



Technology Evaluation of Existing and Emerging Technologies

Water Current Turbines for River Applications

Prepared for

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Executive Summary

In response to a Natural Resources Canada (NRCan) request, Verdant Power has prepared the report “Technology Evaluation of Existing and Emerging Technologies: Water Current Turbines for River Applications”. The report highlights the current state of development of hydrokinetic technologies referred to as water current turbines (WCT) that could or are being applied to river applications.

Section 1 introduces the document and defines the points of NRCan’s original request.

Section 2 provides some definitions that form the basis of the report and background on the state of development of the technologies. Also included are some of the areas critical to future development of a river-based Canadian industry such as:

- Environmental Research
- Technical Research
- Site Assessment Data and Resource
- Potential Funding for Demonstration and Deployment Permitting Issues
- Coordination among Regulatory Authorities

Section 3 describes the various technologies, their applicability to river or tidal situations, and the stage of their development. Table 1 summarizes this information and groups the technologies by appropriate subcategories.

Section 4 discusses technical performance of the various devices. Table 2 summarizes the size, flow and power characteristics as provided by the various developers.

Section 5 explores the cost of bringing the units to commercial implementation based on published information provided by the developers. Figures in sections 5.2 and 5.3 provide a breakdown of capital cost and developers’ projection of installed cost per kW.

Section 6 draws out some of the relevant points from British development programs in the ocean and tidal area that may be relevant to Canadian efforts to promote and develop a river based hydrokinetic industry. Key components for consideration include:

- Creating market pull and reducing financial risk
- Developing the role of EMEC
- Establishing Scotland as the centre for marine energy certification
- Developing a supportive planning and regulatory framework
- Providing a route to market
- Developing academic capacity and supporting R&D
- Supporting skills and manufacturing capability

Section 6 also provides recommendations of key steps Canadian federal and provincial governments may wish to consider to promote the development of WCT’s in Canada.

Section 7 summarizes the report.

Verdant Power hopes this report provides NRCan a useful tool for first assessments of emerging technologies and highlights some of the areas where government effort can be critical to moving the industry forward. We would welcome the opportunity to work with NRCan to explore opportunities to advance the state of the industry through developing protocols for and implementing resource assessment, development of regulatory processes that streamline the timing for deploying technologies, or any aspect of encouraging this emerging technology that NRCan feels we may be of assistance.

1 Introduction

In response to Natural Resources Canada's (NRCan) Request for Proposals on Water Current Turbines Technologies (WCT) for River Applications, Verdant is providing this report "Technology Evaluation of Existing and Emerging Water Current Turbines Technologies for River Applications."

The five major objectives of this report are to:

- **Evaluate the present status of WCT technologies being developed in Canada and internationally and their state of development** – The report provides a brief review of the state of technological development for WCT or hydrokinetic devices and issues reflecting their move to commercialization (need for research funding, need for site assessment data and resource potential, funding for demonstration and deployment, permitting issues and the need for coordinated policies among regulatory authorities). The report also provides a brief review of international development at the European Marine Energy Centre and UK research support, in general.
- **Describe the types of WCT technology and their technical parameters** – The report provides a brief description of each technology and a table listing the important defining parameters for each technology.
- **Investigate energy production estimates of the technologies under review** – For each technology, the report will provide a table of various size ranges provided by the vendors and their estimated unit energy production (e.g., KHPS 5m-diameter, 35 kWh based on 2 metres / second).
- **Estimate cost of energy production** – The report will provide vendors' own current estimates and their self-assessed current state of development as well as published independent industry information so that Natural Resources Canada can make an independent judgment on whether there is sufficient data to support the cost estimate.
- **Analysis of Canadian technologies with respect to international developments** The report discusses the current state sponsored research and the opportunity for development on a general global scale (overview of British research, brief description of Scottish plans for offshore generation, lack of a US program, brief description of New York and California programs, broad global opportunity).

Please Note:

All currency figures in this report are given in Canadian dollars. Original data given in other currency is converted based on Bank of Canada [nominal noon exchange rates](#), as published on 20-4-2006. Figures are not adjusted for inflation in the case of previously published data.

2 Technology Background

2.1 Water Current Technologies (WCT) Definition

Water Current Turbines (WCT's) are defined as systems that convert hydro kinetic energy from flowing waters into electricity, mechanical power, or other forms of energy, such as hydrogen. WCT's are generally types of rotor devices, such as underwater windmills, or water wheels, among others. These devices take advantage of water's density, which is 850 times greater than air.

Specifically, for this report, Water Current Technologies are defined as follows:

- WCT systems rely mainly on the existing kinetic energy in the water stream. They do not rely upon any artificial water-head, such as impoundments, to be created as the energy source for operation. For this report, WCT systems are limited to those that create water level differentials no more than one metre greater than before installation or operation.
- WCT systems do not require large civil works, but they can be placed in existing tailraces and channels, utilizing the kinetic energy available.
- WCT systems operate instream, defined here as the water stream's natural pathway. They do not require the diversion of water through manmade channels, riverbeds, or pipes, although they may have applications in such conduits.
- WCT systems may operate in unidirectional and/or bi-directional (tidal) flowing waters
- WCT systems do not require that the water height change (as in tides) for operation although some are suited for tidal applications.
- WCT systems do not require waves for operation

For the scope of this report the focus was on applications in Non-Tidal Rivers (NTR) (i.e., unidirectional flow) although several of the devices may have application in tidal waters, ocean currents and manmade channels.

2.2 General State of Technology

Several large scale tidal and ocean demonstrations are now underway, some with private capitalization, some with government funding. There are demonstrations of WCT's occurring, however they are, in general, smaller in size and less publicized. Of those occurring, Canadian companies are well represented including New Energy, Alternative Hydro Systems, and Eco Hydro Energy.

Technically speaking, WCT's are now enjoying the benefits of rapid advances in many technologies. Some of the technologies now solving old problems are durable composite materials, low speed generators, underwater construction advancements, and fish monitoring technology, CAD-CAM, CFD modeling, anti-corrosion materials/designs, and high efficiency power electronics.

A major trend that is occurring with tidal WCT's is the elimination of the gearbox by using new low speed generators. River applications will benefit from these improvements which will increase the system efficiency and reduce maintenance costs.

There are several common design themes being pursued by a number of companies. Roughly 1/3 of the companies are focusing on Darrieus turbines and 1/3 of the companies on axial flow turbines. Ducting is present on at least half of the designs. More ducting may be on the way as companies look at ways to utilize slower waterways.

Presently, the demonstrations of WCT's are generally of single units. However, several companies have or are now building the first fields of multiple units. With the installation and testing of the first multiple unit deployments, methods for system integration (e.g., electrical connectivity, grid connection, control) can be evaluated. In addition the most efficient geometric layout of the fields will be determined. Much will be validated about the interaction of WCT's with the environment, but the science of WCT energy recovery and interaction with the environment will remain an area that requires considerable research.

2.3 Issues Affecting Commercialization

The following technical, economic, social and environmental issues appear to be temporary hurdles that will need to be addressed as the industry moves toward the commercialization of WCT's.

2.3.1 Environmental Research

Some of the early environmental questions will revolve around the following issues:

- Fish, turtle, marine mammal, diving bird behavior and interaction with WCT's.
- Expensive environmental impact monitoring tests are likely to be required for the first deployments of new technologies.
- Extensive long term tests can cost millions of dollars which developers are not well positioned to absorb. These tests would be ideal candidates for government efforts with results available to the industry.

2.3.2 Technical Research

- Antifouling
- Deployment methodology
- Maintenance techniques
- CFD modeling
- Best field configurations and packing arrangements for best efficiency.

2.3.3 Site Assessment Data and Resource Potential

The identification of sites can prove to be a very imposing, intensive and expensive process for WCT companies that are skilled in building turbines but not GIS or hydrology issues. However, many governments have such expertise for cataloging and managing their water resources for other uses. Governments can assist budding WCT's companies by providing resource data and expertise as follows:

- Measure (and model) and provide velocity information for more water resources
- Measure and provide bathymetric data for more water resources
- Provide economic and social data
- Modeling focused on icing issues
- Navigation issues

2.3.4 Funding for Demonstration and Deployment

General business technology development grants would aid companies' pursuing new technologies through the costly R&D and demonstration phases. Government funding partnerships for prototypes would reduce the financial burden of demonstrating new technologies and allowing for more rapid development of promising breakthroughs.

2.3.5 Permitting Issues

- Uniform policies on navigational issues
- Standards for fish impact assessments
- Standards for fish monitoring requirements

2.3.6 Coordination among Regulatory Authorities

- Lead agency to coordinate regulatory requirements
- Streamlined well documented permitting process
- Shortened permitting processes for demonstration units intended to provide performance and environmental data

3 Companies and Technologies

3.1 Survey of Established and Emerging WCT Companies

For this report, Verdant Power performed an extensive web-based search and reviewed and updated earlier research performed for the Electric Power Research Institute in 2004. Although this report focused on WCT technologies for rivers, the search first entailed locating all WCT companies, regardless of their site application. Once the companies were identified, the site application of their technology was determined: non-tidal rivers (NTR), tidal areas (rivers or straits), and unidirectional ocean currents.

In many cases WCT technologies are suitable for multiple site types. The most critical factor for whether a tidal system can be applied in a non-tidal application is unit size. The most well publicized tidal technologies to date have been large systems that need 20 m or more of depth to operate (e.g., Marine Current Turbine, Hammerfest-Strom, and The Engineering Business), where the economy of scale theoretically improves the profitability of development. This limits their applicability in a majority of non-tidal rivers. However, many of the devices may have the potential to be scaled down to fit a broader range of river flow and depth characteristics.

For purposes of this report, we have attempted to identify technologies by their applicability to NTR's as opposed to the developer's current market focus. The report emphasizes technologies that are currently scaled to 1 kW or more. Each vendor's stage of development is noted; the stages may be defined as follows:

Laboratory: Scale model testing in a laboratory setting

Prototype: Single unit field test

Pre-commercial: Demonstration of commercial size units

Commercial: Units commercially available

Recent and rapid developments in the WCT industry make separating verifiable technical data from subjective or promotional public statements a serious challenge. Third-party verification of technical claims, especially quantitative performance data, is minimal at present, so information about some technologies is based primarily on qualitative descriptions from the developers. Some of the newest designs are literally just emerging from laboratory secrecy. For the purposes of this report, the authors have chosen to include developers' claims where third party verification is not available in order to provide NRCan with information on the broadest range of technologies.

3.2 Company and Technology Summary Table

Table 1 - WCT Device and Technology Summary Table

Company	WCT Device Name	Turbine Type	Stage of Development	Turbine Efficiency	System Efficiency	Min/Max Depth (m)	Min/Max Speed (m/s)	Blade Pitch	Axis Orientation	Blade Diameter	No. of Turbines per Unit	Ducted or Unducted	Anchor System
AXIAL-FLOW TURBINES													
Thropton Energy Services	Water Current Turbine	Axial flow propeller	Commercial	no data found	12% - 14% @1kW	turbine diameter /no limit	0.5/1.5 †	fixed	horiz	4.0, 3.4, 2.8, 2.2, 1.8m	1	unducted	pontoon boat
Marlec	Amazon Aquacharger	Boat-mount Thropton	Commercial	no data found	12%	1.75/ no limit	0.45/1.5	fixed	horiz	1.8	1	unducted	boat or dock
Verdant Power Canada ULC	Kinetic Hydro Power Sys	Axial Flow	Pre-Commercial	45%	35.9%	7m for 5m dia.	1.0 / tailored for any speed	fixed	horiz	5m, scaleable 2m+	1	unducted	yaw pylon
Clean Current	Tidal Turbine Generator	Ducted Axial Flow	Prototype	no data found	50%	no data found	no data found	no data found	horiz	prototype: 3.5m	1, possibly 2	ducted	pylon, weighted base
UEK	Underwater Electric Kite	Dual Ducted Axial Flow on tether	Prototype	no data found	no data found	no data found	no data found	fixed	horiz	Several models: 2m, 3m and larger	1	ducted	tethered
PEEHR	Hydroreactor Stream Accelerator	Ducted Axial Flow 4 bladed impeller on	Prototype	no data found	~13% calculated from data	no data found	test data at 2.75m/s only	fixed	horiz	1.2	1	ducted	extendable yaw pile
Hydrohélix Energies	Marenergie	Axial-flow	Laboratory	no data found	no data found	no data found	no data found	fixed	horiz	8 m	1	ducted	weighted base?
Swan Turbines	Swan Turbine	Axial flow propeller	Laboratory/ Prototype	no data found	24%	no data found	1.8/2.8 (for 1m proto.)	data not found	horiz	prototype =1m	1	unducted	extendable yaw pylon
CROSS-AXIS TURBINES													
Alternative Hydro Solutions Ltd	Freestream Darrieus Water Turbine	Cross-axis	Commercial	no data found	~32% calc from graph	~0.6 for high speed stream	no data found	fixed	vert	1.25, 1.5, 2.5, 3.0, 6.0 metres	1	unducted	Customer determined
Energy Alliance	Submerged Hydro Unit	Cross-axis	Commercial	80% †	65% †	0.5/unlimited	3/10 †	fixed	horiz	no data found	1	ducted	weighted base & cabled
Ponte di Archimede	Kobold Turbine	Cross-axis flow	Pre-Commercial	no data found	23%	~7 m / unlimited	tested at 2m/s; range data not found	varies	vert	6 m dia x 5 m high	1	unducted	Floating buoy with mooring cables to anchors

New Energy	EnCurrent Hydro Turbine	Cross-axis	Pre-Commercial	no data found	Unducted: 28% Ducted: 55%	no data found	with 5kW Gen: 1.5/1.7 duct. 2.0/3.0 unducted	fixed	vert	1.6 for 5kW	1	ducted & unducted	unknown
Blue Energy -Canada	Mid Range Davis Hydro Turbine	Darrieus, cross-axis	Prototype	no data found	no data found	10†/ no data found	1.74/ TBD †	fixed	vert	6.10 †	2	ducted	floating
GCK Technology	Gorlov Helical Turbine	Helical Darrieus Cross-axis	Prototype	~20-38%	TBD	Vert: no min/limit Horiz: ~1.1	0.6 /no limit	fixed	either	1	1 or more sections	unducted	various
Tidal Energy Pty. Ltd.	TBD	Darrieus, cross-axis	Prototype	no data found	no data found	no data found	no data found	fixed	vert	1.2 to 2.4	2	ducted	unknown
Bosch Aerospace	CycloTurbine	Cycloidal Turbine	Laboratory	39.6% † (ducted)	29.3% † (ducted)	TBD	TBD	varies	horiz	TBD	1	ducted & unducted	various
Water Power Industry	WPI Turbine	Darrieus cross-axis	Prototype	49.9	No data found	TBD	TBD	varies	vert	TBD	1	unducted	unknown
<u>PADDLEWHEEL TURBINES</u>													
Eco Hydro Energy Ltd	Floating Power Station	Paddlewheel	Prototype	no data found	no data found	no data found	no data found	flexing paddles	horiz	Various dia's; e.g. 240MW has 18m wheel + 14m blades	1 or 2 in prototype Modules link	unducted	boat-like float
Encore Clean Energy Inc	River Bank Turbine	Turntable Paddlewheel	Laboratory	no data found	no data found	no data found	no data found	NA, folding bucket	vert	no data found	multiple	ducted	floating platform
<u>HYDRAULICALLY TAPPED DUCT SYSTEMS</u>													
Hydro Venturi	Rochester Venturi	duct with hydraulic tap & air turbine	Prototype	no data found	20% †	<1m/100	1.5 /30.5	NA	NA	NA	1 or more RV's can share 1 airturbine	ducted	weighted base?
<u>FANBELTS</u>													
Atlantis Energy	Aquanator	Fan-belt	Prototype	no data found	no data found	~10/ no data found	1.0/no data found	fixed	NA	9m tall x 57m wide	1 belt	unducted	no data found
<u>FLUTTERVANES</u>													
Arnold Cooper Hydropower Systems	Oscillating Cascade Power System	Fluttervane	Laboratory	58-61% †	TBD	1.5/15 †	1.5/4.5 †	flutters	vert	7.3 x 3.0 x 0.9	N/A	N/A	no data found

NOTE: Most of the information presented is gathered from the company's own website or published literature without third party confirmation and should be evaluated in light of each design-developer's experience and track record to date.

† Data Source: Renewable Energy Technical Assessment Guide - TAG-RE: 2004 Report - Product Number 00000000001008366. Published Dec 2004.

3.3 Types of NTR Devices

The following companies were determined to be viable companies for NTR WCT. In some cases the technology may be marketed solely for tidal applications, but the authors believe that the technology was well suited for NTR's, as is or with minor modifications.

3.3.1 Axial Flow Turbines

Water Current Turbine- THROPTON ENERGY SERVICES

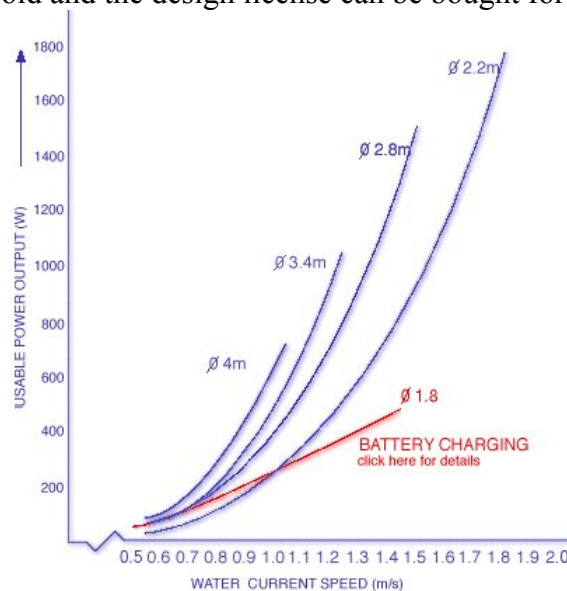
Technology: Thropton is the designer, licensor, and component manufacturer of pontoon-mounted low-power turbines that are used for either electricity generation or for water pumping (for irrigation, drinking water, etc.). The propeller fan style turbine, available in diameters of 4.0, 3.4, 2.8, 2.2, and 1.8m drives an above-water generator. Its "Garman Turbine" is used to drive water pumping versions. Currently, the turbines are designed as stand-alone units having a maximum power output of about 2 kW. The system efficiency is fairly low at 12%-14% (@ 1 kW). The efficiency of individual components (turbine, drive trains, or generators) is not provided by Thropton. The device is deployed by mooring in the free-flowing stream to a post on one bank or another. Minimum site requirements for this turbine are a water current speed of at least 0.50 m/s and a depth approximately equal to the turbine diameter.



Application: Rivers and unidirectional channels. The systems are easily deployed without heavy equipment and thus they are suitable for use in developing countries. The pontoon unit is usually positioned in a free-flowing stream with a cable mooring to a post on one bank and a whisker pole keeping the boat off the bank, or it is moored to an in-river piling.

Stage of Development:

Although this system has been commercially operating for over twenty years according to the company in Somalia, Sudan, Egypt, and Peru, it does not appear to be scalable for utility power requirements. Commercial plans are being sold and the design license can be bought for local manufacturing.



Amazon AquaCharger - MARLEC/ THROPTON ENERGY SERVICES (UK)

Technology: Marlec has teamed up their engineering, renewable energy and manufacturing expertise with Thropton Energy Services, a company specializing in water turbines, to develop a battery charging water current turbine. The Amazon AquaCharger is a turbine, generator and control system designed to mount on an ordinary open moored boat (see below). It is sold as a kit. The turbine is lowered into a river or canal deeper than 1.75 m and generates power between water flow speeds of 0.45 m/s (1 mph or 0.87 knots) and 1.5 m/s (3.36 mph or 2.92 kn). The use of a high efficiency, low friction alternator and aerodynamic blade design has achieved the low water current speed cut-in, maximizing the potential application to a variety of waterways. Power generated is stored in batteries to operate 12V appliances and inverters to operate 240V appliances. Output connectors allow up to six 12V batteries to be charged simultaneously. The unit starts charging at 0.5m/s river speed and generates approximately 500 watts at 1.5 m/s. The unit incorporates a patented furling device that lifts the turbine out of the water if the river speed exceeds the pre-set maximum. An electrical brake is operated when furling to prevent the turbine from freewheeling, reducing wear and tear. The turbine diameter is 1.8 m and the rotor is protected from going aground and from floating debris. The system is simple to assemble, dismantle and transport for relocation. There are minimal running costs and it can run for 24 hours per day unattended.



Application: The Amazon AquaCharger is suitable for areas of the world where large sectors of the population live in dispersed communities along major river and canal banks. The product offers opportunities to establish battery charging stations to serve the local population.

Stage of Development: It is manufactured in kits by Marlec, commercially available.



Kinetic Hydropower System (KHPS) - VERDANT POWER, LLC AND VERDANT POWER CANADA ULC (USA, Canada)

Technology: The KHPS is a 5m diameter 3-bladed axial- flow turbine rated at 35 kW, which incorporates a patented blade design by New York University having a high efficiency over a large range of speeds. The turbine rotor drives a speed increaser, which drives a grid-connected, three-phase, induction generator. The gearbox and generator are in a waterproof streamlined nacelle, which is mounted on a streamlined pylon. The pylon assembly has internal yaw bearings allowing it to pivot the turbine with the direction of the tidal current, ebb or flood. The pylon is bolted via an adjustable adapter to a pile fixed to the river bottom. The turbine will operate below 1.0 m/s but for economic efficiency it recommends velocities greater than of 2.0 m/s and water depths of at least 6.5 metres.

Application: Rivers, tidal estuaries, and near shore ocean. The company is also developing smaller and larger diameter turbines. The smaller systems will be well suited for dam outflows, aqueducts, water transmission systems, and effluent streams. Higher or lower capacity generators can be placed in the systems to adapt to higher or lower site velocities.

Stage of Development: The Company is proceeding with the second phase of a three-phase project, to install six 5 m diameter pre-commercial models each producing 35.9kW at peak (an installed capacity of between 150 and 200kW) in New York City's East River by the summer of 2006. A \$1.7 million fish behavioral monitoring program has been started on the site and will be carried through the full installation of the 6 turbines. Previously, the blade design has been studied and CFD modeled by the Navy. A 1 m, 3 m and 5 m diameter turbines have been tested in both laboratory and field applications. Units were successfully tested for the maximum efficiency with little or no deterioration throughout a wide range of stream flow speeds, as might typically be found in rivers subjected to natural water flow variations or upstream dam management. In 2003 a 3 m prototype model tested in the East River generated 15.5 kW at 2.13 m/s, yielding efficiency (C_p) of 43%.

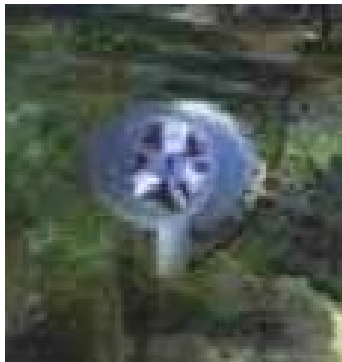


Tidal Turbine Generator- CLEAN CURRENT POWER SYSTEMS- (Canada)

Technology: Clean Current's tidal turbine generator is a bi-directional ducted horizontal axis turbine with a direct drive variable speed permanent magnet generator. One version of the system may incorporate dual side by side turbines with protective screens. Operability is enhanced by a simple design that has one moving part -the rotor assembly that combines turbine and generator functions. The blades have permanent magnets attached to them, and the duct incorporates the coils. There is no drive shaft and no gearbox. The developer states that the proprietary design delivers better than 50 per cent water-to-wire efficiency. The turbine generator has an estimated design life of 10 years (major overhaul every 10 years) and a service life of 25-30 years. The turbine, mounted on a pile in about 15 m of water, is completely underwater and causes no visual impact on marine environments. Commercial scale models are expected to be 14 m in diameter and produce approximately 250 kW.

Application: Tidal sites greater than 15 m deep appears to be focus, but the device could be used in deeper rivers.

Stage of Development: Clean Current is a key partner in the "Clean Current Tidal Power Demonstration Project at Race Rocks Ecological Reserve" about 10 nautical miles southwest of Victoria. The \$4 million project is a partnership between Pearson College, EnCana Corporation of Canada, and Clean Current Power Systems of Vancouver. EnCana is investing \$3 million in the project from its environmental innovation fund. The project is expected to produce more than enough electricity to replace two diesel generators and provide power to the college's marine education centre on Great Race Rock Island by 2006. Clean Current developed and built the prototype of a tidal turbine generator which harnesses the power of ocean currents to produce electricity. Testing will take place in about 15 m of water. The prototype being tested is 3.5 m in diameter and can produce approximately 10 kW. The unit has been tested in fresh water, but will be scrutinized closely over the next 18 months to see how it holds up to corrosion resulting from a marine, saltwater environment. Financial figures and schedule projections reflect the views of the developer only and not any independent assessment.



Underwater Electric Kite - UEK CORPORATION (USA)

Technology: This system employs two axial-flow turbines in a "side-by-side" configuration. Each turbine consists of five blades that drive a single internal generator housed within the nacelle. The double-shroud surrounding the two side-by-side turbines is constructed of composite materials. The system incorporates an augments ring that is integral with the rear edge of the shroud. The augments ring extends outwardly with respect to the axial alignment of the turbine shafts and deflects the flow of water about the shroud. This creates a low pressure zone at the rear of the shroud that "pulls" water through the turbine blades at a velocity greater than that of the normal or surrounding flow of water. The unit is positively buoyant and is secured to the seabed by a single anchorage system, using a cable bridle. When flown as a kite the angle-of-attack is altered by a patented ballasting system that shifts a weight forward and back in the keel. Keeping a controlled operational depth, the units are not affected by the surface effect of large waves or navigation. Lateral positioning controls permit the units to stay in the core of the current.

Applications: The turbine is designed to operate in river, tidal and ocean currents. Various models exist from 2m to 5m and operate in extremely low velocities of 0.20 m/s or less.

Stage of Development: UEK has field tested at least five different WCT configurations since the mid 1980's. Tests include tugboat drag tests and a tailwater test in Ontario, Canada. The specific results from these field tests are proprietary.

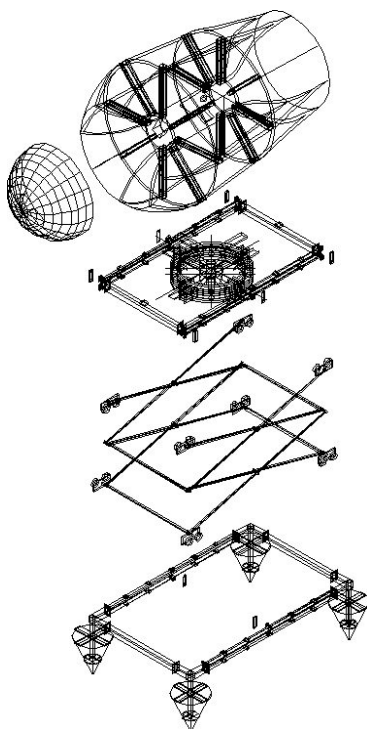
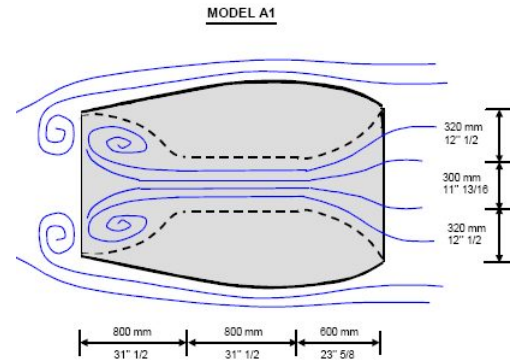


In 2006 UEK reached an agreement with ATEC Power Inc. to build and use these underwater turbines in Atlantic Canada. ATEC Power was founded in 2005 to sell tidally generated electricity to Nova Scotia Power. Preliminary tidal current studies by ATEC Power show the most favorable site for tidal power generation is Minas Passage between Cape Split and Cape Blomidon. The company plans to conduct site mapping and evaluation studies in spring and summer 2006.

Also in 2006, Manitoba Hydro initiated and committed funding for a kinetic turbine research project. Additional funding is anticipated as part of a collaboration with UEK and the University of Manitoba. The project will assess the impact, reliability, and operation of a 60 kW kinetic flow turbine in Manitoba. The turbine is planned to be connected into the distribution grid, and be studied for one year, beginning in 2006.

Hydroreactor Stream Accelerator - PEEHR (Portugal)

Technology: This technology consists of a cylindrical duct with a unique “Hydroreactor” profile that is immersed in streams, attached to an elevating platform by means of a yaw bearing, the platform connected by means of an extendable piling anchored at the riverbed or seafloor. The inside duct is composed of a funneling compression zone, an intermediate narrow venturi zone and finally an expanding exhaust zone where a suction effect is generated by the diffusion of the inside flow and deflection of the outside stream. The duct is automatically and passively oriented according to the stream’s current direction. A debris screen is attached to the duct. A low pressure/high speed axial flow turbine is located at the narrowest section of the duct. The turbines drive a low rpm



generator housed in a watertight chamber located at the duct edge. The unit’s location is marked by a floating buoy. Maintenance is performed by lifting the duct above the water surface. An extendable scissors platform positions the unit for operations or maintenance. The duct’s inside dimensions are roughly 1.2 m at its narrowest, 5.4 m at its widest and 8.4 m long. The axial flow 4 blade impeller has a diameter of 1.2 m. The system is designed for 30 kW at 2.75 m/s. The ducting increases the stream velocity through the duct by 40% with no turbine installed.

Applications: Rivers, Tides, Ocean Currents

Stage of Development: Prototypes of the duct and impeller have been tested under a catamaran which was motored to simulate flowing water.

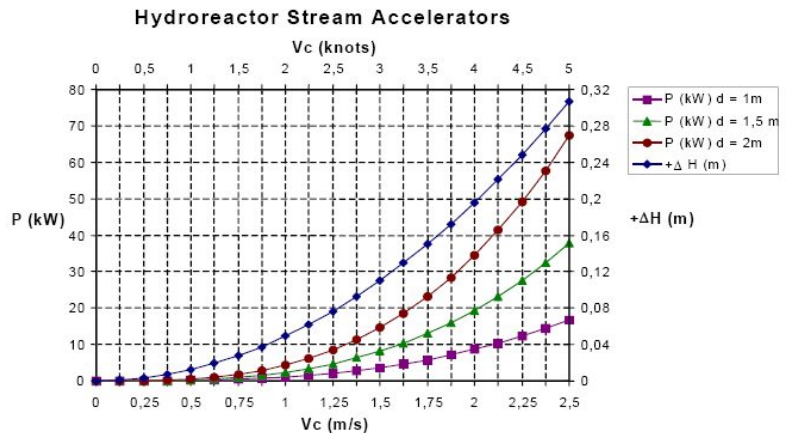


Figure 2: Available power P and increase in head $+ΔH$ with the stream velocity

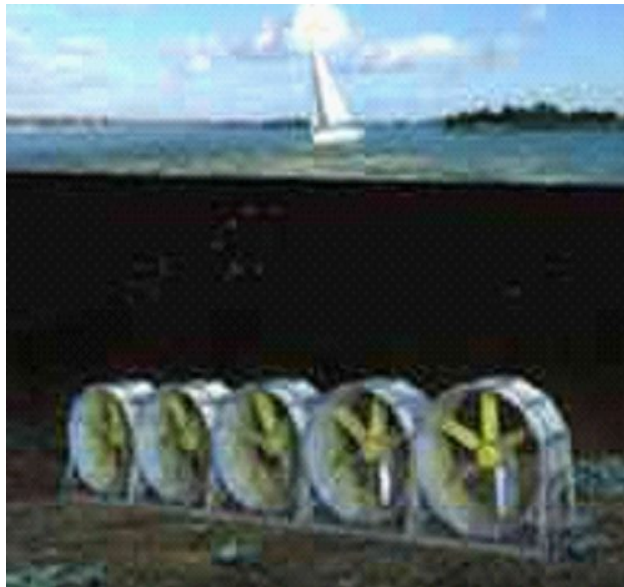


Hydrohélix Turbine- HYDROHÉLIX ENERGIES (France)

Technology: This ducted axial-flow turbine is designed to be arranged in a row or a matrix. The turbine spins very slowly at 6 rpm. The turbines are 8 metres in diameter and will generate 250kW each in their proposed setting 20 m below the English Channel off the coast of France. The French National Centre for Scientific Research (CNRS) has already tested the effect of the underwater turbines on fish. Since the blades rotate slowly, at six rotations a minute, fish are unlikely to be unwittingly caught up in the blades. In addition, the noise from the turbines is not expected to be greater than the average background noise generated by turbulent water.

Application: The turbine is designed to operate in both river and tidal currents.

Stage of Development: A 60W model of an underwater power station has been tested. The Company is proposing to start a 1 MW demo of four underwater turbines in the English Channel within the six kilometre coastal zone from which fishing boats are excluded. Hydrohélix Energies has already received approximately \$280,000 from the French government, and now hopes to attract investors and engineering firms to build the first stations. They project a kilowatt of electricity will be selling at approximately \$0.06.



Tidal Stream Turbine- SWANTURBINES (UK)

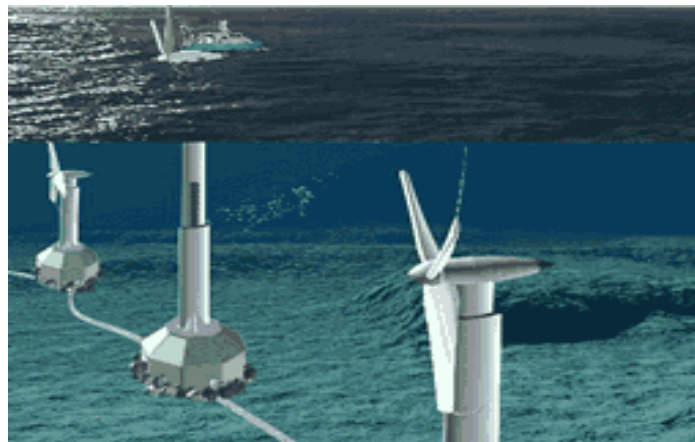
Technology: The unit is a three-bladed axial flow turbine. A gearless low speed generator offers a high efficiency over a range of speeds with minimal maintenance demands through the use of novel structural and electromagnetic topologies. To minimize CapEx and OpEx, offshore specialist CB&I John Brown transferred standard offshore technology and operations to form the basis for a new support structure concept. A simple, robust and serviceable yawing mechanism is used for maximum flow capture and the use of patented materials, developed by Corus will form the gravity base. In collaboration with the University of Wales Swansea, using rotor-dynamic modeling, the concept was designed to allow simple installation and maintenance retrieval in both shallow and deep water and to minimize vibrations, hence increasing the maintenance period. Currently, a 1m diameter prototype with an estimated 1.5 kW output is being tested.

Application: Deep and shallow water tidal applications, but could be used in non tidal rivers.

Stage of Development: The project partners are currently cost optimizing the design for a technical feasibility demonstration. This Collaborative Industrial Research Project is managed by Swansea University to prepare the concept design and specification for a technology demonstrator. The design phase of the project is expected to run until the end of June 2006. The partners are currently seeking funding to build and install the demonstration device in 2006-7. The total value of the project is estimated at \$608,000.

Overall Schedule:

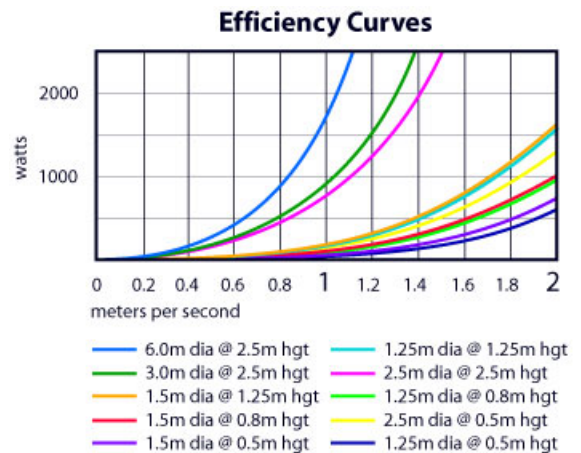
- 2006 Design and develop medium scale demonstrator cost optimization and modeling
- 2008 Install and operate medium scale demonstrator (350kW)
- 2010 Design and commission pre-commercial system
- 2011 Sales



3.3.2 Cross-Axis Turbines

Darrieus Turbine- ALTERNATIVE HYDRO SOLUTIONS LTD (Canada)

Technology: These small Darrieus turbines are constructed of high quality and durable materials. The turbine blades are custom 6063T5 aluminum extrusions with a solid cross-section in order to provide the required strength. The 6063T5 alloy offers excellent resistance to corrosion and a smooth surface finish. The mating to the hub is performed with a patentable mechanism, which incorporates a second female extrusion to the arms male. The shaft is made of stainless steel and is supported by two standard stainless steel pillow block bearings. The frame supporting the two bearings is a standard channel section or flat plate, which may be modified to accommodate a variety of mounting mechanisms. The power is transferred through a flexible coupling to a motor and gearbox combination which allows the motor to run at a higher rpm thereby increasing its efficiency and reducing the torque fluctuations. A number of electrical options are available depending on site requirements. These include a permanent magnet D.C. generator and a brushless alternator. The turbine is available in several diameters: 1.25 m, 1.5m, 2.5 m, 3.0 m, and 6.0 m, each available in custom lengths. The chart indicates the power versus velocity for various combinations of diameter and height.



Application: AHS has taken the Darrieus concepts and modified them to be more suitable for smaller rivers. The diameter of the turbine is larger than the height so that it better fits the cross-section of shallow sites. A number of design simplifications have been incorporated over the previous designs while maintaining the turbine efficiency. Typically these units have been mounted on a pontoon, barge, or small boat; however, for smaller streams other methodologies may be more cost effective. These could include a built-in support beam extending either fully or partially over the river.

Stage of Development: AHS is one of the few companies now building and selling production systems. They have performed testing in the past with NRCan and are now collaborating with the University of Windsor (Ontario) on the Green Corridor project, where they successfully demonstrated a boat-mounted turbine.

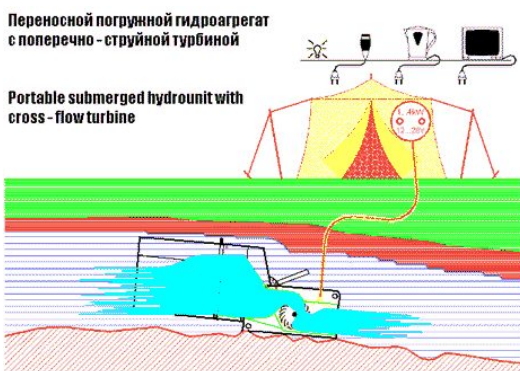
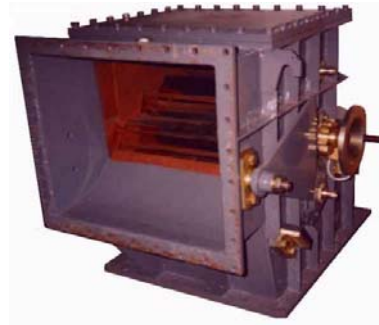


Cross-Axis Turbine- ENERGY ALLIANCE (Russia)

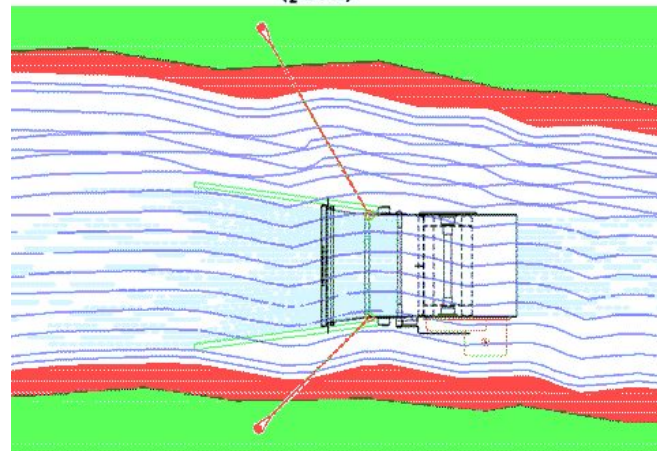
Technology: This technology uses cross-axis turbines traditionally used for low head dam applications. They are housed in a duct that allows them to be placed in a swift flowing river without the use of a dam. The units are expected to stay reliably secured by hydraulic and hydrodynamic forces. The submerged units can be operated the year round, including the case when they are installed in the rivers with incomplete freezing of the river bed. The Energy Alliance plans to produce two versions of submerged hydro-units - portable units with outputs from 1 to 5 kW and stationary units with outputs from 10 kW to 225kW. Portable submerged hydro-units are intended for generation of 12V and 28V direct current, depending on the parameters of stream flow and generator type. The hydro-unit comprises: cross-axis turbine, synchronous generator with rectifier, accumulator and switchboard. Stationary submerged hydro-units are intended for generation of 220V and 380V, 50Hz AC. The turbines require a minimum stream speed of 3 m/s and minimum flow through turbine of 0.46 m³/s flow. The maximum flow through turbine of for the largest system is approximately 3.2 m³/s.

Application: The turbine is designed to work in both river and tidal waters.

Stage of Development: The turbines are currently in production. Cost: up to 16 kW is approximately \$14,600; an up to 30 kW unit is approximately \$25,600; an up to 60 kW unit is priced around \$45,600; and \$62,600 is the estimated price for an up to 100 kW unit.

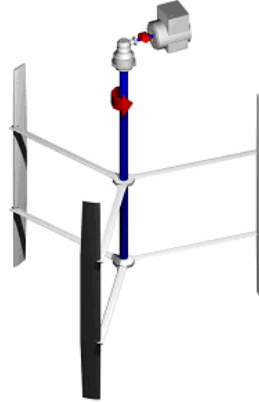


INSTALLATION SCHEME OF THE SUBMERGED UNIT (plan)



ENEMAR with Kobold Turbine- PONTE DI ARCHIMEDE S.P.A. (Italy)

Technology: The ENEMAR system uses a Kobold turbine that was modified by the Aircraft Design and Aeroflight Dynamics Group (ADAG), part of the Department of Aeronautical Engineering at the University of Naples. The Kobold Turbine is a vertically oriented, cross-axis turbine with three straight blades. It is mounted under a buoy and moored with cables to four anchors.



Application: The turbine is designed to operate in rivers, tidal, and ocean currents.



Stage of Development: Field research and experiments were conducted on a pre-commercial model with a turbine 6 meters in diameter and blades 5 meters tall. It was installed in the Messina Strait, Italy in spring 2001. It generated 25 kW at 2.0 m/s.

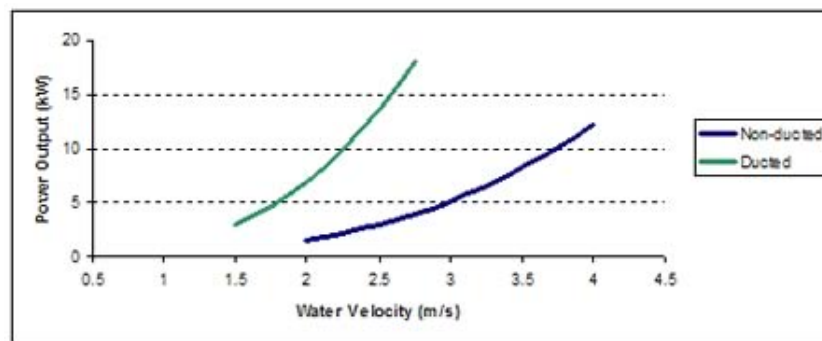
Currently the company is identifying other sites in Europe suitable for producing electrical energy generated by marine currents. Together with the Institute of Energy Conversion of the Chinese Academy of Sciences, studies regarding the application of the ENERMAR system are currently in progress in the Strait of Jintang (Zhoushan Archipelago), People's Republic of China.



EnCurrent Hydro Turbine - NEW ENERGY CORPORATION, Inc (Canada)

Technology: The EnCurrent turbine is a vertical axis Darrieus cross-axis turbine, available in both ducted and non-ducted configurations. The non-ducted configuration uses a 1.6 m diameter x 0.8m tall turbine and requires a minimum water velocity of 2 m/s to provide effective power output. The ducted version places that turbine in a 3.0 m wide by 1.0 m tall duct which reduces the minimum water velocity to 1.5 m/s. EnCurrent technology builds on work carried out by the National Research Council Canada (NRC) on a Vertical Axis Hydro Turbine. During the 1980s, NRC launched a program to demonstrate the technical validity of the Vertical Axis Hydro Turbine, terminating the program at the point they felt the technology was ready for commercialization by the private sector. Based on the design of the Darrieus Wind Turbine, New Energy's turbine is able to extract 40% to 45% of the energy in the water moving through it. One of the unique economic and design advantages of the Darrieus Turbine design is that it can capture kinetic energy from the water irrespective of the current direction. This property enables the New Energy turbine to harness the energy contained in both flood and ebb tides. Furthermore, slowly rotating turbine blades are expected to eliminate fish kill at installations.

The company is currently offering a 5 kW model with plans to introduce a 25 kW model early in 2006, extending to larger sizes in subsequent years. Power output versus velocity curves are shown below:



Application: New Energy Corporation, Inc. is primarily focused on off-grid mini and micro hydro markets. The company identifies this market as off-grid homeowners or businesses located in close proximity to a stream, river or tidal flow and requiring greater than 5 kW but less than 1 MW of generating capacity. The company has a secondary focus on the grid connected distributed energy market, mainly in locations where man-made



waterworks can be utilized for the generation of hydroelectric power. Man-made waterworks refers to structures that have been designed and built to convey water, such as irrigation canals and effluent discharge canals within industrial complexes.



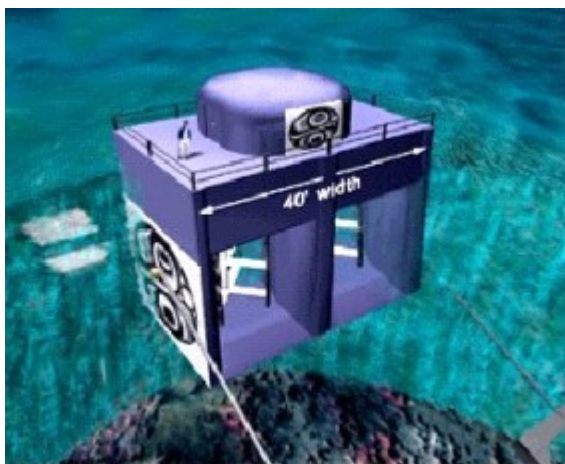
Stage of Development: New Energy Corporation now makes and sells water-to-wire production units.

Davis Turbine, Mid Range Unit- BLUE ENERGY Company (BEC) (Canada)

Technology: This Company uses a ducted 4-bladed fixed pitch Darrieus-type turbine called the Davis Hydro Turbine. The turbine drives an integrated gearbox and electrical generator assembly. Originally, Blue Energy had promoted the turbine to operate in a barrage configuration creating a low head impoundment. The turbines were to be mounted in concrete ducted fence sitting on the river bed or tidal estuary bottom, directing the water flow through the turbines and supporting the couplers, gearboxes, and generators above the water level. The top of the structure can serve as a road or rail platform for servicing the turbines. Since 2000, Blue Energy has shifted its focus to a non-barrage deployment system called “Midrange Units” where the ducted Davis turbine relies solely on free flow velocity. The change reflects concerns from fishermen and environmentalists. The mid range units would be of lower efficiency but easier to construct than a barrage system. BEC’s website also reports that it is pursuing the development of a 500kW pre-commercial demonstration project off the coast of British Columbia comprised of two floating 250kW with 6.1 m diameter turbines. They also are developing a “Micro Power System” WCT, in the 5 to 25kW range.

Application: It is designed for tidal waters, although it could be used in non-tidal applications.

Stage of Development: After a huge demonstration program in the 1980’s, there has been a noted drop in visible projects in the last decade. However, in March 2006 Blue Energy announced its partnering in the UBC Research Capabilities Enhancement Project. The \$172,000 project is co-funded by Western Economic Diversification and the B.C. Ministry of Energy, Mines and Petroleum Resources, and will benefit Blue Energy, the University of British Columbia and the B.C. renewable ocean energy industry. Major project components include the design and purchase of experimental equipment for use at the on-campus towing-tank facility, funding to support the development of computer models and funding to explore the possibility of establishing an Ocean Engineering Centre at UBC.

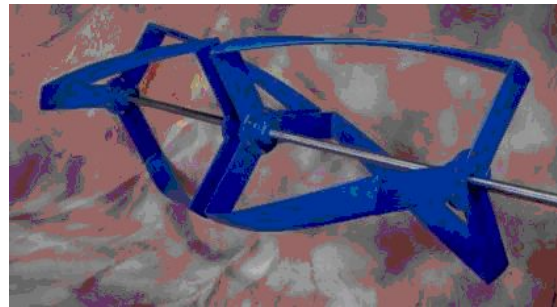


Gorlov Helical Turbine- GCK TECHNOLOGY, INC (USA)

Technology: GCK is the licensee of the Gorlov Helical Turbine (GHT) patents and technology. The GHT is a cross-axis turbine consisting of one or more long helical blades that run along an imaginary cylindrical surface of rotation like a screw thread. The helical airfoil blades provide a reaction thrust perpendicular to the leading edges of the blades that can pull them faster than the fluid flow itself. The GHT allows a large mass of slow water to flow through, capturing its kinetic energy and utilizing a very simple rotor. It can be assembled vertically, horizontally or in any other cross-axis combination using a common shaft and generator for an array of multiple turbines. Generating capacity is proportional to the number of modules. In its vertical orientation the generator and gearing can easily be positioned above water. The standard unit is now 1 m in diameter by 2.5 m in length. It starts producing power at approximately 0.60 m/s, according to studies done in 2004.

Application: The turbine can be operated in tides, non-tidal rivers, or ocean currents. The horizontal arrangement lends itself well to shallower rivers, tailraces or discharge channels from industrial plants.

Stage of Development: In 2004, Verdant Power, assisted by the Massachusetts Technology Collaborative which is part of the Massachusetts Renewable Energy Trust, collaborated with GCK and tested four 1m diameter GHT's mounted on a barge in the Merrimack River of Massachusetts. The project summary and final report can be found at http://www.masstech.org/Project_lst_rslt.asp?ID=54 on MTC's website. Issues raised in the report include concerns about vibration.



Diffuser Augmented Water Current Turbine - TIDAL ENERGY PTY LTD (Australia)

Technology: A 1.2 m diameter (a 2.4m unit is under development) Darrieus turbine mounted in a diffuser duct. The system has been initially demonstrated and tested under a relocatable pontoon, but the final mooring system is not divulged. The duct is made of multiple metal “rings”, with slots between each. Each ring is an airfoil in cross-section. The duct flares towards the rear to create lower pressure region in back of the turbine to increase the natural velocity of the water. The developer claims the duct boosts the power by 3 times. The axis is vertically oriented.

Application: Tidal and Non-Tidal Rivers

Stage of Development: Tidal Energy has recently collaborated with the School of Engineering at Griffith University of Australia to develop and test their Augmented Ducted Darrieus. In 2004 they received a grant to fabricate and install a 2.4m x 2.4m “Diffuser Augmented Water Current Turbine” under a relocatable pontoon to collect test data. The results from this testing is not known.



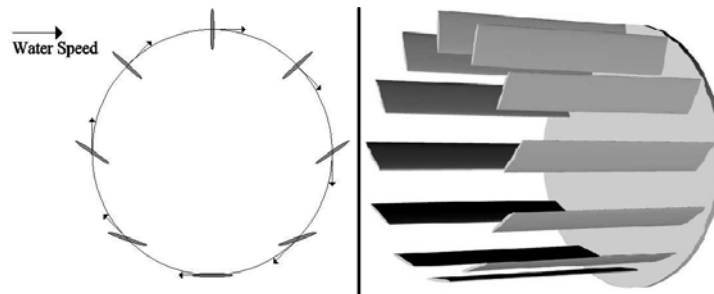
[“Developments in Ducted Water Current Turbines” Brian Kirke, *School of Engineering, Griffith University, PMB 50, Gold Coast Mail Centre, Qld 9726, Australia, 2003*]

CycloTurbine - BOSCH AEROSPACE (USA)

Technology: The CycloTurbine, a form of Cycloidal Turbine, is in essence a paddle wheel with articulating blades. The blades are long, straight, non-varying in width and symmetrical. They are arranged in parallel around the perimeter of a wheel forming a squirrel cage-like arrangement. The blades could be oriented vertically or horizontally. The need for bearings at the far end of the blades is dictated by the length and flexibility of the blade. The pitches of the blades vary independently from one another as the turbine rotates in the stream. This allows the blades' individual lift and drag to be optimized, giving the system its best overall performance. The turbine has the advantage of working without high head pressures. The CycloTurbine works by placing a blade broadside to the flow while the opposing blade is feathered to the local flow. The illustration below shows the blade positions of a horizontal Cyclo Turbine. At all other locations the angle-of-attack of each blade is optimized to produce the maximum power. The maximum power occurs when the turbine tip-speed is equal to $1/3$ the flow speed. In a vertical blade arrangement, the generator and bearings could be situated above water which has great advantages for accessibility during maintenance. It also reduces the complexity and number of water seals. The efficiency can be increased by installing a ramp to "shade" the bottom of the turbine which is moving upstream against the current. An unducted prototype turbine was measured to have an efficiency of 39.6% and a water to wire efficiency of 29.3%.

Application: These turbines would work in rivers, tidal estuaries, and in manmade canals. The horizontal application is particularly well suited to shallow rivers. The system could operate in tidal applications by reversing the pitch control pattern.

Stage of Development: A small hydro CycloTurbine was demonstrated in a laboratory setting in the summer of 2002. The development of the CycloTurbine for its primary application in vertical lift-off aircraft has been moving forward steadily since 2001. In 2006 a new hydro prototype is being constructed which replaces the belt drive with gears which should increase efficiency.



WPI Turbine- WATER POWER INDUSTRIES (Norway)

Technology: The WPI Turbine is an unducted Darrieus type cross-axis turbine with independent electric motors controlling the pitch for each blade. From the diagrams it appears that the blades are symmetrical, straight, and uniform in width. A number of vertical foils are suspended from a horizontal star down into the running water. The foils' angle of attack is electronic controlled by chips and special encapsulated motors and based upon the present water speed. The turbine can be stopped or started by feathering or un-feathering the blades. The turbine's rotational speed can also be controlled by the blade pitch. In normal operation the pitch of each blade varies independently from the other blades as the turbine rotates allowing each blade's individual lift and drag to be optimized throughout 360 degrees of rotation. A third party measured the turbine's efficiency at 49.9%. The turbine's physical size, velocity requirements and site requirements are not publicly available on WPI's website. WPI is investigating systems with the following power ratings: 100, 200, 300, 500 and 1000 kW.



Application: These turbines are suitable for tidal straits as well as non-tidal rivers and in manmade canal applications, such as hydropower plant tailraces, which are the focus for WPI.

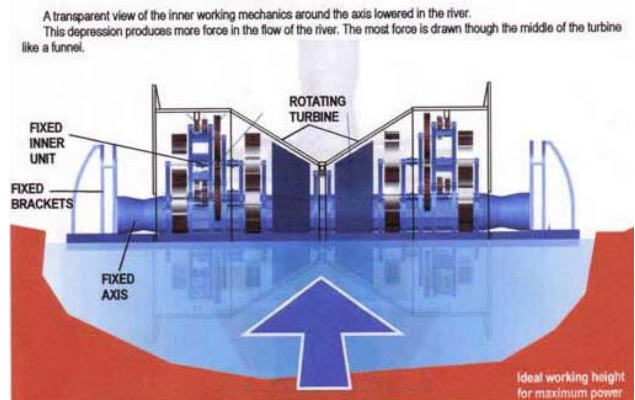
Stage of Development: In 1999 WPI had favorable tests with a small model. In 2000 they received a grant from the Norwegian Research Council of 1 million NOK to build a larger scale prototype for river testing but it was capsized in a river flood. They have continued performing lab testing over several years. WPI has patents in Eurasia, Australia, OAPI, China, and the EU and pending patents in India, USA, Canada, Brazil, Japan and Norway.



3.3.3 Paddlewheels

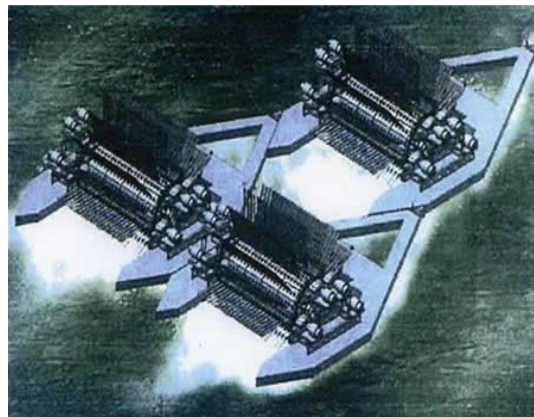
Floating Power Station- ECO HYDRO ENERGY LTD. - (Canada)

Technology: The floating power station is anchored in an existing river system. Flexible rotor blades are mounted on an axis which rotates, providing a turbine effect. The flexible rotor blades are arranged along the rotor axle in staggered rows. The blades also extend gradually outwards in relation to the axis. The effect creates a very high level of torque at the axle. The rotating assembly directly drives conventional electromagnetic generators. The system also causes an aeration effect which oxygenates the river at and downstream from the generation site. The complete unit can be towed from one location to another thus providing significant level of power generation on a given site at extremely short notice and on a highly economical basis. The developer claims the system can be built in any size from 100 KW hours to 500 megawatt hours dependant upon power requirements as well as river characteristics including depth, width and flow velocity. Because the units are modular, larger floating power systems can be assembled from individual units.



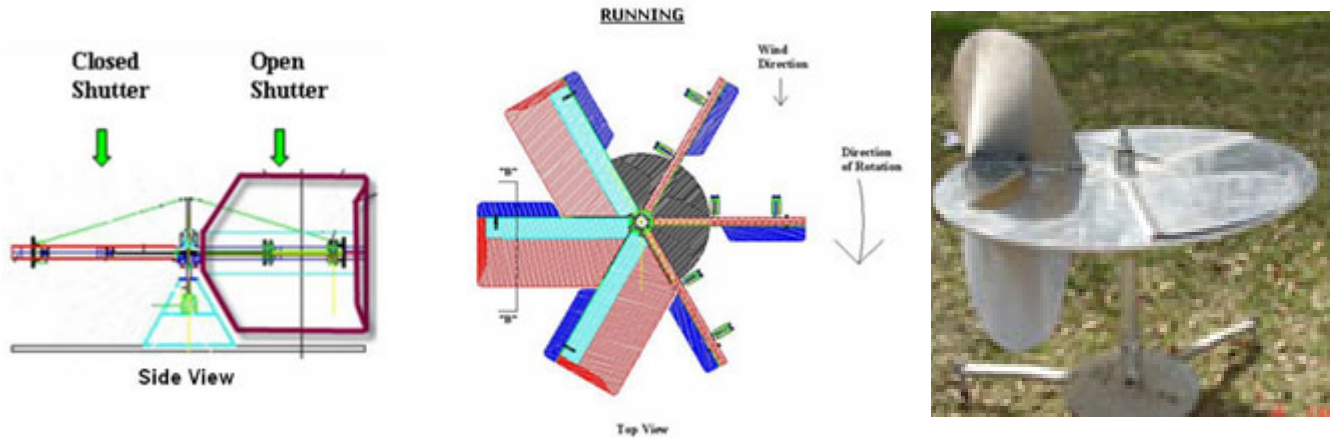
Application: NTR's. Possibly tidal rivers if platform is allowed to swing around with changing tide. Depending on the river, floating turbines can be installed in arrays, a fixed distance apart.

Stage of Development: The Company manufactured five prototypes in Brazil with various generating capacities. These prototypes went through extensive testing. While the developer believes the product is now ready for market, further testing will continue under the auspices of the Federal University of Itajuba in the state of Minas Gerais. Manufacturing and installation protocols are nearing completion to enable manufacturers in multiple global locations to manufacture the product to Eco Hydro's specifications and quality requirements. The Company is marketing the technology through a global network of Licensees. Each Licensee entity will have responsibility for marketing and sales and also for manufacture, installation and commissioning of systems.

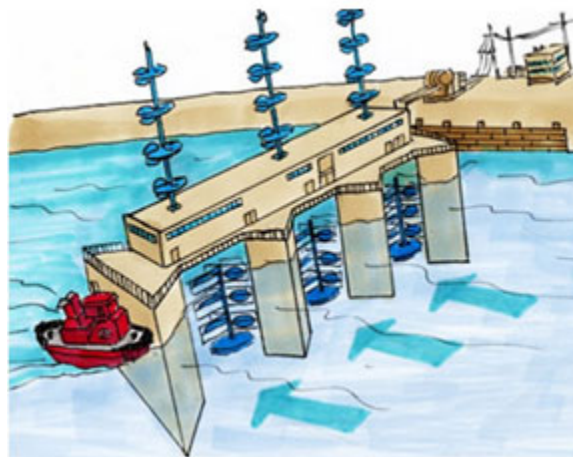


RiverBank Hydro Turbine- ENCORE CLEAN ENERGY INC (Canada)

Technology: A patented high-torque fully submerged folding-vane turntable paddlewheel in which the buckets are open for the drag portion of the cycle, but folded flat/closed for the upswing and lateral portions of the rotation. The large flat “shutters” open, like a sail, to create a large surface area that can optimally capture the force being exerted by on-coming wind or water to rotate the carousel-like device.



As the open shutter is pushed by the energy of the wind or water flow, it rotates the turbine shaft, producing high-torque to drive a generator. When the shutter snaps open from the force of the water flow, hydraulic cylinders connecting the shutters pump pressurized hydraulic fluid, producing high-pressure hydraulic energy which may power a separate hydraulic motor to boost rotation and efficiency of the turbine. As the open shutter rotates away from the water flow, the shutter closes, like a clam-shell, lowering its profile like an aerodynamically-balanced airplane wing to reduce drag resistance along the drag-side of the rotation into the wind. Encore is also designing a floating partial barrage system that would incorporate the described turbine and could be easily towed into place and moored in a river.



Application: NTR's, Tidal, and ocean currents

Stage of Development: Encore is constructing operational prototypes of its RiverBank turbine. No test data is yet available. Encore is the majority partner in the World, Wind and Water LLC,

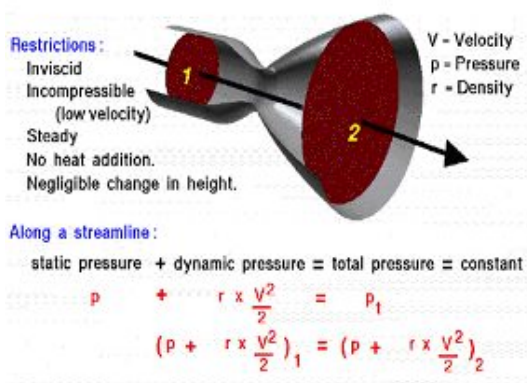
3.3.4 Hydraulically Tapped Duct Systems

Rochester Venturi - HYDROVENTURI (UK, USA)

Technology: The Rochester Venturi exploits two simple well known phenomena—it is difficult to compress water, and, liquid or gas passing over a curved surface will generate a vacuum on the trailing edge of that surface. These phenomena are described by the Bernoulli Effect. HydroVenturi uses a technology based on these simple principles to accelerate water through a choke system (see figure below). The acceleration creates a pressure drop in the device. This pressure drop is used to drive turbines. Using coupling devices, the turbines can be situated above water or even on shore. This removes the need for complex moving parts or electrical parts in the water. There are three main advantages of this method of extracting energy: 1) The absence of moving mechanical or electrical components in the water implies minimal maintenance costs; 2) The HV systems could be submerged so that there are no visual impacts and shipping would not be impeded; and 3) The suction output from several venturis could be connected in parallel to the same generator, providing economy of scale. An underwater barrage, honeycombed with venturis, can consist of a string of concrete caissons sunk roughly in a line. These could be re-floated for maintenance or for moving to another site, by pumping out the water used to flood them when they were sunk. RV's are modular and can be used to create systems from 50kW to 500MW which have a 20% water to wire efficiency.

Application: The system is designed to operate in tidal, ocean, and river currents.

Stage of Development: HydroVenturi has spent the past 3 years developing and improving their systems by 1) extensive testing in our installation in the North of England, and more recently their current design near Derby. 2) development of new and improved technologies in the primary system and in the power take-off and control electronics, 3) development of novel applications in our technology for low head hydro and tidal sites, 4) in-depth feasibility studies of a range of locations, for example in Scotland, Canada, New York, Iceland and New Zealand. Since 2005, HydroVenturi has been developing an ultra-low head hydropower demonstrator site in the English Midlands.



3.3.5 Fan Belt

Aquanator- ATLANTIS ENERGY- (Australia)

Technology:

The Aquanator use a series of aquafoils (lift vanes) mounted on a belt or chain which slides on an oval track 57 m across and 9 m high. The structure is mounted completely underwater. Its mooring method is undisclosed. When the tide shifts the belt rotates in the opposite direction. Flows of about 1.0 m/s will rotate the aquafoils and generator, producing 1.0 MW of electricity.

Application:

The company's main focus is capturing the energy of the Australian (ocean) current. Its horizontal layout and low aspect ratio (height over width) makes it ideal for river applications. The present design is 9 m tall x 57 m long which limits its use to mid-range and deeper rivers. The device may be scalable to a smaller configuration which would be appropriate for river applications. It is designed to produce 1 MW at a water velocity of 1 m/s.

Stage of Development:

Prototypes of unknown size have been field tested as seen in the photo. They hope to have up to 25 units in production in the next five years.

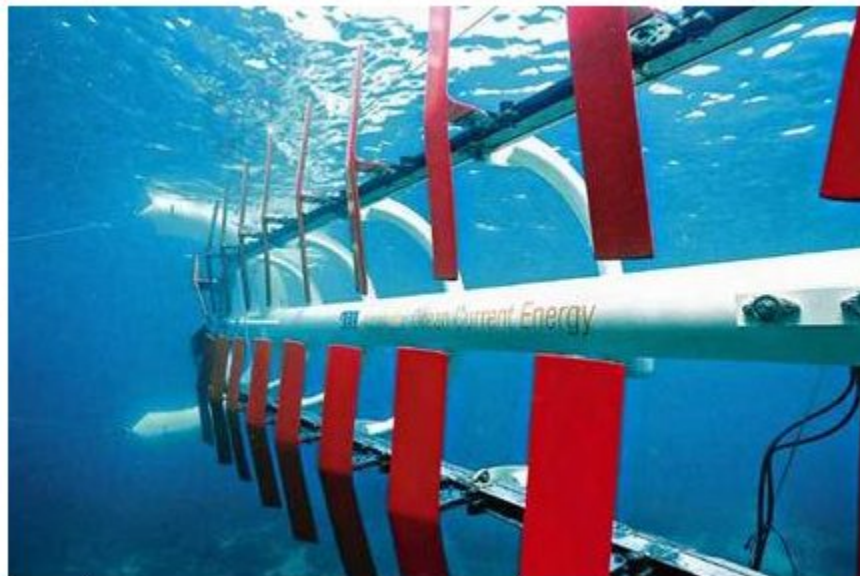


Photo: Sydney Morning Herald

3.3.6 Flutter Vanes

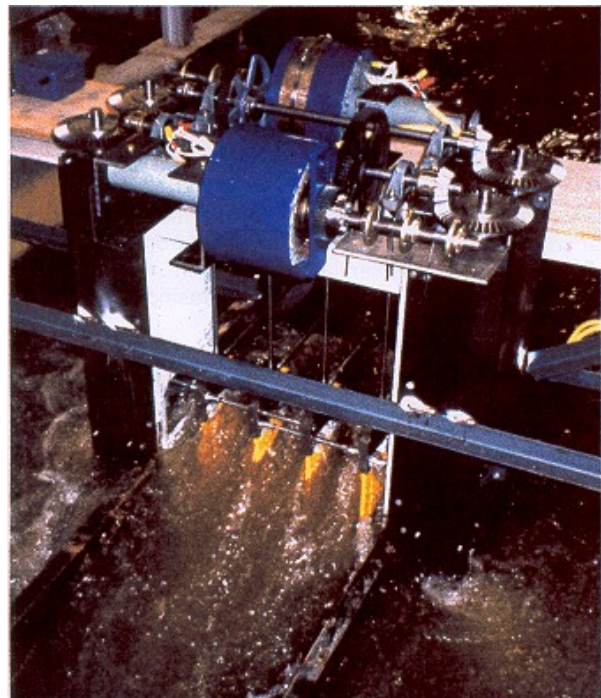
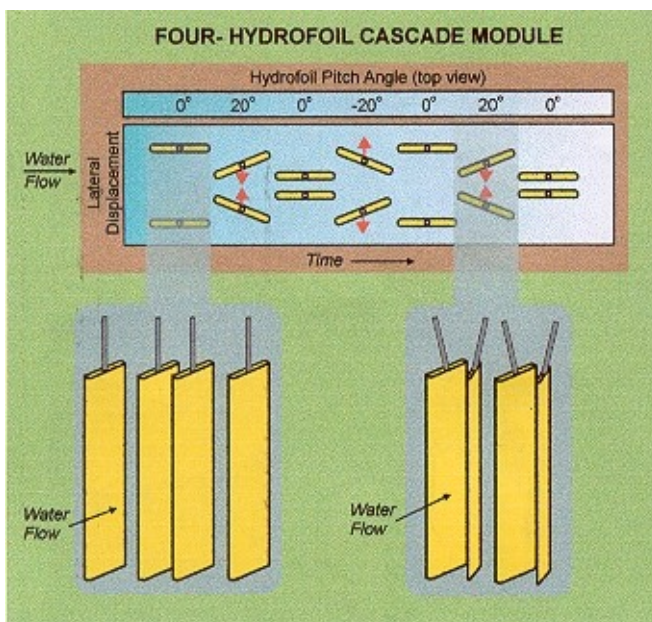
Oscillating Cascade Power System - ARNOLD COOPER HYDROPOWER SYSTEMS (USA)

Technology: In the Arnold Hydroelectric Power System or Oscillating Cascade Power System (OCPS), the hydrofoils are long, straight, non-varying in width and symmetrical (see figures below). They are arranged in parallel and in foursomes such that the blades are allowed to move towards and away from each other in a mirroring fashion. The interaction between the blades is quite complex in that the pitch of the blades is varied and the blades are alternatively attracted and then repulsed by the adjacent blade such that an oscillating motion is created. The gearing translates this back and forth motion into rotational energy for a generator. The pitch of the blades may be forced mechanically via the gearing or may be naturally induced by the unstable path of the water. The blades can be arranged vertically or horizontally to best fit the stream cross section. The efficiency of the system is not known. In a vertical blade arrangement the generator and gearing could be situated easily above water which has great advantages for accessibility during maintenance and in reducing the complexity and number of water seals. The need for bearings at the far end of the blades would be dictated by the length and flexibility of the blade.

Laboratory tests have shown that a typical 7.32m x 3.05m x 0.91m module in a 3.05 m/s flow will produce about 200 kW and 60 percent efficiency in conversion of kinetic hydro energy into electric power.

Application: Shallow water NTR's, tidal areas, and manmade channels. The system can be made to operate easily in reverse for tidal applications.

Stage of Development: Prototypes have been built and run in flow tank settings. Presently, changes are being made to replace the complex gearing with some other technology, possibly hydraulics. No commercial units have been built to date.



4 Investigating Energy Production Estimates:

4.1 Technology Performance

The primary means of quantifying WCT technical performance is by measuring various system efficiencies. Of primary importance are the efficiency of the turbine, gearing, bearings, generator, electric power conditioning system, and power transmission system. This can be represented as follows:

- **Turbine Efficiency** =
$$\frac{\text{Mechanical Shaft Output Power of Turbine}}{\text{Kinetic Power in Water Impacting Turbine}}$$

- **Total System Efficiency** =
$$\frac{\text{Grid Ready Electric Power Output}}{\text{Kinetic Power in Water Impacting Turbine}}$$

$$= f_{\text{WCT}} = f_{\text{Turbine}} \times f_{\text{Drivetrain}} \times f_{\text{Generator}} \times f_{\text{PowerConditioning}}$$

The turbine at present is the weakest link in the efficiency chain.

The table below gives the performance characteristics for the units discussed in Section 3.

Table 2 - Device Comparison Based on Turbine Type, Size, Water Velocity, and Unit Power Output

<u>Company</u>	<u>Technology Type</u>	<u>Turbine Size</u>	<u>Water Velocity</u> [m/s]	<u>Unit Power Output</u> [kW]
Alternative Hydro Solutions	Freestream Darrieus Water Turbine	3.0m dia x 2.5 H	1.4	2.6
Arnold Cooper	Oscillating Cascade	7.3 x 3.0 x 0.91	3.04	200
Atlantis Energy	“Aquanator”, fan-belt lift vane	57m wide x 9m tall	1.29	1,000
Blue Energy-Canada	“Davis Hydro Turbine”, Ducted Darrieus	2 turbines @ 6.1m dia.	no data found	500 = (250 x 2)
Bosch Aerospace	“CycloTurbine” Cycloidal Turbine	Prototype is 1m dia.	no data found	no data found
Clean Current	Tidal Turbine Generator, Ducted Axial	14m	no data found	~1 MW
Eco Hydro Energy Ltd	Floating Power Station	(2) x 18 m wheel + 14 m blades	1.35 m/s	no data found
Encore Clean Energy Inc	Turntable paddlewheel in floating ductwork	no data found	no data found	no data found
Energy Alliance	“Submerged Hydro-Unit” Ducted cross-axis	1-5 kW portable and >10 kW stationary unit	no data found	1-5 kW and >10 kW
GCK Technology	“Gorlov Helical Turbine”, twisted Darrieus	1.0 m dia. x 2.5 m long	@1.3 m/s	0.70 kW

Hydro Venturi	Hydraulically tapped Venturi with surface air turbine	no data found	no data found	no data found
Hydrohélix Energies	“Marénergía”, ducted axial	8 m dia.	no data found	250 kW
New Energy	“EnCurrent Hydro Turbine” Ducted Darrieus	Turbine: 1.6 m dia x 0.8 h Duct: 3.0 wide x 1.0 high	2.5 m/s 2.5 m/s	2.8 kW unducted 13.0 kW ducted
Marlec	Axial, unducted	1.8 m dia	1.5 m/s	0.50 kW
PEEHR	“Hydroreactor”, ducted axial flow	1.2 m dia turbine in 5.4 m dia duct	2.75 m/s	30 kW
Ponte di Archimede	Kobold Turbine	6.0 m dia and 5.0 m high	2.0 m/s	25 kW
Swan Turbines	Axial, unducted	1.0 m (small prototype)	Operating range 1.80 to 2.83	1.5 kW
Tidal Energy Pty. Ltd	Ducted Darrieus	no data found	no data found	no data found
Thropton Energy Services	Axial, unducted	4.0, 3.4, 2.8, 2.2, 1.8 m	0.5 to 1.5 operating range †	up to 2 kW at 12-14% system efficiency
UEK	Dual Axial, ducted	Dual 3 m	2.57	90 kW
Verdant Power	Axial, unducted	5 m	2.1	35.9 kW
Water Power Industries	Active Pitch Controlled Vertical Axis Darrieus Turbine	No data found	No data found	100, 200, 300, 500 and 1000

NOTE: The data is based on manufactures claims

†Data Source: Renewable Energy Technical Assessment Guide - TAG-RE: 2004 Report - Product Number 00000000001008366. Published Dec 2004.

5 Investigating Production Cost Estimates

5.1 General Considerations

To paraphrase EPRI's comments in its soon to be released 2006 study of Tidal In-Stream Power Plants, the economics associated with WCT systems are uncertain. There have been, to date, no long term commercial-scale demonstrations of a meaningful number of systems. Individual developers' projections of all inclusive costs suffer from a lack of maturity in the electricity generation industry, marketing hype published to attract critical private equity dollars, and a healthy dose of wishful thinking. More dispassionate analyses seem to be forthcoming from those developers with several years of exposure to real world conditions, especially those who have advanced from the laboratory to full scale field testing. Even more so, significant detail on cost history and projections can be gleaned from reliance on a growing body of analysis emanating from the closely aligned tidal energy industry. Indeed, many of the initial entrants into the WCT arena will be transplants from the tidal stream industry. Thus some degree of reliance might be made on projections generated by this slightly more developed sector.

Cost comparison between WCT systems and tidal stream systems

Factors suggesting *reduced* WCT costs:

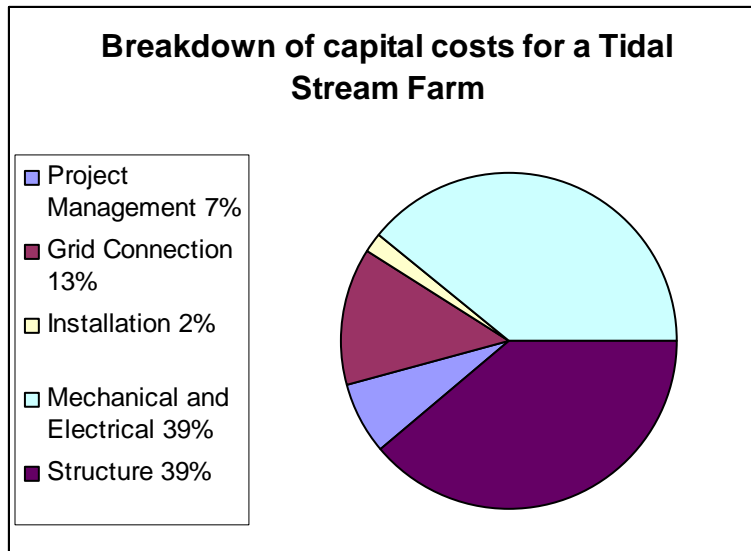
- 1) Per kW/installed costs should be lowered due to greater capacity factors based on increased potential operating parameters; i.e., due to the ebb and flow of tides and the inability of the tidal units to operate below certain velocities, capacity factors on tidal units generally run between 25 and 35 %. Other than scheduled and unscheduled maintenance properly sited WCT systems should operate close to 100% of the time. Commercial scale systems should have equipment availability factors comparable to traditional hydroelectric plants in the 90% + range.
- 2) Generally deployed in more shallow water, requiring less sophisticated mounting structures, including less costly mounting related personnel and equipment costs
- 3) Reduced mechanical complexity due to uni-directional flows of rivers and man made conduits versus tidal operations. The one way current flow eliminates the need for yawing mechanisms and or variable pitch controls on blades, traits found on many tidal oriented systems,
- 4) Generally not deployed in salt water, resulting in less corrosion
- 5) Some WCT designs hold all electrical components out of the water, reducing the need for expensive seals, perhaps reducing O&M intervals, and reduced scheduled servicing costs due to easier access
- 6) Underwater cabling costs should be lower as WCT units will normally be closer to shore facilities, as the energy conversion devices will not be far out to sea
- 7) Smaller, thus more easily manufactured by a greater number of fabricators, using a larger variety of possible fabrication materials and techniques

Factors suggesting *increased* WCT costs:

- 1) Per kW installed costs may be greater due to lower kW system capacity over which to spread fixed costs such as permitting, site engineering, shore equipment/facilities, transmission costs, etc.
- 2) Icing and or debris management costs may be higher than experienced in open tidal areas

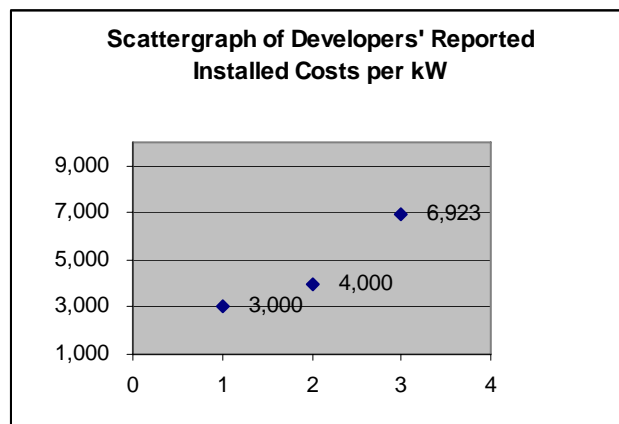
5.2 Component Cost Breakdown

The most recent comprehensive study¹ of WCT’s closely aligned tidal stream systems confirms internal analyses conducted by this study’s authors. The cost allocation of capital costs for a generic tidal stream farm is as follows:



5.3 Developer Disclosures

Most developers have not yet had any third party sales of their units, much less complete installed, permitted operating systems, and therefore lack any product cost data. In addition, many have not yet realized any operating history in real life conditions and thus lack any O&M experience.



What the above graph illustrates is the wide disparity in reported costs amongst a representative sample of developers currently engaged in the WCT market. Several factors may explain the variance including; lack of standard definition as to what components are included in a typical system (some may include only the energy conversion device itself with no interconnection support), lack of standard definition as to operating parameters (some developers assume availability of high velocity natural resources found only in rare instances), and assumed production volumes. Starting at minimal current

¹ “Future of Marine Energy, Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy”, The Carbon Trust, UK, January 2006.

production volumes, and with learning curves projected to be approximately 15%², the assumption of higher volumes quickly drives down resulting costs. Standardization of these assumptions may considerably tighten the range of responses.

5.4 Industry Analyses

While the quality and quantity of data originated by developers increases there are several key observations that can currently be made. The first is that instant installed costs are not unfavorable relative to solar or even conventional hydropower. Nor are they unfavorable relative to wind power costs at a similar stage of development according to this Carbon Trust historical review³.



Over and above relative capital costs comes the question of the resulting cost of energy, which includes all cost factors such as fuel, O&M, re-furbishments, etc. Again, the closest technological relative to WCT is the slightly more mature tidal stream industry. Recent analyses and projections performed by The Carbon Trust (ibid, page 21) in January 2006 indicate opening costs of energy at approximately 9 pence (equal to 18.2 ¢), dropping to as low as 3.5 pence (equal to 7¢) in optimal sites when total installed capacity reaches approximately 3,000 MW. Again, adjustments need to be made to convert the conditions of tidal operation to uni-directional river flow and conduit systems. See section 5.1.

² “Experience Curves for Energy Technology Policy”, IEA, 2000.

³ “Future of Marine Energy, Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy”, The Carbon Trust, UK, January 2006.

6 Canada in Perspective

6.1 Canadian WCT Companies and Technology

Six Canadian companies are at the forefront of WCT NTR technology; Alternative Hydro Solutions, Clean Current, New Energy, Eco Hydro Energy Ltd, Verdant Power Canada and Blue Energy. Another company Encore Clean Energy Inc is in more preliminary design work. All together, the Canadian companies cover the complete range of WCT technologies including axial flow turbines, cross-axis turbines, paddlewheels, ducted and un-ducted systems, floating, piling, and weight deployed WCT's. They range in size from approximately 1 kW to 1 MW. At least two of the companies, Alternative Hydro Solutions, and New Energy are selling production units. These two represent perhaps half of companies in the world doing so (the others being Energy Alliance and Marlec).

6.1.1 Review of UK Research Support

A review of British efforts is relevant as their efforts can provide a template that Canada can build on to become a world leader in riverine based hydrokinetic power.

Britain's efforts have focused primarily on large ocean and tidal applications, Britain's main testing facilities are in Scotland around the Orkneys with state-of-the-art facilities at Stromness. Marine Energy Group (MEG) formed by EMEC to assess the potential for tidal and wave energy development. Very little of the effort to date has been focused on river development. A key driver in developing British wave and tidal energy capacity is the economic benefits that will flow from device deployment. The development of commercial scale wave and tidal farms (as opposed to demonstration projects), and the orders for devices this will create, are expected to produce significant job benefits.

The next 5 years are considered crucial in determining whether the UK and Scotland in particular, can build on technology advantage and create a viable domestic and international market for marine energy devices. The conclusions and suggested actions that follow are not listed in order of priority or sequence. Rather, they describe a range of complementary themes and issues that MEG believes can and must be addressed in parallel if marine energy is to make a significant contribution to the Government's renewable energy aspirations and targets beyond 2010:

- Creating market pull and reducing financial risk
- Developing the role of EMEC
- Establishing Scotland as the centre for marine energy certification
- Developing a supportive planning and regulatory framework
- Providing a route to market
- Developing academic capacity and supporting R&D
- Supporting skills and manufacturing capability

These same basic steps will need to be incorporated into any Canadian plan to establish world preeminence in NTR technologies.

6.1.2 International Development Path Divergences

A difference in approach to the harnessing of the potential energy available in the movement of water is manifesting itself primarily between the UK and other countries. Although there are exceptions, the trend for UK R&D has been to focus on relatively larger (150 – 300 kW) energy conversion devices. Due to the size of these units, many of them 30 -40 tonnes and 20 metres tall, they require water depths of 30+ metres. With few exceptions this scale is met only by offshore locations, with which the UK has in relative abundance. The UK may have the world's most favorable offshore resources of this nature, ratifying its attention to this capacity scale.

Outside the UK developers are generally pursuing smaller scale energy conversion devices, many in the tens of kW capacity range, rather than in the hundreds of kW per unit. These smaller scale units appear to be a reflection of the widespread availability of shallower and particularly inland river sites found commonly throughout the world.

While both approaches envision the installation of significant numbers of units working in tandem to potentially produce substantial capacity, the UK model seems to be more in keeping with the centralized power generation model, dependent on a supportive transmission system (including physical infrastructure as well as amenable policy attributes) more than the non-UK systems.

6.2 WCT Resource Potential in Canada

6.2.1 NTR WCT Resource

A major study of Canada for the NTR WCT potential resource was performed back in 1980 by the UMA Group [An Evaluation of the Kinetic Energy of Canadian Rivers & Estuaries, the Underwood McLellan Ltd (the UMA Group), March 1980]. In the study, 14 major rivers were evaluated for potential energy production using “no-head” hydroelectric devices. The study assumed that 1.5 metres per second was the minimum feasible current velocity. It was further assumed that the minimum cross-section flow required is 50 metres wide, by 3 metres deep. As the following table (reproduction of Exhibit 1.1 of the study report) summarizes, three main river reaches and thirteen tidal current cross-sections within two tidal areas were deemed to meet the minimum criteria, potentially producing 110 megawatt-hours per year of kinetic energy.

The following table contains the total power estimates found in the 1980 study.

Location	Total Available Power (MWh/year) x 10 ⁶	Average Annual* Power Output (MWh/year) x 10 ⁶	Existing Electric Power Plan Capacity (MWh/year) x 10 ⁶	
Fraser River - from Strait of Georgia to Chinee Creek	2.01	0.38		
West Coast tidal areas:				
-Discovery Passage	10.07	3.54		
-Okisollo Channel	1.55	0.54		
-Cordero Channel	0.34	0.12		
Total (B.C.)	11.96	4.20	61.81	
Mackenzie River -from Jean-Marie Creek to Fort Simpson	33.18	3.87		
Slave River -from Great Slave Lake to Brule Point	45.67	8.55		
Total (N.W.T.)	78.85	12.42	1.07	
Bay of Fundy	20.59	3.85	81.86 (Maritimes)	
Cross-section reduction assumptions used to calculate Average Annual Power Output:				
	Width	Depth	Navigation	Mechanical & Electrical Efficiency
Fraser River	80%	67%	100%	35%
West Coast	100%	100%	100%	35%
Mackenzie River	80%	67%	67%	35%
Slave River	80%	67%	100%	35%
Bay of Fundy	80%	100%	67%	35%

NOTE: The flows stated above include river and tidal flows. The data is inadequate to try to attribute power to the different types of flow.

6.3 Canadian Government Support

The following sections deal with key areas that the federal and provincial governments may consider in order to promote the development of NRT.

6.3.1 Funding

Encourage and fund new commercial hydrokinetic power projects by establishing low cost renewable energy debt financing instruments/grants that include hydrokinetic power generation as a qualified generation source to be used to fund construction of hydrokinetic projects.

To encourage the deployment of renewable, secure, locally distributed hydrokinetic power generation as a qualifying source, implement appropriate incentives to accelerate energy deployment in the following types of programs at the federal and provincial level:

- Renewable Portfolio Standards (RPS)
- Renewable Energy Credits (REC)
- Net Metering Programs
- Feed-in Tariff

6.3.2 Research

Support research, development and deployment projects to collect information on the technical performance and environmental impacts of hydrokinetic power systems. This should be done on a provincial and regional policy basis.

Provide financial support for development of emerging water technologies with federal and provincial research and development programs. Such programs are extremely important in helping developers assume the risk of demonstration projects to test new technologies.

Develop joint federal and provincial program to update the work done on river assessments in 1980 and to develop uniform assessment of river, tidal and ocean current that is publicly available to developers and planners to coordinate optimal use of resources balanced with environmental concerns.

6.3.3 Permitting

Clarify permitting programs to encourage demonstration projects by making a distinction between the requirements for demonstration projects and long term commercial development. This would speed the process to put demonstration projects in the water to gather performance and environmental information. Information gathered from these demonstrations could serve as the basis for conditions for licensing of full scale commercial operations.

Develop collaborative permitting programs at the provincial and regional level that coordinate requirements from all of the jurisdictional agencies, including federal, to avoid duplicative processes and reduce the time and cost to deploy demonstration and ultimately commercial projects.

6.3.4 Regulations

Ensure that development rights are allocated through a transparent process that takes into account provincial, local, and public concerns

7 Summary

This report is intended to provide NRCan with an overview of the state of development of water current turbines which can potentially be used to take advantage of Canada's abundant river resources without the need for additional impoundments. The report has focused on five critical objectives:

Evaluate the present status of WCT technologies being developed in Canada and internationally and their state of development

Describe the types of technologies and the parameters

Provide energy production estimates

Estimate cost of production

Analyze Canadian technologies relative to international developments

The intent is to provide the NRCan with the broadest background on technologies and the state of development to use in its internal decision process as to how the Canadian federal and provincial governments can best establish policies and programs to aid the development of river based water current turbines for domestic application and international export.

APPENDIX

Appendix 1 -- Definitions

ADCP - Acoustic Doppler Current Profiler: a computer interfaced sonar device that is used for measuring water velocities at any depth. It is usually mounted to a boat which then would cross the river. The ADCP would then be able to construct a two dimensional cross section of the river showing the water velocity at all points and depths.

Back Pressure: any obstacle in a river such as a rock or turbine that creates a pressure rise immediately in front of the obstacle and a slight increase in the elevation of the water (a “bulge”); the size of the bulge depends on the water velocity and the size and permeability of the object. If the obstacle were too close to the tailwaters of a hydropower operation, this rise in tailwater elevation would effectively decrease the head across the hydropower turbines, decreasing their performance. For this reason, WCT’s would not be sited immediately downstream of an operating hydropower facility.

Capacity Factor:

$$\text{Capacity Factor} = \frac{\text{Actual Annual Energy Output [kWHrs]}}{\text{Generator or System Capacity [kW]} \times 8760 \text{ [Hrs]}}$$

Deployment: the physical structure for mounting a WCT system in a river; also can refer to the act of actually mounting WCT’s.

Excedences: used in this report to denote the percentage of time within a year a current’s velocity is equal to or greater than its specified velocity.

Free-Flow Hydropower: Another term for WCT

Green Energy: energy whose production causes minimal negative impacts on the environment with regard to varying norms.

Hydrokinetic Energy: is the energy associated with the motion of water currents. In the case of WCT, this energy is found in rivers, tidal and ocean currents, and manmade channels such as aqueducts, canals, sluices, and tailraces.

Impoundment Hydropower: uses a dam to store water and/or increase the head. Water may be released either to meet changing electricity needs or to maintain a constant water level.

Water Current Technologies (WCT): devices used to convert the kinetic energy from the motion of water currents into mechanical and electrical power. The devices do not rely on manmade impoundments, nor do they greatly restrict water velocities. They also do not create large amounts of head with blockage or back pressure.

Minimum Start-Up Speed: from a stop, a WCT will usually require a water velocity higher than its low end operating speed to start spinning. This is because when it is not spinning the turbine blades are usually in a stall condition. Axial-flow turbines have the highest (worst) minimum start-up speed.

Cross-axis turbines are better in that one or more blades will usually be in lift position even at zero speed. Depending on the technology, roughly 1.0 to 2.5 knots is the start-up speed for WCT. Once up and running the turbine can usually operate below this start-up speed.

Computational Fluid Dynamic (CFD) Modeling: new software simulation tools that can create a virtual model of a waterway, or turbine, and predict the behavior of the water flow through it. For river modeling, the operator can alter flow regimes, stage levels of upstream and downstream reservoirs, and add in manmade structures such as WCT turbines. Use of such systems may allow WCT resource analysts to determine WCT performance in a given river within hours at the desk instead of months in the field.

Run-of-River: used to describe hydropower projects in which the flow rate entering an impoundment equals the flow rate leaving the impoundment *in real time*. In other words, the water level in the impoundment remains constant. Run-of-river projects are often used for micro-hydro on steep slopes, where a small impoundment or natural rock weir acts to divert a portion of the flow through a penstock pipe which runs down the hill to the turbine. Sometimes WCT's are called Run-of-River technologies, but this can be confusing.

Tip Speed Ratio (TSR): the ratio of the velocity at the tip of the turbine blade over the velocity of the water. Turbines employing hydrodynamic lifting surfaces (hydrofoils) such as axial flow and cross-axis turbines will have TSR's greater than 1.0 and are more efficient. WCT's that employ impulse blade/buckets such as paddlewheels will have TSR's less than 1.0 and are less efficient.

Unconventional Hydropower Technology: unconventional turbine designs are developed for low power (< 1 MW) and low head (< 30 feet); free-flow turbines, and micro hydropower. There are three general types of unconventional hydropower systems: (1) elevation-drop systems; (2) free-flowing river/streams; and (3) micro hydropower projects. An elevation-drop hydropower system is defined as any arrangement that uses a dam or natural drops. Free-flowing systems use the kinetic energy from the water in motion. Micro hydropower sites are 100 kW or less. Micro hydro plants can utilize low heads or high heads.

Appendix 2 - Developer Contact Information

Company	Website	Contact information
Alternative Hydro Solutions Ltd.	www.althydro.com	Stephen Gregory, M.A.Sc., P.Eng., President Alternative Hydro Solutions Ltd. 323 Richmond Street East, Suite 421 Toronto, Ontario M5A 4S7 CANADA Tel: 416.368.5813 Mobile: 416.570.5813 sdgregory@althydro.com
Atlantis Energy	http://www.atlantisenergy.biz (website under construction at time of writing)	Mick Perry, Atlantis Energy Ltd, Level 1, 247 River Street, MacLean, NSW 2463 Australia
Blue Energy Canada Inc	www.bluenergy.com	Martin Burger, President and CEO Box 29068, 1950 West Broadway Vancouver, BC V6J 1Z0 CANADA Tel: 604-682-2583 General Info: inform@bluenergy.com Martin Burger: mjb@bluenergy.com
Bosch Aerospace	jboschma@islinc.com (no technology specific webpage available)	LTC (R) James H. Boschma Bosch Aerospace, Inc. 205 Lawler Drive Brownsboro, AL 35741 USA Tel: 256-852-5033
CLEAN CURRENT	www.cleancurrent.com (website under construction at time of writing)	Dr. Stephen Allison, President 1025 Belmont Avenue North Vancouver, BC V7R 1K3 CANADA Tel: (604) 924 9749 sva@aquaconsult.org
Cooper Union (Arnold Cooper Hydropower Systems)	ahmad@cooper.edu (no technology specific webpage available)	Dr. Jameel Ahmad Chairman, Dept of Engineering The Cooper Union for the Advancement of Science and Art 51 Astor Place New York, NY 10003-7185 USA Tel: 212-353-4294
Eco Hydro Energy Ltd	www.ecohydroenergy.net	Vancouver, BC CANADA info@ecohydroenergy.net

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New Energy Corporation Inc	www.newenergycorp.ca	Clayton Bear 3553— 31st Street NW Suite 473 Calgary, Alberta T2L 2K7 CANADA Tel: (403) 260-5240 clayton.bear@newenergycorp.ca

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SwanTurbines	http://www.swanturbines.co.uk/	James Orme Tel: +44 1792 295217 Fax: +44 1792 295903 Dr Ian Masters Tel +44 1792 295688 Fax +44 1792 295676 UK enquiries@swanturbines.co.uk
Thropton Energy Services	http://ourworld.compuserve.com/homepages/throptonenergy/homepage.htm	Dr. B. Sexon, Thropton Energy Services Physic Lane, Thropton Northumberland, NE65 7HU UK Tel: +44-1669-621288
Tidal Energy Pty. Ltd	none	Mr. Aaron Davidson, Director PO Box 273 172 Townson Ave PALM BEACH, QLD, 4221 Australia Tel: 61 7 5534 4421 Fax: 61 7 5520 2504 tidalenergy@yahoo.com.au
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