. Cross flow rotors are characterized by having the axis of rotation perpendicular to the flow.

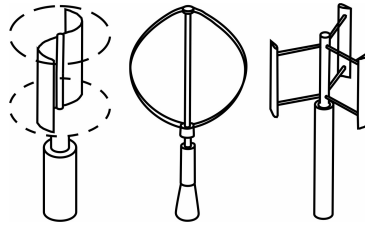


Figure 1: Different types of cross flow rotors illustrated (from left to right) by a Savonius rotor, a Darrieus type rotor and an H-rotor.

Regardless of the design, a turbine can only harness a fraction of the available power in the free flowing water. The extractable power can be expressed as

$$P = \frac{1}{2} C_p \rho A v^3$$

where ρ is the density of the water, A is the area swept by the turbine and v is the mean velocity of the flowing water. The turbine power coefficient, C_p , is the percentage of power that the turbine can extract from the current. The Betz limit of 59% is usually assumed to be the theoretical upper limit for C_p .

Characteristic for the cross flow rotor is that it does not need to be oriented to the flow. This design also allows the gearbox and generator to be located above or below the rotor to avoid interference with the flow across the rotor. Axial flow rotors for MCECs resemble rotors commonly seen for wind turbines, but are in general designed with shorter blades. Furthermore, axial flow rotors need to face the oncoming current and thus require a mechanism that allows the turbine to operate with the flow in both directions. This can, for instance, be achieved by pitch control of the rotor blades through 180° at turn of tide.

Due to low current velocities, the rotor of a marine current turbine will experience low rotational speeds, typically in the range of 5 to 30 rpm (1). Standard generators are in general designed for a higher rotational

speed. Thus, most marine current turbine prototypes have been equipped with a gearbox between the rotor and the generator (see section 1.3.1.3). Traditionally, a high speed generator together with a gearbox has also been used in the wind industry, but today wind turbines with gearless direct drive generators designed for a low rotational speed are commercially available. In line with this development, MCEC concepts with direct drive generators excluding the gearbox are suggested in literature (19).

2.2.1.2 Support structure concepts

MCEC designs presented so far are either fixed to the seabed or moored buoyant structures. The choice of suitable support structure will depend on depth, unit size, seabed material and also economical considerations.

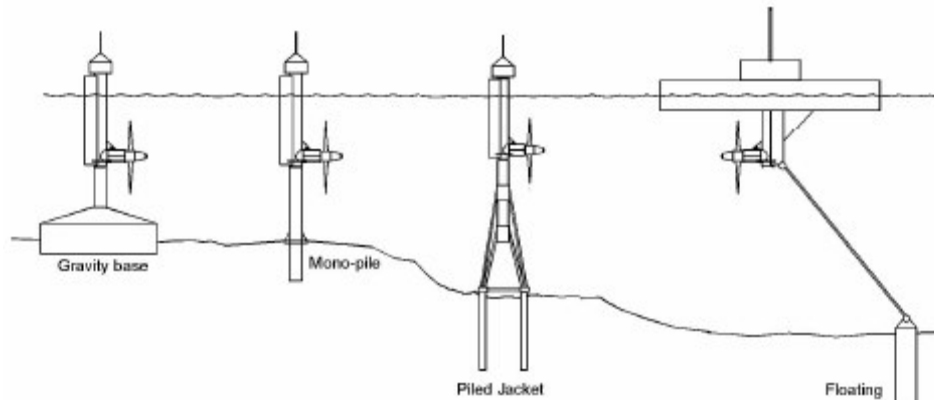


Figure 2: Different support structures for MCEC with axial flow rotor (17)

Specific site requirements imposed by the technology would be depths of 20 to 40 m for first generation MCEC, and between 40 to 80 m for second generation devices (3). Increased depth does not only mean higher installation costs, it also leads to significantly higher forces on the structure as a whole. The expected limit for any surface piercing structure is thought to be around 30 to 50 m, depending on several factors such as flow velocity and seabed material (1).

Experience shows the difficulties of deploying an MCEC in intense currents and great depths. Larger jack up barges have been developed over the years for installation of offshore wind farms. These barges, however, are not necessarily developed for the extreme currents found at sites for MCECs (20).

2.2.1.3 Prototypes

Several small scale prototypes have been tested over the years, but few have reached an advanced state of development. A study in early 2005 includes a list of over 70 companies actively pursuing development in the

marine renewable sector (28). Of these, three prototypes that have been deployed at sea for some time will be detailed below.

Marine Current Turbines Ltd (MCT), Lynmouth, Devon, UK

The Seaflow has been the five-year project of a consortium of seven organisations working with financial support from both the European Commission and the UK Department of Trade and Industry (DTI). In the summer of 2003, MCT in association with Seacore successfully installed the 300 kW Seaflow in the Bristol Channel near Lynmouth.

The turbine is mounted on a surface piercing tubular steel monopile structure fixed into a socket in the seabed. The power train can be raised above sea level for maintenance and the 11 m diameter rotor can reverse the blades, pitching them through 180° at turn of tide. The turbine has been tested under remote operation, but uses a dump load in lieu of a grid connection (20).



Figure 3: The Seaflow with the collar raised above sea level (used with permission).

The next step for MCT is to showcase the commercial potential of tidal energy with the twin-rotor system SeaGen rated at 1 MW. Installation in Northern Ireland's Strangford Lough is planned during 2006⁴.

Hammerfest Strøm AS, Kvalsundet, Norway

Working with Statlief, ABB and Rolls-Royce, Hammerfest Strøm AS connected a 300 kW tidal current turbine to the national power grid in late 2003⁵. Located in the Strait of Kvalsundet in northern Norway, the turbine is deployed at a depth of about 50 m in an average current of 1.8 m/s.

Similar to the Seaflow, this tidal current turbine consists of an axial flow rotor coupled to a gearbox to increase the low speed of the turbine shaft to the desired operating speed of the generator. The three-bladed rotor has a diameter of 20 m and is mounted on a completely submerged steel structure with a gravity base foundation. An extension of the present prototype with twice the output power is planned for commercial use.

⁴ <http://www.marineturbines.com/home.htm> - 2005-12-29

⁵ <http://www.e-tidevannsennergi.com/index.htm> - 2005-11-27



Figure 4: Installation in Kvalsundet. The nacelle and rotor is lowered down to the already installed structure (used with permission).

The ENERMAR project, the Messina strait, Italy

The ENERMAR system, owned by the Ponte di Archimede Company⁶, has been installed in the Strait of Messina off the Sicilian coast since 2001. The system is moored by four anchoring blocks where the water depth is 18-25 m and the expected current velocity is about 2 m/s.

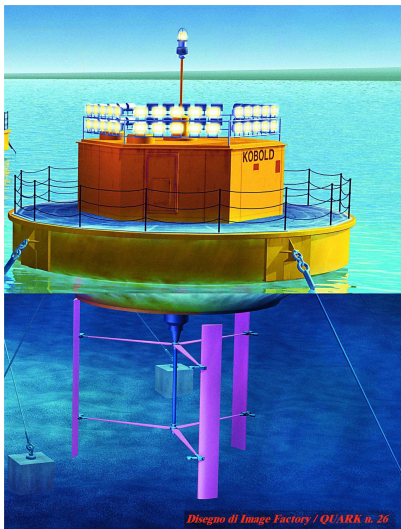


Figure 5: Artist's impression of the ENERMAR system (used with permission).

The system consists of a buoyant support platform and the patented Kobold turbine. The platform, designed by the Ponte di Archimede Company, houses the gearbox, a 160 kW synchronous generator and the necessary electrical equipment. The Kobold turbine (cross flow rotor, 6 m in diameter, equipped with three blades with a span of 5 m) is placed under the platform. The turbine has been developed by the Department of Aeronautical Engineering (DPA) at the University of Naples with an automatic pitch control mechanism and non-symmetrical airfoil designed to be cavitation free.

The Aircraft Design and Aeroflight Dynamics Group (ADAG) at DPA is aiming to increase the global efficiency of the system using a direct drive generator developed in cooperation with the Division of Electricity and Lightning Research at Uppsala University, Sweden. The use of a gearbox

⁶ http://www.pontediarchimede.com/language_us/ - 2005-12-02

and step-up transformer can be avoided with the new generator designed for the low rotational speed determined by the turbine (5 rpm) (19).

2.2.2 Oscillating Hydrofoils

Rather than utilizing the rotational movement of the more traditional turbine concept to generate electricity, it is also possible to capture



Figure 6: The Stingray (used with permission).

energy using an oscillating hydrofoil. Lift and drag forces causes the wing-like hydroplane to move in the oncoming current. The oscillating motion can be controlled by changing the angle of attack relative to the stream.

The Engineering Business Ltd has demonstrated the oscillating hydrofoil technique proof of concept with the 150 kW prototype, the Stingray (Figure 6) (21). As the hydroplane and the supporting arm oscillate, hydraulically powered cylinders pump high-pressure oil

driving a hydraulic motor. The motor, in turn, drives an electric generator.

The Stingray has been tested during 2002 and 2003, achieving a mean hydraulic power of 85,4 kW in an average current speed of 2 m/s over a 30 minute period. The demonstrator unit did not seem to have any significant environmental impact and the projected future cost of electricity by a commercial 100 MW farm is 0,1 /kWh (9)⁷. However, any further development on Stingray has been put on hold due to economic difficulties⁸.

2.2.3 Tidal barrages

Mankind has harnessed tidal energy in small scale water mills for centuries (22). In modern times, tidal barrages can be considered the first ocean energy technology to reach maturity exemplified by the 240 MW La Rance scheme operational in northern France since the late 1960s. The early development of tidal barrages is probably due to its similarities with conventional run-of-river hydropower plants with bulb turbines (23).

⁷ Exchange rate 1 GBP = 1,46 €

⁸ <http://www.engb.com/> 2005-11-29

The La Rance estuary, near Mont Saint-Michel, is blocked by a 750 m long and 13 m high structure housing 24 bulb turbines each rated 10 MW (24). The project as such can be considered a technical success after almost 40 years of operation, delivering enough energy to supply around 250000 households⁹. However, the construction of a dam or a barrage will unavoidably have an impact on the physical environment and subsequent changes in the estuarine ecosystem. In the case of La Rance, a long period of time was required for a new equilibrium to establish after the complete closure of the estuary during construction. Furthermore, with the barrage in place, primary biological production in the La Rance basin has been observed to be higher than in comparable estuaries (25).

Even if the environmental impact is neglected, there are only a handful of sites suitable for the development of tidal barrage schemes. It requires an estuary with a favorable reservoir complete with a short and shallow dam closure, and is only considered economically feasible with a mean tidal range of five meters or more (23). One potential site is the Severn estuary in the UK with a mean tidal range of 8,5 m (26). In 1989 the Severn Tidal Power Group proposed a scheme capable of generating 17 TWh annually, a scheme that has recently gained renewed interest (27). Tidal barrages might find its place in favorable locations such as the Severn estuary, but it requires large amounts of construction material and civil engineering work.

2.2.4 Future Marine Current Energy Converter Technologies.

- So called “off-the-shelf” equipment and solutions will be superseded by genuine new technology and focus will shift toward optimization (1).
- The importance of high reliability to keep maintenance costs low could make simple devices preferable even at some sacrifice in efficiency (1).
- Using direct drive generators makes it possible to eliminate the gearbox, effectively reducing the number of moving parts and thus reducing both the initial cost of the system and maintenance (16).
- Better developed sealing and improved anti-fouling could diminish the need for maintenance.
- Increased knowledge and recognition of site dependent and technology dependent environmental impacts and improved procedures for mitigating any impact.

⁹ <http://www.electricite-de-france.com/html/en/decouvertes/voyage/usine/usine.html> 2005-12-01

- A solution to the problem of deploying MCECs in energetic flows at great depths, or where seabed topography does not allow for conventional anchorage, could increase in the number of sites possible to explore.
- From an environmental viewpoint, trying to limit the use of hydraulic oil would be preferable.

2.3 Present Tidal Current Energy Market

At present there are many promising concepts striving to go beyond the very costly prototype stages and reach full commercialization. Increased financial support and investment is important for generating the momentum needed to carry the MCEC industry forward.

While discussing financing and support issues, it can be fruitful to raise the question of targeted or generic research. In some areas common to most MCEC technologies, generic research could be called for. Areas of interest include potential resource assessments, guidelines for testing and certification of MCECs and environmental impact assessments (7). But at this stage of development, some of the questions can only be answered when developers have had a chance to test their prototypes and verify their ideas.

The most important aspect for unlocking the tidal current energy might be to prove that the design lifetime, and hence economic viability, of first generation MCEC technology can be reached. So far the most successful prototypes have only been operational for a few years. In comparison, tidal barrages can be considered a mature technology. The tidal barrage at La Rance has proven its worth during almost 40 years in operation without major breakdowns, producing electricity below Electricité de France's average generation costs¹⁰.

2.4 Future development

Even though tidal currents are very predictable, they are still a fluctuating energy source and thus have to be accompanied by different balancing energy sources and/or storage techniques. Introducing large MCEC farms into the electric grid makes it necessary to develop farm control capabilities and strategies that have features equivalent to conventional power plants. These features include capabilities to control the output power of the total MCEC farm and robustness to faults in the grid.

The future influence of policies, subsidies and level of public support is not yet clear, but could prove to have a strong impact on investment

¹⁰ <http://www.electricite-de-france.com/html/en/decouvertes/voyage/usine/usine.html>, 2005-10-20.

decisions in the MCEC industry. In Europe, the UK will most likely continue to be a key market given the significant tidal energy potential in UK waters. In time, a well developed European MCEC industry could also be a leader in the global market for tidal current energy.

Today, the market for tidal current energy is only just beginning to develop with initial MCEC farms expected within the next few years. The market is likely to grow substantially up to year 2010 and beyond. However, estimates of the installed power for the years 2020 and 2030 are scarce. MCEC devices to have an impact on the electricity supply up to 2030 are likely to be extensions and refinements of present concepts and prototypes. Looking ahead to 2050, completely novel devices might be developed as well as new technology and deployment vessels for deep water sites.

2.5 Conclusion

There is a substantial potential for marine and tidal current energy in European waters with an estimated extractable potential in the range of 39-58 TWh per annum (1, 5, 6). Looking at the source of the energy, marine and tidal currents do offer a high degree of utilization with no emission of GHG during operation. However, further research and increased funding is required to better adapt the MCEC technology to the nature of the source.

Because MCECs can be kept small and modular, the technology can be expected to see similar cost reductions in manufacturing as for instance wind turbines. With favorable experience curves and economics of scale, the potential future cost for tidal energy is in the range of 3.8-9.5 c /kWh (18).

Working through all the details of such complex system as an MCEC is time consuming and expensive. Thus, a long term commitment to R&D financial support of a concept in its entirety is likely to suit the long development times of MCEC technology better than complete funding of a few stages in the project lifecycles. Once reaching the commercial phase, market incentives similar to those seen for other renewables might be needed further increase the installed capacity. In our efforts to decrease GHG emissions, the potential of wave and tidal energy cannot be neglected.

The market for tidal current energy is only just beginning to develop and is expected to grow substantially up to year 2010 and beyond. However, estimates of the installed power for the years 2020 and 2030 are scarce. MCEC devices to have an impact on the electricity supply up to 2030 are

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3. Wave power [29, 30]

Wave energy is a concentrated form of wind energy issued from the sun. The 20 first meters of water of Atlantic Ocean are sweep over by a swell energy of about 2,5kW/m². Most part of the European coasts is concerned.

From the economical point of view, costs have strongly decreased. The investment is about 1000-3000 /kW, depending on local conditions, for an annual operation of about 4000 hours. Current electricity costs range between 50 and 100 /MWh.

Ocean waves can produce electricity using an Oscillating Water Column (OWC). This system consists in a large column open in the sea at the bottom and a turbine at the top. When a wave hits the OWC, the water inside the column rises, and the air inside is compressed and moves upwards. When the wave falls the air is sucked back down. A two-way turbine spins when the air is forced upwards by a wave, and continues to spin in the same direction when the wave drops and the air is drawn back down again. The air turbine at the top of the column is connected to an alternator generating electricity.

The first successful OWC device was produced in Japan to power light for navigation. Most OWC's are experimental. An OWC used in Norway is one of the most advanced wave-to-energy generators in the world, developing an electric power of 500 kW. This had a 19.6 meter steel chimney pipe that went 7 meters into the ocean. This device, along with most others, suffered from the unpredictability of the ocean waves and damage to the plant may occur when gale or storm are raging.

Other devices, such as "Salter Ducks", use the bobbing motion of waves. When they were tested, rough seas damaged them.

The Tapered Channel Station, or TAPCHAN, directs waves into an ever-narrowing channel in which the water is forced to climb 10 to 15 meters into a dam. Water from this dam then flows back down to the sea through a hydro turbine to produce electricity.

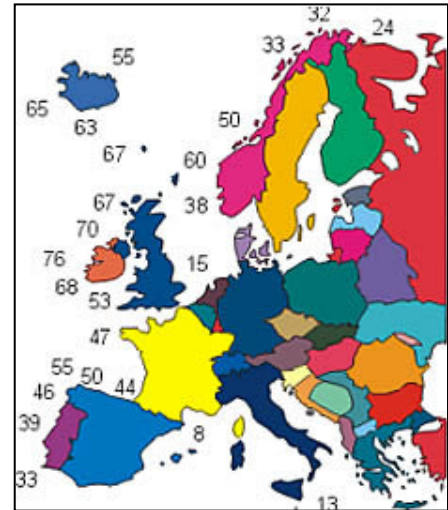


Figure 1 Average wave power on European coasts (kW/meter of coast)

Trials have been conducted on various types of wave electricity-generation equipment since the early 1970's, but Oscillating Water Column (OWC) systems have been the most successful.

OWC's have been built and tested in Japan, Norway, India, China, Scotland and Portugal. Portugal and Scotland use this technology to produce small amounts of electricity. The Islay Oscillating Water Column, in the west coast of Scotland, has been running for 10 years and produces a power of 75 kW.

These units are designed to generate up to 2 MW, for short periods, but have not been operated during extended periods.

Wave electricity generation is a source of clean, renewable energy and does not produce any greenhouse gases. The unpredictable characteristics of the sea waves remain a problem with wave electricity generation.

Facilities need to be built to withstand the effects of waves under exceptional circumstances. Indeed, waves can exert forces 10 times stronger than normal waves.

Electricity generating facilities using waves may cause changes to coast lines and local ecosystems.

3.1 Conclusion and synthesis

There are several possibilities to exploit energies from the sea. The four technologies discussed here have a large potential of development although they are still not economically competitive. Anyway, environmental impacts should be systematically studied.

Energy	Offshore wind power	Wave power	Tidal currents	Tidal power
Development in UE	612 MW in 2004 2000MW in development			
Availability	Intermittent	Intermittent	Intermittent	Intermittent
Predictability	In progress	Good	Excellent	Excellent
Predicted costs	50-100 €/MWh since 2015	50-70€/MWh since 2015	50-70€/MWh since 2015	

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