THE HALCYON SOLUTION

A NEW APPROACH TO TIDAL RANGE POWER GENERATION

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Introduction

The potential for 'Tidal Range Power Generation' to make a significant contribution to the world's electric supply has been well understood for years. Successful projects have been constructed in France (1966) and Nova Scotia (1984). However, the prohibitive cost of traditional construction methods and the adverse environmental impact of conventional turbine operating methodologies have limited further deployment. Halcyon Marine Hydroelectric LLC ("Halcyon Marine") has now patented (x) techniques that will dramatically reduce the cost and time of construction of such projects and (y) an operating cycle that will resolve the related environmental concerns. These breakthroughs create the opportunity to develop low environmental impact tidal range projects capable of delivering electricity at prices competitive with fossil-fuel, nuclear and other renewable sources of generation, with the potential for numerous individual projects located near major load centers ranging in scale from $100 million to $10 billion or more.

Tidal range power is (1) clean, (2) renewable, (3) requires no feedstock and (4) more predictable, with higher capacity factors than wind or solar. In fact, the amount of energy generated from a tidal range power plant can be predicted reliably within minutes for years into the future unaffected by seasons and weather conditions.

The tidal range power plant on the Rance estuary near Saint Malo, France provides an illustrative example of these benefits. This facility has a nameplate capacity of 240 MW and, according to its owner, Electricitie de France ("EDF"), it produces clean, renewable power for less than .022 Euro per kWh, a price cheaper than power from any fossil fuel, nuclear [EDF ought to know – they own and operate France's large fleet of nuclear power plants] or other renewable power plant. Further, the La Rance project has produced electricity for almost 50 years without requiring a turbine overhaul and will continue producing electricity for at least an additional 70 years! With these positive characteristics, why are tidal range power plants not deployed everywhere?

The simple answer is twofold. Historically, the cost of the civil works has been prohibitively high, and the construction period too long. More recently, as environmental issues have taken center stage in power production, many have voiced concerns over the negative impact of loss of intertidal zones. For the past eight years, Halcyon Marine has developed fundamentally new solutions to these obstacles.

Halcyon Marine has developed a lower cost construction methodology from recent advances in the construction of offshore oil and gas platforms. The prefabricated construction methodology has led to much shorter construction periods. The Halcyon Solution to the tidal range civil works underwent a two-year technical review by the Department of Energy and Climate Change of the United Kingdom during the Severn Tidal Power Consultation (2008-2010), which is discussed in further detail below. The Halcyon Solution to environmental impacts of tidal range power was developed in collaboration Alstom Power, the largest and most technically advanced provider of hydroelectric turbines in the world.

Additional benefits derive from the Halcyon Solution. High cost traditional construction has limited tidal range power projects to short barrages along highly indented coasts. These geographical constraints limit barrages to a fraction of those sites experiencing high tides. Low-cost Halcyon construction makes shore-connected lagoons (**Figure 1**) economic endeavors. Shore-connected lagoons can be built along the shore of any coastline with high tides. The number of such sites is perhaps five to ten times greater than those requiring highly indented coastlines. The Halcyon Solution therefore greatly expands access to the vast tidal resource. Moreover, shore-connected lagoons leave channels, rivers and estuaries open to migrating fish, marine mammals and shipping.

We believe that the Halcyon Solution provides an enormous opportunity to develop large cost-effective, clean energy projects at prices competitive with all other sources of electrical generation over their useful lives. Because their useful lives stretch from 80 to 120 years, *all* tidal range power plants will provide power at prices lower than current natural gas-fired generation facilities (note the La Rance Project above) once project debt is retired. Given the enormous scale of tidal resources throughout the world, coupled with the benefits of installing tidal range facilities employing the Halcyon Solution, such as low environmental impact, operational reliability, predictability, long economic useful lives, electric power price stability and zero emissions, Halcyon Marine is convinced that it has provided the springboard to substantial tidal power production.[1]

THE HALCYON SOLUTION: CIVIL WORKS

The Civil Works of Conventional Tidal Power Projects

Historically, the high cost of construction has been the major reason for the failure to build an otherwise attractive tidal range project. Construction costs using conventional methods typically account for two-thirds of the total cost of a tidal power project. The fundamental problem of cost has been the length and substructure of the marine enclosure. The Severn Barrage proposed for the Severn Estuary between England and Wales would be 15 kilometers in length. The tidal lagoons for similar projects envisioned by the French utility, EDF, would be 65 kilometers in length. Projects on this scale require low-cost construction to be feasible. It is precisely such low-cost construction that the Halcyon Solution provides.

Conventional construction methods are of three types. The first is ‘construction in the dry’, the traditional way in which dams are constructed. This is the method used to build La Rance tidal power plant. It is prohibitively expensive, requiring the construction of a cofferdam preliminary to barrage construction. Second is ‘embankment construction’, a method used to create ‘earthen dams’ or ‘levy’s’. Because of its geometry, the volume of material required quadruples each

[1] Tidal range power should be distinguished from ‘tidal stream power’, sometimes referred to a hydrokinetic power. Tidal stream or hydrokinetic power is essentially underwater ‘wind’ driven by tidal flows. Tidal power is used in this document to refer to tidal range.

time the height of the embankment doubles. The result is that embankments become totally uneconomical at water depths in excess of 10 m, limiting embankment construction of marine enclosures to shallow water. Embankments are therefore limited to small, low energy output tidal power projects. The third method, 'caisson construction'[2], was developed in the 1950's as a method to build in deep water. To enclose a basin, caissons are set side by side to form the marine enclosure. The method looks deceptively simple. In order to support tidal loads, massive caissons are required. Some of the caissons for the Severn Barrage Proposal (1989)[3]would have measured 75 m wide by 100 m long by 42 m high. Further, these caissons require a level surface on which to rest. Suction cutter dredgers would have had to excavate 18 million cubic meters of rock along the 15 km length of the barrage. Because of their massive size, these caissons could only be towed out and placed during neap tide, restricting the number of installations to two per month. The installation of all 200 caissons would have required seven years! The financing cost associated with the long construction period would alone add 30 % to the cost of the project. Although more economical than embankments in deep water, caisson construction costs remain very high.

The 'Halcyon Marine Enclosure' is a low-cost alternative to dam, embankment or caisson construction. The Halcyon Marine Enclosure is a pile-supported enclosure using advancements made over the last 20 years in (x) large-diameter piling methods developed for the construction of offshore oil and gas platforms and (y) pre-stressed reinforced concrete.

In 2007, the UK's Department of Energy and Climate Change ("DECC") initiated a major (£ 13 million) study to assess tidal power options in the Severn Estuary between England and Wales. The DECC retained the engineering and construction concern of Parsons Brinkerhoff ("Parsons") to conduct the 'Severn Tidal Power Consultation'. Additionally, the DECC appointed an Expert Committee to further review Parsons' findings and conclusions. The DECC then published the Parsons' results in the *Strategic Environmental Assessment for Tidal Power Development in the Severn Estuary: Options Definition Report* (the "*Report*").

Halcyon Marine submitted its pile-supported enclosure design in response to a 'Call for Evidence' from Parsons for information regarding available technologies that might apply to construction of five projects under consideration. Parsons performed a two-year technical review of the Halcyon Marine Enclosure design, which was further reviewed by the DECC's Expert Committee. Because of its potential for cost-reduction, Parsons investigated the application of Halcyon Marine methods to the Bridgewater Bay Lagoon, a shore-connected lagoon 16.1 kilometers long. Specifically, Parsons' *Report* stated "the Halcyon [S]olution is an innovative modular solution to the construction of the lagoon enclosure."[4] The *Report* goes on to describe the construction method – "The proposal is to construct the lagoon enclosure with a line of

[2] A caisson is essentially a floatable concrete 'box'. Caissons for tidal power plants can be (x) powerhouse caissons containing turbine generators, (2) sluice caissons to control water flow in and out of the enclosed basin, or they can be (3) a 'blank caisson', caissons whose function is to tie the other caissons to each other and to the shore.
[3] If built, the Severn Barrage with an installed capacity of 8800 MW would be one of the largest power plants ever constructed. It would provide more than 5% of the UK's total power consumption.
[4] Prepared by Parsons Brinkerhoff, Ltd in association with Black and Veatch, Ltd for the Department of Energy and Climate Change *Strategic Environmental Assessment of Proposals for Tidal Power Development in the Severn Estuary – Options Definition Report, Version 3, Volume 2, April 2010,* p. A 130]

precast concrete mini caissons [panels] on a line of precast concrete supporting columns inserted into sockets pre-drilled into the underlying rock…. Locking posts inserted into channels cast into the supporting columns and the edges of the mini caissons [panels] provide lateral support.” [5] The Halcyon Marine Enclosure is shown in the form of a tidal lagoon in **Figure 1.**

Pile support is a fundamental innovation. Conventional embankment and caisson methods use massive elements to support the differential head generated by the rise and fall of the tides. By providing pile support, the Halcyon Marine Enclosure eliminates the need for large mass. The result is a thin (3 to 4 m), light, but extremely strong wall in place of massive embankments or caissons. The relative dimensions are shown in **Figure 3**. The minimal dimensions of the Halcyon Marine Enclosure are a major factor in maintaining its low cost, since they reduce the amount of concrete and sea floor modifications. The *Report* confirmed this reduction in cost for the Halcyon Solution, as follows, “A reasonably detailed evidence based estimate of the wall cost has been provided by Halcyon [Marine]…. The estimate provided by Halcyon [Marine], including an allowance for fabrication yards omitted from the [original] Halcyon [Marine] estimate is about 50% of the estimated cost of embankment construction.”[6]

A reduction of 50 % over the next least cost alternative is transformational to the cost of construction, since, to re-iterate, the civil works typically represent two-thirds of the total cost of the facility. Further, because these mini caissons can be floated by barge to the site and set in place between the pile supports, the length of the civil works construction period is also substantially reduced, leading to another incremental reduction in cost.

Additionally, the cost of the Halcyon Marine Enclosure increases slowly with depth. This also has a profound effect on the economics of the project, and here’s why. Doubling the length of the enclosure of a shore-connected lagoon increases the area of the enclosed basin by four. The energy produced is proportional to the area of the basin while the cost is proportional the length of the enclosure. Therefore, doubling the length of the enclosure doubles the cost but quadruples the energy output! Stated another way, the cost of civil works for each megawatt-hour of electricity produced is halved for each doubling of enclosure length.[7] By building large shore-connected tidal lagoons, the Halcyon Solution delivers utility scale power at low cost.

In addition, Halcyon has developed a low-cost powerhouse. Halcyon Marine, in consultation with Alstom Power, has developed a low environmental impact operating cycle for tidal range facilities (described further below). It turns out that a low-cost powerhouse is sufficient to support this operating cycle. The powerhouse is a modification and simplification of a powerhouse developed by LB Bernshtein and his Soviet Team for the tidal power plant constructed at Kislaya Guba (1968). The Kislaya powerhouse was built and tested in Murmansk, which has a marine climate marked by long, severe winters with temperatures dropping to -40^{o}C.

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[5] *Options Definition Report,* Vol 2, p. A 130.

[6] *Options Definition Report,* Vol. 1, p. 170. Halcyon construction was applied to the Bridgewater Bay Tidal Lagoon, one of five projects short-listed for detailed examination. The Halcyon Solution construction methodology was applied to the Bridgewater Lagoon because of its great length (16.1 km). Water depth reached 12 m.

[7] The reason that the cost of the Halcyon Marine Enclosure increases slowly with depth is directly correlated to the construction cost structure. The cost of the equipment is substantially greater than the cost of the materials used. Since the cost of materials doubles with each doubling in depth and the cost of the equipment increases much more slowly with each doubling of depth, the overall cost of the civil works increases more slowly with depth.

The powerhouse was pre-fabricated in dry-dock, floated, towed to the site, and then flooded into place. By 1993-94, the powerhouse had undergone 12,000 cycles of freezing and thawing, with no sign of damage.[8]

Patents

International Patents for Halcyon Marine's pile supported construction have been, or are being secured. Patents under the name of The Tidal Energy System have been granted in the United States (Patent No. 6,967,413, Nov. 2005), Australia (Patent No. 200427976, Aug 2007), ***Canada*** (Patent No. 2537578, Feb. 2011), China (Patent No. ZL2004800029972.8, Jan. 2009), Mexico (Patent No. 257845, June 2008) and the Russian Federation (Patent No. 2326264). Applications for patents have been filed and are in prosecution in Brazil, the European Union, and India where patents are provisionally protected under PCT regulations pending final decision. Communications indicate that patents in India will be granted soon.

Halcyon Marine will authorize the use of these patented processes by Halcyon Tidal Power LLC ("Halcyon") and its tidal power operating subsidiaries.

In the final analysis, the viability of the construction methodology of the Halcyon Solution was confirmed when the Halcyon Marine Enclosure design underwent the aforementioned two-year technical review by Parsons Brinkerhoff and the Expert Committee appointed by DECC in the Severn study. The *Report* concluded that, "In general terms, the modular wall system [Halcyon Marine Enclosure] and construction methodology is considered technically viable…."[9]

THE HALCYON SOLUTION: ENVIRONMENTAL IMPACTS

The Environmental Impacts of the Civil Works for Conventional Tidal Power Projects

With increasing concerns regarding the impact of the human element on the environment, the potential negative environmental impact of conventional tidal power plants has played an increasingly key role in tidal range development. There are three major issues. The first is the negative environmental impact of most barrage proposals. The second is the alteration of the natural tidal cycle and the resulting loss of intertidal habitat. The third is fish mortality during passage through the turbines.

Conventional tidal power developments are typically of the barrage type. As noted earlier, since such construction is expensive at any meaningful length, use of such methodology makes shore-connected lagoons uneconomical. Because of this length limitation, virtually every conventional tidal power development has been placed at the narrowest part of estuaries and rivers flowing into the sea. Of course, such riverine and estuarine systems are usually essential for spawning

[8] V.F. Stepanova , N.K. Rozental, and I.L. Kondratova, Russian Experience with Marine Concrete Structures at the Kislaya Guba Tidal Power Station, in O.E.Gjorv, N. Sakai, N. Banthia, Ed., *Concrete Under Severe Conditions*, Vo.l2 pp. 596-605, Spon 1998, and L.B. Bernshtein, *Tidal Power for Electric Power Plants*, Translated from the Russian by the Israel Program for Scientific Translation, Published for the US Department of the Interior and the National Science Foundation 1965.
[9] *Options Definition Report*, Vol. 2, p. A 133.

fish. Macrotidal estuaries are among the most productive, as well as fragile, ecological environments. By blocking the entrance to such systems, barrages have a major negative environmental impact. Both the Annapolis Royal tidal power plant and the power plant at La Rance are of this type. The construction of shore-connected lagoons eliminates the need to enclose such systems; and, since low-cost Halcyon Solution construction makes shore-connected lagoons economically viable, there is no need to enclose estuarine and riverine systems in order to generate power from the movement of tides.

The Environmental Impacts of Operating Conventional Tidal Power Plants

Operating conventional tidal range power plants at the mouth of an estuary severely disrupts the natural tidal cycle. These facilities are typically operated *only* on the ebb or flood tides – one-way generation. Because these conventional facilities act more like a dam where water is released only after the tidal head reaches its peak behind or in front of the barrage, either the existing intertidal zone remains permanently inundated or barren of tidal flows. In regions of the world where there is a high tidal range (macro-tidal regions), and where the water is also shallow in depth, vast areas of intertidal zone are submerged by the rising flood tide and then exposed by the receding ebb tide. The effect is particularly pronounced in estuaries where rivers deposit large amounts of rich sediment, creating large areas of shallow water. These estuaries are among the richest ecological environments on Earth. Marine plants grow readily in their rich soils with nutrients added from the incoming tides. Fish fry, shellfish and micro-invertebrates also thrive in this environment. Large numbers of shore birds feed on these fish at high tide, as well as shellfish and invertebrates at low tide. This delicate tide-dependent ecosystem is disrupted by conventional modes of operating tidal power plants.

The most common mode of operation is ebb generation.[10] Ebb generation is the mode employed at Annapolis Royal in the Bay of Fundy. In this mode of operation, the basin is filled through sluices with the rising or flood tide. Power is generated as the water flows out of the basin through turbines during the falling or ebb tide. When ebb generation is employed, water levels in the basin never fall below mid-tide level resulting in a loss of *half* of the original intertidal zone. That half of the intertidal zone, which is exposed between mid-tide and low tide, becomes permanently submerged. For the ebb generation of the Severn Barrage (Project B3 in the Severn Tidal Power Consultation), it was estimated that 14,050 hectares of intertidal habitat would become permanently submerged,[11] disrupting a delicate ecological system that supports an internationally important assemblage of stationary and migratory birds numbering over 20,000.[12] The value of compensatory habitat loss was estimated to range between £ 632 million and £ 1897 million by Parsons. The scale of the negative environmental impact played a major role in the UK's decision to put the Severn Projects [including further consideration of the Halcyon Solution] on hold, in spite of its massive energy and carbon reduction benefits.

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[10] The details of these cycles can found in many reference works such as Robert H. Clark, *Elements of Tidal-Electric Engineering*, IEEE Press, Wiley-Interscience, 2007.
[11] *Options Definition Report*, Vol.1, p. 163.
[12] Prepared by Parsons Brinkerhoff Ltd in association with Black and Veatch, Ltd for the Department of Energy and Climate Change, *Analysis of Options for Tidal Power Development in the Severn Estuary – Interim Options Analysis Report, Vol. 1,* Dec. 2008, p. 56), p. 59.

The 520-MW Garorim Tidal Barrage in Korea also proposed using ebb generation. Construction was due to begin in 2012 with completion scheduled for 2017. Environmental groups as well as local fishermen who use the intertidal zone to harvest shellfish mounted strong opposition to the project, citing its negative environmental impact. The project has not been able to secure environmental permits from the government because of the inevitable loss of intertidal habitat. Additionally, conventional construction costs for the barrage escalated far beyond projections. Predictably, the cost of the civil works and loss of intertidal habitat put the future of the Garorim Tidal Barrage in doubt along with Korea's ambitious plans to install 2,544 MW's of tidal range power.

Flood generation is yet another mode of operating a tidal power plant. Flood generation results in the loss of the upper half of the intertidal zone. Flood generation and ebb generation result in loss of intertidal habitat in equal measure. A third mode - two-way generation - produces power with water flowing into the basin at flood tide and out during ebb tide by using turbines that can generate power with flow in either direction. Two way generation results in a partial loss of both the lower and upper sections of the intertidal zone.

The Parallel Cycle – Resolution of Environmental Impacts

Intertidal Zones

The need to address the loss of intertidal habitat is imperative for environmentally responsible tidal range power generation, whether such facility is located at the mouth of an estuary or part of a shore-connected lagoon – as noted earlier. The Halcyon Solution permits the construction of low-cost shore-connected lagoons, significantly limiting environmental impacts from the start. In 2009, Halcyon Marine developed an operating method, the Parallel Cycle, which retains the natural boundaries of the intertidal zone by preserving the natural hydrology within the enclosed basin. As a result, the Parallel Cycle also maintains the natural sedimentary regime within the basin -- no net accumulation of sediment occurs within the basin or lagoon. The Parallel Cycle is a major component of the Halcyon Solution.

Figure 2 provides a simplified rendition of the Parallel Cycle. Modern bulb turbines have the capability of generating power with water flow in either direction. The same bulb turbines also have the capability to act in reverse as high volume pumps. The Parallel Cycle employs these capabilities to empty and fill the basin as would naturally occur during the unimpeded ebb and flood tides, while at the same time permitting two-way generation of electricity. Unfortunately, two-way generation by itself will not maintain the intertidal zone, for without pumping, the water level in the basin will never attain the natural high tide maximum water level, nor the minimum natural low tidal level. The results are loss of intertidal habitat. By mobilizing the pumping capacity of bulb turbines, the Parallel Cycle reproduces the natural cycle within the enclosed basin. **Figure 4** shows the level of water in the basin (violet line) and the level of the sea (blue line). The rise and fall of water level in the basin mimics or parallels the rise and rise and fall in the sea driven by the tides. The effect of the tidal range power plant is to retime the rise and fall of the tides in the basin to a slightly later hour. (The flat section, F to G, can be ‘rounded’ to more closely follow the sinusoidal curve by starting the turbines sequentially). The title ‘Parallel Cycle’ derives its name from the fact that the water level in the basin closely parallels or mimics the natural rise and fall of the natural tidal cycle in the basin, the cycle that would have obtained in the absence of tidal power. A tidal range power plant operated using the Parallel Cycle might aptly be called a ‘retiming tidal power plant’.

While it’s true that the pumping portion of the Parallel Cycle requires a draw of energy from the grid reducing the net output of two-way generation, the net effect is far less severe than one might guess. The reason is that pumping is carried out against a small head (E to F in **Figure 4**), while power generation is carried out under a much higher head (G to H in **Figure 4**). A more detailed accounting is beyond the scope of this discussion, but was recognized by French utility engineers in the 1940’s.[13] Therefore, tidal range facilities employing the Parallel Cycle approach a 40 % capacity factor, a capacity factor higher than any other tidal range or hydrokinetic cycle. This capacity factor is also higher than that reported by the US Department of Energy for offshore or onshore wind.[14]

The Parallel Cycle has additional advantages. Because it maintains the natural rise and fall of the tides [the natural hydrology] without any meaningful withdrawal of energy, no net sedimentation results. Other tidal cycles do not share this advantage, since they typically withdraw energy from the tidal stream.

Although bi-directional turbines with the capacity to generate with flow in either direction and to pump in either direction have been available for years, the Parallel Cycle is a fundamentally new development. Past analyses, based on a barrage placed across large estuaries, have cast doubt on the efficacy of bi-directional power generation. This doubt has been due to the failure of the requisite quantity of water necessary to empty and fill the basin to pass through the turbines. An account of the issues here is also beyond scope of this discussion.[15] It turns out, however, that the Parallel Cycle is always possible for a shore-connected tidal lagoon. The area enclosed by a shore-connected tidal lagoon and the installed capacity can always be matched to ensure the proper operation of the Parallel Cycle.

In 2010, Halcyon applied the Parallel Cycle to the Pennamaquan Tidal Power Project proposed for Cobscook Bay, Maine -- a project for which a preliminary permit has been secured from the Federal Energy Regulatory Commission (FERC)[16]. Halcyon Marine in collaboration with Alstom Power undertook detailed computer modeling of the cycle for the Pennamaquan Project. This research completed the analytical tools necessary to determine the installed capacity, power output and other properties for any shore-connected lagoon at any tidal range.

Fish Passage

Fish survival during passage through a turbine is always an issue that must be addressed. Fish passage through the Straflo turbines at the Annapolis Tidal Power Station has been studied.

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[13] For an elegant derivation of this result see Gibrat, R. L'energie des marees, Bulletin de la Societe Francaise des Electriciens, 7-e serie, Vol. 3. pp.287-288. Gibrat was principal engineer for La Rance tidal power plant.

[14] Energy Information Administration, Annual Energy Outlook 2011, December 2010, DOE/EIA-0383 (2010)

[15] See, for example, A.C. Baker, *Tidal Power*, Peter Peregrinus Ltd. on behalf of the Institution of Electrical Engineers, 1991, chapter 2.

[16] Details of the Pennamaquan Project can be found on the FERC website under FERC project no. 13884.

Such studies showed significant mortality, two-thirds of which was due to sudden pressure changes.[17] To avoid pressure related mortality, the Halcyon Solution employs horizontal bulb turbines. These have been shown to virtually eliminate fish mortality due to pressure changes by laboratory studies carried out by the Pacific Northwest laboratories for the US Department of Energy[18] These results have been confirmed by observational data from various hydroelectric projects using bulb turbines.[19] The elimination of the source of two-thirds of the fish mortality is an important step forward.

Further design modifications to the turbine/generators can increase the physical impact survival rate. Survival rates from physical impacts depend on fish length, the rotational speed of the turbine runner, the number of blades and the length of time fish require to make passage through the turbines. Optimization of fish survival from physical impacts has also been carried out in collaboration with Alstom. Runner rotational speed has been minimized by using a speed increaser for the generator. The number of blades has been reduced to three. While larger diameter turbines may appear to be the right choice for large tidal range facilities, it turns out that smaller diameter turbines (having low blade peripheral velocity) reduce physical impacts with fish, as well as volatile pressure gradients.[20]

A final important aspect of fish survival is the siting of a tidal power plant as a shore-connected lagoon, which does not enclose a river or estuary. As noted earlier, when the Halcyon Tidal Enclosure is configured as a shore-connected lagoon, it is an economically viable alternative to tidal range power production.

Decommissioning

Halcyon construction is modular. All major elements have been designed for flotation into place. At decommissioning, all major elements can therefore be refloated and towed away. Any support columns or piles would be cut to at the seafloor. Thus, decommissioning of any Halcyon Tidal Enclosure is straightforward, low-cost, can be accomplished in a timely fashion and leaves virtually no footprint.

Integration of Halcyon Solution Tidal Range Power with Conventional Hydro and with Hydrokinetic

Tidal range power can be readily integrated with conventional run-of-river and pumped storage hydroelectric facilities providing base load power. The details of such integration were worked-

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[17] (Stokesbury, K, & Dadswell, J, *Mortality of Juvenile Clupeids during passage through a Tidal,Low-Head Hydroelectric Turbine at Annapolis Royal, Nova Scotia* North American Journal of Fisheries Management, Vol. 11(2), Spring 1991, pp149-154).

[18] Abernathy C.S., Amidan, B.G., Čada, G.F., *Fish Passage Through a Simulated Horizontal Bulb Turbine Pressure Regime: A Supplement to "Laboratory Studies of the Effect of Pressure and Dissolved Gas Supersaturation on Turbine-Passed Fish"*, Prepared for the US Department of Energy by, the Pacific Northwest National Laboratory, 2003

[19] Pre-Application Document (PAD), Pennamaquan Tidal Power Project, July 2012, FERC no. 13884, pp. 13-23.

[20] A detailed discussion is found in the PAD cited above.

out by Soviet engineers in the 1950's.[21] Since tidal range power is not seasonal, it was determined that significant additional pondage would not be required.

Another opportunity is the integration of tidal range with tidal stream. Tidal range and tidal stream are synergistic technologies. When operated together, the two can also produce continuous power.

The Halcyon Solution - An Integrated Approach to Tidal Range Power Generation

The Halcyon Solution is an integrated approach to tidal range power generation. The problem of tidal range power generation consists of a set of interlinked problems, which cannot be resolved separately.

At the root of the problem is the cost of the civil works. The high cost of conventional construction of marine enclosures makes it necessary to limit conventional tidal developments to barrages placed along the narrowest point of a body of water into which streams or rivers flow. These bodies of water are essential to a large number of spawning migratory fish. Barrages restrict access to these spawning grounds, to marine mammals that often follow fish migrations and to commercial shipping.

Barrages result in other problems. Because there is often a mismatch between the requisite quantity of water necessary to completely fill the basin behind a barrage and the flow of water through the turbines, the intertidal zones are not protected and sedimentation build-up occurs.

The Halcyon Solution provides an integrated solution to these interlinked problems. The Halcyon Solution rests initially on the Halcyon Marine Enclosure -- a low-cost, pile-supported caisson enclosure. Because of its low cost, the Halcyon Marine Enclosure makes it cost effective to build shore-connected tidal lagoons, which can be sited to avoid enclosing river and estuaries eliminating negative effects on spawning fish and shipping. Once the Halcyon Marine Enclosure is in place, the Parallel Cycle is employed to preserve the natural hydrology within the enclosed basin retaining the intertidal zone and eliminating sedimentation.

[21] L.B. Bernshtein, *Tidal Power for Electric Power Plants*, Translated from the Russian by the Israel Program for Scientific Translation, Published for the US Department of the Interior and the National Science Foundation 1965. Chapter vi provides a detailed discussion of regulation of tidal power with hydro and thermal power plants.

APPENDICES

HALCYON KEY MEMBERS AND CONTRIBUTORS

Alstom Power, Inc. - Alstom is the world's leading turbine manufacturer. Alstom and Halcyon have a collaboration agreement. Alstom would provide the turbine/generators and the balance of plant for the Pennamaquan Project. Alstom has submitted estimates for the electrical works of the Pennamaquan Tidal Power Plant.

Parsons Brinkerhoff, Ltd - Parsons Brinckerhoff is a global consulting firm assisting public and private clients to plan, develop, design, construct, operate and maintain critical infrastructure. Parsons has formally expressed interest in acting as project managers for the Pennamaquan Tidal Power Project. It is significant that Parsons carried out the £ 13 million Severn Tidal Power Consultation for the Department of Energy and Climate Change of the UK. As a result, Parsons Brinkerhoff is fully conversant with Halcyon's construction methods. Parsons' interest is grounded in its familiarity with Halcyon's construction methods.

MEG Consulting, Ltd. – MEG is highly respected geotechnical consulting group. MEG has provided geotechnical consulting for onshore and offshore oil & gas infrastructure projects. Their clients include Chevron-Taxco, Conoco/Phillips, ExxonMobil/Neftegas Ltds, as well many other well known firms associated with offshore oil and gas. MEG has significant experience with offshore piling in connection with offshore oil & gas platforms. MEG provided piling calculations for Halcyon during the Severn Tidal Power Consultation. MEG additionally provided the initial geotechnical assessment for the Pennamaquan Tidal Power Project.

Fugro-Seacore – Fugro-Seacore is probably the world's leading overwater Marine Drilling Contractor. Fugro-Seacore provided Halcyon with estimates for the large diameter pile drilling during the Severn Tidal Power Consultation. Fugro-Seacore provided the estimated cost for carrying the drilling and for installation of the support columns for the Pennamaquan Tidal Power Project.

MIAH Inc. – MIAH manufactures custom onshore and offshore hard rock trenchers. MIAH provided the preliminary design and estimated cost for the trencher required for the foundation of the Pennamaquan Tidal Power Project. The trencher is a major piece of equipment.

Global Marine – Submitted a trenching proposal for the Pennamaquan Tidal Power Project in consultation with MIAH. Global Marine has a global presence in the installation of sub-sea cables. In particular Global Marine has worldwide experience in trenching for installation of sub-sea cables.

Perry Marine & Construction – Perry Marine and Construction is a local marine and construction company operating from Perry, Maine a few kilometers from the Pennamaquan Tidal Power Project site. Perry Marine & Construction submitted an estimate to carry out the small diameter core drilling required for the geotechnical analysis. Perry Marine & Construction successfully carried out core drilling for ORPC, a hydrokinetic tidal power company with a project in the area. Perry Marine & Construction have local knowledge of marine conditions so important to operating in the high current conditions of Cobscook Bay. In addition, Perry Marine & Construction operates a suitable construction yard for the construction of the powerhouses, wall elements and support columns for the Pennamaquan Tidal Power Project.

Weeks Marine – Weeks Marine is a major marine construction equipment provider on the East Coast of the US. Weeks provided Halcyon with major equipment rental costs for the project the project. The estimate included heavy lift jack up and conventional barges as well as tugs.

The Port of Eastport - The Port of Eastport is seven kilometers away from the Pennamaquan Project. The Port of Eastport operates tugs which guide large ships into the deep-water port of Eastport. The Port has highly experienced pilots. The Port of Eastport provided cost estimates for the use of the port's tugs and piloting expertise.

Preti-Flaherty – Pennamaquan Tidal Power, LLC is represented by Preti-Flaherty. Preti-Flaherty is the premier law firm in Maine. Preti has a major energy practice. Preti has a great deal of experience in legislative matters in Maine.

Halcyon Marine Hydroelectric – HMH is a Utah corporation. HMH manages the patents associated with the Halcyon Solution. It is also a sister company to Halcyon Tidal Power LLC and an affiliate of Pennamaquan Tidal Power LLC.

Dr. Ramez Atiya – Founder of Halcyon Marine and President of Halcyon and affiliates. See CV attached.

Ted Verrill – Chief Financial Officer of Halcyon and affiliates. See CV attached.

Business-to-Business - HMH and Pennamaquan Tidal Power have maintained a low profile and do not have a web presence preferring to operate on a business-to-business basis. The low profile approach maintains technical confidentiality.

Dr. Ramez Atiya
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Salt Lake City, Utah
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Educational Background

BA Physics, University of Utah, 1968
BA Philosophy, University of Utah, 1968
MA Physics, University of Utah, 1972
PhD, Philosophy of Science / Physics, University of Utah, 1978

Curriculum Vitae: Tidal Power

Technology Development & Patents

2002 -2004
Research on a pile supported civil works for tidal range power generation. Research focused on the application of large diameter piling methods to the civil works of tidal range power plants. These methods were originally developed by the offshore oil gas industries in the construction of offshore oil & gas platforms. The use of large diameter pile supports reduces the need for massive civil works in the construction of tidal range power plants. The result is a steep reduction in the cost of the civil works. Reduction in the cost of construction leads to commercially viable tidal range power. In addition reduction in cost permits low environmental impact designs of tidal range power plants. The technology is the first fundamentally different approach to the civil works of tidal range power since the introduction of caisson methods (construction in the wet) in the 1950's. The research culminated in US and international patents.

2005- 2010
Patents under the name of The Tidal Energy System have been granted in the United States (Patent No. 6,967,413, Nov. 2005), Australia (Patent No. 200427976, Aug 2007), Canada (Application No. 2537578, Feb. 2011), China (Patent No. ZL2004800029972.8, Jan. 2009), Mexico (Patent No. 257845,June 2008), and the Russian Federation (Patent No. 2326264). Applications for Patents have been filed and are in prosecution in Brazil, the European Union, and India where patents are provisionally protected under PCT regulations pending final decision. Communications indicate that patents in India will be granted soon.

2008 – 2010
Halcyon Marine Hydroelectric

Halcyon Marine Hydroelectric Corp. was formed in 2008 to manage the patents, extend and develop tidal range technology. Halcyon was formed under the leadership of Ramez Atiya.

The Severn Tidal Power Consultation: The Halcyon Proposal

In 2008, the UK's Department of Energy and Climate change retained the engineering firm of Parsons Brinkerhoff to identify and study potential schemes. The Study was conducted over a two year period at a cost of £ 13 million. In 2008 Parsons Brinkerhoff selected five projects (three barrages and two lagoons) and issued a Call for Evidence asking interested companies to submit innovative construction methods. Halcyon submitted its proprietary pile supported construction methods.

Halcyon's construction methodology was subject to two year technical examination by Parsons Brinkerhoff whose findings were further examined by the Expert Committee appointed by the Department of Energy and Climate Change. The results were published by the Government's Department of Energy and Climate Change in *Strategic Environmental Assessment of Proposals for Tidal Power Development in the Severn Estuary, Options Definitions Report, Vols.I-III* (Prepared by Parsons Brinkerhoff in association with Black.& Veatch, Ltd)

The Halcyon Wall Solution (as it came to be called) was examined as a candidate construction method for the Bridgewater Bay Tidal Lagoon (L3D), a 16.1 kilometer shore connected lagoon with an estimated power output of (5.6 to 6.6 TWh annual energy output). The Halcyon Wall Solution offered a low cost alternative, an essential requirement because of the great length of the enclosure. The Department of Energy and Climate Change described "The Halcyon solution is an innovative solution to the construction of the lagoon enclosure. [It] provides a rapid method of construction using a line of precast concrete mini caissons [wall panels] installed between precast pile supported column."[Options Definitions Report Vol. 1, p. 28]. Further, "... It is concluded that the modular wall system and construction methodology is ... a technically viable solution." [ODR Vol. 1, p. 28]. In addition the Report states: "A reasonably detailed evidence based estimate of the wall cost has been provided by Halcyon. The estimate ... is about 50% of the estimated cost of embankment construction."[ODR Vol. 1, p. 170]

The Halcyon Collaborative

2009
In the course of 2009 Halcyon formed a collaborative team capable of full project delivery. These companies are Fugro-Seacore, Glosten Associates and MEG Ltd. Fugro-Seacore (www.seacore.com/) is pre-eminent in large diameter drilling which is key to Halcyon's pile supported construction methodology. Fugro-Seacore is a UK firm based in Bristol Glosten Associates (www.glosten.com/) are Naval Architects, and Marine & Ocean Engineers. Glosten is an American company with headquarter in Seattle, WA. Halcyon and Glosten have agreed to collaborate on the design of a $52 million Halcyon Catamaran Jackup Barge, a key piece of major construction equipment proposed to minimize construction time. MEG Ltd www.megconsulting.ca/ are geotechnical and piling consultants. They have provided expertise to many of the world's major offshore oil and gas developers including Chevron-Texaco, ExxonMobil/Neftegas, and PEMEX. MEG carried out the pile calculation for the Halcyon Severn proposal.

2010
Agreement with Alstom Power –

In October 2010 Halcyon entered into a collaboration agreement with Alstom, the world leader in hydro-turbine manufacturer.

The Pennamaquan Tidal Power Plant

Halcyon is proposing to construct a tidal power plant in Pennamaquan River in Cobscook Bay, Maine near the Canadian border. The Pennamaquan Tidal Power Plant would serve as the demonstration project of Halcyon's proprietary construction methodology. It is also intended to serve as a full scale tidal power research facility.

Pennamaquan Tidal Power LLC - The Pennamaquan Tidal Power LLC (Maine) was formed as the development company for the Pennamaquan Tidal Power Plant.

A Preliminary Permit for the Pennamaquan Tidal Power Project was granted in March 2011.

Parsons Brinkerhoff – The firm of Parsons Brinkerhoff, Ltd. (www.pbworld.com) has expressed its interest in acting as project manager. It is significant that Parsons carried out the Severn Tidal Power Study and behalf of the Department of Energy and Climate Change and is therefore full conversant with Halcyon Construction. Parsons is an engineering firm with a worldwide presence

Agreement with Alstom Power - In October 2010, Halcyon signed a Cooperation Agreement with Alstom Power.

2011
The Parallel Power Cycle

In 2009 Halcyon developed the Parallel Cycle. During 2010, Halcyon and Alstom carried out research to apply the Parallel Cycle to Pennamaquan Project for which Pennamaquan Tidal Power, LLC has preliminary permit from FERC (FERC Project No 13884. The research was completed in January 2011. The resulting power cycle maximizes energy output for tidal lagoons. In addition, the cycle resolves the main environmental problem faced by the conventional tidal range power cycle, the permanent alteration of the intertidal zone.

Provisional Patent: Parallel Cycle

In June 2012 an application was submitted to the PCT. The technology is provisionally protected in 142 countries.

2010 – 2012
Over the course of 2010 to 2012 meetings were held with Maine government officials, and environmental regulators, as well as representatives of Federal regulatory agencies, the Maine

Public Utilities Commission, Pembroke Town government, Eastport City Council, and Washington County Officials. These include meetings with:

Governor John Baldacci, Maine
Ken Fletcher, Director, Office of Energy Independence and Security, Office of the Governor

2012
Extensive consultation was carried out with Maine environmental regulators and agencies as well as Federal environmental agency representatives in drafting the Pre-Application Document (PAD) for the Federal Energy Regulatory Commission (FERC). Pre-Application Document (PAD) was submitted to the FERC. FERC has accepted the PAD and called for a two day Scoping Meeting in Maine. The first meeting with FERC Officials, Federal regulatory agencies, the Maine Department of Environmental Protection, and Maine regulatory agencies is scheduled for October 25. On October 26, FERC representative will visit the site for the proposed Pennamaquan Tidal Power Project and will host a meeting for all stakeholders and members of the community.

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Beaver Wood Energy LLC
Managing Director 2009 to Present
Owner/Developer of two 29.5 MW integrated wood biomass electric generating and wood pellet manufacturing facilities in VT

New England Alternative Energy LLC
Managing Director 2009 to Present
Owner/Developer of renewable and alternative energy resources in New England

Naugatuck Energy Development LLC
Sasco River Advisors LLC
President 2005 to Present
Owner/Developer two natural gas-fired electric generating facilities in southwestern Connecticut
- Owner and original developer of Waterbury Generating Facility – 100 MW peaking facility – one of four facilities awarded a long term capacity contract with a CT utility – majority interest sold to Energy Capital Partners/First Light Power/G.D.F.Suez in June 2007
- Owner and developer of Ansonia Generating Facility – 65 MW CHP facility – awarded a $26 million grant to construct the facility on a brown field site in southwestern Connecticut – permitting completed, gas and electrical interconnects in final stages

Providing advisory and other financial services for the renewable and clean tech energy sectors
- Arranged sale of 55 MW biomass to energy facility in Benson, MN
- Advised Padoma Wind on 125 MW wind project in New Mexico
- Advised Fox Island Wind project in Vinalhaven, Maine

Allco Finance Corporation
Senior Vice President 2001 to 2005
Responsible for originating, arranging debt and equity, managing and closing domestic and cross-border structured finance, lease finance and project finance transactions
- Successfully financed rolling stock, water and waste water transactions in the US and Europe valued at over $2 billion.
- Raised equity capital for the foregoing transactions from relationships in banking and finance sectors
- Assisted biomass to energy and fuel cell developers in raising development capital

DaimlerChrysler Capital Services, Inc.
Managing Director 1989 to 2001
Successfully led a team of marketing, accounting, pricing, credit and tax personnel and technical experts in identifying, selecting, acquiring and managing $5 billion of investment in US, Asian, European and Australian transportation and facility assets with $100 million of annual earnings
- Negotiated sophisticated multi-party transactions involving commercial aircraft, rolling stock, shipping, pulp & paper, water and waste water facilities, renewable (hydro, solar and waste to energy), fossil fuel (natural gas, coal and oil) and nuclear energy generation facilities, with a working knowledge of the associated tax, accounting, credit, pricing and legal issues
- Met or exceeded annual budgets and business plans - liaising with credit, finance and tax at Chrysler Corporation in Auburn Hills, MI and Daimler Benz AG in Stuttgart, Germany

Integrated Resources Corporation
Vice President 1985 to 1989
Successfully negotiated the terms of and acquired $500 million of commercial aircraft from Continental, American, United, Eastern and Delta. Assisted with the development of new products in a changing tax law environment

Thacher Proffitt & Wood
Associate 1981 to 1984
Engaged in all phases of asset-based and lease finance of transportation and project assets, as well as general corporate finance, tax, banking, securities and real estate law – Represented Comdisco Financial Services, Chemical, Fifth Third and Wells Fargo banks, Emery Air Freight and Livanos Shipping

Ernst & Young
Tax Staff 1980 to 1981
Involved in researching and providing advice with regard to a variety of domestic and foreign US corporate tax matters

Price Waterhouse Coopers
Consultant 1976 to 1978
Involved with high-tech venture capital enterprises and the Fidelity group of funds

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Fordham University/University of Maine Schools of Law, JD, 1981
University of Arizona/Eller School of Management, MBA, Finance, With Distinction, 1975
Bowdoin College, BA, 1971
Member of the Bar (Retired), New York 1984, Connecticut, 1991

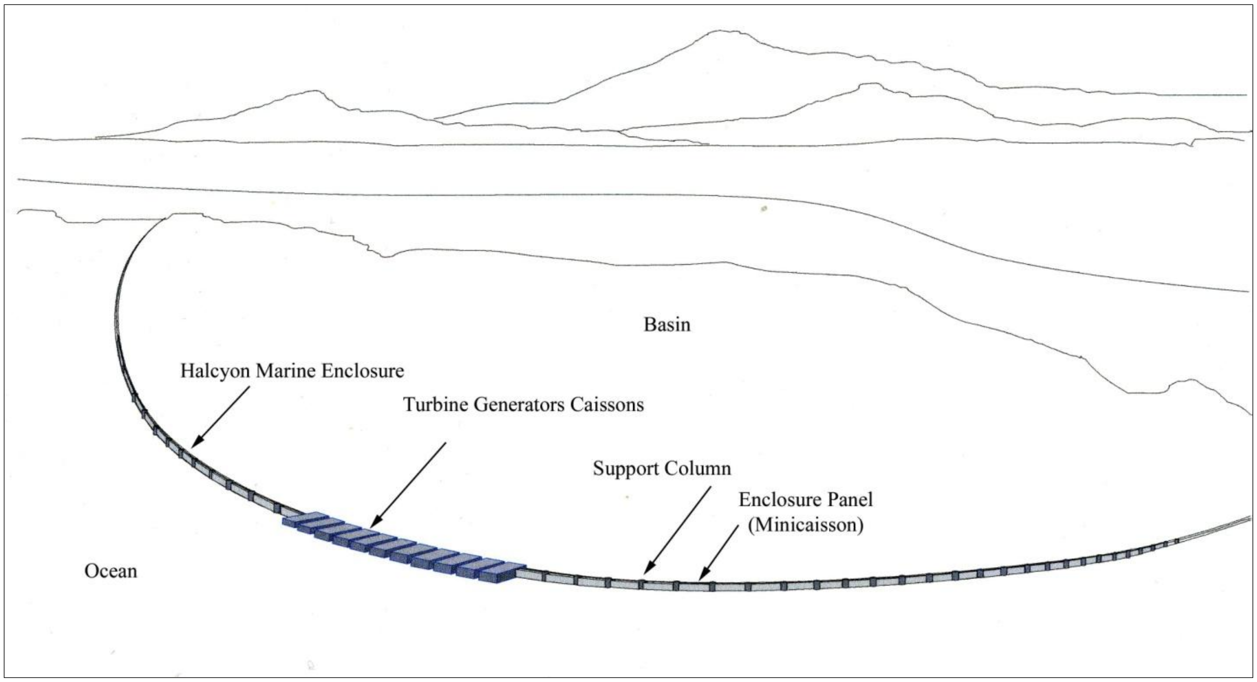

Figure 1. Halcyon Marine Enclosure

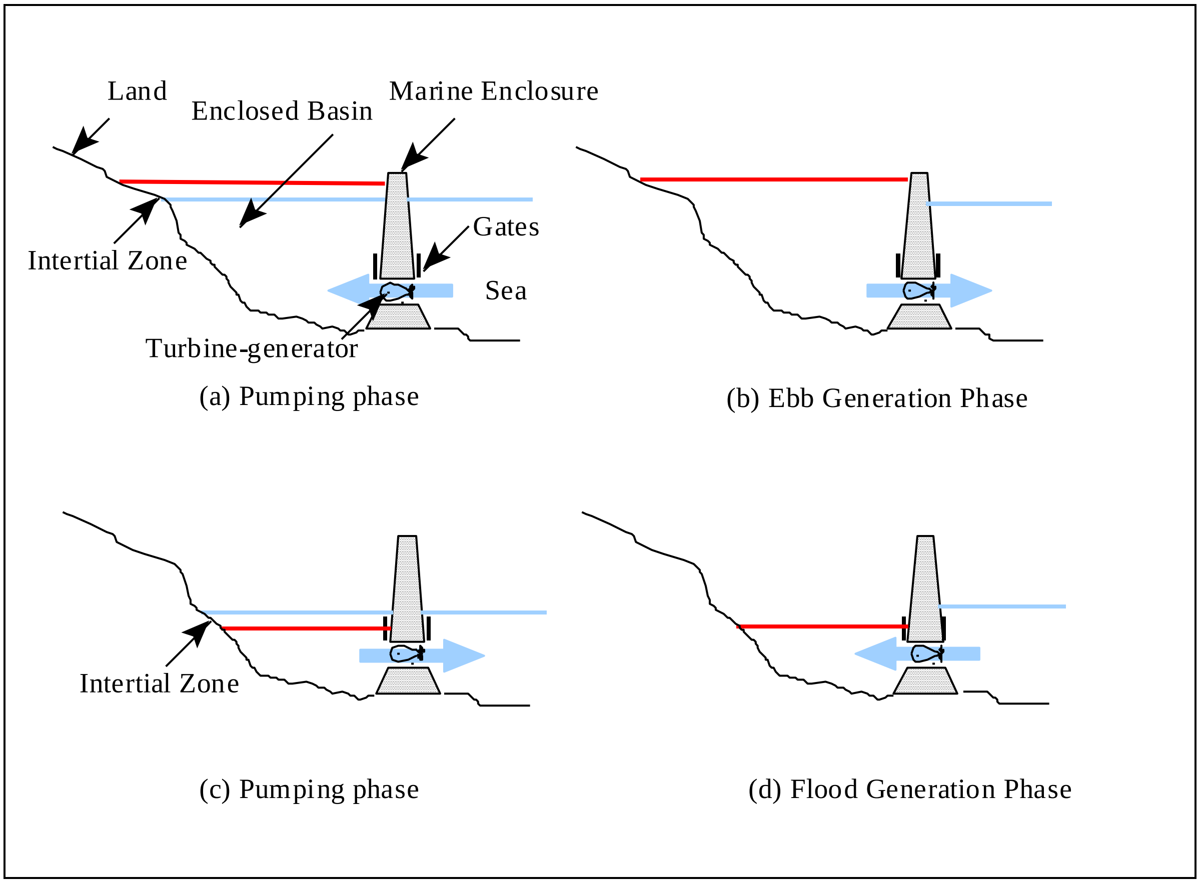

Figure 2. The Parallel Cycle. The Parallel Cycle consists of four major phases: A *pumping phase (a)* begins when the level of the water in the sea and in the basin are equal (blue lines). The turbine-generator is operated as a pump, transferring water from the sea into the basin to raise the water level to the natural high tide level. The natural tide level is shown by the red line. Without pumping, the water level in the basin would never attain its natural high tide water level. It would only reach the level indicated by the blue line. The intertidal zone, the section of land between the blue and red lines would remain permanently exposed. Pumping is followed by an ebb *generation phase (b)*. Water flows from the basin to the sea through the turbine-generator producing electric power. As the water level in the sea continues to fall with the ebbing tide, water continues to flow from the basin into the sea through the turbines until the water level in the sea and in the basin are equal (blue lines in (c)). Another *pumping phase (c)* then begins transferring water from the basin into the sea until the water level in the basin reaches its natural low tide level indicated by the red line. In the absence of pumping, the intertidal zone normally exposed at low tide would become permanently exposed. *Pumping phase (c)* is followed by *flood generation phase (d).* Water flows from the sea into the basin producing electric power. As the water level in the rises with the flooding tide, water continues to flow from sea, filling the basin. Flood generation continues until the level of the water in the sea and the basin are equal (shown by the blue lines in (a)). The cycle then repeats itself. (For clarity, the simplified version presented here omits several intermediate phases).

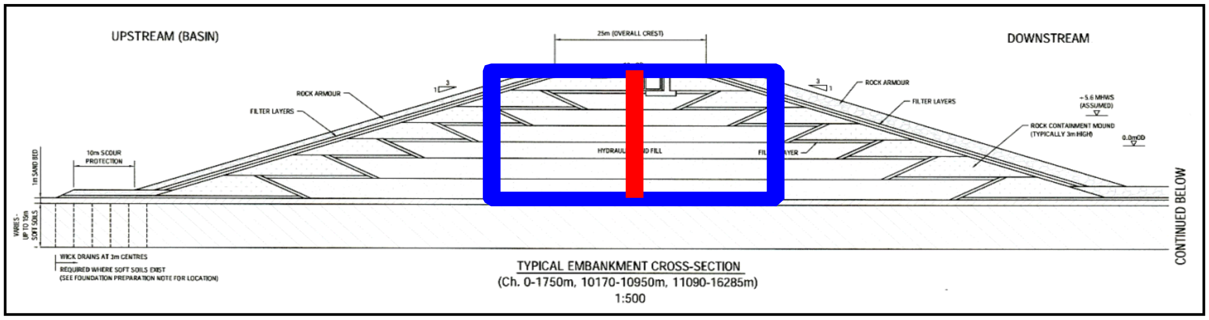

Figure 3. Relative dimensions: A cross-sectional view of The Halcyon Marine Enclosure (shown in red) in comparison to a conventional caisson and an embankment.

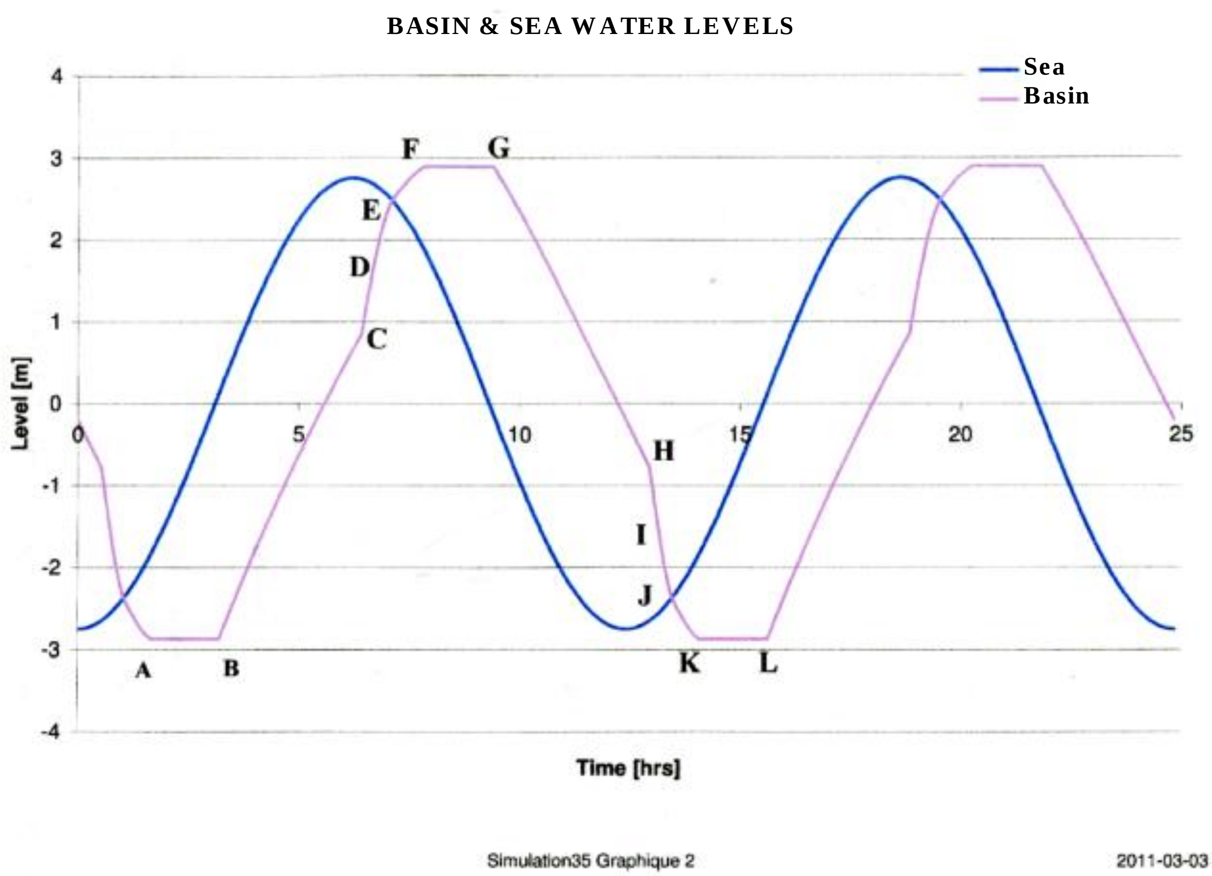

Figure 4. The Parallel Cycle for an average tide (tidal range 5.5 m).

Phases:
A to B – Waiting phase.
B to D – Flood power generation: water flowing from sea to basin.
D to F – Pumping to raise the level of the basin to its natural high level.
F to G – Waiting phase.
G to I – Ebb power generation: water flowing from basin to sea.
I to K – Pumping to lower the level of the basin to its natural low level.
K to L – Waiting phase