A Marshall Cavendish publication in weekly parts

Part 4

insight

Understand the fascinating technology that affects your life

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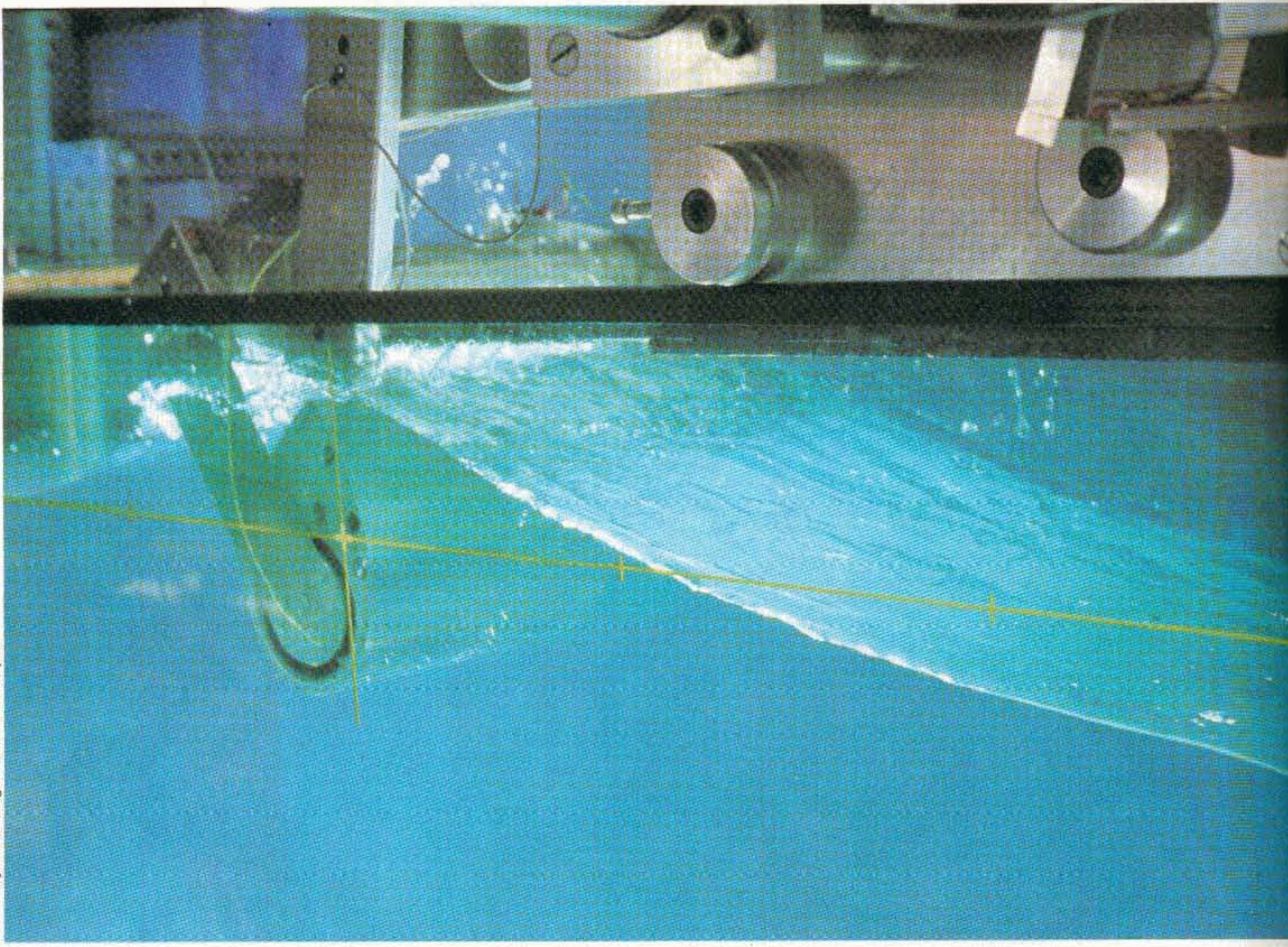


Jamie Taylor/Edinburgh Wave Power Project

Energy from the sea

As the world's oil wells begin to run dry and oil prices rocket, scientists are increasingly turning their attention to 'free' energy sources such as wave power. The power in a wave can be as much as 94 horsepower (70 kW) for every metre of wavefront, and all kinds of strange devices, including rafts, 'ducks', water columns and air bags are being tested to see how much of that energy can be extracted for human use. Wave energy comes from the Sun which, by uneven heating of the Earth's surface, causes winds which in turn whip up the sea into waves. Waves are built up gradually over long stretches of ocean and can be seen as a concentration of both solar and wind energy.

The energy in a wave depends on its length and height and this varies considerably round the world. Two of the best locations for harnessing wave power are off the coast of Scotland and in the sea around Japan, where the height of waves can exceed 25 m (80 ft), the size of an eight-storey block of flats. In the UK this represents a potential resource of something like 50,000 MW, harnessed from 1,000 km (620 miles) of collectors from the Hebrides to Cornwall.

In practice, it is unlikely that such a large wave-power station could ever be built, or that the available energy could be captured, converted and transported back to land with more than 30% efficiency. Nevertheless, it is quite possible that a large conventional power station supplying 1,000 MW could be replaced by a wave-power station composed of collectors stretching across about 80 km of sea, probably off the outer Hebrides.

A 2 MW experimental power station, th
Kaimei, has been operating in Japanes
coastal waters since 1978, feeding electricit
into the grid. So far this is the most impressive working demonstration of wav
power producing energy.

Most research into wave power has concentrated on the supply of electrical power t
a national grid system, although it could b
useful as a supplier of local power to remot
locations too far from the mainland to b
connected to a national grid, such as floatin
chemical, or water-desalination plants. A
wave-power station consists of a collection o
wave energy converters either moored to o
mounted on the sea bed.

These converters accept the irregular
cyclic motion of the waves and change it int
a smooth, uninterrupted and unidirectiona

motion suitable for a generator producing electricity. The electrical output from a large number of these converters is combined and sent ashore to a sub-station which feeds the national grid.

Even though the converters themselves are only part of the whole power station, it is their design that has been the subject of the most interest and inventiveness. A good wave energy converter should be small in proportion to the power it can produce, and it should also be efficient in a wide range of sea conditions. In addition, a converter must be tough enough to survive long periods in rough seas with little or no maintenance.

Many different designs for converters have been developed since the oil crisis of the early 1970s, when serious research began, mostly in the UK. The three major ones being studied are the *oscillating water column,* the *duck* and the *raft.*

In its simplest form an oscillating water column (OWC) consists of a long vertical tube open to the air at the top and with the bottom open to the sea below the surface. As a wave passes, the column of water inside the tube rises and falls, acting like a piston to blow and suck air in and out of the top of the column. An air turbine mounted on the top can be turned by this passage of air and then coupled to a generator to produce electricity. The air is made to flow through the turbine in one direction only by means of a system of valves, or else a special *self-rectifying* turbine, using the aerofoil principle, can be installed.

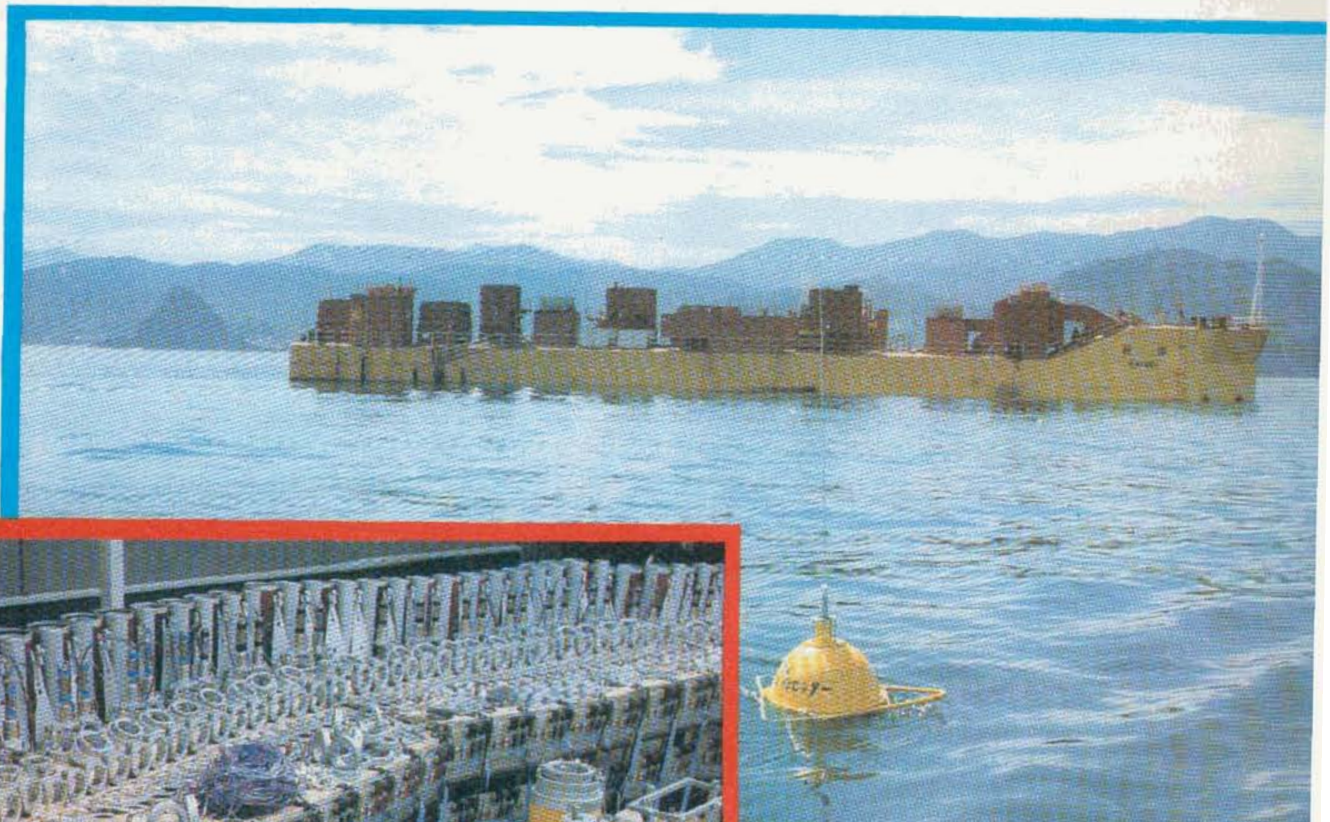
Some OWCs are floating, others are fixed to the sea floor. The underwater types are less exposed to stormy weather, but more expensive to maintain, and there is also a loss in collectable power which falls off rapidly with the depth. OWCs in general are attractive because they are simple and contain a minimum of moving parts.

The experimental power station in Japan is based on the OWC principle. The *Kaimei* resembles a large squat barge, 80 m (262 ft) long and 12 m (39 ft) wide. The ship is flat-bottomed, and 22 separate chambers are open to the sea underwater and to the air on deck. Turbines are installed on top of each pair of chambers to extract electricity from the air that is blown out and sucked into each chamber as waves pass under the ship.

The 'Duck'

Research is being carried out in the UK to develop and improve a device along similar lines to the *Kaimei,* as well as on other designs using the OWC principle. The duck, also called Salter's duck after its inven-

Left Freak waves can be simulated in test tanks. Here, a model 'duck' is being hit. *Below* The wave power team at Edinburgh have had to develop a whole range of special components in order to maximize the potential efficiency of their design. In fact their 'duck' design can make use of as much as 80% of the wave energy.



Above *The wave power generator Kaimei* in open sea tests in August 1979. The tests are part of a joint research project by the International Energy Agency, involving Eire, Canada, Japan, the UK and USA in wave power research. The key components are air turbines comprising blades fitted to aluminium and bronze discs. Water under the ship acts as a piston and valves allow air to flow through the turbines in one direction only.

rax Ltd/ETSU

tor, Stephen Salter, a pioneer of wave power, is being developed at Edinburgh University. This is perhaps the best-known wave energy converter and is generally regarded as an ingenious concept, compact and economical to construct, but relatively complex. A single duck consists of a float shaped like a pear in cross-section.

The float lies on the surface of the water with the 'beak' extending horizontally, and the whole duck is able to nod up and down with the waves. Because the float is shaped so that the rear end is circular, no waves are reflected and so absorption of the available energy is very high, typically above 80%. A large number of these ducks are mounted on a long tubular spine which floats horizontally on the water. Each duck—which, full-scale, would be the size of a family house—can move independently of this spine.

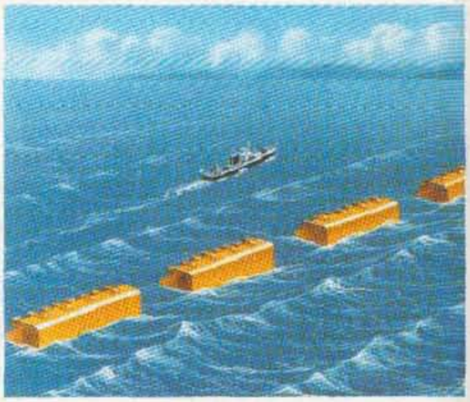
To convert the nodding motion of the ducks into electricity, Salter has developed a system of gyroscopes. In the beak of each duck are four 17-tonne gyroscopes. As each duck rocks up and down, *precession* forces generated by the spinning of the gyroscopes cause them (the gyros) to flip back and forth. This rapid, forceful movement is ideal for working an oil pump to produce hydraulic power which can then be used to work a generator directly, or else, during times of maximum output, it can be used to increase the speed of the gyros. Subsequently, when little power is coming from the rocking motion of the duck, energy can be withdrawn from the gyros to drive the generator.

Rafts and rectifiers

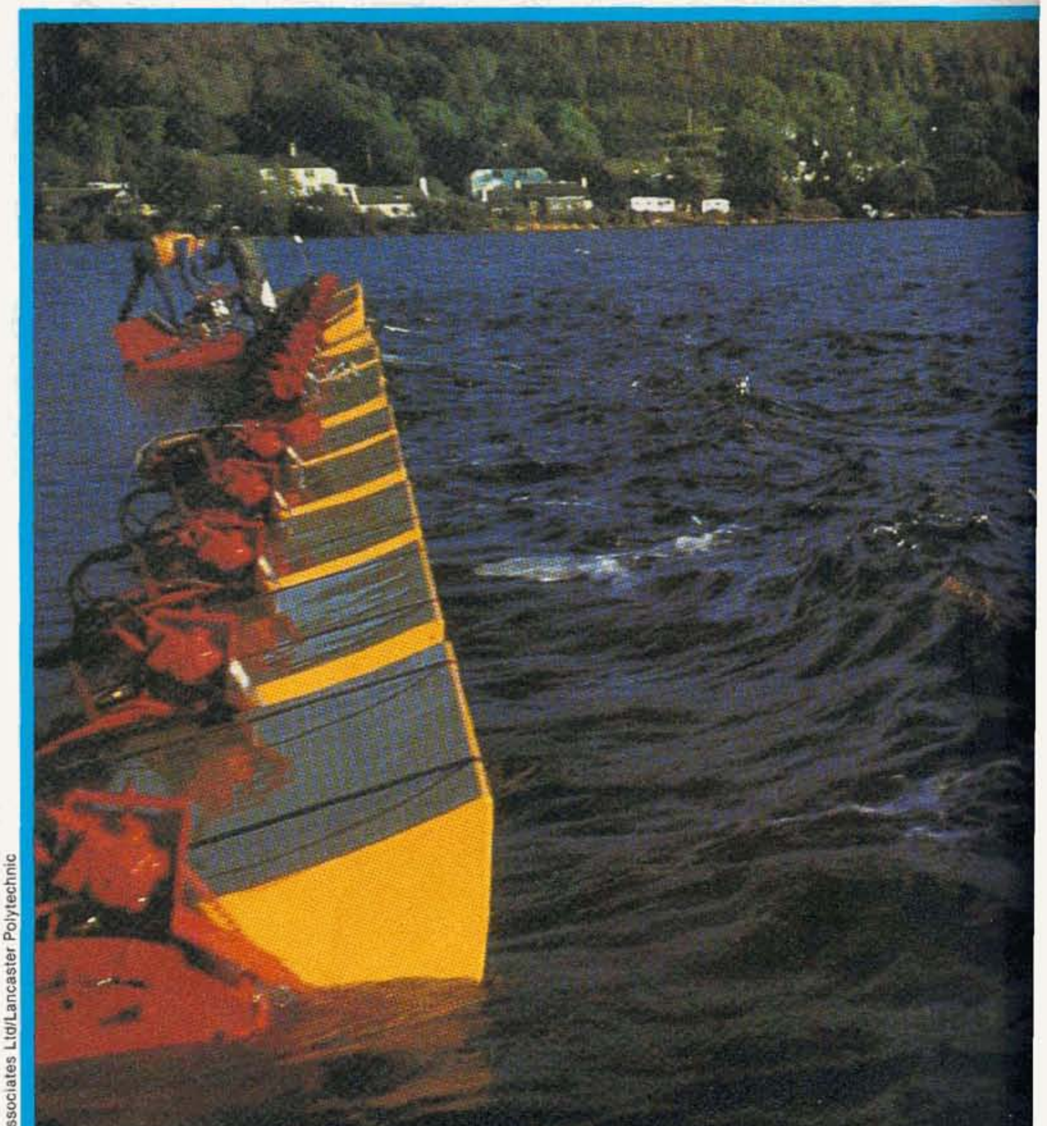
The gyroscopes thus serve a secondary role as a temporary store of energy which can be used to smooth the fluctuating input from the waves. The whole system would have to be under comprehensive computer control and is evidently complex, demanding either regular maintenance or rigorous standards of construction. Many doubts have been raised over the duck's chances of long-term, reliable operation at sea, although in 1978 a one tenth scale model—still 50 m (165 ft) long—was tested successfully in Loch Ness. The duck is very small considering how much power it can be expected to produce, and this makes it one of the cheaper systems.

The *raft* was designed by Sir Christopher Cockerell, who invented the hovercraft. It consists of a large, flat, rectangular pontoon with one or two smaller pontoons attached to it by hinges, and moored in line with the prevailing wind direction. As waves pass under it, the smaller sections move up and down, while the larger one stays relatively still. This forceful hinging motion can be used to pump hydraulic fluid, or possibly sea water, up to high pressure to drive a turbine and generator.

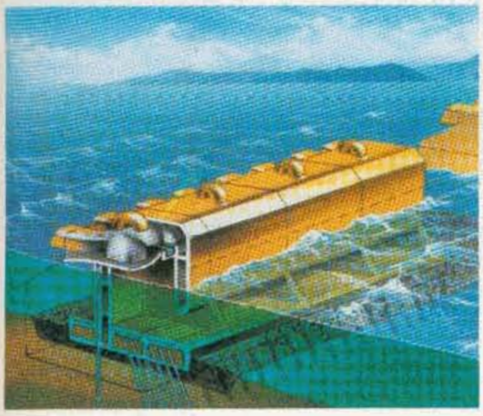
A one tenth prototype was tested in the Solent in 1977, when it produced up to 1 kW. This may not seem very much, but output increases steeply with size, so a full-scale raft could generate 1 MW of power, or more. It would also be very large, however, about 150 m (500 ft) long by 50 m (165 ft) wide full-scale. This size is essential if the main section is to be stable enough for the smaller pontoon to react against, but it makes the raft an expensive design.



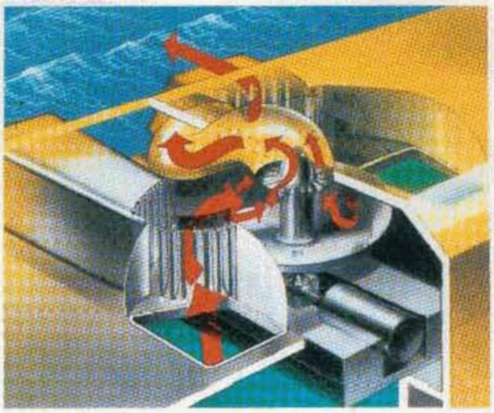
The OWC (oscillating water column) principle is being developed in the *Kaimei* experiment in Japan and by the National Engineering Laboratory in the United Kingdom.



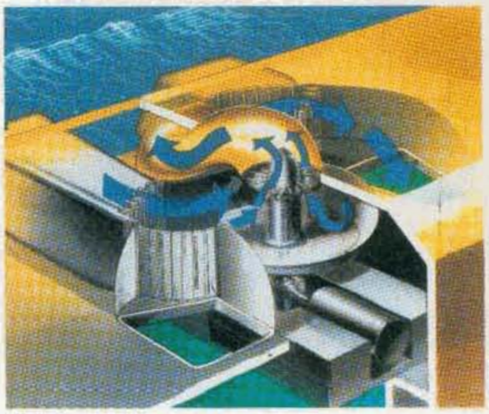
Sea Energy Associates Ltd/Lancaster Polytechnic



The optimum length of the converter is 1.2 to 1.7 times that of the average wave length. The bottom mounted OWC is fixed to the sea bed by diagonally driven piles.



As waves approach, the column moves vertically, acting like a piston. This forces the air above the water surface through the turbine mounted in the top stucture.



The turbine is directly coupled to an electric generator which is normally housed behind the front chambers in the main body of the converter.

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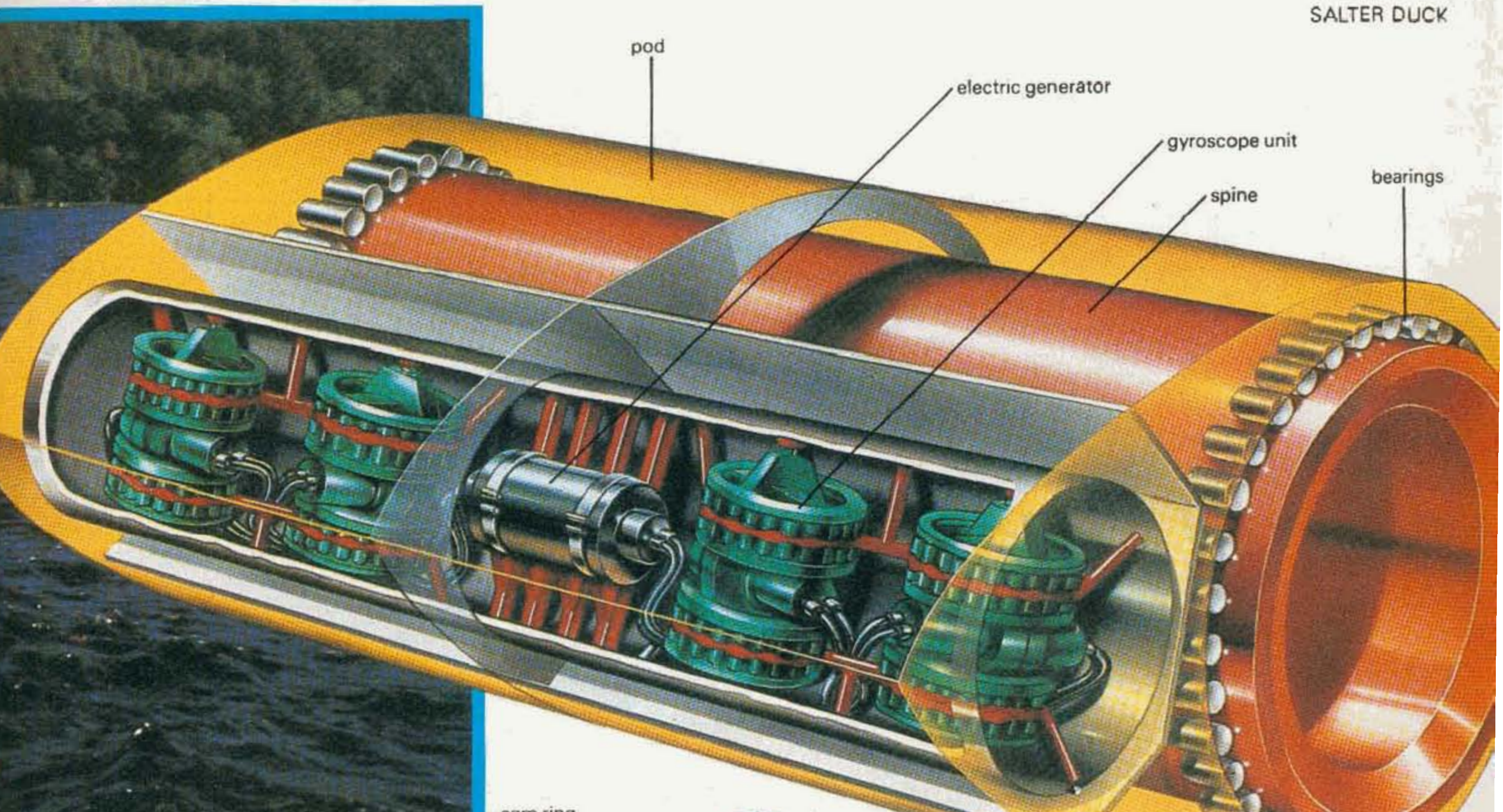
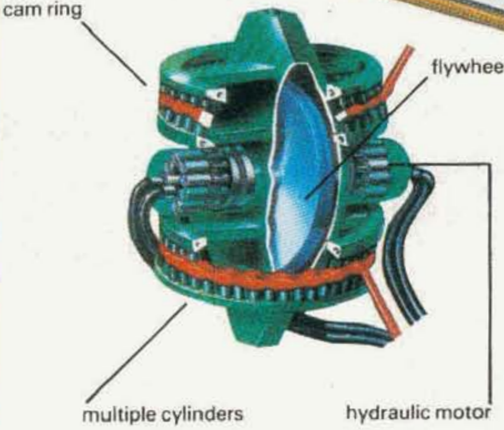
SALTER DUCK





Above The Salter 'duck' is oscillated by wave action about the floating cylindrical spine. Four gyroscopes (left) are housed in the nose of the duck and are activated by the oscillations. The rotary action causes the multiple cylinders to interact with the cam ring, generating high pressure hydraulic fluid which itself powers the generator.
Far left Ducks under test in Loch Ness.

Another device to be studied, called the *rectifier,* consisted essentially of two reservoirs, one above the other. Each reservoir opened to the sea through ports controlled by a series of flap-valves. When a wave reached them, the gates leading to the top reservoir would open, filling it with water. As soon as the wave fell away, the gates would close, leaving the water trapped. A head of water thus built up and would be allowed to flow down into the lower reservoir and back out to sea through a low-pressure water turbine generating electricity.

Research into the rectifier was abandoned in 1979 when it was realized that it would have to be extremely bulky in order to produce 1 MW of electricity, which would still be ten times as expensive as electricity from conventional sources. The research into it demonstrated that passive devices such as this were not as efficient as active ones, whose structural elements move with the waves.

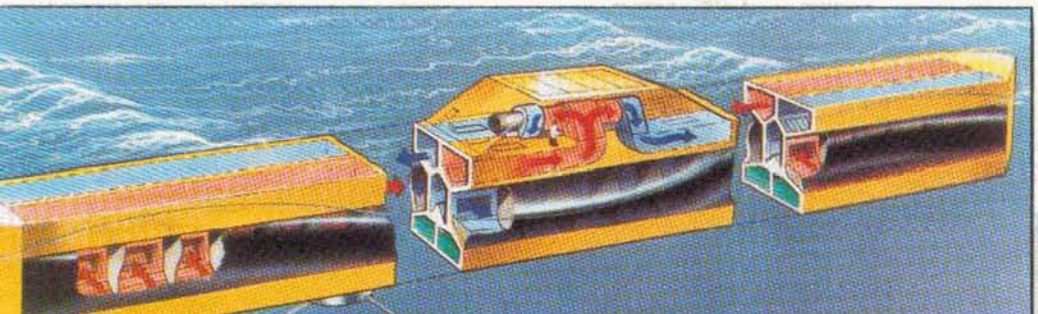
Another converter design is the *Lancaster air bag,* which is shaped rather like a submarine and made largely of flexible rubber. Internally the air bag is divided into a number of compartments. It lies head-on to the sea and as waves pass along its length, compartments are alternately squeezed by rising water, then released as the wave falls. When pressure in any compartment falls, a different set of valves open and air can flow back into the compartment from a common low-pressure manifold. An air turbine, connecting the two manifolds, is driven continuously by the pressure difference, and coupled to a generator to yield electricity.

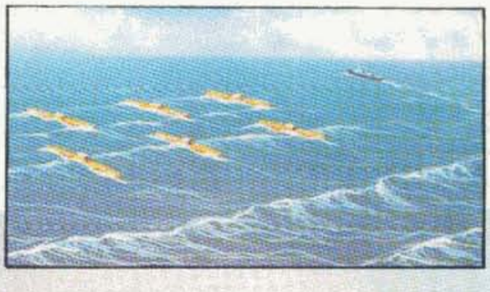
Clams and cylinders

The air bag is comparatively small—200 m (650 ft) long, full-scale—with a light structure, and is consequently one of the cheapest designs yet developed. However, it is not certain that a flexible rubber material can be found which will last long enough at sea, and there are problems associated with ensuring that the device angles itself correctly to the waves.

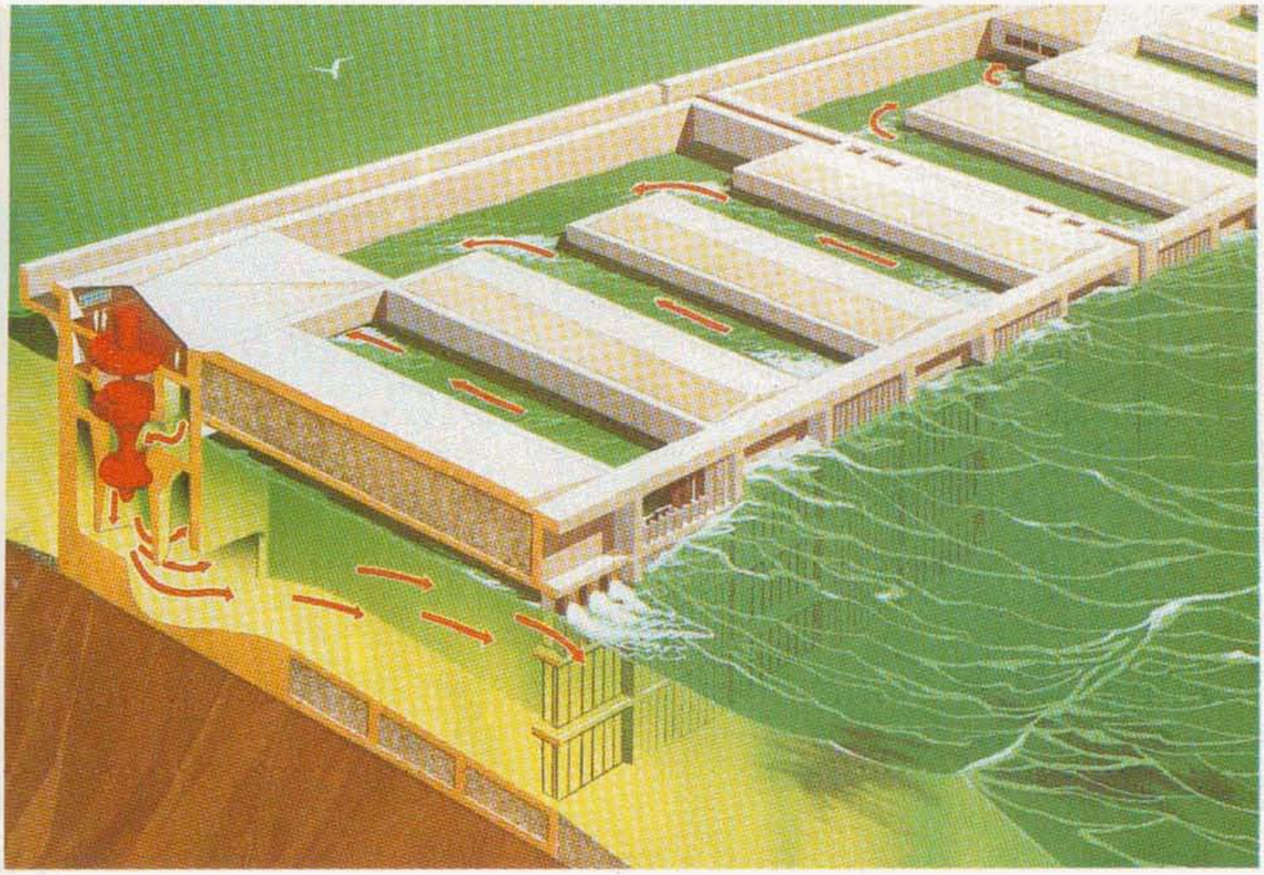
The *clam* is another design currently being developed. It combines the spine-based frame of the duck with the air-turbine method of power take-off used in the air bag. The clam is long and thin and floats with one long side facing the waves. Along the bottom of this side a series of metal flaps are hinged under water, and behind each flap is a flexible bellows filled with air. As a wave strikes each flap, the air is squeezed into a passage leading to the air turbine. As the wave falls, the weight of the flap pulls each bag open, and air is drawn in from the atmosphere.

Another active device, known as the *Bristol cylinder,* consists of a large buoyant cylinder held in a horizontal position just under the surface of the sea by four stout chains anchored to the sea bed. The cylinder is aligned parallel to the prevailing waves which cause it to undergo an approximately





Above and left The flexible air bag system involves submerging the main part of the hull with its base 13 m (40 ft) below wave level. *Below* Tests on the wave-contouring raft have shown that the optimum size of a pontoon would be in the region of 100 m × 50 m.



Left The *rectifier* converter is nearest in design to a conventional water turbine. The seaward face contains panels of one-way flaps, arranged alternately to let water in and out. In operation, it would have consisted of a line of caissons resting on the seabed in parallel to the general shore line. However, it was not found capable of producing power proportionate to its size—a converter 100 m wide would generate only 3 MW at peak capacity.

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circular motion as they pass. This motion causes corresponding forces in the four mooring chains, which can be used to work pumps actually on the sea bed, to pressurize sea water. The pumps comprise the very bottom section of each mooring chain, connecting it to the sea bed anchor. The high-pressure output from the pumps of several cylinders would be connected to a main supplying a central tower with one large generator. Because the largest part of the Bristol cylinder, the float, is so simple, it would probably be cheap in terms of materials. There are problems, however, associated with installing and maintaining the pumps at a depth of 50 m (165 ft) or so.

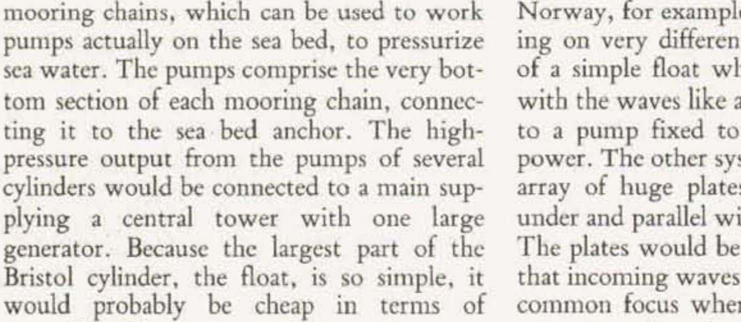
There are many other research projects underway, both in the UK and elsewhere. In Norway, for example, two groups are working on very different systems. One consists of a simple float which bobs up and down with the waves like a buoy. A cable tethers it to a pump fixed to the sea bed to extract power. The other system would consist of an array of huge plates round the coast, just under and parallel with the surface of the sea. The plates would be arranged in such a way that incoming waves would be diffracted to a common focus where the energy would be concentrated, and extracted by any of the methods already described.

In 1978, all the wave power designs being developed in the UK were carefully examined with the aim of pricing the electricity that they might produce. The initial results were rather disheartening, but subsequent work has brought down the cost range to a level which is still at least 1.5 times more expensive than electricity from coal or nuclear stations. But the calculation ignores the essence of wave power: serial production—the costs decline as more units are produced.

Another reason why it is unrealistic to price electricity from these devices at this stage of development is that so far very little money has been spent on research.

One of the best-placed countries for extracting wave power is the UK, but official attitudes remain cautious, and the government is unwilling to spend the money necessary for further research. It seems that, to be supplied with electricity from wave power, it must be seen to be worth investing in energy which is free from the environmental and political problems of nuclear power. The number of jobs that would be created by the construction and maintenance of a wave-power station might be a factor in persuading a government to consider investing in a full-scale research programme.

It is likely that Japan, which has few fossil fuel reserves and a strong mistrust of nuclear energy, will be the first country to find wave power a practical alternative to increasingly expensive imported coal and oil. And as our fossil fuel reserves dwindle, wave power is bound to appear an increasingly attractive solution to the world's energy problems.



Sea Energy Associates/Lancaster Polytechnic

Left The clam wave energy converter has undergone successful tests at 1/10 scale on reservoirs and at Loch Ness in Scotland. Fully operational, 10 *Clam* units would be linked on a 300 m long spine moored facing the waves. They would be capable of a peak generating capacity of 10 MW. The target cost per kWh is now a quarter of original estimates for wave power energy.