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Marine Energy

Contents

Strategic insight

1. Introduction

WEC's Survey of Energy Resources (2010) provided a comprehensive commentary on Marine Energy under three separate sections:

- Tidal Energy
- Wave Energy
- Ocean Thermal Energy Conversion (OTEC)

It is perhaps symptomatic of a certain lack of progress in the development of these technologies over the intervening three years that this update is considerably shorter than its predecessor. There have indeed been definite advances but also a realisation that the deployment risks in many of these technologies have been underestimated.

Technology developers in all of these sectors have been constrained primarily by a shortage of capital and, in particular, by reluctance on the part of investors generally to commit to the significant level of capital necessary to demonstrate commercial feasibility.

Factors influencing investors include but are not limited to:

- The intensifying of the Global Financial Crisis (GFC), particularly the weakening of confidence in the Eurozone. This has led to a fall in energy demand in many developed countries and significant generation overcapacity in some.
- The major reassessment of global fossil fuel resources following the unprecedented success of shale gas production in the United States.
- The failure of successive developed country governments to properly price carbon in the primary energy fuel mix. The recent collapse of the EU Emissions Trading System (ETS) is but the latest failure in this rather sorry saga.
- The large losses suffered by investors in “Green Tech” as governments under financial strain arbitrarily cut back on financial supports —the removal by the Spanish government of subsides to the solar industry being a particularly apposite case in point.

Against this background it is not surprising that investors remain slow to commit capital to high risk marine technologies and prefer to wait until the energy industry generally settles into some new equilibrium with a lower level of investment risk.

Despite the foregoing, some notable investments have taken place.

Some utilities have provided financial support to developing new technologies although more on a project by project basis rather than through direct investment in the technologies. It is probably fair to say that most utilities do not perceive technology development to be a mainstream company activity and many of those that have become in involved in technology development have done so in response to a certain amount of political pressure.

It is therefore the involvement of either Original Equipment Manufacturers (OEMs) or Engineering Procurement and Construction (EPC) companies that is key to the development of the sector. Major milestones in this respect include:

- The purchase by Siemens AG of Marine Current Turbines (MCT) (Tidal Energy)
- The Purchase by DCNS SA of 57.9% of Open Hydro (Tidal Energy)
- The acquisition by Andriz Hydro of Hammerfest Strom (Tidal Energy)
- The acquisition by Alstom of Tidal generation Ltd. From Rolls Royce. (Tidal Energy)
- The investment by ABB in Aquamarine Power (Wave Energy)

The foregoing list is not exhaustive but clearly indicates that Tidal Energy in the form of tidal stream is maturing with Wave Energy some years behind but beginning to gain traction with investors.

OTEC continues to struggle to raise the necessary investment capital for commercial scale projects but recent announcements would appear to indicate a much improved investment climate for the technology.

2. Tidal Energy

The development of tidal energy has a long history. Tidal barrages and lagoons to power small mills have been used in Europe for many centuries. One of the important limitations on tidal technology development is its site specificity. This will always constrain tidal technology (much as site availability constrains hydroelectric technology) and limits its total potential to a fraction of what might be achieved from other marine technologies (Wave Energy and OTEC)

Barrages and Lagoons

Early modern developments in tidal energy focussed on barrage type arrangements such as that at La Rance in France. Many technically suitable sites exist for such developments worldwide. However, only a limited subset is close to centres of high demand thus facilitating transmission.

The Severn Estuary in the UK is typical of such sites and proposals for its development have been advanced on many occasions in the past. However it is becoming increasingly obvious that the likely environmental impact associated with such a development are not acceptable to the general public.

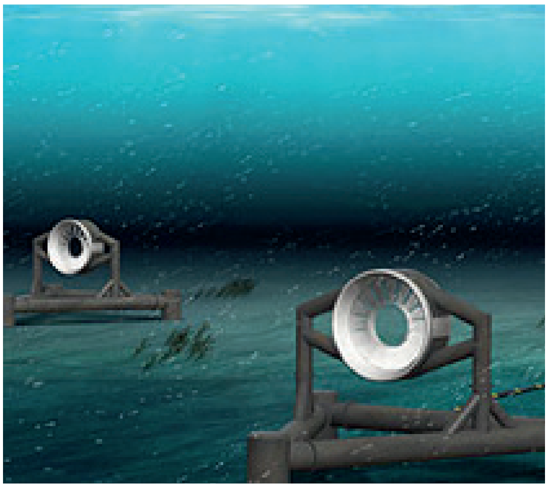
The environmental impact issue will continue to dominate barrage and lagoon type proposals and, at least in the developed world, will greatly constrain such developments.

Tidal Current technologies

In contrast to the foregoing, Tidal Current technology continues to make impressive strides and is, at the moment, the leading marine technology. The following sections detail some of the advances made by selected companies in the Tidal Current technology area in the recent past.

Open Hydro
Based in Greenore on the East Coast of Ireland, Open Hydro has developed an open centre turbine and a deployment strategy which aims to put the turbine in position close to the sea floor in a very short time. The company has developed a specialised deployment vessel and

16m turbine being placed onto a deployment vessel at Brest, France



has successfully deployed and recovered turbines in extreme conditions at the Bay of Fundy in Canada.

DCNS, a French naval engineering company has recently acquired a controlling interest in Open Hydro and the company is engaged in deploying the technology off the North Coast of France. EDF, the utility customer, has committed €40m to an initial project which will see the installation of 4 X 2MW units each 16m in diameter.

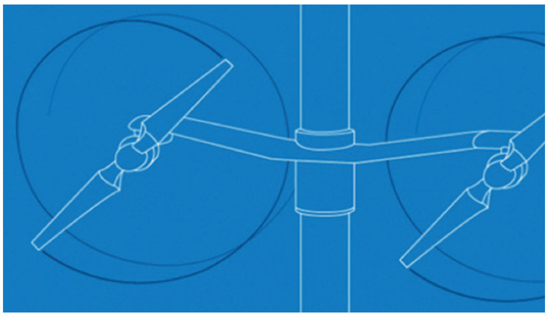
Marine Current Turbines (MCT)
MCT's SeaGen system consists of twin power trains mounted on a crossbeam. The cross beam can be raised above the water for routine maintenance by winching it up a monopole support structure.
The turbines have a patented feature by which the rotor blades can be pitched through 180 degrees, allowing them to optimise energy capture and operate in bi-directional flows.

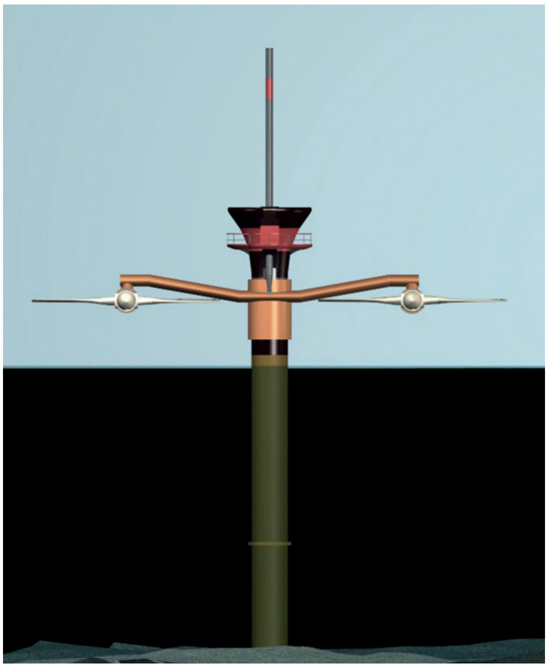
The rotors are positioned in the top third of the water column where tidal currents are strongest, therefore maximising the energy capture. The first test unit was deployed at Strangford Lough in Northern Ireland in 2008.

Siemes AG acquired a minority stake in MCT in early 2010 and subsequently achieved majority control in early 2012.

Marine Current Turbines is focused on the development of the first tidal array projects in the UK located at selected sites that will deliver an adequate commercial return for investors. The company states that a number of sites, suitable for the SeaGen technology, have been identified and initial work has already been undertaken in developing projects at these locations (see illustrations overleaf).

MCT is focussed on the supply of the technology to projects as well as coordinating maintenance during operation. Project-specific companies have been established for each of the sites to act as the developer with the intention being that investors in the SPV companies will take the projects forward.





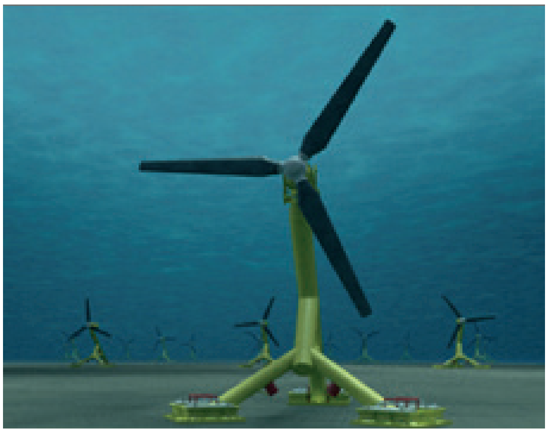
SeaGen S

Andritz Hydro Hammerfest (previously Hammerfest Strom)
The company has developed a technology focussed on rapid deployment and sitting relatively low in the water column as illustrated.

Its 1MW unit has been operating at the EMEC test site in Orkney since early 2012.

The blades and nacelle of the HS1000 tidal turbine in transportation to the European Marine Energy Centre in Orkney

The substructure of the HS1000 tidal turbine on its way from the Arnish Yard near Stornoway, where it was constructed, to Orkney.



Summary.
Tidal Stream technology has made considerable progress over the past three years and commercial scale development is now well in sight. Costs remain high pending the deployment of larger scale projects but there is considerable optimism on the part of investors that these costs can be driven down to competitive levels.

3. Wave Energy

One of the main attractions of wave energy capture over tidal stream technology is the size of the resource. It is at least an order of magnitude greater than tidal stream. Despite this, it is not an easy technology to commercialise and a number of failures over the past decade have shown just how easy it is to underestimate the difficulties associated with designing a robust wave energy converter (WEC) given the extreme conditions to which it may be exposed.

It is reported for example that the average annual energy per metre of wave off the West coast of Ireland is approximately 40kW. This is the primary energy input and the WEC has to be designed as economically as possible to produce the maximum average output. However in a major Atlantic storm this energy is reported to exceed 4MW/metre on an instantaneous basis and this is the energy that the device has to survive if it is to remain operational.

Survivability thus becomes critical and various designs seek to maximise this while retaining reasonable efficiency characteristics.

It is an inescapable fact that WECs must be deployed in areas of high wave energy if they are to be economic. This high energy environment is often coupled with short weather windows for the safe operation of vessels. Deployment risks and costs often dominate and there are inescapable economies of scale in both the size of individual units and the size of projects if the technology is to reach commerciality. Such size implies heavy capital expenditure and considerable investment risk.

The foregoing lessons have been learned however and robust WECs are now coming off the drawing board and into the sea.

There is as yet no “standard” wave technology concept. Wikipedia for example lists 22 separate concepts at various stages of development! Some of the main concept groups are described below but the list is far from exhaustive

“Heaving Buoys” typically harness the differential movement between two parts of a floating structure. This can be transmitted to power generators using mechanical or hydraulic means. Other arrangements propose the use of linear generators.

Oscillating Water Column converters typically use compressed air directly to drive turbines.

Elongated structures may capture energy from a series of waves. They may be flexible structures such as Anaconda’s device or rigid but articulated structures such as Pelamis.

Near-shore technologies may use a buoy or flap to generate hydraulic energy which can be piped to shore and used to power conventional hydroelectric plants.

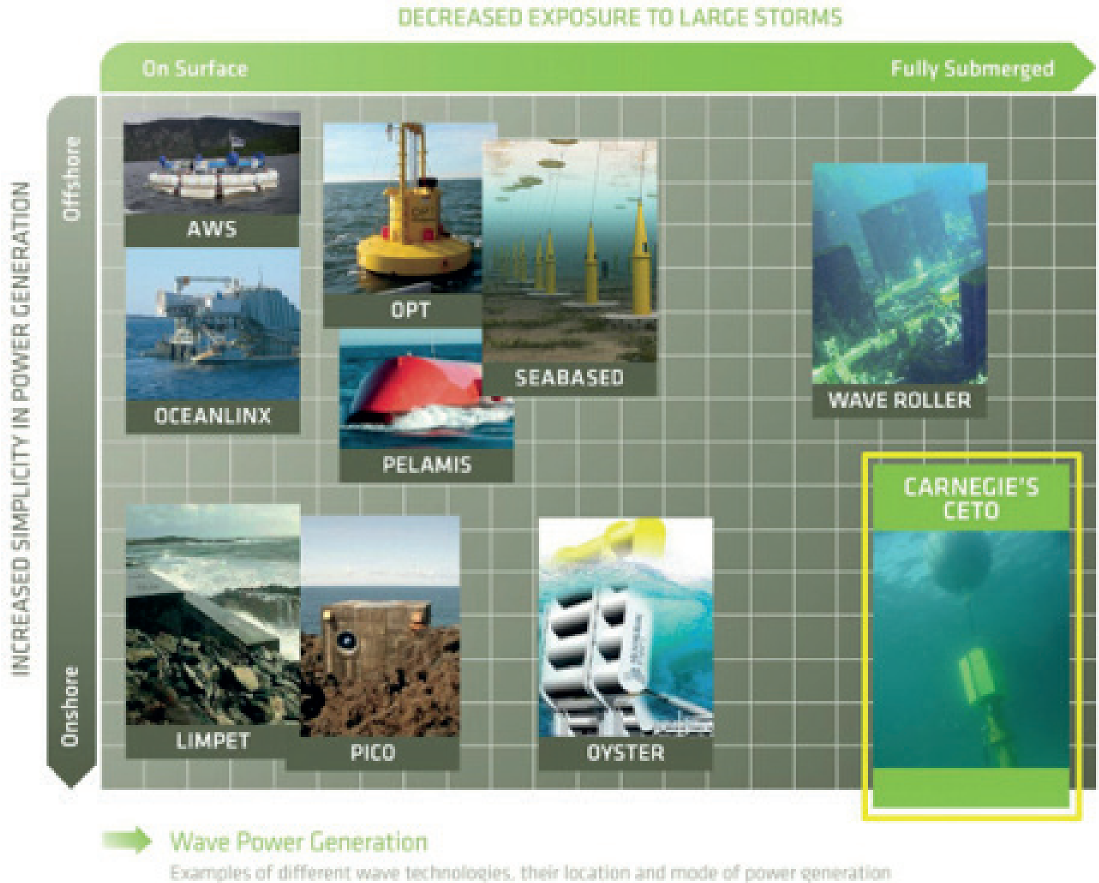
A number of concepts directly mounted on shore or on artificial barrages have also been designed.

Carnegie Wave Energy, an Australian Wave Energy developer, characterises current technologies along two axes:

- Generation onshore or offshore
- Equipment submerged or on the surface

Its technology characterisation looks as follows:

This technology list is by no means exhaustive.



Carnegie Wave Energy Technology Chart

In the top left quadrant are technologies that are on the surface and generate at sea.

One of the most advanced is possibly Pelamis and it is currently undergoing testing at the EMEC site at Orkney.

Two P2 (second generation) machines are undergoing test for the German utility E.ON and the Scottish utility, Scottish Power. E.On plans to use 66 such machines for a 50MW plant off the Scottish coast. At present the P2 machine has a proven average output over 30 minutes of approximately 270kW

Ocean Power Technologies (OPT) has been developing wave energy technology for over a decade. The equipment is a “point absorber” which harnesses the relative movement between two parts of the buoy. Tests of a 150kW (Peak) unit shown below were undertaken in Scotland in 2011.

The company also proposes to deploy its technology off the North America coast. Under development is a 500kW (Peak) device which is planned for installation in a commercial wave farm off the Oregon coast.

Left: tests of a “point absorber”, Scotland 2011

Right: tests of Pelamis, Orkney

AWS floating generation technology

AWS is another floating generation technology which has recently been acquired by Alstom (France) and is being developed in Scotland.

The result of this approach is the AWS-III: A multi-cell array of flexible membrane absorbers which convert wave power to pneumatic power through compression of air within each cell. The cells are inter-connected, thus allowing interchange of air between cells in anti-phase. Turbine-generator sets are provided to convert the pneumatic power to electricity.

A typical device will comprise an array of 12 cells, each measuring around 16m wide by 8m deep, arranged around a circular structure with overall diameter of 60m. Such a device is estimated to be capable of producing an average of 2.5MW from a rough sea whilst having a structural steel weight of less than 1300 tonne. The AWS-III will be slack moored in water depths of around 100m using standard mooring spreads.

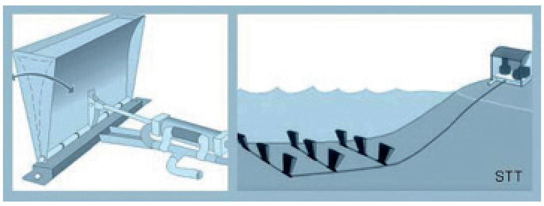
In the top right quadrant of the diagram are technologies that are fully submerged and generate at sea

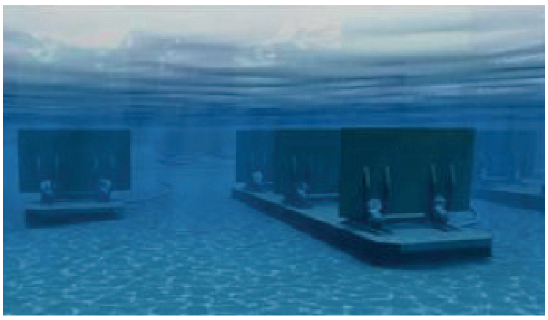
Waveroller is a Finnish technology, owned by the AW Energy Company, which is fully submerged and generates underwater. It consists of a series of flaps which move laterally in response to wave energy pulses. These flaps are in turn coupled to hydraulic cylinders which develop pressure in a hydraulic circuit and in turn are used to power a hydraulic Motor / Generator set.

Top left: Waveroller principle

Bottom left: Waveroller Artists impression

Right: Waveroller deployment September 2012





The current design is based on a 500kW unit. Testing has taken place in late 2012 at a Portuguese site.

On the left bottom of the diagram are examples of on-shore wave technologies, respectively Limpet and Pico.

Voith Hydro's (Wavegen) Limpet unit at the Isle of Islay uses oscillating water column technology and generates using a Wells turbine. The unit was installed in 2000 and has operated for more than 10 years. Further development of the technology has however been limited.

The Pico plant is also an oscillating water column device located onshore in the Azores.

Both the Limpet and Pico plants are early examples of wave energy converters and have demonstrated the operational capability of oscillating water column devices using air turbines.

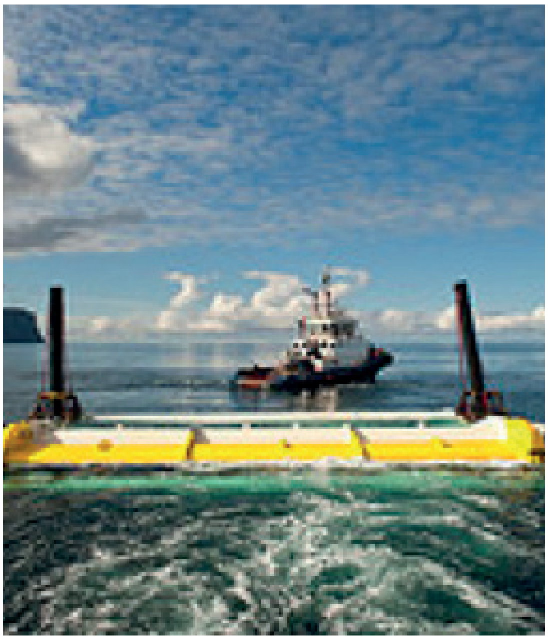
At the bottom right of the diagram are devices which capture hydraulic energy at sea, transmit it to land and generate electricity on-shore.

Aquamarine's Oyster technology is typical of this approach. Although it is not completely submerged while operating it can be folded flat below the surface if desired in certain sea conditions.

One of the main advantages of this approach is to take complex hydraulic-mechanical-electrical energy conversion out of the marine environment and locate it on shore (or potentially on offshore platforms)

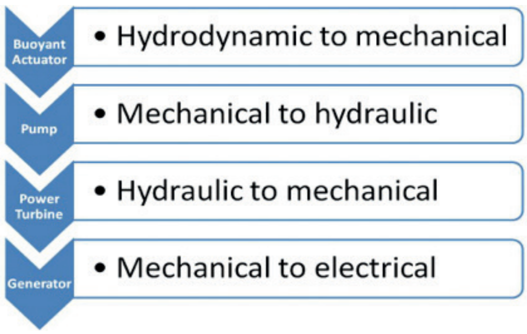
Oyster wave power technology captures energy in near-shore waves and converts it into electricity. Essentially Oyster is a wave-powered pump which pushes high pressure water to drive an onshore hydro-electric turbine. The technology uses a closed circuit with fresh water as a hydraulic fluid and drives a Pelton Turbine on –shore.

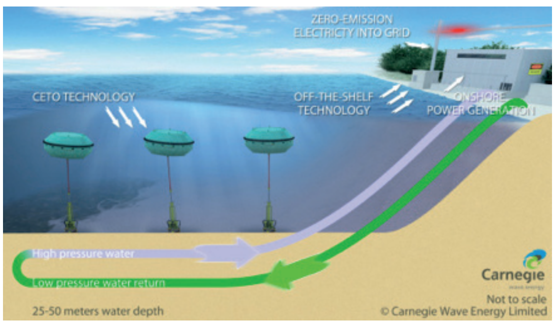
The current unit size at 800kW is being deployed at the EMEC test site in Orkney. The company plans to develop a commercial 40MW plant off the Isle of Lewis.



Left: Aquamarine's 800kW device

Right: Device installation in 2012.





Assembly of the Buoyant Actuator at La Reunion. CETO 4 (Average output estimated at 180kW over 20 minutes)

Carnegie Wave Energy (CWE) has developed a fully submerged technology (called CETO). The technology consists of a number of buoys designed to operate hydraulic cylinders anchored to the sea floor. The hydraulic energy produced is transmitted ashore by pipeline and used to drive a hydraulic motor coupled to a generator. The hydraulic circuit is closed and uses fresh water.

In 2011 the company successfully tested its CETO 3 prototype at a site near Garden Island, south of Perth WA. The unit developed an average output over 20 minutes of 80kW.

CETO technology:

- Sacrifices some energy capture in the interest of survivability by being fully submerged.
- Incorporates design features which limit the capture of energy in high sea states.
- Seeks to utilise proven components from the offshore oil and gas industry
- Focusses on engineered simplicity, particularly in the area of deployment and unit recovery

CWE's CETO 4 generation of technology is undergoing tests currently for EDF at la Reunion. The deployment is being managed by DCNS (France).

The company plans to install a grid connected array of 5 X 240kW CETO 5 units at its Garden island site in 2013.

Summary

Wave energy technology continues to make progress and there is a much improved appreciation of the importance of robust design and careful testing. The more recent development of near shore technologies indicates an investor comfort with the concept of engineered simplicity in offshore equipment. Many companies seek to adapt technologies and learn lessons from the offshore oil and gas industry which has pioneered offshore engineering.

There are perhaps a half dozen competing technology concepts at the forefront of wave energy development at the moment. It is not possible to call the winner and indeed some early stage technology may yet emerge to beat the others.

Investors have been generous to the industry and have suffered several disappointments. It is essential that they see a route to commercialisation emerging over the next two to three years.

The involvement of utilities like E.ON, Scottish Power and EDF as well as OEMs like ABB and EPC companies like DCNS (France) is a very positive sign. These are the companies that will ultimately provide the finance for large scale deployment.

4. Ocean Thermal Energy Conversion (OTEC)

Ocean Thermal Energy Conversion (OTEC) is a marine renewable energy technology that harnesses the solar energy absorbed by the oceans to generate electric power. OTEC uses the temperature differential between cooler deep and warmer shallow or surface ocean waters to run a heat engine and produce useful work. However, the temperature differential is small and this significantly impacts the economic feasibility of ocean thermal energy for electricity generation.

OTEC installations typically use a low boiling point working fluid such as ammonia in a closed cycle arrangement utilising a Rankine cycle. However open cycle arrangements utilising warm surface water as a working fluid are also possible and hybrid arrangements have also been proposed.

Because of the low operating temperature differential, the thermal efficiency of OTEC plants is limited to approximately 7%. Practical efficiencies of 2% - 3% have been demonstrated.

The technology is not new. Operating plants have been demonstrated as long ago as the 1930s. However the plants tend to be very capital intensive, vulnerable to damage in the marine environment and highly uncompetitive in terms of competing power generation technologies.

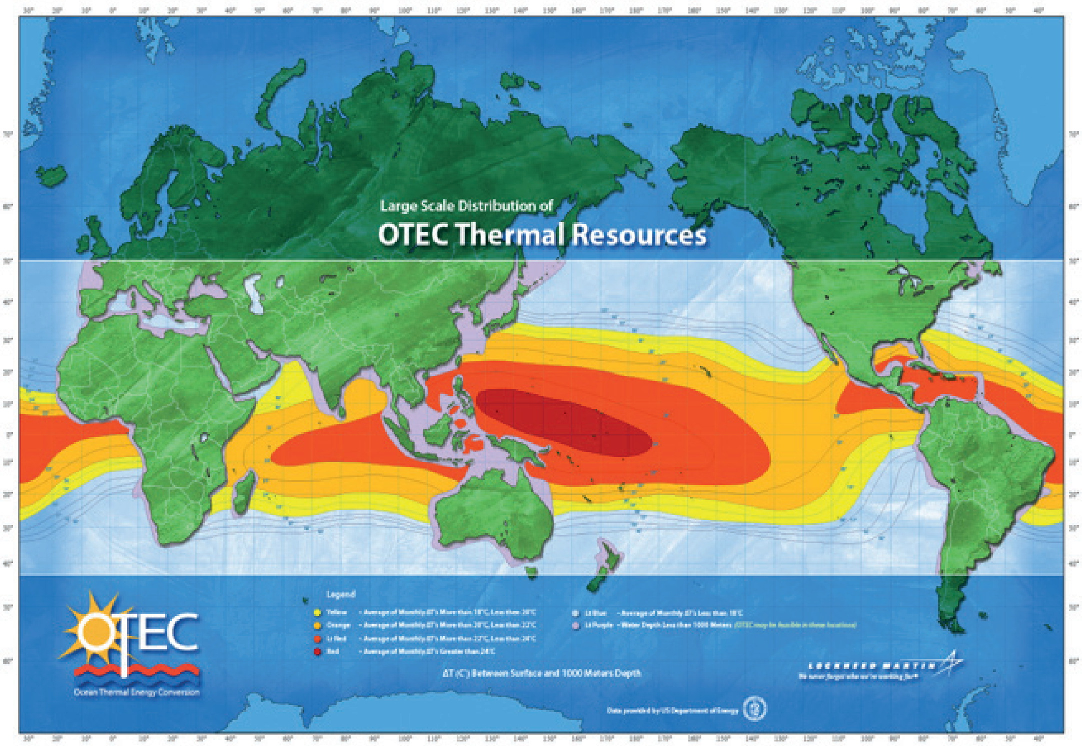
OTEC plants may operate in base load mode which is commercially very attractive and can also be utilised to provide cooling for buildings as well as desalinated water. The production of hydrogen is also feasible permitting the use of ocean thermal energy at locations remote from generating sites.

The largest naturally occurring temperature differentials are located in tropical waters and it is in this area that most experimentation has been focussed, particularly on volcanic Islands like Hawaii where deep cool ocean water is available relatively close to shore (see diagram overleaf).

Three basic plant arrangements have been considered:

- Land based
- Shelf based
- Floating

Land based systems depend on long pipelines from the shore reaching depths of a 1.0km or more in order to access cool ocean water. These pose particular engineering problems in terms of large pipelines crossing the surf zone (see diagram overleaf).



Concepts for floating OTEC plants

Shelf based systems are located beyond the surface zone in relatively shallow water. However they still require pipelines that reach the aforementioned depth.

Floating systems require vertical pipelines reaching down to the cooler waters.

While much engineering effort has been and continues to be expended on OTEC technology, no commercial plants are in existence and the technology continues to strive to be competitive.

Companies and Projects

A number of companies are active in the OTEC area. Some current projects are described below. However this is not an exhaustive overview of current developments.

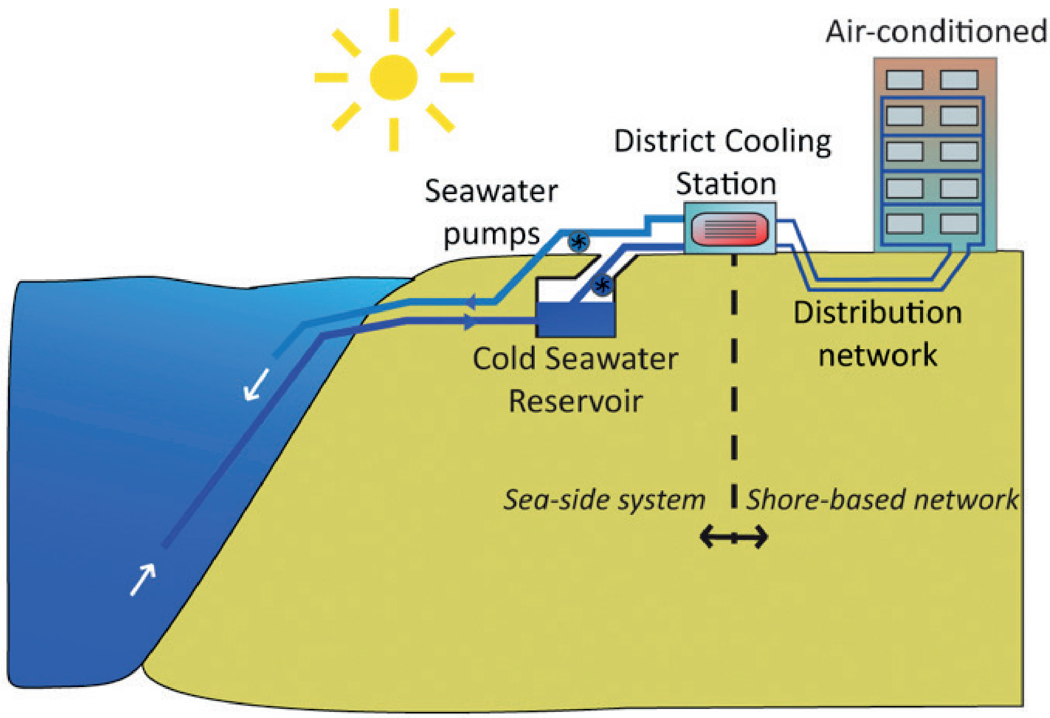
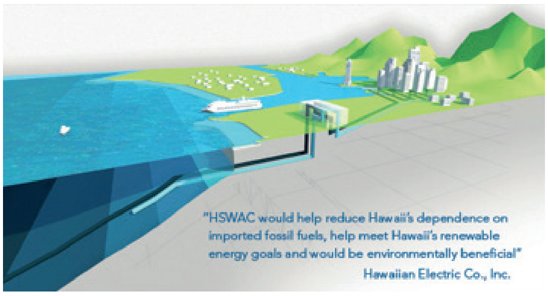
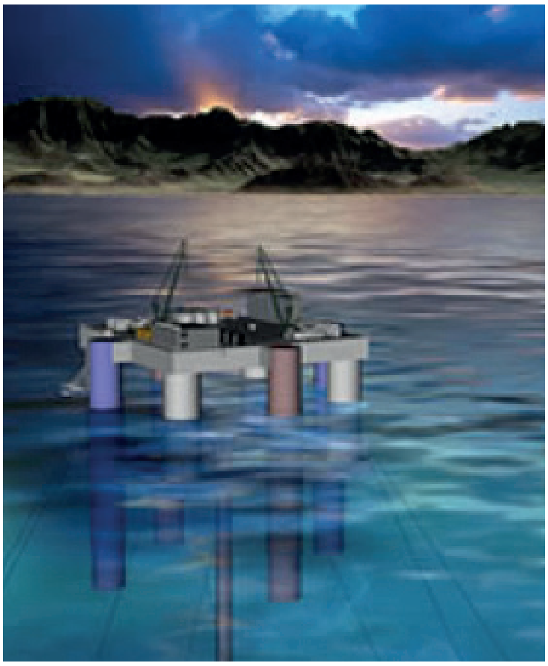


Diagram showing land based system used for cooling





Artistic rendition of a 100MW OTEC plant

For the past few decades the US Government through various agencies, particularly the Department of Defense, has supported the development of OTEC technology, primarily in Hawaii. Lockheed Martin and Makai Ocean Engineering have been engaged in steady development of a commercial scale technology for the past decade.

Lockheed Martin and Makai Ocean Engineering are currently completing the design of a 10MW closed cycle pilot plant. The plant will be designed to be expanded to 100MW. The US Naval Facilities Engineering Command is the main funding source for this project.

Ocean Thermal Energy (OTE) Corporation has signed an MOU with the Bahamas Electricity Corporation to construct two commercial OTEC plants which will produce electricity and water. It also plans a seawater cooling plant to provide cooling to a number of commercial buildings in the Bahamas.

The company reports that it is also in negotiation with an East African Government and the authorities on a Pacific Island for further plants.

Also in Hawaii, The Honolulu Seawater Air Conditioning Company (HSWAC) announced in January 2013 a project to provide cooling to a number of commercial buildings in Oahu. A number of companies are reported to have signed off-take contracts for the $250m project which is scheduled to commence in early 2013.

The district cooling plant will be located on-shore. The cold water pipe will be 1.5m in diameter, will reach a depth of more than 600m and will extend 6.5km from shore.

In Europe DCNS is active in the OTEC development sphere. Much of the development is centred on tropical islands like La Reunion and Tahiti.

DCNS aims to demonstrate the technology's feasibility and its promise for tropical zone communities that are typically highly dependent on fossil fuels. In April 2009, DCNS and the Reunion Island regional council signed an initial R&D agreement to study the feasibility of installing a 1.5-MW OTEC demonstrator on this Indian Ocean Island.

In February 2010, the local government of French Polynesia, the national government, Pacific OTEC and DCNS signed an agreement to conduct a feasibility study of an OTEC plant for Tahiti.

In 2011, the Martinique regional authority in the Caribbean responded to the European Commission's NER 300 call for tenders with a proposal for a 10-MW OTEC pilot plant. As a result, DCNS and the Martinique authority signed a preliminary sizing agreement for a plant that could come on stream as early as 2015.

Summary

While OTEC technology has been demonstrated in the ocean for many years, the engineering and commercial challenges have constrained the development of the technology. In particular the attractiveness of the technology has waxed and waned as the price of oil rose or fell.

Current high oil prices are supporting investor interest in the technology. Proper carbon pricing would further increase its attractiveness.

After a number of years of effort, companies are securing financial support for the first commercial scale projects. The engineering challenges remain however and large scale commercial sized plants have yet to be shown to be competitive with alternative generating technologies.

While oil prices continue to be high, there is a useful niche market for this technology in tropical island locations. It is in such locations that the technology will first be demonstrated at a commercial scale. It remains to be seen if the "cost down" curve is such that the technology will achieve the scale necessary to make it a significant global contribution to electricity production