

North America Tidal In-Stream Energy Conversion Technology Feasibility Study

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Abstract

An Electric Power Research Institute (EPRI) study investigated the techno-economics of in-stream tidal energy conversion (TISEC) and, based on study results, recommends TISEC technology be evaluated at as a potential energy supply source to diversify and balance the energy supply portfolio of North America.

A group was out fishing under the Golden Gate Bridge and noticed that they had drifted west into the ocean. A young boy asked why. An older man pointed up at the moon and down at the water that was pushing them west and said "it is the moon pulling water towards it." The boy did not believe him. Then the older man said "engineers know how to build machines to use the energy in the moving water of the tides to make electricity." This time, the boy did believe the man and said "when I grow up I want to be an engineer and make clean electricity from the tides for all the peoples of the world."

The boy recognized that it would be wonderful to get energy from a resource as clean and pollution free as ocean tides. The technology, though young, exists to convert the power of ocean tides into electricity, the life blood of our society.

Existing tidal power plants include a 240 MW plant in France, a 20 MW plant in Nova Scotia and a 0.5 MW plant in Russia. These existing plants use dams to impound the tidal waters before releasing them through generators to convert the potential energy of the elevated water to electricity similar to conventional hydroelectric plants.

In 2005, the Electric Power Research Institute (EPRI) evaluated the techno-economic feasibility of tidal in-stream energy conversion (TISEC) in North America. TISEC devices are placed in the flowing tidal stream and harness the kinetic energy of the moving water. They do not require a dam or impoundment of any type.

Seven states and provinces in North America participated in this EPRI collaborative feasibility study; namely: Alaska, Washington, California,



Proposed Plant submerged and not visible

Massachusetts, Maine, New Brunswick and Nova Scotia. Cash and in kind funding support was provided by state energy agencies, the US Department of Energy through the National Renewable Energy Laboratory, utilities in those states and the worldwide TISEC development community. Key organizations that participated in the EPRI collaborative are shown in Figure 1.

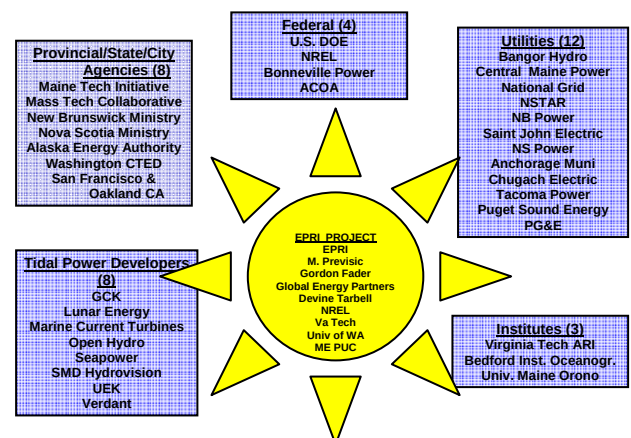


Figure 1. Collaborative Participants

The Benefits of TISEC Technology

Using tidal in-stream energy to generate electricity would provide many far-reaching benefits to North America. The primary benefit is that the construction, installation, operation, and maintenance of tidal power plants would create jobs, promote economic development, and improve energy self-sufficiency.

There are many compelling arguments for the use of tidal in-stream energy conversion technology. First, with proper siting, converting tidal in-stream

energy to electricity is believed to be one of the more environmentally benign ways to generate electricity. Second, since kinetic energy is a function of the density of the moving mass and its speed and water has high density, the power density of the tidal resource is high. Third, in-stream tidal energy offers a way to minimize the aesthetic issues that plague many energy infrastructure projects, from nuclear to coal and to wind generation. Since most TISEC devices are totally submerged they are not visible. Although variable in power level like many other renewable resources, tidal energy is predictable and therefore can be more easily integrated into the electricity grid for providing reliable power. Since a balanced and diversified portfolio of energy sources is the bedrock of a robust electricity system, tidal energy is consistent with North America's energy needs and goals. In-stream tidal energy is an important energy source and deserves a fair evaluation of its potential to add to the energy supply mix of North America.

A relatively minor investment today might stimulate a worldwide industry generating billions of dollars of economic output and employing thousands of people while using an abundant and clean natural resource.

Description of Study Technical Approach

EPRI feasibility studies use a systems approach (see Figure 1). The tidal study began with two parallel tasks; a survey of the potential sites in terms of a dozen or so attributes which make a good tidal site and a survey of the worldwide TISEC device technology.

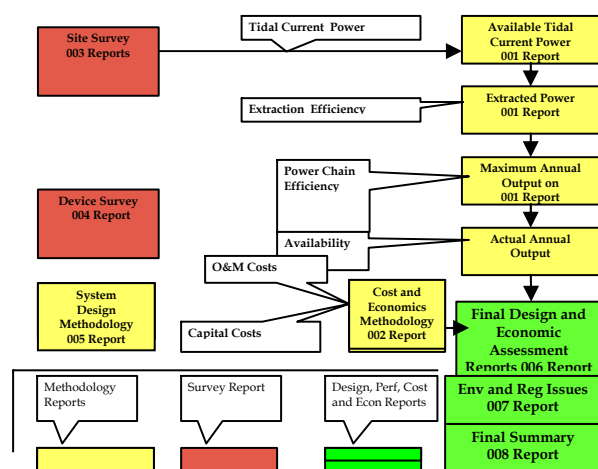


Figure 2. Feasibility Study Technical

State and provincial advisors selected a specific site and device for a techno economic feasibility study. The site selection results in how much energy is

available to be extracted and the device selection results in the efficiency of extracting that energy. The EPRI Project Team designed a plant system, calculated its annual energy output, estimated its cost both initial installed and yearly operation and maintenance, and calculated the levelized busbar cost of electricity (cents per kWhr) as described in EPRI performance and cost assessment methodology reports (Ref: 1 and 2).

Description of Sites

A good in-stream tidal site is one that has a large amount of fast moving water, has bathymetry and seabed properties that will allow a TISEC device to be sited, has minimum or no conflicts with other uses of the sea space and is close to a load and grid interconnection. EPRI surveyed potential sites in Massachusetts, Maine, New Brunswick and Nova Scotia and documented that work in four EPRI TP 003 reports (Ref: 3 - 6). In Alaska, Washington and California, the site and device was pre-selected. The seven (7) feasibility evaluation sites are shown in Figure 3 and described in the table below.

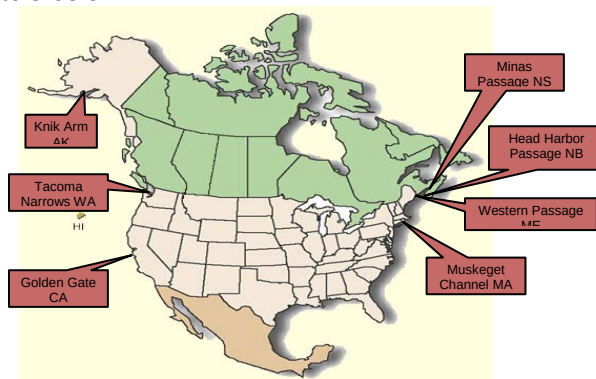


Figure 3. Tidal Sites in EPRI Feasibility Study

	AK	WA	CA	MA	ME	NB	NS
Cross Section Area (m ²)	72,500	62,600	74,700	17,500	36,000	60,000	225,000
Power Density (kW/m ²)	1.6	1.7	3.2	0.95	2.9	0.7-2	4.5
Available Power (MW)	116	106	237	13.3	104	43-100	1,013
Extract Power (MW)	17.4	16	35.5	2.0	15.6	6.5-15	152
# Homes Powered	12,000	11,100	27,300	1,500	12,000	5,000-11,500	117,000

Power is average annual; extractable power is limited to 15% of available power; assumed 90% power take off efficiency
 Number of homes powered assumes 1.3 kW per average home
 NB and NS power estimates have a higher degree of uncertainty than US sites due to lack of measurement stations in Canada

Description of TISEC Technology

Tidal energy extraction is complex and many different designs have been proposed. It is helpful to introduce these in terms of their physical arrangements and energy conversion mechanisms. Water turbines, like wind turbines, are grouped into two types: 1) horizontal axis turbines in which the axis of rotation is horizontal with respect to the ground and parallel to the flow direction and 2) vertical or cross flow axis turbines where the axis of rotation is perpendicular to the flow direction. Typical subsystems include rotor blades which convert the energy in the water to rotational motion, a drive train, usually including a gear box and a generator that convert the rotational shaft motion to electrical energy, and a structure that supports the rotor and the drive train. Other ways of grouping these devices include:

- Support Structure – devices may be either gravity base bottom mounted, attached to a monopile foundation or anchored and moored and allowed to “fly” in the tidal stream.
- Open versus shrouded rotors
- Fixed versus variable pitch blades
- Yaw control versus fixed yaw angle
- Drag versus lift water foil (vertical axis only)

Tidal power research programs in industry, government and at universities in the UK, Norway, Ireland, Italy, Sweden, Canada and the US over the last half dozen years has established an important foundation for the emerging tidal power industry. Today, a number of companies backed by private industry, venture capital and European Governments are leading the commercialization of technologies to generate electricity from tidal streams. In early 2005, EPRI requested information from all known TISEC device developers. Eight (8) devices were characterized with the objective of determining technology maturity and any critical issues relating to technological readiness for pilot plant demonstration testing in the 2009 time period (Ref: 7). A summary and photos and illustrations of the eight devices in alphabetical order follow:

GCK	Lunar	MCT	Open Hydro	Sea power	SMD Hydro	UEK	Ver-dant
V axis Lift	H axis Duct	H axis Dual	H Axis Rim Gen	V axis Drag	H axis Dual	H Axis Dual	H axis
1 m dia	21m dia	18 m dia	15 m dia	1 m dia	8 m dia	3 m dia	5 m dia
7 kW	2 MW	1.5 MW	1.5 MW	44 kW	1 MW	400 kW	34 kW

1) Axis type; 2) Diameter of the rotor and 3) Rated power

EPRI Advisors selected three TISEC devices for the design phase of the study: Lunar Energy, Marine Current Turbines (MCT) & Verdant Power.

- Lunar Energy's RTT 2000 is a fully submerged ducted turbine with the power conversion system inserted in a slot in the duct as a cassette. This allows the critical components to be recovered for operation and maintenance. Lunar performance was estimated (see Ref: 9 and 11-15), however, since the engineering design was not completed at the time of this study (Jan- Mar 2006), no cost estimates were made by EPRI of the RTT 2000.
- Marine Current Turbines' (MCT) SeaGen consists of two horizontal-axis rotors and power trains (gearbox and generator) attached to a supporting monopile by a cross-arm. The entire assembly is called a “turbine.” The monopile is surface piercing and includes an integrated lifting mechanism to lift the rotors and power trains out of the water for maintenance. MCT provided engineering specifications upon which an EPRI independent cost estimate was made.
- Verdant Power's turbine was designed for the East River in New York and is 5 meters in diameter. This design was judged to be too small for the seven sites under study. Furthermore, we judged it inappropriate for EPRI to attempt to scale up the design for costing purposes.

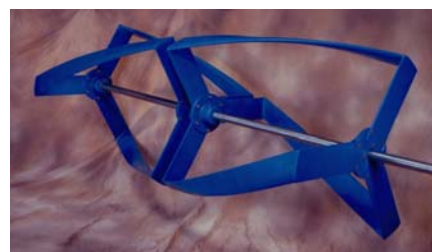


Figure 4. Gorlov Helical Turbine

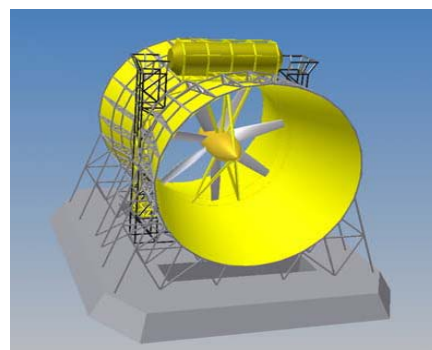


Figure 5. Lunar Energy RTT Turbine



Figure 6. MCT Experimental SeaFlow

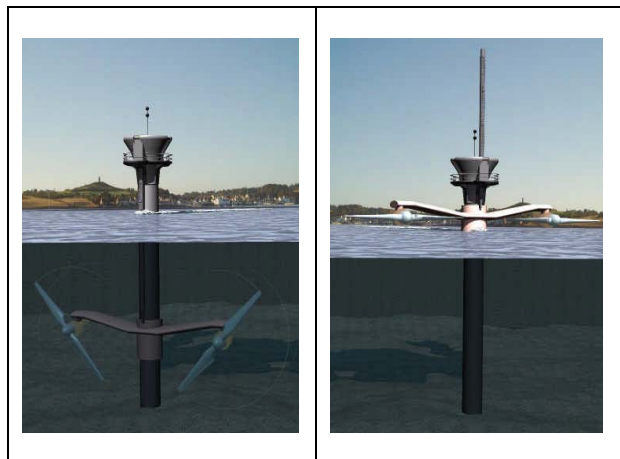


Figure 7. MCT SeaGen Prototype



Figure 8. Open Hydro Rim Drive Turbine

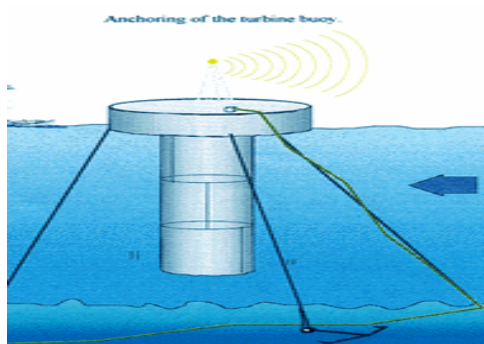


Figure 9. Seapower Vertical Axis Turbine

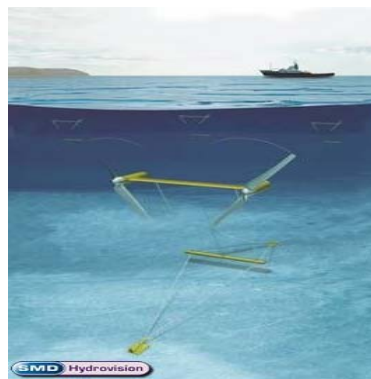


Figure 10. SMD Hydrovision



Figure 110. UEK Shrouded Turbine



Figure 121. Verdant Power RITE Turbines

The purpose of the EPRI study was to assess the techno-economics feasibility of TISEC technology and was not to compare individual device technology. EPRI is heartened with the large numbers of devices and different types of devices being developed. The technology is much too young for anyone to be able to know which of these technologies will turn out to be the most cost-effective in the future.

Tidal Plant Design, Performance and Cost

For most of the study sites, installation of an array of TISEC devices will overlap with existing shipping channels. As such, only fully submerged devices can be used in order to allow sufficient overhead clearance for unimpeded navigation. While the MCT SeaGen is surface piercing, the company has

conceptualized a fully submerged 2nd generation design that is patent pending. MCT's 2nd generation technology consists of 6 rotors mounted on a single structure which can be raised to the surface for maintenance using an integrated lifting mechanism, as illustrated in Figure 13. Given similar scale and technology used on MCT's 2nd generation fully submersed technology (same rotor, drive train and foundation as SeaGen with a modified support structure and lifting mechanism), it is likely that cost and performance will be similar to the surface piercing SeaGen. It is unlikely; however, that MCT's 2nd generation device would be ready for commercial pilot demonstration for at least 2 years as proof of high reliability is a prerequisite.



Figure 13. MCT Next Generation Concept

Pilot scale (a single device) and commercial scale plant (sized to extract 15% of the energy from the tidal stream) performance is contained in the table below. The 15% size limit is to preclude any significant ecological effect due to the plant and is an estimate from experts in the UK. In two cases (Golden Gate, California and Western Passage Maine) the 15% extraction limit could not be reached since the relatively small high current area limits the number of turbines which can be deployed (using existing prototype designs). Since both these channels are deep, future stacked arrays could allow extraction up to the 15% limit. Those two sites are colored in yellow below.

	AK	WA	CA	MA	ME	NB	NS
Site	Knik Arm	Tac Nar's	Golden Gate	Musk-eget	West Pass	Head Harbor	Minas Pass
Unit Rated Power (MW)	0.76	0.7	1.1	0.46	0.83	0.31	1.11
Unit Rated Speed(m/s)	1.9	1.9	2.1	1.6	2.0	1.4	2.2
Unit Avg Yrl Power (MW)	0.22	0.21	0.37	0.18	0.38	0.13	0.52
# of Com'l Units	66	64	40	9	12	66	250
Avg Power (MW) (3)	14.6	13.7	16.5	1.6	4.6	7.3	130
1000 Homes Powered	11.2	10.5	12.8	1.3	3.5	6.5	100

(1) Extractable is 15% of available

(2) Rated power at rated speed is optimized for lowest COE

(3) 1.3 kW per average U.S. home per IEA

(4) Yellowed rows are existing prototype design limited

The EPRI system-level conceptual designs are not designs from which a system can be built. Micro siting of each turbine requires 3-D modeling of the site region with multipoint velocity measurements for model calibration.

Conceptual Tidal Plant Economic Assessment

EPRI independently estimated the plant system cost based on the MCT SeaGen dual 18 m diameter rotor device design. Using the economic methodology, financial assumptions and incentives described in Ref: 2, EPRI calculated the cost of electricity (COE) for a taxable utility generator, a municipal non taxable generator, and the internal rate of return for a taxable non utility generator. The results are shown below.

	AK	WA	CA	MA	ME	NB	NS
Site	Knik Arm	Tac Nar's	Golden Gate	Musk-eget	West Pass	Head Harbor	Minas Pass
Number of Turbines	66	68	40	9	12	66	250
Total Plant Cost (\$M)	110	103	90	17	24	68	486
Yrly Level O&M Costs	4.1	3.8	3.6	0.6	1.0	2.3	18
Annual Energy (GWh)	128	121	129	1.5	40	64	1,140
Utility Gen COE	9.2 - 10.8	9.0 - 10.6	6.6 - 7.6	8.6 - 9.9	5.6 - 6.5	10.0 - 11.7	3.9 - 4.6
Muni Gen COE	7.1 - 8.4	7.2 - 8.4	4.9 - 5.6	6.0 - 6.7	4.2 - 4.8	9.2 - 11.2	3.9 - 4.6
Non Utility Gen IRR	None	None	21%	None	34%	None	31%

Cost of electricity (COE) in U.S. cents/kWh

The cost of electricity (COE) is defined as the total plant cost times the fixed charge rate plus the annual operation and maintenance (O&M) all divided by the annual energy produced. The fixed charge rate is the percentage of the total plant cost that is required over the project life to cover the minimum annual revenue requirements, and as such, accommodates the individual state and provincial tax rate and incentives structure. The COE for a utility and municipal generator is in the range of 4 – 12 cents/kWh (2005 US\$).

The internal rate of return (IRR) is defined as the discount rate that sets the present worth of the net cash flows over the project life equal to the equity investment at the commercial operating date. Neither Alaska, Washington, Massachusetts nor New Brunswick designs produced a rate of return for a non-utility Generator. California, Maine and

Nova Scotia designs do offer a non-utility generator an estimated 21 to 34% rate of return on their investment.

TISEC device technology is similar to wind technology and has benefited from the learning curve of wind machine production experience, both on shore and off shore. Therefore, the entry point for a TISEC plant is much less than that of a wind plant back in the late 1970s and early 1980s (i.e., over 20 cents/kWh). Additional TISEC cost reductions will be realized through value engineering and economies of scale.

The current comparative costs of several different central power generation technologies are given below. We are using generally accepted average numbers and ranges from EPRI sources (Ref: 17). The tidal plant capacity factor is a function of the tidal flow profile with capacity factors higher in the East Coast than on the West Coast because of large tidal diurnal differences on the West Coast. The tidal plant capital cost is a function of the plant size, tidal flow profile, the bathymetry and the geotechnical properties of the seabed. The COE is a function of the power density of the tidal stream and the plant size.

	Capacity Factor (%)	Capital Cost (1) (\$/MW)	COE (2)(cents/kWh)	CO2 (lbs per MWh)
Tidal In-stream Power Den > 3.0 Power Den 1.5-3.0 Power < 1.5 kW/m ²	29-46	1.7-2.0 2.1-2.4 3.3-4.0	4 - 7 4 - 11 6 - 12	None None None
Wind (class 3- 6)	30-42	1.2 - 1.6	4.7-6.5	None
Solar Thermal Trough	33	3.3	18.	None
Coal PC USC (2)	80	1.3	4.2	1760
NGCC @ \$5/MM BTU (3)	80	0.5	4.8	860
NGCC @ \$7/MM BTU (3)	80	0.5	6.4	860
IGCC with CO2 Capture (4)	80	1.9	6.1	344

(1) All costs in 2005 US\$

(2) 600 MW Plant, Pittsburgh #8 Coal

(3) GE 7 F machine or equivalent

(4) 80% removal

Central Power versus Distributed Power

Except for the Minas Passage which has the size to be considered central power, all other sites studied in the U.S. and Canada fall in between the classic definition of distributed generation (DG) and central power generation.

We use the term distributed generation (DG) or distributed resources (DR) to describe an electric generation plant located in close proximity to the load that it is supplying and is either connected to the electric grid at distribution level voltages or connected directly to the load. Examples of DG/DR (DR when some form of storage is included) are rooftop photovoltaic systems, natural gas micro turbines and small wind turbines. Large wind projects and traditional fossil fuel plants are examples of central generation where the electricity delivers power into the grid at transmission voltage levels.

DG types of systems traditionally find applications in niche markets because of unique market drivers such as:

- Delay or defer an upgrade to T&D infrastructure that would otherwise have been necessary to bring power generated away from a load center to that load center
- Voltage stability support
- Displace diesel fuel in off grid applications
- Satisfy local citizens desires to have control of their own power source

A realistic comparison to equitably evaluate the cost of deferring T&D expenses with the cost of installing DG/DR is complex and requires considering depreciation and tax benefits, property tax and insurance for both options, maintenance and fuel costs of operating the DG/DR and employing discounted cash flow methods. This comparison must be made on a case-by-case basis.

EPRI Conclusions

U.S. Tidal In-stream Potential

Knik Arm in Alaska, Tacoma Narrows in Washington, Golden Gate in California and Western Passage in Maine all have good cross-sectional area size (36,000 to 72,000 square meters), good power density (1.5 to 3.2 kW/m²) and an interconnection which is easily managed. The Muskeget Channel in Massachusetts is somewhat small (17,500 square meters), low in power density (0.95 kW/m²) and is not easily

interconnected to the grid. We found no other good tidal sites in Massachusetts, except for the Cape Cod Canal, which is currently used for shipping with no unused and available cross section for power generation.

Canada Tidal In-stream Potential

The available tidal energy potential for the Minas Passage Nova Scotia is over 1 GW. Harnessing just 15% of the available tidal energy resource base would generate enough electricity to power about 120,000 Canadian homes (assuming an average of 1.3 kW per home).

The Head Harbor Passage site, although large in size (60,000 square meters), is low in power density (0.94 kW/m²). Perhaps higher power density sites in the Cumberland Basin or a joint project with the U.S. in Western Passage might be a future direction for the province.

Sensitivity Studies

Sensitivity studies show that the power density and number of turbines have a significant effect on COE. Kinetic power varies as the cube of the tidal current velocity; therefore high velocity tidal stream sites are necessary for economic tidal plants. Fixed costs, such as mobilization costs, are spread over a larger number of turbines for a large array. Details of the sensitivity studies are described in the device design reports (Ref: 9-15)

Technology Development Status

In-stream tidal energy technology is an emerging technology with some small scale and some surface piercing devices now ready for pilot demonstration testing in the US and Canada. Large scale non-surface piercing devices will be ready for pilot scale demonstration testing in the US and Canada within a year or two. Most sites require non surface piercing devices.

The MCT 300 kW experimental prototype has been operating in the UK for over 3 years and much has been learned. The 18-month Verdant Roosevelt Island Tidal Energy (RITE) East River NY 200 kW demonstration project (6 turbines at 34 kW each) is now licensed and will commence testing in mid-2006. The MCT SeaGen 1 MW commercial prototype is being fabricated (Figure 14) and will also commence testing in 2006 at Strangford UK; an environmentally sensitive site. Both the Verdant and MCT test programs include extensive environmental and marine life monitoring. Additional tidal systems including an Open Hydro Turbine, a Lunar Energy RTT1000 and a SMD

Hydrovision 1 MW prototype are scheduled for installation and testing at the European Marine Energy Center in the Orkneys in late 2006 or 2007. Although technologically ready for demonstration, many important questions about the application of in-stream tidal energy to electricity generation remain to be answered, questions such as:

- What type/size will yield optimal economics?
- Will the installed cost of tidal energy conversion devices realize its potential of being less expensive than solar or wind?
- Will the predictability of tidal earn a capacity credit for its dispatch ability?
- Will the performance, cost and reliability projections be realized in practice once tidal energy devices are deployed and operated?

We believe that this study makes a compelling case for investing in tidal energy technology research, development and demonstration in the U.S. and Canada starting with multiple demonstration projects as soon as possible.



Figure 14. MCT SeaGen geo technical testing at Strangford for foundation design and a blade mold

EPRI Recommendations

Collaboration

Encourage collaboration of State, Provincial and Federal Governments, Utilities, Power Producers and Non-Governmental Agencies, and Project and Tidal Energy Device Developers.

Research and Development (R&D)

Encourage tidal energy technology R&D at universities and support graduate students desiring to earn advanced degrees with theses in tidal energy. Areas of needed research include:

- 3D computational fluid dynamics coupled with accurate velocity measurements for micro-siting tidal plants, including pilot plants

- Understanding how turbulence, ice and suspended sediment affect the choice of technology and its performance and lifetime
- Understanding the energy extraction limit for precluding significant ecological effects
- Turbine interaction within an array to minimize spacing in limited seabed situations

Demonstration Test Projects

Encourage pilot scale demonstrations to show the technical and environmental feasibility of the technology and to reduce uncertainties in performance, reliability, cost and servicing requirements

Government Role

EPRI believes that the Government has a very important role to play in the advancement of this technology to where it can be an option in our energy supply portfolio; namely:

1. Providing leadership for the development of an ocean energy RD&D program to fill known R&D gaps identified in this report, and to accelerate technology development and prototype system deployment
2. Operating a national center to test the performance and reliability of prototype ocean energy systems under real conditions
3. Development of design and testing standards for ocean energy devices
4. Leading activities to streamline the process for licensing, leasing, and permitting renewable energy facilities in U.S. and Canadian waters
5. Studying provision of production tax credits, renewable energy credits, and other incentives to spur private investment in ocean energy technologies and projects, and implementing appropriate incentives to accelerate ocean energy deployment
6. Ensuring that the public receives a fair return from the use of ocean energy resources
7. Ensuring that development rights are allocated through a transparent process that takes into account state, provincial, local, and public concerns.
8. Continue membership in the International Energy Agency (IEA) Ocean Energy Systems (OES) program.

EPRI Perspective

EPRI believes that a diversified and balanced portfolio of energy sources is the foundation of a robust and reliable electrical system and that in-stream tidal energy technology needs to be

evaluated for its role in contributing to our national portfolio of energy supply technologies.

The Electric Power Research Institute (EPRI) was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together member organizations, the Institute's scientists and engineers, and other experts to work on solutions to the challenges of electric power. For more information, please contact:

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References: FINAL Reports are available at www.epri.com/oceanenergy/

- (1) EPRI TP-001-NA, Tidal In-stream Energy Resource and Device Performance Estimation Methodology
- (2) EPRI TP-002-NA, Tidal In-stream Energy Conversion Economic Assessment Methodology
- (3) EPRI TP-003-MA, Massachusetts Site Survey
- (4) EPRI TP-003-ME, Maine Site Survey
- (5) EPRI TP-003-NB, New Brunswick Site Survey
- (6) EPRI TP-003-MA, Nova Scotia Site Survey
- (7) EPRI TP-004-NA, TISEC Device Survey and Characterization
- (8) EPRI TP-005-NA, System Design Methodology
- (9) EPRI TP-006-AK, Alaska Pilot and Commercial System Level Design Study
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- (12) EPRI TP-006-MA, Massachusetts Pilot and Commercial System Level Design Study
- (13) EPRI TP-006-ME, Maine Pilot and Commercial System Level Design Study
- (14) EPRI TP-006-NB, New Brunswick Pilot and Commercial System Level Design Study
- (15) EPRI TP-006-NS, Nova Scotia Pilot and Commercial System Level Design Study
- (16) EPRI TP-007-NA, North America Environmental and Regulatory Issues Report
- (17) EPRI Summer Seminar, 2005

Appendix - Frequently Asked Questions

What is tidal energy?

Tides are the result of gravitational forces exerted by the moon and the sun, with the moon having the predominant influence. The changing relative positions of these bodies cause the surface of the oceans to be raised and lowered periodically, creating two bulges, one closest to the moon and the other on the opposite side of the globe. These 'bulges' result in two tides a day, called semi-

diurnal tides, the dominant pattern in the world's oceans.

Will TISEC devices affect the environment?

Given proper care in site planning, in-stream tidal power promises to be one of the more environmentally benign electrical generation technologies. We anticipate that these projects will require coordination with local, state and federal agencies and may include field studies. Baseline assessments can frequently be accomplished through review of existing information and databases, in coordination with other proposed project siting evaluations and through consultation with appropriate resource agencies and stakeholders. During the environmental permitting process for each project, it is expected that resource agency staff, other stakeholders, and developers will discuss concerns regarding potential project effects, project operation characteristics, and how effects can be avoided or minimized.

In-stream tidal energy power plants are sized to extract only a small fraction of the energy available in a tidal stream; that fraction is one that results in no noticeable effect to the ecology.

Will TISEC devices affect the fish?

While no definitive "in-situ" monitoring studies have been conducted to date, due to the newness of the technology and lack of deployed systems, anecdotal information from numerous temporary testing activities in the U.S., UK and abroad have not observed any harm to aquatic life. Further, desk-top theoretical evaluations based on technology specifications (such as rotation speed and other physical parameters) and extensive fish studies based on traditional hydro turbine systems suggest these new technologies are environmentally friendly.

The blades of TISEC devices turn very slowly (around 10 rpm for a 18 meter diameter rotor) and the speed at the tip of the blade is about 10-12 m/s (22-27 mph). The devices are self limiting in that any faster speeds result in cavitation, a situation which cannot be allowed to exist by design.

Two TISEC test programs with thorough environmental assessments of sea life and effects will start in 2006; the Verdant RITE project in the East River in NY and the MCT SeaGen project in Strangford UK.

Will these systems survive storms and hostile marine environments?

Yes. Being totally submerged means that tidal energy conversion systems will not need to bear the full brunt of a storm. Relative to long-term survival in the environment, the anti-corrosion and biofouling technology is such that oil and gas platforms are surviving 50 years. The MCT 300 kW experimental prototype, has been continuously operating for almost 3 years (since May 2003) off the coast of the UK with very little evidence of biofouling.

Will the regulatory authorities grant a permit for in-stream tidal power plant?

The novelty of the technology will likely trigger cautious environmental assessments and extensive approval processes. The difficulty of obtaining a permit for an in-stream tidal power plant presents a significant barrier to the development of TISEC technology because:

- There is a wide variety of regulations and large number of involved agencies
- No specific "fast-track" regulations have been developed for short-term marine renewable demonstration projects which are small scale and geared for research activities.

Permitting early tidal energy plants will be a challenge since there is no precedence in the US for regulatory authorities to base a licensing decision. Nevertheless, we believe that, with strong public support and the positive experiences in the UK and other countries, the Federal Energy Regulatory Agency Commission (FERC) and other federal, state and local agencies will allow this emerging technology power plant project to go forward.

Will TISEC technology provide reliable and cost-effective electricity?

Yes. TISEC technology in a good tidal site can provide a cost of electricity in the same range as existing commercial on-land wind technology, natural gas (at \$5/mmBTU) and ultra supercritical coal and is a couple pennies less expensive than coal with 85% CO₂ capture and solar; and like wind technology, emits no pollutants nor greenhouse gases.