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Marine Renewable Energy – Wave, Tidal and Water Current

Canadian Technology Status Report

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Canada

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FOREWARD

The marine renewable energy sector, which includes wave, tidal and water current energy, is at a critical point. Globally, there are many technologies that under development and there is yet to be a clear convergence towards an energy extraction method that most efficiently generates electricity while remaining cost-efficient. This sector is gaining recognition as a potential source for reducing greenhouse gas emissions and meeting future energy requirements. This renewed interest is providing technology developers with a push forward to continue on the path to commercializing their technologies.

In 2008, Natural Resources Canada published a report entitled, *Review of Marine Energy Technologies and Canada's R&D Capacity,* which included a section that provided an overview of the status of marine energy technologies being developed.

This publication is a continuation of the 2008 study and focuses only on the status of Canadian technologies. This report will be updated every two years and will contain information directly provided by Canadian technology developers. This report presents technology development progress, including observed trends.

If you are a Canadian marine energy technology developer that has not been included in this report, please contact CanmetENERGY[1] to ensure that you are included in future editions.

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1. INTRODUCTION

In 2008, Natural Resources Canada commissioned a study to examine the marine energy technologies being developed globally and to provide an analysis of the research and development (R&D) activities taking place within Canada[2].The study also included a full review of Canadian wave, tidal and water current energy technologies. Since the publication of this report, there has been an increase in activity and interest in this sector. One example is the development of the tidal demonstration facility: Fundy Ocean Research Centre for Energy (FORCE). FORCE has four berths available for in-stream tidal technology developers to deploy their device in some of the largest and fastest tidal currents in the world. One of these berths has been originally awarded to Clean Current Power Systems Inc., a Canadian technology developer, who has now partnered with Alstom Power.

The objective of this report is to provide a recurring status update based on information provided by Canadian technology developers. It is intended that this report will be updated every two years and will assist in monitoring technology and project advances, recognizing any potential trends, and provide the public with a central record of information.

The process for populating this report included a scan of the Canadian marine energy sector to identify developers of wave, tidal and water current energy technologies. These technology developers were then directly contacted to provide input into the report. At this time, fifteen technology developers were contacted, but only eleven reported back in time for publication of this report.

The format of this report includes a summary of each technology and any updates received from each developer. It concludes with a brief analysis of any observed trends. The complete technology description, as provided by the technology developer, is provided in the Appendices as a reference.

[2] Devine Tarbell and Asssociates & Natural Resoureces Canada, "Review of Marine Energy Technology and R&D Capacity", Natural Resources Canada – CanmetENERGY, 2008 -- report available at http://canmetenergy.gc.ca

2. CANADIAN TIDAL AND WATER CURRENT ENERGY TECHNOLOGIES

There are currently 6 Canadian companies who reported on their pursuit of tidal and water current energy conversion technologies. Of these technology developers, only one, Mavi Innovations, has been identified as a new addition from the report published in 2008. The six companies that have reported on their progress are listed below and are discussed further in this section.

- Blue Energy International
- Clean Current Power Systems
- Mavi Innovations
- New Energy Corporation
- Verdant Power
- Water Wall Turbines

2.1. Blue Energy International

Blue Energy International is pursuing the development of a ducted vertical axis hydro turbine that can generate electricity from the movement of water in tidal and in-stream river currents. This rotor is mounted in a marine caisson which serves many tasks to this technology: anchors the unit to the ocean floor, directs the water flow through the turbine, and supports the coupler, generator and electronic controls above in a dry climate controlled machinery room above the water surface.

In 2009, Blue Energy submitted a patent on its Tidal Bridge system. The tidal bridges will be composed of modular turbine units that are gravity mounted and may be stacked to extend from the ocean floor to the water surface. These are large scale, site specific installations that will vary in size and output capacity for each location. The power of the combined caisson modules in a tidal bridge could range from several megawatts (MW) to 2,000 MW.

Currently, Blue Energy is applying its tidal bridge design for a 1MW demonstration project to be deployed in Scotland. The second phase of the project could include an expansion totalling up to 10MW capacity.

2.2. Clean Current Power Systems

Clean Current Power Systems Incorporated (from here on, referred to as Clean Current) has developed a bi-directional ducted horizontal axis turbine with a direct drive variable speed permanent magnet generator. The water stream energy is converted to rotational mechanical energy through a unique bi-directional turbine blade which allows for the extraction of energy both from the ebb and flow of the tidal regime. The rotational energy is then converted to electrical energy by Clean Current's proprietary direct drive variable speed permanent magnet generator, which can produce either alternating or direct current.

In 2008, Clean Current was awarded one of three berths, and was the only Canadian technology developer selected to demonstrate its technology in the Bay of Fundy at FORCE. As of 2009, Clean Current licensed its tidal and ocean current technology to Alstom Power on an exclusive worldwide basis, where Alstom is responsible for commercializing the technology and marketing it worldwide. This partnership has provided access to Alstom to the berth-holder rights at the Fundy Ocean Research Centre for Energy (FORCE). This has restricted Clean Current to provide any proprietary information regarding modifications that Alstom and Clean Current have made to the existing Clean Current design.

2.3. Mavi Innovations Inc.

Mavi Innovations (Mi3) has designed an ocean class ducted vertical axis turbine that has been integrated into a floating platform. The turbine is rated at 50kW in 3 m/s current speeds. The floating platform also provides accessibility to raise the turbine module above water for routine maintenance of all mechanical and electrical components as required. The technology developer has completed the engineering design of their pre-commercial unit, with scaled prototype testing completed in October 2008.

2.4. New Energy Corporation

New Energy Corporation's proprietary EnCurrent turbine technology is based on the Darrieus wind turbine. The direction of rotation of the turbine's eggbeater shaped blades is perpendicular to direction of water flow. The turbine rotates in the same direction regardless of the direction of the water current and captures between 35-40% of the energy in moving water.

Since A *Review of Marine Energy Technologies and Canada's R&D Capacity* was printed, New Energy has begun developing and marketing their low-flow 25kW design. This turbine has a cut-in speed of 1.0 m/s and requires only 2.4 m/s to reach its rated capacity. Their standard design required a 1.5 m/s cut-in speed and 2.4 m/s to reach its rated capacity. The low-flow design requires a larger rotor design. This low-flow design has planned installations for 2010 in various locations across the world, including Alaska (USA), Northwest Territories (Canada), and India.

2.5. Verdant Power

The Verdant Power Kinetic HydroPower Systems (KHPS) is a water-to-wire system that uses 3-bladed, unducted axial-flow turbines to convert the kinetic energy of rival and tidal flows into electricity. The Verdant Power KHPS tidal version is assembled with internal yaw bearings, much like wind turbines, which allows the unit to pivot with the changing tides. Verdant Power had successfully demonstrated its technology in New York City's East River. Utilizing the operational data from this demonstration, starting in 2009, Verdant Power is developing the 5th generation design to further improve the technology as part of a Canada-US bilateral effort. This Gen5 design will be demonstrated as part of Verdant Power Canada's Cornwall Ontario River Energy (CORE) Project Phase Demonstration in the St. Lawrence River.

2.6. Water Wall Turbines

The Water Wall Turbine (WWT) is a cylindrical structure that is less than 50 percent submerged into the current and is designed to capture energy, made available by the head induced across the blades during the extraction of energy from the current. The WWT system can be designed to operate in in-stream river and tidal current conditions. Between 2008 and 2009, device trials were conducted. The results will be used to assist in developing WWT's first full-scale pilot plant installation.

3. CANADIAN WAVE ENERGY TECHNOLOGIES

There are currently 5 Canadian companies who reported on their pursuit of wave energy conversion technologies. Of these technology developers, two (Grey Island Energy and Seawood Designs) have been identified as new additions from the report published in 2008. The five companies that have reported on their progress are listed below and are discussed further in this section.

- College of the North Atlantic
- Grey Island Energy
- Seawood Design (Surfpower)
- Solar Inspired Energy
- Wave Energy Technologies

3.1. College of the North Atlantic

The wave pump developed by the College of the North Atlantic (CNA) is a point absorber type pump. A floating buoy oscillates with the waves, moving against a submerged, damped base and driving seawater through a piston. The main application is direct use of the pumped seawater for aquaculture, but desalination or power generation is also possible. The current plan is to have water pumped to a storage tank located within a shore station, which will provide a constant 3m pressure head to plumbing systems. Overflow from the storage tank will be mixed with effluent from the aquaculture tanks and returned to sea through a low-head electrical generator. Recently, the College of the North Atlantic has continued to work on optimizing their device.

3.2. Grey Island Energy

Grey Island Energy has designed a Sea Wave Energy Extraction Device (SEAWEED^{TM}) applying the point absorber technology. The system has been designed such that it allows it to tune in with the changing ocean waves in order to yield maximum energy extraction. SEAWEED^{TM} has the ability to alter its natural frequency, thus allowing the device to resonate with varying ocean wave frequencies at maximum efficiency. Grey Island Energy is in the process of testing its first prototype device (at 1.5kW size) at the National Research Council Institute of Ocean Technology (NRC-IOT).

3.3. Seawood Designs

Seawood Designs is pursuing the development of a point absorber system that employs a buoyant rectangular wing, which they've named SurfPower. The wing is free to rotate in all directions and can accept oncoming waves from all directions. Energy is recovered by a tethering pump that delivers high pressure seawater to a collection main on the sea floor. The collection main gathers the sea water from multiple devices setup in an array, which allows for a continuous flow delivery of high pressure water onshore to an electrical generator and a reverse osmosis desalination plant for fresh water if required. In Spring 2010, Seawood Designs entered into a collaborative agreement with NRC-IOT to test a 1:10 linear scale model – this will assist in refining their SurfPower technology.

3.4. Solar Inspired Energy

The SIE-CAT™ Wave Energy Accumulator technology being developed by Solar Inspired Energy extracts energy from the waves through an array of individual point absorbers mounted on a single submerged frame. The point absorber arrays are used to compress air (or other gas) to store the energy from the waves, which can then be converted to either produce electricity, potable water through osmosis, or hydrogen through electrolysis.

3.5. Wave Energy Technology

The Wave Energy Technologies (WET) is applying the point absorber approach to their device, the WET EnGen®. Their devices comprises of a float (Smart Float) which travels along a rigid spar at a 45 degree inclination, which is moored to the sea bottom. The spar is moored such that the device can fully rotate on all three axes (pitch, roll and yaw) to face the waves from any direction. Through the use of computational fluid dynamics (CFD), the WET EnGen® can be tuned to specific wave regimes. Recently, WET EnGen® has been refining and testing their device at NRC-IOT to optimize their mooring design and hydraulic system design. In 2010, WET will finalize their wave basin testing and numerical modelling to prepare for a future demonstration with the potential to expand to an array.

4. ANALYSIS AND RECOGNIZED TRENDS

Since 2008, Canadian tidal and water current technology developers have been continuing to optimize their devices and scaling up their technologies for commercial applications. There remains no convergence between technologies leading to a single design.

In some cases, technologies are being developed for the use in bi-directional and uni-directional flows (i.e.: tidal current and in-stream river flows). Although the river current resource is still unknown, technology developers are recognizing the potential opportunities in extracting this resource using their tidal concepts.

Within Canada, the wave energy industry has not experienced a significant milestone, such as a dedicated large scale open sea demonstration facility, to significantly increase the interest in wave energy. However, the technology developers have continued to further develop, optimize and scale up their technologies despite some technology developers indicated that they were experiencing funding issues.

In the 2008 report, it was noted that wave energy technology developers were following many different methods to extract the energy from waves, with a majority leaning towards a point absorber design. In Canada, the point absorber method seems to dominate the technology approach being pursued. Each technology developer has differentiated its technology by having a specific component for their device making their system more efficient and reliable. Although the technology approach remains the same for each wave energy technology developers in Canada, the device itself and the approach to the point absorber concept is quite different without much correlation between the devices.

It has been recognized by both tidal and wave energy technology developers that these technologies will rarely be used as a single unit in a commercial application. Some technology developers have begun investigating methodologies for integrating the application of arrays into their design. As was identified by Solar Inspired Energy, an array of point absorbers collectively pumps a fluid through a turbine where other technologies have considered integrating the arrays into the same deployment platform.

5. CONCLUSION

The new tidal energy demonstration facility, FORCE, has increased the visibility of tidal power which has ramped up interest and public knowledge related to this form of renewable energy. This has instigated an increase in activity by technology developers to optimize and scale up their device for future testing at FORCE. Once the first awarded technologies are deployed and grid connected at FORCE, the experience and knowledge gained could create an increase in activity for the tidal energy sector. The "lessons learned" from this experience could provide the information needed for technology developers to work on optimizing the energy extraction, or move towards the next step of creating arrays.

The tidal current, water current, and wave energy industry have all experienced various levels of support to assist in developing their technologies. Although some companies had identified funding roadblocks, the development on their devices continues.

Appendix A: – Complete Reports from

Tidal and Water Current Technology Developers

Blue Energy International

(http://www.blueenergy.com)

Device Description

The Blue Energy turbine is a vertical axis hydro turbine that generates electricity from the kinetic movement of water in rivers and tidal currents. Four fixed hydrofoil blades of the Blue Energy Turbine are connected to a shaft that drives a variable speed direct drive permanent magnet electrical generator. This rotor is mounted in a marine caisson which anchors the unit to the ocean floor, directs the water flow through the turbine and supports the coupler, generator, and electronic controls above it in a dry, climate controlled machinery room above the water surface. The caisson consists of four elements: the base, thin wall sides that provide the venturi flow shaping, a machinery room and a road deck. The vertical hydrofoil blades employ a hydrodynamic lift principle that causes the turbine foils to move proportionately faster than the speed of the surrounding water. A computer optimized cross-flow design ensures that the rotation of the turbine is unidirectional on both the ebb and the flow of the tide. The turbine is designed to work through the entire tidal range with a typical cut-in speed of 1 meter per second.

The tidal bridges will be composed of modular turbine units that are gravity mounted and may be stacked to extend from the ocean floor to the water surface. As the rotor of the turbine is a vertical axis the length of the rotor is independent of its standardized 10 meter diameter. The base of the caisson will be 17 meters wide and 10.5 meters long with heights ranging from 10 to 20 meters. This makes the application of the bridge suitable to a number of different depths as great as 50 meters by stacking turbine modules on top of each other to suit the conditions of the project site. These are large scale, site specific installations that will vary in size and output capacity by location. The power of the combined caisson modules in a tidal bridge will range from several MW to 2,000 MW, making this technology one of the largest scale renewable technologies available today.

Blue Energy is currently designing a 1MW tidal bridge turbine to be deployed in Scotland. This project will be expanded to a 10 MW capacity with the addition of 3 3MW turbines. The turbines will operate current velocities of up to 5 meters per second and will serve as a demonstration of the tidal bridge technology.

The device cross section view and overhead view is illustrated in Figures 1 and 2, respectively, with a sample illustration of the commercial demonstration in Figure 3.

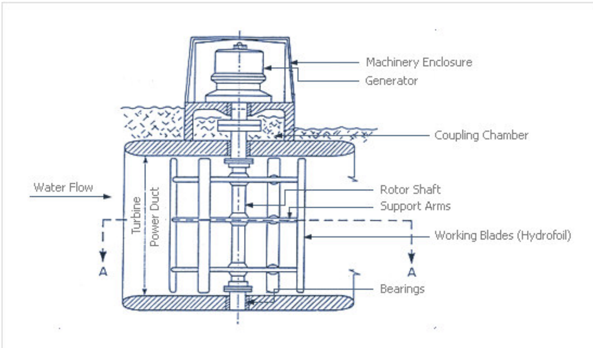

Figure 1 Blue Energy International Turbine Cross Sectional View

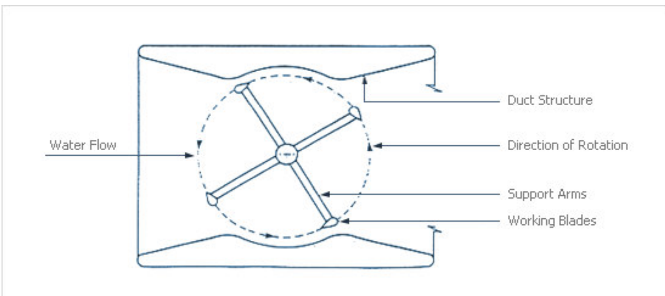

Figure 2 Blue Energy International Turbine Overhead View

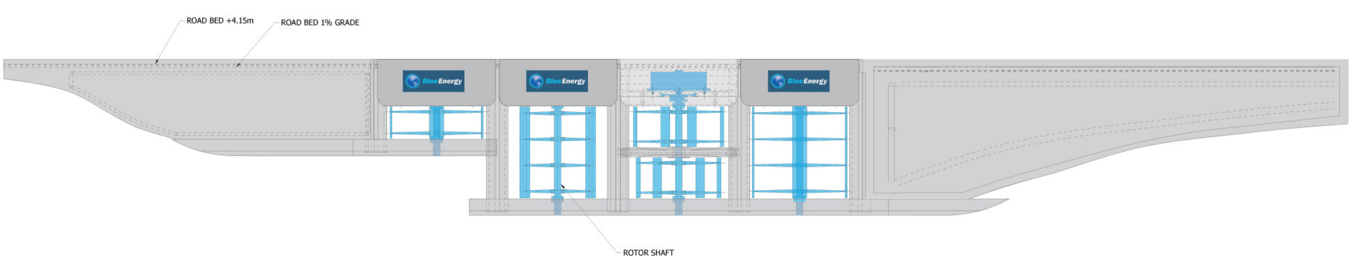

Figure 3 Blue Energy International Commercial demonstration

(Source: Courtesy Blue Energy Canada)

Turbine and Performance Specifications

Outlined below in Table 1 are the turbine and performance specifications.

Table 1 Blue Energy International Turbine Subscale Specifications

PARAMETER	SPECIFICATION	
Rated capacity	1MW@5 m/s	3MW@5 m/s
Rotor diameter	10 m	10 m
Rotor height	3.6 m	10.4 m
RPM	5.5@ 1 m/s - 28.6@ 5 m/s	5.5@ 1 m/s - 28.6@ 5 m/s
Tip speed	14.5 m/s	14.5 m/s
Drive train efficiency	Direct drive, no drive train	Direct drive, no drive train
Protective inlet screen	No	No
Total height	6.6 m	13.4 m
Total length	14 m	14 m
Total width	11 m	11 m
System weight	n/a	n/a

Physical Device Structure (Materials/Construction)

The caisson is constructed of a thin-shelled marine concrete reinforced with steel. The rotor will be constructed of stainless steel and composite materials. The rotor shaft will be made of alloyed steel coated with a corrosion resistant coating.

Conversion Systems

The Blue Energy turbine will use a variable speed, direct drive, permanent magnet generator. The generator will have an in line vertical axis orientation to the shaft and its output will either be AC or DC, depending on voltages and distances to the nearest utility grid connection point.

Mooring Systems/Foundation

The foundation for the system will vary with site location. In general, the turbine modules will be gravity mounted on a prepared level crushed rock substrate that will "step down" to accommodate various working depths for turbine banks which enables the stacking of turbines for depths of up to 50 meters.

The centerline of the array will be supported by an I-beam and the caisson footings will be supported by pin pilings that will be driven into mud or sandy bottoms, or socket drilled into scoured rock substrates.

Grid Interconnection

All transmission cabling will be run within the tidal bridge and will grid connect to the nearest utility via a land based substation. If the output from the tidal generators is direct current (DC), then this substation will also include an invertor. The turbine modules may be organized into banks through which the electricity will be conditioned to the appropriate local alternating current (AC) frequency and voltage.

Device Access and Operational Consideration

The Blue Energy Tidal Bridge Turbine is designed for ease of maintenance. The turbine's coupler, generator, electronic controls, and safety equipment are all located at or above the surface of the water in a machinery enclosure for access during maintenance and repair activities. This enables regular maintenance of the generator, power electronics, and safety equipment to take place in a dry environment without the need for diving. With the removal of the access hatch along the centerline of the bridge, between the road decking, a crane is able to remove the generator, coupling, and rotor without the need of a large and costly sea vessel and without interrupting traffic. Over a fifty year service life of the project this offers significant cost savings on maintenance and risk of equipment to water damage from compromised seals.

Costs as Estimated by Developer

- Installed cost per kW for first installed commercial development of 200MW: $2,250/kW
- Target cost per kW for technology: $0.07/kW within six years for commercial development of 200MW

Development Status

1981-1982	Blue Energy's predecessor, Nova Energy Ltd., conducted preliminary tests at National Research Council Hydraulics Laboratory test flume.
1982	Free stream 25 kW unit (B-1) tested in St. Lawrence River at Cornwall, Ontario and tested for two seasons by National Research Council.
1983	70 kW ducted unit (B-2) installed at Low Head Dam on Sheet River in Nova Scotia.
1985	B-2 unit rebuild and reinstalled.
1984-2005	Davis Turbine VEGA-1 prototype installed the first successful corporate effort to generate power from the Florida Gulf Stream.
1987	TOR 5 (5 kW) unit mounted on boat and tested at tidal site concurrent to being towed in the ocean near Halifax.

1997	Nova Energy Ltd. renamed Blue Energy Canada.
2000	Proposal submitted for Dalupiri Ocean Power Plant (San Bernardino Strait, Philippines), a four-kilometer long tidal fence between the islands of Samar and Dalupiri. Project put on hold in 2001 due to political upheaval.
2006-2007	Turbine successfully tested in tow tank at University of British Columbia.
2009	Blue Energy submits patents on its Tidal Bridge System.
2010	The company designs 1MW turbine for demonstration project in Scotland for deployment early 2012

Clean Current Power Systems

(http://www.cleancurrent.com/)

Device Description

The Clean Current Power Systems Incorporated (Clean Current) proprietary technology is a bi-directional ducted horizontal axis turbine with a direct drive variable speed permanent magnet generator. The turbine generator is equally efficient in both directions to fully utilize reversing tidal currents. The generator is a direct-drive permanent magnet generator.

In 2009, Clean Current licensed its tidal and ocean current technology to Alstom Power on an exclusive worldwide basis. Alstom is responsible for commercializing the technology and marketing it worldwide.

The Clean Current turbine is governed by the same principles employed by horizontal axis wind turbines. The water stream energy is converted to rotational mechanical energy through a unique bi-directional turbine blade. This turbine rotor assembly consists of five rotor blades with Neodymium permanent magnets attached to the inner rim (adjacent to central hole). Rotational energy is then converted to electrical energy by Clean Current's proprietary direct drive variable speed permanent magnet generator, which incorporates features that allow the generator to be configured to produce either alternating or direct current. The output electricity is then rectified and inverted to produce grid compatible power.

The turbine is designed to operate through the full range of tidal current speeds. The unit starts at 1 m/s and stops on a declining tide at about 0.75 m/s. Control of the unit is performed at the onshore substation by a control algorithm that extracts a pre-programmed amount of power based on the generator voltage (or in effect the rotor rpm). The onshore control feature eliminates the need for submerged control systems on the unit itself.

The device has been designed to extract power from both ebb and flood tides with equal conversion efficiencies. This is achieved through the proprietary design of symmetric blades, guide vanes, and augmenter sections. The central hole serves as both a bypass for fish and marine mammals as well as a method of increasing the overall performance of the turbine.

Turbine and Performance Specifications

Clean Current and Alstom Power are in the process of modifying the turbine and thus the performance specification. At the time of publication, this information could not be made public.

Physical Device Structure (Materials/Construction)

Clean Current's tidal turbine is primarily constructed of steel and composite materials. Clean Current has also tested corrosion resistant coatings and fouling release coatings as part of the demonstration program at Race Rocks. These findings have been incorporated into the redesigned Race Rocks unit which was redeployed during the fall of 2008.

Mooring Systems/Foundation

The Clean Current foundation system is site specific. There are several types of foundation systems that they consider using to anchor their tidal turbine to the seabed, including piled foundations, gravity base structures and suction caissons. The decision on which technology to use is highly dependent on the site conditions. For the Bay of Fundy demonstration project, a Gravity Base Structure (GBS) has been chosen as the foundation system. In this system, the base is designed to provide a wider footprint for overturning resistance (which is the governing load condition on the GBS). The base has been sized to provide flotation with the turbine attached to the GBS and towed to site. This is considered to be the simplest and lowest risk installation scenario as it does not require specialized equipment such as a jack-up drill rig. It is also the easiest system to remove from the site, because it can be de-ballasted and re-floated.

Grid Interconnection

As the distance to the on-shore substation will be short (~ 5-10 km or less) in most applications, the generator will be configured to produce AC power. For the Minas Passage demonstration site, it is anticipated that the distance from the Turbine to the shore substation will be in the order of 3 km. All of the equipment is “off-the-shelf” hardware. The system contains an IGBT (Insulated Gate Bipolar Transistor) power supply unit that is used in regenerative drive systems to convert the three-phase AC voltage to the common DC bus voltage. The inverter module is then directly fed from the DC link within the cabinet to produce grid compatible 3 phase power.

Device Access and Operational Consideration

The developer indicates that due to the simple design of only one moving part - the rotor assembly that contains the permanent magnets – maintenance should be minimal. Clean Current is anticipating routine maintenance at five year intervals and is expecting a system service life of 25 to 30 years. As part of the technology development program, Clean Current retrieved the pilot tidal turbine at Race Rocks in April 2007 after 8 months of operation to inspect the turbine and refit the turbine with a new bearing system. The turbine was retrofitted with a mature technology sealed roller bearing, which the developer believes is a proven technology and requires maintenance on a 5-year interval to replace bearing seals.

Development Status

2001	Clean Current Power Systems Incorporated founded.
2001	Clean Current files patent for underwater ducted turbine.
2002-2003	Clean Current builds two prototypes.
2004	Clean Current completes proof of concept testing at National Research Council Institute for Ocean Technology.
2006	The Clean Current tidal turbine generator (TTG) was installed near Race Rocks by September 2006 and the hydraulic and electrical performance were tested using an

offline load bank for the following 2 months. After test completion in December, 2006, the TTG was connected to the control system that feeds electricity into the battery storage system at Race Rocks.

2007 The Race Rocks TTG successfully extracted power in flows up to 6.6 knots and was retrieved in April 2007 for inspection and bearing replacement.

2008 Clean Current is one of three and the only Canadian company selected to demonstrate in the Bay of Fundy at newly created Fundy Ocean Research Centre for Energy.

2009 Clean Current Power Systems Incorporated licensed its tidal and ocean current technology to Alstom Power on an exclusive worldwide basis. Alstom is now the berth-holder for the FORCE. Alstom is responsible for commercializing the technology and marketing it worldwide.

Mavi Innovations

(http://www.mavi-innovations.ca)

Device Description

The Mavi Innovations free-stream turbine design (Mi3) converts kinetic energy of flowing water in tidal or river currents, into clean and reliable power. Ideal locations for the turbine units require a mean flow of 5 knots and depths over 4.5 meters.

The Mi3 consists of a high-efficiency turbine module consisting of a vertical axis rotor housed inside a duct to concentrate the flow of the water current. The turbine module is scalable, and can be adapted for deployment through either floating platforms, installation directly on the seabed, or installations into existing civil infrastructures.

The off-grid application of the Mi3 can generate enough electricity for 15-20 homes, which would help reduce the consumption of diesel. For the off-grid application, the Mi3 would be used with the floating platform, which provides access to all the electrical equipment as it would be all located above water.

A larger-scale version of the Mi3 is currently being designed with an increased capacity to power larger coastal communities and feed electricity into the grid.

Mavi Innovations has submitted a patent application for their technology. Once the patent is granted, further detailed information will be available about the technology and some of the associated components.

Turbine and Performance Specifications

The Mi3 turbine is rated at 50kW in 3m/s current. Outlined below in Table 2 are the turbine and performance specifications.

Table 2 Specifications of the Mi3 device

PARAMETER	SPECIFICATION
Rotor diameter	3 m
Swept area	9 m (based on rotor, i.e. excluding ducting)
RPM	0 - 75
Tip speed	2.25-3.25
Cut-in speed	1.0 knot
Protective rotor screen	Optional
Drive train efficiency	90-95%
Rated capacity	50 kW in 3m/s

System Weight (in air)	15 tonnes (excluding mooring system)

Physical Device Structure (Materials/Construction)

The majority of the components are fabricated out of marine grade aluminum with select structural components made of marine grade steel.

Power Conversion Systems

The permanent magnet generator and associated power electronics designs are dependent on the application (i.e.:. grid connected or remote system).

Mooring Systems/Foundation

For the floating platform application, the technology is moored in place via a two-point mooring harness. The anchor selection is dependent on the seabed composition at the specific deployment site.

Grid Interconnection

The Mi3 is designed for both off-grid application (to offset diesel reliance) as well as connection to the electrical grid for utility scale deployments.

Device Access and Operational Consideration

For the floating platform application, the turbine module is designed to raise above water for routine maintenance of all mechanical and electrical components.

Development Status

2008	Completed prototype test of scaled unit at NRC-IOT
2010	In the process of completing the engineering design of pre-commercial unit

New Energy Corporation

(http://www.newenergycorp.ca/)

Device Description

New Energy's proprietary EnCurrent Turbine converts the energy inherent in moving water into electricity. The technology is based on the Darrieus wind turbine, also called an eggbeater or whisk turbine due to its shape. The EnCurrent Turbine is a cross-flow turbine, meaning that the direction of rotation is perpendicular to direction of water flow.

When the turbine rotor is placed within a water current, the hydrofoils generate a lift vector in the forward orientation which can be captured at the shaft as a positive rotation. The hydrofoils experience their maximum forward torque at the top and bottom of their rotation, when the water moving past them is tangential. The turbine rotates in the same direction regardless of the direction of the water current and captures between 35 percent and 40 percent of the energy in moving water. It rotates at speeds between 2 and 2.5 times the speed of the water in which it is submerged.

A permanent magnet generator is mounted on the turbine shaft to convert the torque generated by the rotor into electricity. The output from the permanent magnet generator is a variable voltage AC signal which is rectified to DC and fed into an inverter. The inverter takes the DC signal as input and provides an AC output. Different inverters can be used to provide the appropriate power for the regulatory requirements of any given area in the world.

Figure 4 New Energy Corporation: Deployed 5kW EnCurrent Power Generation System

(Source: Courtesy New Energy Corporation Inc.)

Figure 5 New Energy Corporation: Deployment of 25kW EnCurrent Power Generation System

(Source: Courtesy New Energy Corporation Inc.)

Turbine and Performance Specifications

The turbine specifications are outlined in Table 3 below.

Table 3 Turbine and Performance Specifications

Parameter	**Specification (Non-Ducted)**			
Turbine Size	5 kW	10 kW	25 kW	Low-flow 25 kW
Rotor height	0.76 m	1.52 m	1.70 m	2.41 m
Rotor Diameter	1.52 m	1.52 m	3.40 m	4.83 m
Rated capacity	5 kW	10 kW	25 kW	25 kW
Water Velocity @ Rated Capacity	3 m/s	3 m/s	3 m/s	2.4 m/s
RPM	90	90	40	25
Cut-in speed	1.5 m/s	1.5 m/s	1.5 m/s	1.0 m/s
System height	2.25 m	3.24 m	4.24 m	5.41 m
System weight (in air)	340 kg	640 kg	1910 kg	2665 kg

Physical Device Structure (Materials/Construction)

Steel is used as the primary construction material. Aluminum is used for the hydrofoils.

Power Conversion Systems

The system uses a permanent magnet generator coupled with an inverter. Inverters are available for both grid-tie and standalone systems.

Mooring Systems/Foundation

Initial systems are anchored using the floating structure shown in the figures.

Grid Interconnection

Grid connectivity is provided through the supplied inverter.

Device Access and Operational Consideration

The turbine's coupler, gearbox, and generator are all located at or above the surface of the water, to ease maintenance and repair.

Costs as Estimated by Developer

The list price of New Energy's EnCurrent turbines is outlined in table 4.

Table 4 Costs of New Energy's EnCurrent turbines

	5 kW	10 kW	25 kW	Low Flow 25 kW
List Price	$25,000	$45,000	$105,000	$115,000
Floating Structure Price	$9,000	$12,000	$23,000	$30,000

Development Status

2003	New Energy Corporation Inc. is established.
2005	NECI completes development turbine and test barge. Phase I Turbine Test Program conducted to establish performance characteristics in free flow unducted configuration.
2006	Received funding from Sustainable Development Technology Canada to demonstrate tidal power generation on British Columbia's west coast. The Canoe Pass Tidal project consists of installing up to 500 kW of power-generating capacity in a narrow channel between Maude Island and Quadra Island, adjacent to Seymour Narrows near Campbell River, BC.
2007	Installation of 5 kW EnCurrent Power Generation System at Pointe du Bois, Manitoba for the University of Manitoba upstream from a Manitoba Hydro dam.
2008	Output from 5 kW EnCurrent Power Generation System at Pointe du Bois connected to the grid.
2008	Installation and grid connection of 25 kW EnCurrent Power Generation System at Pointe du Bois Manitoba for the University of Manitoba.
2008	Installation and micro-grid connection of 5 kW EnCurrent Power Generation System by ABS Alaskan Inc. in Ruby Alaska for the Yukon River Inter-Tribal Watershed Council.
2009	Installation of four (4) 25 kW EnCurrent Power Generation Systems that were deployed in South Eastern BC.
2010	Installing low-flow 25 kW system in Eagle Alaska for Alaska Power and Telephone. Installing low-flow 25 kW System in Fort Simpson NWT for Northwest Territories Power. Installing two (2) low-flow 25 kW Systems in India for DLZ Private Power Ltd. Installing 5 kW System in Calgary Alberta for the City of Calgary.

Verdant Power

(http://verdantpower.com/)

Device Description

The Verdant Power Kinetic Hydro Power System (KHPS) is a water-to-wire system that uses 3-bladed axial-flow turbines to convert the kinetic energy of river and tidal flows into electricity. The KHPS turbine is designed for high efficiency over a large range of water speeds. The turbine's 3-bladed unducted rotor drives a speed increaser, which in turn drives a grid-connected three-phase induction generator. The gearbox and generator are enclosed in a waterproof streamlined nacelle mounted on a streamlined pylon (Verdant, 2008). The pylons are comprised of a faired outer pylon and a fixed pylon. The tidal version of the turbine is assembled with internal yaw bearings, which allow the unit to pivot with the changing tide and thus capture energy on both flood and ebb tides. The KHPS is scalable to various sizes and installed capacities, allowing for placement in a wide variety of settings worldwide.

During 2006-2008, Verdant Power demonstrated a Generation 4 KHPS comprised of six 5-meter turbines at its Roosevelt Island Tidal Energy (RITE) project, located in New York City's East River. For this demonstration, the fixed inner pylon of each turbine was bolted via an adjustable adapter to a pile fixed to the river bottom. Underwater cables, held in place by concrete weights, carried alternating current to shore, where energy from the turbines was delivered to the grid using standard equipment. The RITE demonstration turbines (five 35kW generator units and 1 dynamometer unit) generated power in array (world first) and ultimately provided 70 MWh of electricity to two commercial end users over 9.000+ turbine hours of operation. Each turbine at the RITE project was 16.4 feet (5.0 m) in diameter, 19.7 feet (6.0 m) high and 15.8 feet (4.8 m) in length. Based on these dimensions and the profile or the water resource in the project area, there was 6 feet (1.8 m) of water under the turbine rotor at all times and 5 feet (1.5 m) above the rotor at the mean low-water level. The KHPS turbine is illustrated in Figure 6 below.

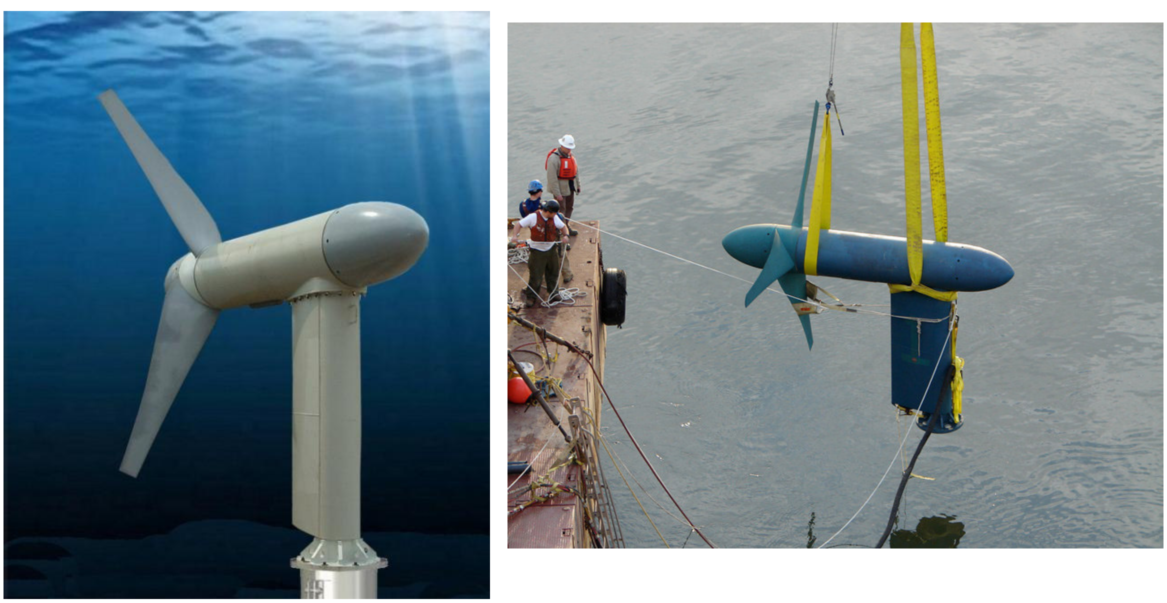

Figure 6 Verdant Power: Turbine Design (Illustration) and the Installation at the New York Demonstration (2006)

(Source: Verdant Power, Inc.)

Turbine and Performance Specification

Outlined below in Table 5 are the turbine and performance specifications.

Table 5 The Verdant Power KHPS Specifications

PARAMETER	SPECIFICATION
Rotor diameter	5 meters (16.4 feet)
Swept area	19.6 m2
RPM	Approx. 35
Tip speed	Approx. 9 m/s
Cut-in speed	Approx. 0.8 m/s
Protective rotor screen	No
Drive train efficiency	Approx. 86%
Rated capacity	35 kW @ 2.1 m/s
Total height (to top of rotor)	6 m
Total length	4.82 m
System Weight (in air)	Approx. 3,629 kg

Physical Device Structure (Materials/Construction)

The RITE demonstration KHPS (Generation 4) consisted of steel pipe and tube weldments with bolted flange joints and stainless steel elements for static o-ring sealing areas. Water-wetted plastic yaw bearings in stainless steel races are part of the structure. Blades constructed of Fiberglass Reinforced Plastic (FRP) and of Aluminim Magnesium (AlMag) were tested during the demonstration.

Verdant Power is utilizing operational data from the RITE demonstration to advance the KHPS design to the 5th generation (Gen5), which will include an overall parts reduction and enhanced durability and ruggedness. Development of the Gen5 KHPS is advancing as a bilateral US-Canada effort. Verdant Power, Inc (US) is partnering with the US Department of Energy's National Renewable Energy Laboratory and Sandia National Labs, as well as the University of Minnesota St. Anthony Falls Laboratory to develop larger, higher-power composite rotors, under a US Dept. of Energy Advanced Water Power Projects (AWPP) contract. In parallel with this effort, Verdant Power Canada, ULC is partnering with the University of New Brunswick and NRCan's CanmetENERGY to advance the internal electricity generation and interconnection subsystem of the KHPS turbine to the next generation.

The full Gen5 KHPS will be demonstrated as part of Verdant Power Canada's Cornwall Ontario River Energy (CORE) Project Phase I Demonstration in the St. Lawrence River.

Power Conversion System

Within the nacelle, the power conversion system consists of bearings, couplings and a planetary speed increaser with a modified vent and using synthetic biodegradable oil.

Mooring Systems/Foundation

For the RITE demonstration (2006-2008), a jack-up barge was used to drill into the bedrock river bottom and piles were grouted with rebar within the rock socket. The fixed pylon turbine mounting flange was bolted via an adapter to the pile top. For subsequent projects, starting with the Cornwall Ontario River Energy (CORE) Project in the St. Lawrence River, the drilled piles will be replaced by a gravity-based mounting system, which will sit on the riverbed floor.

Grid Interconnection

The KHPS turbine design allows it to run at near constant speed in varying water speeds while its three-phase induction generator is connected to the electrical grid and running at a near-constant speed.

Device Access and Operational Considerations

The method to access the device for service and maintenance at the RITE demonstration was to have to have divers detach or unbolt the mounting flange from the piling. The rotor can also be detached without removing the entire device; however a diver is required to unbolt and detach the rotor. For future projects, particularly in continuous flow rivers such as the St. Lawrence, new methods for turbine installation and retrieval will be utilized whereby device installation, and recovery for service and maintenance, will be done from surface vessels and with minimal diver use.

The operation of the turbine is completely passive and switching of each turbine's generator to the line when the water current reaches required velocity is fully automatic and autonomous. Auxiliary power or control is not required as the bi-directional yawing (tidal version) occurs with the forces of the natural tidal cycle that exists in the resource.

The turbine has a minimum maintenance cycle target of 2-years with a major overhaul after 10 years. Projects with sizable arrays will have the economic ability to do rapid switch-out of turbines with all maintenance off-line. The modular nature of the turbines will allow the refurbishment of units with critical wear parts replaced or upgraded, and thereby indefinite unit life.

Costs as Estimated by Developer

- Installed cost per kW for first commercial development: Near-term (3-7 years) capital cost for project sizes in the range from 5 to 10 MW is projected to be US$5M to $7M/MW, installed.

- Target cost per kW for technology: Long-term (12+ years) target capital cost for project sizes exceeding 20 MW is projected to be US$1.5M to $4M/MW, installed.
- Power Density at the reference site: 4.7 kW/m^2 at the RITE Project site and 6.9 kW/m^2 at the CORE Project site.
- Annual Output per machine (MWh): Given 8,760 hours per year; the estimated annual production for each Gen4 RITE demonstration machine (35kW) is 92 MWh/yr; and for the proposed turbine at the CORE Project (60 kW) would be 368 MWh/yr.
- Expected cost of electricity: Near-term (3-7 years) the operating price range for project sizes in the range from 5 to 10 MW is estimated to be from US$.15 to $.26/kWh, declining to US$.05 to $.11/kWh in approximately 12 years for project sizes of more than 20 MW.

Development Status

2000	Verdant Power established.
2002-2003	Generation 3 model of a 3-meter diameter KHPS turbine was field tested in Chesapeake Bay, MD.
2002-2006	Phase I of the RITE Project included development, demonstration and testing of a prototype turbine.
2006	Verdant Power Canada ULC incorporated
2006-2008	Phase II Demonstration at the RITE Project proved KHPS technology, with six-turbine KHPS (five 35kW generator turbines, one dynamometer turbine) delivering 70 MWh of energy from tides of East River to two commercial end users. RITE demonstration KHPS operated for over 9.000 turbine-hours and provided world's first environmental and operational array-based data, which is informing next-generation KHPS design. Updated blades (Gen 5a) were developed, tested and proven in partnership with the US DOE National Renewable Energy Laboratory. Extensive fish monitoring data gathered during demonstration provided empirical evidence of safe fish interaction with KHPS.
2008	Draft license application (DLA) filed with US Federal Energy Regulatory Commission (FERC) for commercial pilot license to expand RITE Project to 30-turbine, 1-MW project.
2009	Verdant Power DLA approved by FERC; Actvities in support of Final License Application (FLA) begun.
2009-2010	Generation 5 turbine design proceeding. Rotor advancement (composite rotors for higher power, longer life, lower cost) taking place in US (in partnership with USDOE, NREL, Sandia Labs, Univ. of Minnesota); and internal electrical generation system (IEGS) development taking place in Canada (in partnership with Univ. of New Brunswick, CanmetEnergy).
2010	Additional design advancements related to Gen5 turbine, gravity-based mounting system, associated deploy/retrieve methodologies, cabling and underwater controls proceeding under CORE and Navy Puget Sound-KHPS Projects.

2010	Environmental permitting and resource assessment activities taking place on St. Lawrence River in support of CORE Project Phase I Demonstration.
2010	In-water testing of gravity-based mounting (equipped w/simulated turbines) and deploy/retrieve methodology planned for Summer/Fall 2010 under CORE Project Phase I Demonstration

Water Wall Turbines

(http://www.wwturbine.com/)

Device Description

The Water Wall Turbine (WWT) is a cylindrical structure that is less than 50 percent submerged into the current and is designed to capture energy, made available by the head induced across the blades during the extraction of Energy from the current.

The WWTs are scalable to various sizes and installed capacities. The systems integrate suitable technologies and components to meet the individual project requirements. A conceptual design of the WWT is illustrated in Figure 7 below.

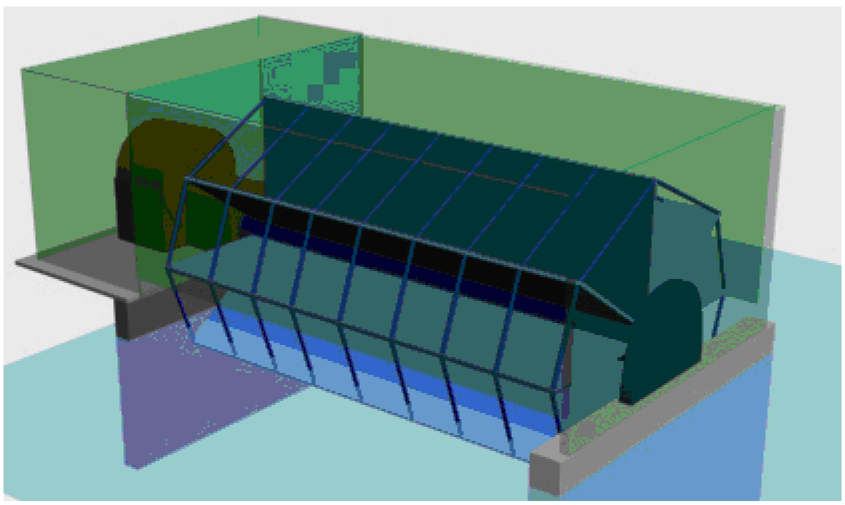

Figure 7 Conceptual Illustration of Water Wall Turbine

(Source: Courtesy of Water Wall Turbine Inc.)

Turbine and Performance Specifications

Outlined below in Table 6 are a few of the WWT's performance specifications.

Table 6 The WWT Technology specifications

Parameter	specification
RPM	1 – 50 rpm
Cut-in speed	~ 1.5 m/s
Rated capacity	2.5 MW @ 5.5 m/s

Physical Device Structure (Materials/Construction)

Conventional construction materials (steel), methods, and engineering practices are anticipated for the standard structure. The WWT System is modular and can be assembled on site.

Power Conversion Systems

All power conversion equipment will be accessible above water. The system will include a synchronous generator and a frequency converter, however detailed information related to the type of drive is proprietary.

Mooring Systems/Foundation

The developer is currently designing applications for fixed and floating installations.

Grid Interconnection

WWT is developing the technology for grid-connected applications and is anticipating a standard unit power output delivered to grid of: 100kW, 500 kW, 1MW, 2 MW, and 5 MW. Off grid installations are of equal consideration for WWT power plants.

Device Access and Operational Consideration

The WWT system is designed to operate in one direction for constant streams and in both directions for a tidal generation. Other than the portion of the blade and the blade supporting frame, all of the equipment will be above sea level and enclosed, however the environment is still corrosive.

Costs as Estimated by Developer

- Installed cost per kW for first commercial development: $1,000- 2,000/kW.
- Target cost per kW for technology: Varies by application.
- Power Density at the reference site: Unavailable.
- Annual Output per machine (MWh): Varies by application.
- Expected cost of electricity: $.05 -.10/kWh.

Development Status

2006 - 2007	Technology was tested in 1/10 scale installations in different configurations and canal tests.
2008 - 2009	Device trials initiated in May 2008 and conducted through 2009.
2010	The developer is planning for a full scale pilot plant installation in 2010. WWT is preparing engineering details for WWT Power Plants with individual turbines in various locations.

Appendix B:– Full Reports from

Wave Energy Technology Developers

College of the North Atlantic

(http://www.cna.nl.ca/oar/research.asp)

Device Description

The wave pump developed by the College of the North Atlantic (CNA) is a point absorber type pump. A floating buoy oscillates with the waves, moving against a submerged, damped base and driving seawater through a piston. The main application is direct use of the pumped seawater for aquaculture, but desalination or power generation is also possible (Powertech, 2008*a*).

The current plan is to have water pumped to a storage tank located within a shore station, which will provide a constant 3m pressure head to plumbing systems. Overflow from the storage tank will be mixed with effluent from the aquaculture tanks and returned to sea through a low-head electrical generator.

The device consists of a central tower that contains a float and pump cylinder. In use, the system will be submerged so that the top of the tower just breaks the water surface. Appropriate valve systems will ensure that, as the float and piston rises, the lower portion of the cylinder is filled and water in the upper portion is forced through piping to shore. As the wave passes and the float falls, the upper portion of the pump will fill and the lower portion will displace water on shore. The wave-powered pump is illustrated in Figure 8.

Figure 8 College of the North Atlantic's Wave-Powered pump

(Source: Courtesy College of the Atlantic)

Turbine and Performance Specifications

Outlined below in Table 7 are a few of the CNA's wave-powered pump performance specifications.

Table 7 The College of the North Atlantic Wave-Powered Pump Technology Specifications (1/4 scale prototype)

Parameter	Specification
System height	3m
System length	2m
System width	2m
System weight	4 tons
Pumping rate	5 liters/s
Power Generation	1 kW (current design not optimized for power generation)
Water resource	Approx. 25kW/m and within 1 km from the shore.

Physical Device Structure (Materials/Construction)

The primary buoy construction consists of steel; however there are other Teflon and nylon components.

Mooring Systems/Foundation

The mooring system consists of a 5 x 250 kg danforth anchor.

Grid Interconnection

The device is not intended for commercial scale development; therefore grid interconnection research is not being conducted.

Device Access and Operational Consideration

The current use of the buoy is primarily intended for pumping seawater to an onshore facility. Therefore, locations within 1 km are being considered for its current configuration

Costs as Estimated by Developer

The cost for the ¼ scale prototype is approximately $15,000.

Development Status

2005	Conceptual design of Wave-Power Pump system.
2006- 2008	Wave-Power Pumping buoy deployed periodically for testing in Lord's Cove of Burin Peninsula, Newfoundland.
2008-2010	Continued testing and design modifications to improve system stability and operation

Grey Island Energy

(http://greyislandenergy.ca/)

Device Description

The Sea Wave Energy Extraction Device (SEAWEED^{TM}) system, shown in Figure 9, utilizes innovative technology that allows it to “tune in” with ever-changing ocean waves in order to yield maximum energy extraction. Just as a windmill adjusts the pitch of it's blades to match the resonant frequency of the wind, the SEAWEED^{TM} has the ability to alter its natural resonant frequency, thus allowing the device to resonate with varying ocean wave frequencies at maximum efficiency.

The SEAWEED^{TM} also has the ability to capture both the kinetic (heave) and potential (fall) energy of the point absorber thus providing consistent power output.

Easy to manufacture, maintain and deploy.

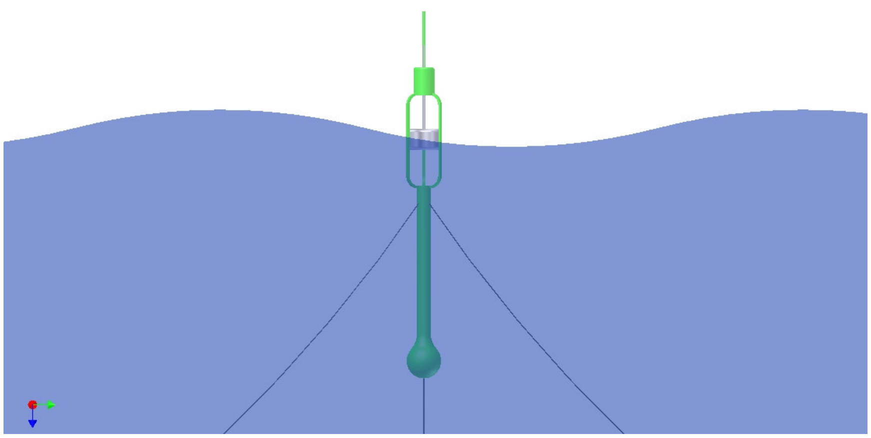

Figure 9 The Sea Wave Energy Extraction Device (SEAWEED^{TM})

(Source: Courtesy of Grey Island Energy)

Turbine and Performance Specifications

The 1st small scale prototype has been designed at 1.5kW. Detailed performance specifications are included in Table 8

Table 8 Specifications for SEAWEED^{TM}

Parameter	Specification
Float Dimension	1m dia. X 1m
Other dimensions (describe)	5m overal height

Rated capacity	1.5kW
Power generation	Electrical Turbines
Water resource	Ocean Waves
System Weight	150kg

Physical Device Structure (Materials/Construction)

The materials used for the prototype use a combination of plastic, steel, and resin.

Power Conversion Systems

The device is mechanical linear driven

Mooring Systems/Foundation

Will be either moored (TLP) or fixed to foundation (customizable).

Grid Interconnection

Future design optimization will incorporate grid interconnection for the device.

Device Access and Operational Consideration

Easily accessible via boat and will operate in calm to extreme conditions.

Development Status

2010 Currently testing its 1st prototype at NRC-IOT

Seawood Designs

(http://www.surfpower.ca/)

Device Description

SurfPower is a point absorber system that employs a buoyant rectangular wing, shown in Figure 10. The wing is tethered to the sea floor via a long stroke water piston pump. The wing is free to rotate in all directions and can therefore present its long axis to oncoming waves from all directions.

SurfPower's buoyant wing is fitted with onboard sensors and a control system that provides optimum extraction of both potential and kinetic energy, present in ocean waves. Energy is recovered by the tethering pump that delivers high pressure seawater (1000 psi) to a collection main on the sea floor. Fifteen or more buoyant wings are connected to the main that allow delivery of essentially pulse-free flow of high pressure water onshore where it is used to drive an electrical generator and a reverse osmosis desalination plant if fresh water is required.

Figure 10 The SurfPower prototype model

(Source: Courtesy of Seawood Designs Inc)

Turbine and Performance Specifications

Table 9 Specifications of the SurfPower point absorber

Parameter	Specification
Wing Width Wing Length Wing Height	13 meters 25 meters 1 meter
Pump Diameter Pump Stroke	0.55 meters 8 meters
Rated capacity	680 kW (3.7 meter waves)
Power generation	Seawater-driven pelton turbine
Water resource	18-30 meter depth
System Weight (excluding anchorage and high pressure collection main)	Aluminum construction – 55 metric tons Steel construction – 89 metric tons

Physical Device Structure (Materials/Construction)

Seawood Designs has computer modelled buoyant wings fabricated from welded steel and welded aluminum. Both performed well. They anticipate that life cycle costs will favour aluminum even though initial costs will be lower with steel. The wing is designed for total submergence to 8 meters that requires a 9 mm steel skin or 13 mm aluminum skin to withstand the pressure of submergence. The ability of the system to withstand high seas overtopping the wing is key to SurfPower's survival strategy.

The wing is controlled to dive through large waves and thereby limit pump stroke while keeping structural loading within 15 per cent of that encountered at rated output.

The sensors and control system onboard the wing that optimize energy recovery also activate the survival strategy when an extremely powerful wave or waves are encountered.

Power Conversion Systems

High pressure seawater delivered to shore by the collection main drives a conventional pelton turbine/generator plant that is available from a number of international suppliers. SurfPower, therefore, does not have any electrical power or electrical generating equipment in seawater.

Mooring Systems/Foundation

Seawood Designs intends to use a gravity base made from a pre-cast shell filled with rock as their universal anchoring solution, but where conditions permit, a suction caisson system will be used.

Grid Interconnection

In that electrical power is generated onshore at 50-60 Hz as required, grid connection is straightforward using conventional approaches.

Device Access and Operational Consideration

The buoyant wing with the pump assembly attached is designed for towing which is convenient when delivering to the site for initial installation and later on for maintenance. Servicing is accomplished by exchanging wing/pump assemblies and towing the unit requiring service to a maintenance facility.

SurfPower designers believe their system, with relatively few and robust components in the ocean, will have low maintenance cost. This is key in that the wave and tidal development communities believe operation and maintenance cost may account for half the cost of energy delivered.

Costs as Estimated by Developer

Early on in their development cycle and as the concept evolved, Seawood Designs has continued to estimate system costs and energy yield to ensure they are pursuing an economically viable approach and improving the cost of energy. They believe they have a reasonable objective to deliver installed systems which have a *capital cost to energy* yield ratio equal to wind systems.

Energy yield estimates were established by developing energy yield versus individual wave heights and then computing energy recovery using real time wave heave data for some Canadian sites over annual intervals. Typically, an earlier 25 MW system design yielded 59 GWH annually. The cost of this system was estimated (2005) at $35million (fully mature design/installation cost for tenth system). The design has evolved considerably since then and wave tank trials with an improved wing design are scheduled May 2010 at NRC- Institute for Ocean Technology in St. John's Newfoundland. On completion of these trials new system costs and energy yields will be developed.

Development Status

2003	SurfPower was created by Seawood Designs Inc
2004	A U.S. patent application was filed
2005	U.S. patent 7,042,112 B2 issued Spring 2005

2005	June – a 1:22 scale model of the pontoon was tested in Lake Huron, Ontario Canada; the pontoon behaved as anticipated. The test rig provided a means to record mechanical energy recovery from the waves over extended periods (up to one hour); the maximum power in one run exceeded 4W – obviously a trivial amount of power, however this is equivalent to 321 kW that would be delivered to the grid for a full sized SurfPower pontoon, operating in 5-12 foot waves.
2005	July – a patent application was filed in the United Kingdom
2009	September – extensive dynamic computer modelling of SurfPower was undertaken by Dynamic Systems Analysis (enabled by NRC-IRAP funding)
2009	October – United Kingdom patent, GB2428747 was issued
2009	Summer – A preliminary design of all pump components was created as a computer solid model
2010	Spring – entered into a collaborative agreement with NRC-Institute of Ocean Technology in St. John's Newfoundland to test 1:10 linear scale model (much larger than the Lake Huron model). NRC -IOT will undertake the testing in their wave basin. The model incorporates all of the components required in a full scale system. It pumps water under controlled pressure to simulate operation pumping to a collection main. Testing will establish energy recovery from a range of representative wave heights and confirm system dynamic behaviour when the buoyant wing is overtopped by storm waves. Performance data will also be provided to help validate computer modelling completed to date.

Solar Inspired Energy

(http://www.wave-energy-accumulator.com/)

Device Description

The **SIE-CAT™ Wave Energy Accumulator** technology provides a two-phase approach in harnessing the distributed energy on the ocean's surface and large bodies of water. The technology for a single array includes 10 or more individual light-weight floats mounted on a single well submerged frame, as seen in figure 11. Work performed by waves in compressing air becomes the optimum medium for energy capture and accumulation. Compressing air allows for the storage of energy and the technology is capable of energy capture by each float and from all wave sizes at a given resource area. The SIE-CAT™ technology does not rely on a resonance solution and has no need for damping considerations.

The first phase enlists the energy in each and every wave to do maximum work. This phase captures and converts the available wave energy into potential energy stored as a compressed gas. The technology accumulates this energy and simultaneously elevates it to a higher energy level with each stage. The coupling arrangement allows each stage of the process to be equally efficient, and each stage sees all waves as the first wave. By compressing air in small increments, 1.5 times (or less) the previous pressure, the magnitude of these incremental pressures incurs minimal and manageable heat of compression that is easily mitigated and dissipated without any loss in efficiency. This technology avoids the higher temperatures of compression generated and associated with high compression ratios.

The second phase sees conversion of the accumulated and elevated energy, resident in the compressed gas, in a single Wave Energy Conversion (WEC) unit. In addition to generation of electricity, the two-phase process allows for the production of hydrogen through electrolysis, and potable water through reverse osmosis.

Multiple SIE-CAT™ arrays can be deployed in an energy farm arrangement, all contributing to central pneumatic energy accumulation, allowing single point Wave Energy Conversion (WEC).

These unique and innovative attributes, coupled with a technology that provides a two-phase approach to harnessing wave energy, makes it analogous to and competitive with a land based hydraulic project. The result is magnitude of scale grid connected generation. Phase one accumulates and elevates the energy level; while Phase two provides large-scale Wave Energy Conversion (WEC) leading to three options:

1) electricity;

2) the production of potable water through reverse osmosis; and/or

3) the production of hydrogen utilizing electrolysis. Details of the competitiveness of the SIE-CAT™ technology are revealed in this document.

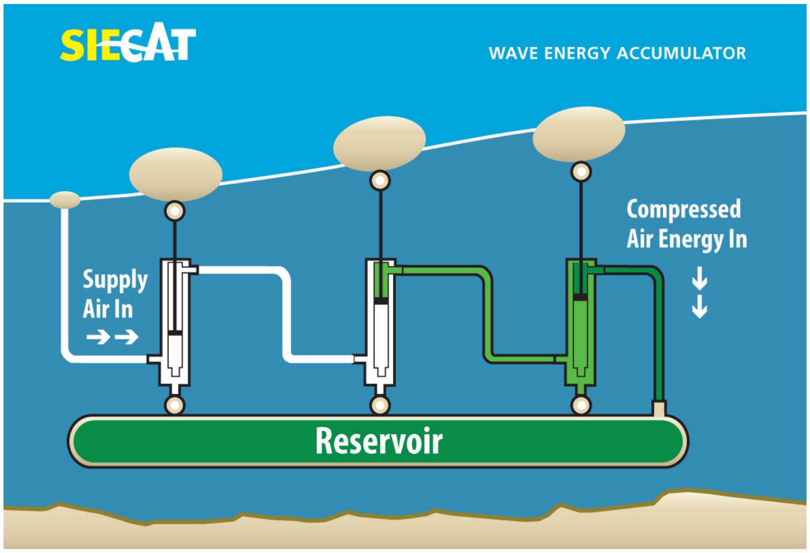

Figure 11 An illustration of the SIE-CAT™ Wave Energy Model by Solar Inspired Energy

(Source: Courtesy of Solar Inspired Energy)

Turbine and Performance Specifications

Outlined below in Table 10 are a few of the SIE-CAT™ Wave Energy accumulator performance specifications.

Table 10 The SIE-CAT™ Wave Energy Accumulator technology specifications

PARAMETER	SPECIFICATION
Float Diameter (1of 5)	3.7 m
Float thickness	0.25 m
Closed Loop volume	Unavailable
Turbine efficiency	50%
Rated capacity for 5 float system	28 kW (1m wave), 176 kW (5m wave)
System height	0.5m above surface, 30m below surface
System length, base	30m
System width, base	7.5m
System weight, fabricated material	20 tons

Physical Device Structure (Materials/Construction)

The base is a well-submerged reservoir/reaction plate/support structure accommodating multiple light-weight surface floats (work elements). The light-weight working components and the low mass energy capture medium (gas) contribute to ensuring the lowest mass of fabricated material per kW of energy generated. SIE expects most materials to be readily available as off the shelf items.

Power Conversion Systems

The developer maintains that maximum power takeoff can be achieved in any wave regime by this technology due to its ability to quickly change the length of stroke by repositioning the light-weight piston in the cylinder. The specific information related to power conversion from the compressed air is unavailable; however the developer suggests that low-pressure turbines similar to compressed air motors, but with improved sizes and efficiencies, need to be developed.

Mooring Systems/Foundation

A slack mooring system is employed as part of SIE-CAT™ Wave Energy accumulator technology. The foundation is the well submerged Reservoir/Reaction Plate/Support Structure which will be suspended at the appropriate depth for the deployment location selected.

Grid Interconnection

There is limited information on grid interconnection components, installation techniques and cable anchoring. The developer indicates that depending on farm size, multiple interconnection points may be required for multiple SIE-CAT arrays. Near shore installations allow on shore energy conversion.

Device Access and Operational Consideration

The base consists of a single or segmented submerged reservoir, reaction plate, and support structure that can be floated to the surface for periodic maintenance, or towed, as a catamaran to a local facility. The compressed gas system incorporates unidirectional pressure sensitive valves which allow for individual and direct operation without the need for overriding controls. Selection of the pressure increments allows for maximum energy retrieval and storage as potential energy in the compressed gas.

Although adjustments to the piston stroke length can be made within a fraction of second to maximize power takeoff, the developer maintains that this technology does not require tuning due to the light float employed and its ability to react to any wave amplitude and wave period. Due to the depth of the foundation, rogue waves or large waves impinging before the desirable stroke adjustment is achieved will merely wash over the device which provides a higher likelihood of survivability during storm conditions.

Costs as Estimated by Developer

- Installed cost per kW for first commercial development: A single averaged-sized 5-float array (~100 kW) is estimated to cost $1500.00 /kW.
- Target cost per kW for technology: A single full-sized 5-float array (~350kW) is estimated to cost $300.00/ kW.
- Power Density at the reference site: 30 kW/m (avg).
- Annual Output per machine (MWh): 876 from a 100 kW array, and 3066 from a 350 kW array.
- Expected cost of electricity: $0.07 to $0.10 / kWh.

Development Status

2003	Desktop prototype successfully demonstrated.
2004 - 2005	Technology recognized in the Telus New Ventures BC (TNVBC) Competition.
2005	Technology won the TNVBC - B.C. Hydro Sustainability award.
2005	Three prototype stages were constructed and tests were performed at the Vizon Scitec wave tank facility at the University of British Columbia.
2005	Proof-Of-Concept demonstration exceeded NRC_IRAP targets.
2006	Solar Inspired Energy, Inc was formed in August, 2006 to continue the development of the patented SIE-CAT Wave Energy Accumulator technology.
2007	The Vancouver Island Advanced Technology Centre (VIATeC) Technology Awards Competition awarded double finalist achievement for Emerging Technology Company of the Year and Innovative Excellence.
2008	Design in progress for advanced wave tank testing at NRC-IOT, Memorial University, Saint John’s Newfoundland.
2008	‘Strand A’ application submitted to the Carbon Trust.
2008	Three new Patent Applications are in various stages of progress.
2009	Patent 3 has been granted.

Wave Energy Technologies

(http://www.waveenergytech.com/wetEnGen.aspx)

Device Description

The Wave Energy Technologies (WET) EnGen® is comprised of a float (Smart Float), a long spar and mooring. The Smart Float travels along a rigid spar at a 45degree inclination, which is moored to the sea bottom. The spar is moored at a single point of contact which allows the device to be fully compliant on all three axes (pitch, roll and yaw), so that the float can rotate to face the waves from any direction.

The WET EnGen® float consists of multiple water ballast and buoyancy compartments, which allow the natural oscillating frequency of the float to be matched to the dominant wave period. Through the use of CFD (Computational Fluid Dynamics), a computationally-based design and analysis technique, the WET EnGen® can be tuned to specific wave regimes. Further development is required to incorporate a control system which can adjust the buoyancy to ballast ratio thereby tuning the natural oscillating frequency to the wave period. Through satellite monitoring of wave conditions in the region the wave period can be predicted and transmitted to an onboard PLC (Programmable Logic Controller). The amount of contained ballast water can be adjusted on daily and seasonally basis for optimal performance of the float.

The WET EnGen® is illustrated in Figure 12 below.

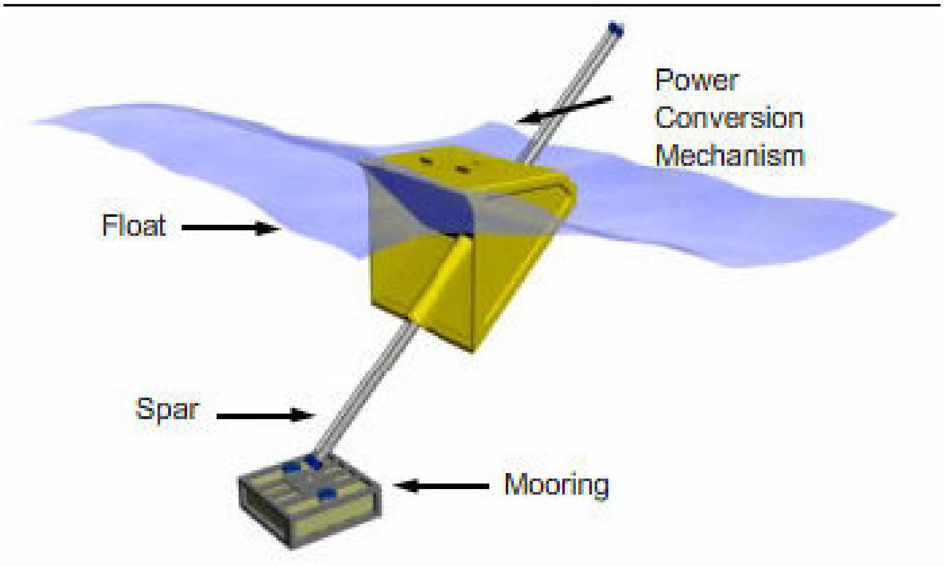

Figure 12 An Illustration of WET EnGen™

(Source: Courtesy Wave Energy Technologies Inc.)

Turbine and Performance Specifications

Outlined below in Table 11 are a few of the WET EnGen® performance specifications.

Table 11 200kW WET EnGen™ Specifications

Parameter	Specification
Smart Float Width	10 meters
Smart Float Height	5.3 meters
Smart Float Length	7.5 meters
Spar Length	40 meters
Spar Diameter	1.5 meters
Rated capacity	200 kW
Power generation	Mechanical drive to circular generator.
Water resource	> 40 m
System Weight	Material dependent*

* The developer specifications indicate that the 1 MW prototype will weigh 350 tons.

Physical Device Structure (Materials/Construction)

The developer specifies that the first functional 200 kW capacity WET EnGen® will be constructed of steel with a non-corrosive marine coating. It is anticipated that the one MW commercial devices will be fabricated from high density molded composites. WET anticipates that employing a modular design will facilitate production of multiple units at significantly reduced labor costs. Marine composites will incorporate anti-microbial additives, which repel marine growth. The selection of the appropriate anti-microbial additives will be determined based on local conditions in the region in which the machines will be installed. Electrical components will be either of a sealed or encapsulated design.

The basic triangular shape of the WET EnGen® float produces structural rigidity and, given that the device is fully compliant and free to move in all directions, the float surfaces will not be subject to the full impacts that would be incident on a “terminating” device.

Power Conversion Systems

The Power Take Off assembly consists of a mechanical friction winch drive. A synthetic cable is fixed to either end of a rigid spar, and is wound around a drum housed in the float, causing the linear motion of the float to translate into rotary motion of the winch shaft. The friction winch, in turn drives a low speed, direct drive circular generator, which is specially designed to operate at low RPM with a power conversion efficiency of greater than 90 percent. The power conversion system is all housed in the upper section of the float, which allows for easy service and maintenance from surface.

In the case of fresh water production the friction winch will be designed to drive a positive displacement rotary pump, which in turn will supply high pressure feed water to a reverse osmosis (RO) desalination system. Ideally multiple WET EnGen® modules will supply a single RO plant in a more sheltered location away from the array of WET EnGen® modules.

Mooring Systems/Foundation

The mooring design may vary depending on water depth and bottom type. A buoyant, inertial reaction mass damping system will be taught-moored to the sea floor by means of a clump anchor with additional backup station keeping anchors.

Grid Interconnection

A flexible riser cable connects the WET EnGen® float to a junction box on the seafloor. Transmission to shore via sub-sea cable will be DC to minimize line loss. Power will be synchronized to the grid by means of a variable speed DC-AC converter.

Device Access and Operational Consideration

All routine servicing and maintenance of the WET EnGen® is done from above water and without the need for divers. Access is by means of small service vessel and all maintenance activities can be carried out in dry environment to reduce cost and maximize safety. The WET EnGen® is designed for rapid deployment. The float is designed to be easily towed and installed. This reduces the cost of initial deployment and periodic servicing required to be done when the device must be retrieved for servicing in a boatyard. Servicing and maintenance can be done by a locally trained work force.

Costs as Estimated by Developer

for a 1 MW WET EnGen™:

WET predicts that by 2011 electricity can be produced at a cost of US $0.09 to US $0.11 per kW hour with its WET EnGen® technology in locations where there is a resource of greater than 25 kW per meter of wave front (Roscoe, Harley, 2008).

- Installed cost per kW for first commercial development: US $1500/kW
- Target cost per kW for technology: US $750/kW
- Power Density at the reference site: 42 kW/m
- Annual Output per 1 MW capacity machine, assuming a 33 percent capacity factor (MWh): 2674

- Expected cost of electricity: US $0.073 /kWh

Development Status

2004	Wave Energy Technologies, Inc. was established.
2004	WET EnGen® Design conceived, tested in wave tank and in open water.
2006	Ocean testing of 20 kW WET EnGen®.
2006	Additional Wave Basin testing at the National Research Council Institute for Ocean Technology, St. John's, Newfoundland.
2007	Power Take off design, testing at National Research Council Canadian Hydraulics Centre, Ottawa
2008-2009	Mooring design, testing at the National Research Council Institute for Ocean Technology. Detailed hydraulic system design. Preliminary numeric modeling
2010	Letter of Agreement signed with Independent Power Producer for a 200 kilowatt demonstration facility and 3-5 megawatt array. Final wave basin testing and numeric modelling of float and mooring system.