System Level Design, Performance, Cost and Economic Assessment – Massachusetts Muskeget Channel Tidal In-Stream Power Plant

Report: EPRI – TP - 006 - MA
Principal Investigator: Mirko Previsic
Contributors: Brian Polagye, Roger Bedard
Date: June 10, 2006

Organization(s) that prepared this document

Global Energy Partners LLC

Virginia Polytechnic Institute and State University

Mirko Previsic Consulting

Brian Polagye[1] Consulting

[1] PhD Student, Department of Mechanical Engineering, University of Washington

Table of Contents

List of Figures

List of Tables

1. Introduction and Summary

Muskeget Channel is an opening 6 miles wide on the south side of Nantucket Sound between Muskeget and Chappaquiddick Islands. The currents through the channel are strong, having a velocity of 3.8 knots on the flood and 3.3 knots on the ebb about 1.5 miles east of Wasque Point and providing an average of 13.8 MW of kinetic power. About 2MW (15%) of it can be extracted without any significant environmental impacts. A power plant of that scale could reach a peak capacity of just a bit over 4MW. Given the relatively small generation potential, the site could be tapped as a distributed renewable generation source.

This document describes the results of a system level design, performance and cost study for both a demonstration pilot plant and an economics assessment of a commercial size in-stream tidal power plant installed at the site. The primary purpose of this design study was to identify and quantify the risks and benefits of using TISEC technology at site. As such it addresses the technology, energy production, cost of a pilot and commercial power plant system and cost of electricity.

The study was carried out using the methodology and standards established in the Design Methodology Report [5], the Power Production Performance Methodology Report [2] and the Cost Estimate and Economics Assessment Methodology Report [2].

For purposes of this design study, the Massachusetts stakeholders and EPRI decided to work with two TISEC device developers: Lunar Energy and Marine Current Turbines (MCT). Lunar Energy's RTT 2000 is a fully submersed ducted turbine with the power conversion system (containing rotors and power generation equipment) inserted in a slot in the duct as a cassette. This allows the critical components to be recovered for operation and maintenance without having to remove the whole structure. MCT's SeaGen consists of two horizontal-axis rotors and power trains (gearbox, generator) attached to a supporting monopile by a cross-arm. The monopile is surface piercing and includes an integrated lifting mechanism to pull the rotors and power trains out of the water for maintenance access. MCT also offered information on their conceptual fully submersed design, which consists of 6 rotors mounted on a single structure, which can be raised to the surface for maintenance using an integrated lifting mechanism.

The purpose of working with two TISEC device developers was to provide a redundant check of the performance and cost design points and to increase the confidence level oif the assessment work. There is no intent to compare the two device developers or their technology. At this nascent stage of TISEC development, a pursuit towards the development and demonstration off as many good ideas as possible is warranted.

The deployment site in the Muskeget channel is sufficiently large that devices could be deployed without directly interfering with recreational and commercial boat traffic. As such, the Muskeget channel is one of the few sites in the US that could accept surface piercing SeaGen technology. Turbines could be placed in such a way that they clearly mark the channel and actually increase the safety of passing boats at the site.

A pilot consisting of a single SeaGen unit would cost $5.6M to build and would produce an estimated 1,610 MWh per year. This cost reflects only the capital needed to purchase a SeaGen unit, install it on site, and connect it to the grid. Therefore, it represents the installed capital cost, but does not include detailed design, permitting and construction financing, yearly O&M or test and evaluation costs.

A commercial scale tidal power plant at the same location was also evaluated to establish a base case from which economic comparisons to other renewable and non renewable energy systems could be made. The yearly electrical energy produced and delivered to bus bar is estimated to be 1,610 MWh/year for an array consisting of 9 dual-rotor MCT turbines. These turbines have a combined installed capacity of 4.1MW, and on average extract 1.93 MW of kinetic power from the tidal stream, which is roughly 15% of the total kinetic energy at the site. The elements of cost and economics (in 2005$) for MCT's SeaGen are:

- Utility Generator (UG) Total Plant Investment = $16.9 million

- Annual O&M Cost = \$0.57 million
- UG Levelized Cost of Electricity (COE) = 8.6 (Real) – 9.92 (Nominal) cents/kWh with renewable financial incentives equal to that the government provides for renewable wind energy technology
- Municipal Generator (MG) Levelized Cost of Electricity (COE) = 6.0 (Real) – 6.7 (Nominal) cents/kWh with renewable financial incentives equal to that the government provides for renewable wind energy technology
- Non Utility Generator (Independent Power Producer) does not obtain an Internal Rate of Return

While being limited in size, this resource should be tapped strategically as it will contribute to a balanced energy supply system. In order to tap into it, further work needs to be carried out to better quantify and qualify the resource, address regulatory issues and continue to work with device developers and help them apply their technology to the site and it's unique requirements. The next immediate step is to work towards the implementation of a pilot demonstration system. A pilot system is an important intermediary step before proceeding to a commercial installation and is used to:

- Proof technology reliability and performance at the site and reduce commercial risks
- Measure and quantify environmental impacts
- Focus the consenting process for a commercial installation

Before proceeding with the installation of a pilot plant, remaining uncertainties might need to be addressed. Some of these uncertainties include:

- Tidal velocity distribution at the site
- Seabed geology required for detailed foundation design
- Ownership issues
- Consenting issues
- Political and public education issues

In order to promote development of TISEC, EPRI encourages that stakeholders build collaboration within Massachusetts and with other State/Federal Government agencies by forming a state electricity stakeholder group and joining a TISEC Working Group to be formed by EPRI to be called “OceanFleet”. Additionally, EPRI encourages the stakeholders to support related R&D activities at a state and federal level and at universities in the region. This might include:

- Implement a national ocean tidal energy program at DOE
- Operate a national in stream tidal energy test facility
- Promote development of industry standards
- Continue membership in the IEA Ocean Energy Program
- Clarify and streamline federal, state and local permitting processes
- Study provisions for tax incentives and subsidies needed to incentivize potentiual investors and owners to bring this technology to the marketplace
- Ensure that the public receives a fair return from the use of tidal energy resources
- Ensure that development rights in state waters are allocated through a fair and transparent process that takes into account state, local, and public concerns.

2. Site Selection

Muskeget Channel is an opening 6 miles wide on the south side of Nantucket Sound between Muskeget and Chappaquiddick Islands. The opening is full of shifting shoals. The currents through the channel are strong, having a velocity of 3.8 knots on the flood and 3.3 knots on the ebb about 1.5 miles east of Wasque Point. The flood sets north-northeastward and ebbs south-southwestward. The general area is outlined on the overhead image of Figure 1. The main channel area extends from west of Muskeget Island east to Chappaquiddick Island. The tidal difference between the Nantucket Sound and the open ocean forces the water through this narrow channel, creating high current velocities suitable for locating TISEC devices.

The Massachusetts stakeholders selected the Muskeget Channel for an assessment of in stream tidal power. Site selection is determined by the following primary considerations:

- Good tidal energy resource
- Ease of interconnection and accessibility to an electrical demand
- Proximity to major port with marine infrastructure

The Muskeget Channel satisfies these considerations. The Muskeget Channel may have a potential as a distributed energy resource.

Fabrication, assembly, installation, operation and maintenance would be performed out of Edgartown or Boston. Grid interconnection would be to a substation on Chappaquiddick Island. Figure 2 shows a local map of the Muskeget Channel and surrounding water bathymetry. Figure 3 shows a nautical chart of the area.

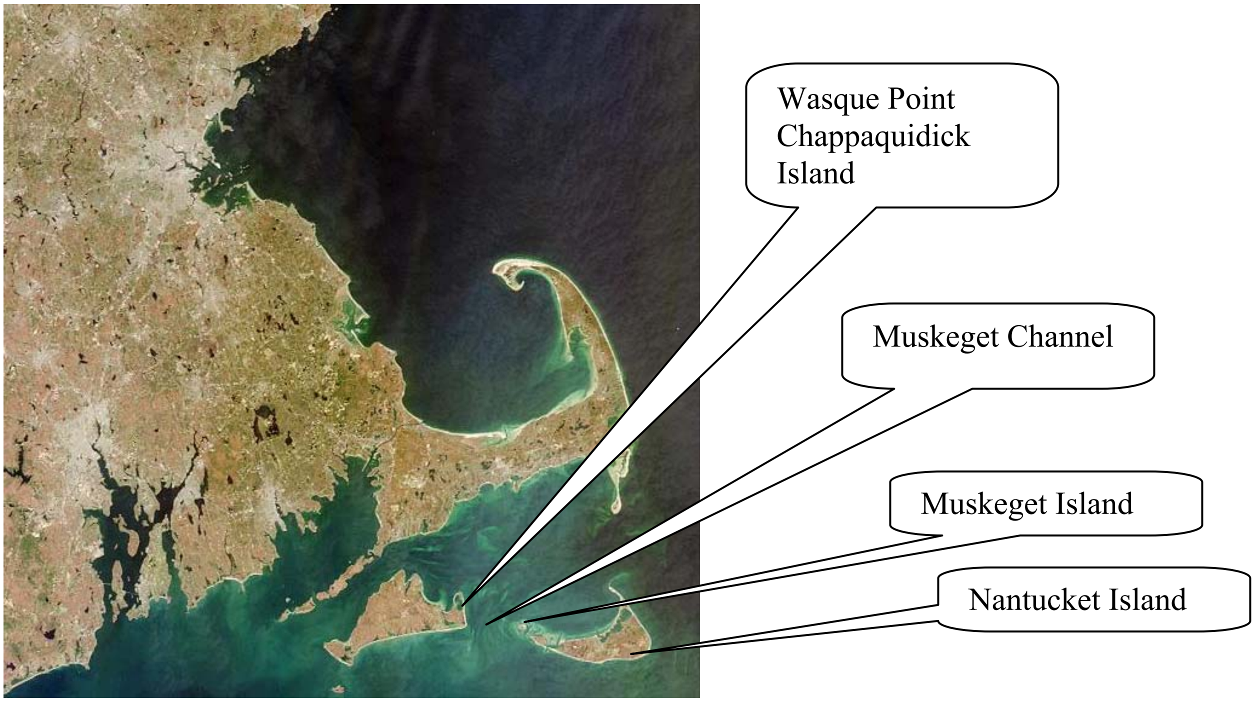


Figure 1: Regional View of the Muskeget Channel

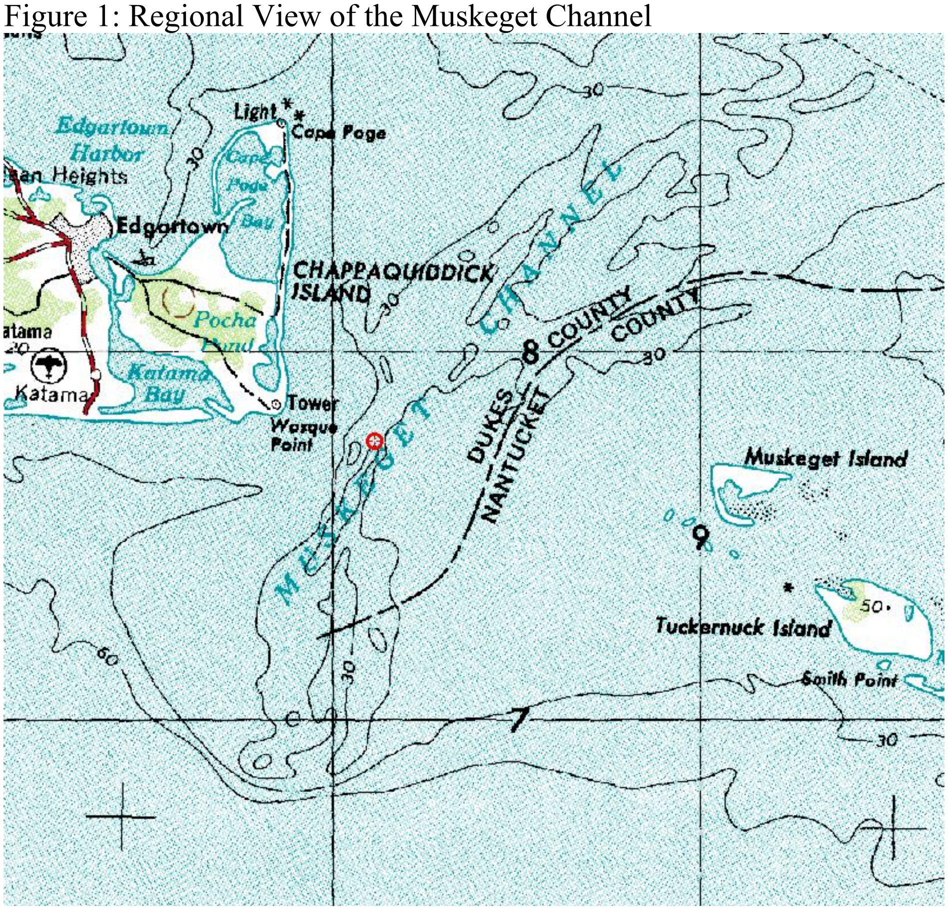


Figure 2: Local Map of Muskeget Channel showing Bathymetry

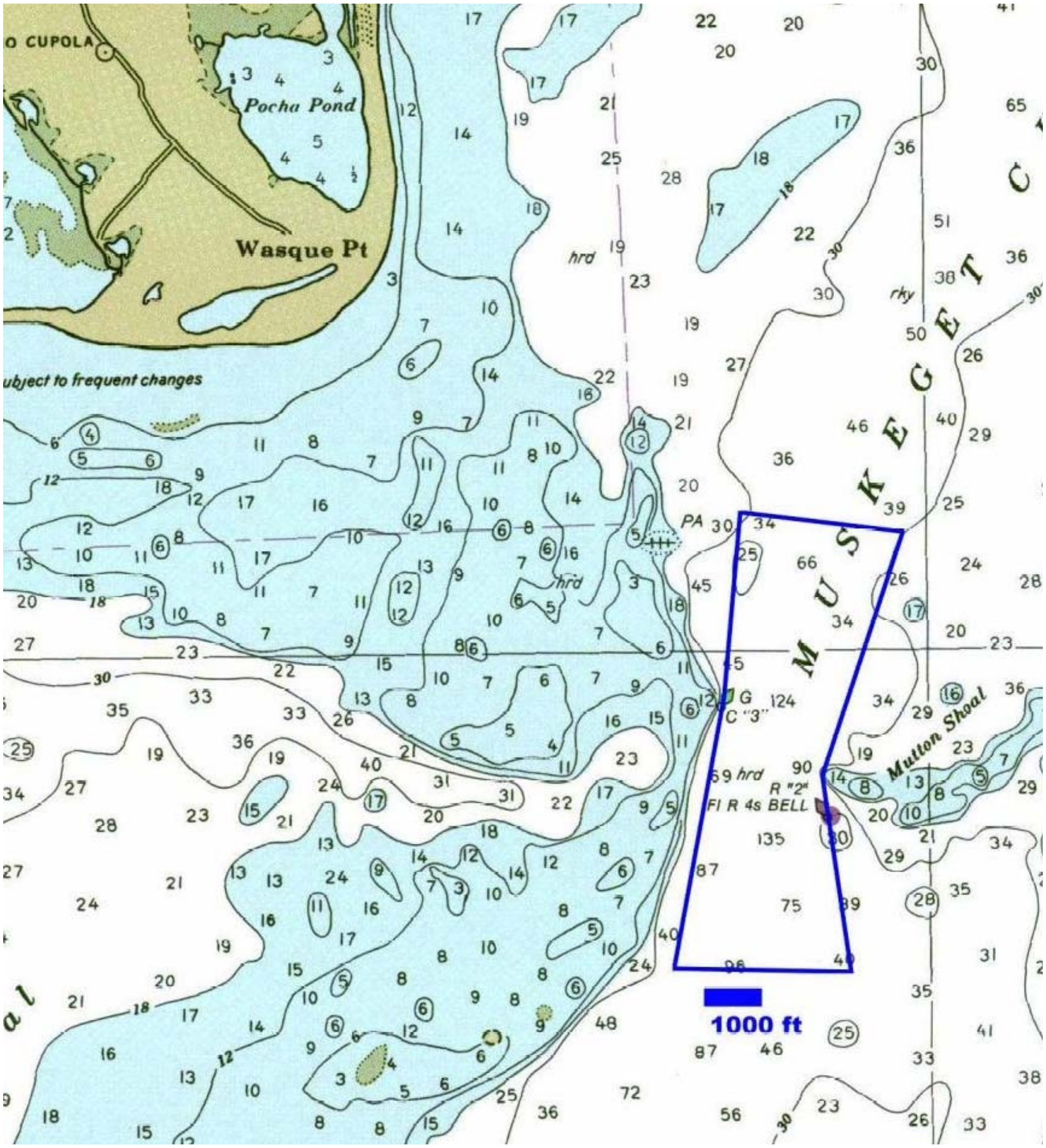


Figure 3: Nautical Chart of the Muskeget Channel (water depth in feet)

Tidal Energy Resource

The velocity distribution at the Muskeget Channel NOAA Station (40o 20.9N, 70o 25.2W). This data is later used to calculate the annual performance of the device in the site.

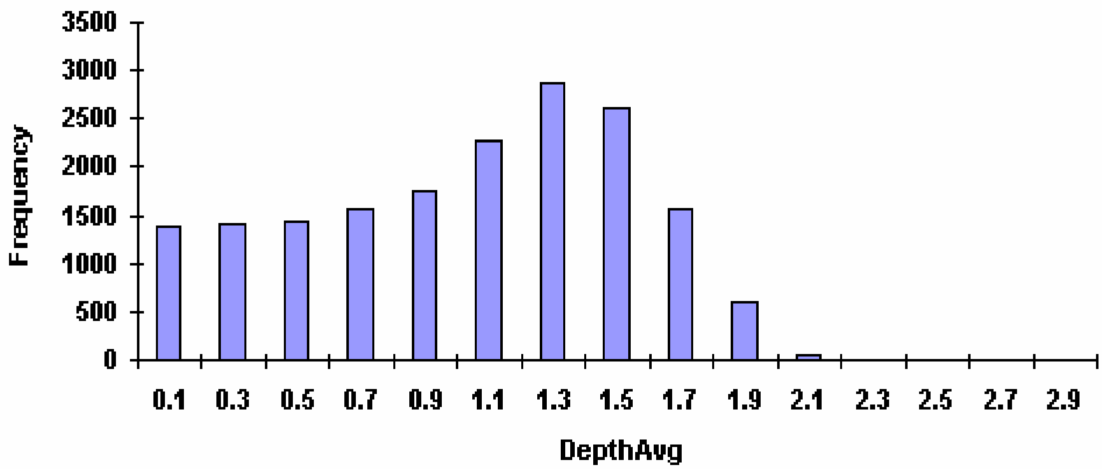


Figure 4: Depth averaged velocity distribution at the target site. Velocity shown is in m/s

Table 1 - Velocity Distribution at Site

Velocity (m/sec)	Power Density (kW/m^2)	Number of Cases	Percentage of Cases	Number of Hours	Energy Density (kWh/m^2-year)
0.1	0.0	1388	7.9%	694.0	0.4
0.3	0.0	1400	8.0%	700.0	9.7
0.5	0.1	1427	8.1%	713.5	45.7
0.7	0.2	1574	9.0%	787.0	138.3
0.9	0.4	1753	10.0%	876.5	327.5
1.1	0.7	2269	13.0%	1134.5	773.9
1.3	1.1	2877	16.4%	1438.5	1,619.7
1.5	1.7	2623	15.0%	1311.5	2,268.5
1.7	2.5	1561	8.9%	780.5	1,965.2
1.9	3.5	593	3.4%	296.5	1,042.3
2.1	4.7	55	0.3%	27.5	130.5
2.3	6.2	0	0.0%	0.0	0.0
Sum		**17520**	**1**	**8760**	**8,321.7**
Average Power Density					**0.95**
Cross Sectional Area (m^2)					**14,000**
Total Resource Base (MW)					**13.3**
Extractable Resource (MW)					**2**

The following charts show the resource variability and magnitude over time. All of these resource profiles are based on a preliminary extrapolation, which was used for this study. Detailed 3-dimensional theoretical modeling and measurements should be carried out in a detailed design phase to properly quantify the resource and show cross-sectional variability as well as potential resource stratification, which may occur at the site and can have a critical impact on the device deployment location as well as device cost and economics.

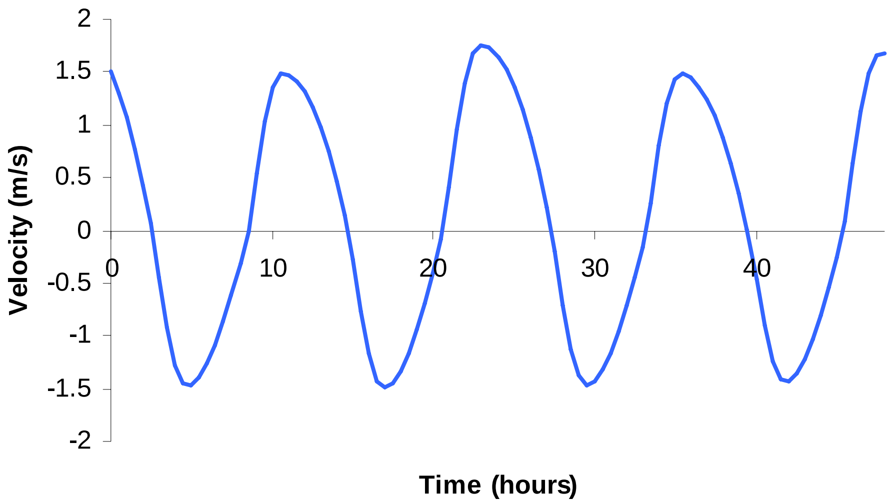


Figure 5 - Typical depth-averaged velocity profile over a 48 hour period

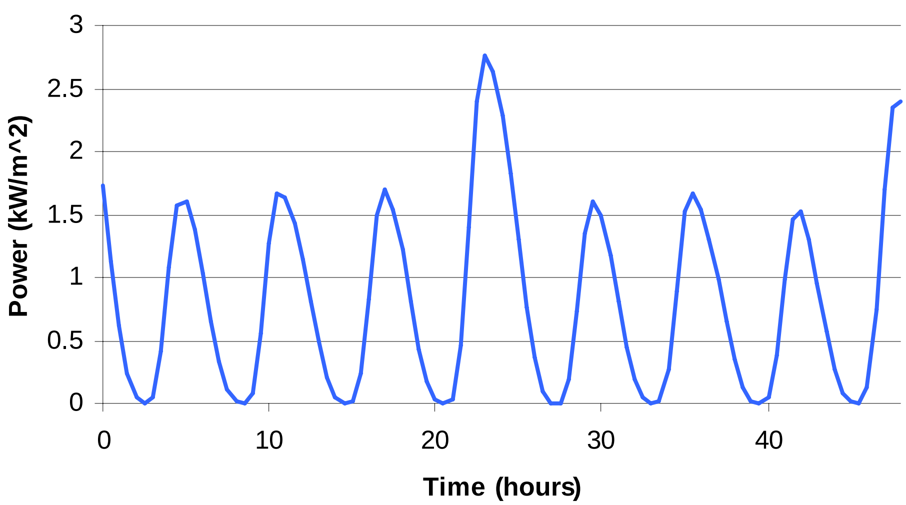


Figure 6 - Typical depth-averaged power variation over a 48-hour period

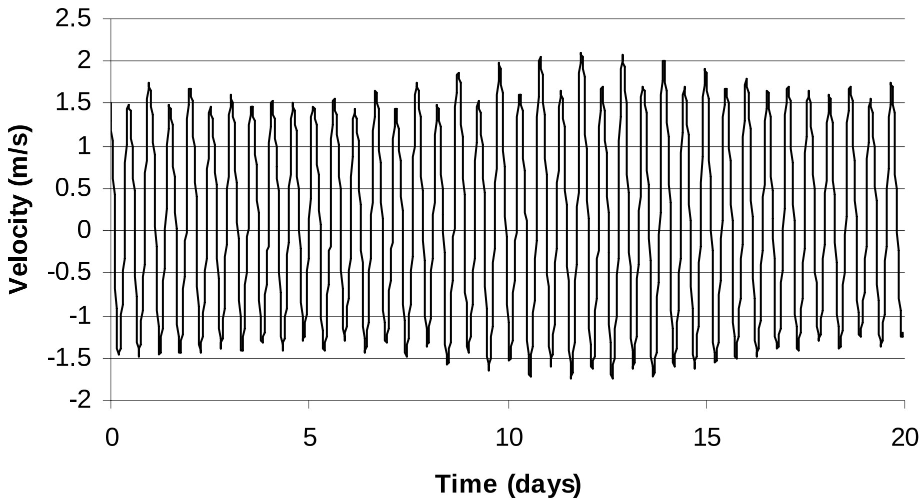


Figure 7 - Velocity profile over a 20 day period covering more then a full lunar cycle

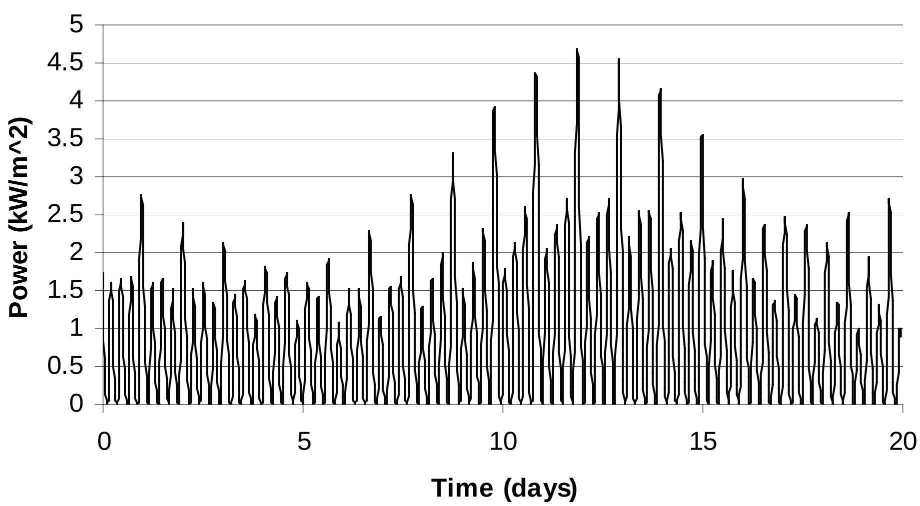


Figure 8 - Power variation of a 20-day period

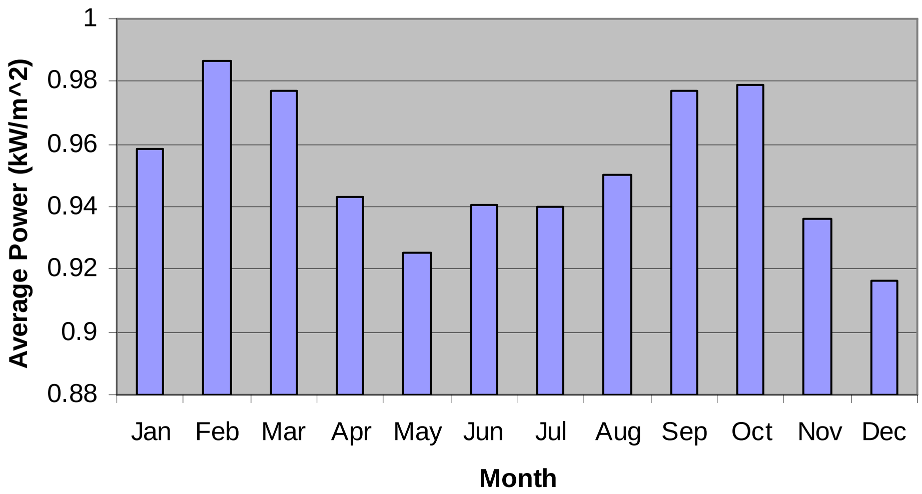


Figure 9 - Annual monthly relative power variation

Grid Interconnection options

The nearest distribution line is a 4.8kV circuit on Chappaquiddick island which ends close to the beach on the islands east facing coast. The lines rated capacity is 3.5MVA. The nominal load on that circuit is 2.8MVA. A 500kW demonstration size plant could be interconnected at that location without any requirements to build-out the existing infrastructure. Higher levels would require significant build-outs of the existing infrastructure.

It is unclear what the line ratings are at various locations, but given that a plant would first displace electricity on the distribution line and export any excess capacity into the substation, the infrastructure could handle up to about 3.5MW, provided that proper care is given in properly designing the interfaces and upgrading the substation. The grid interconnection point is 4 km from the pilot demonstration site as shown in Figure 10 - Grid Interconnection location.

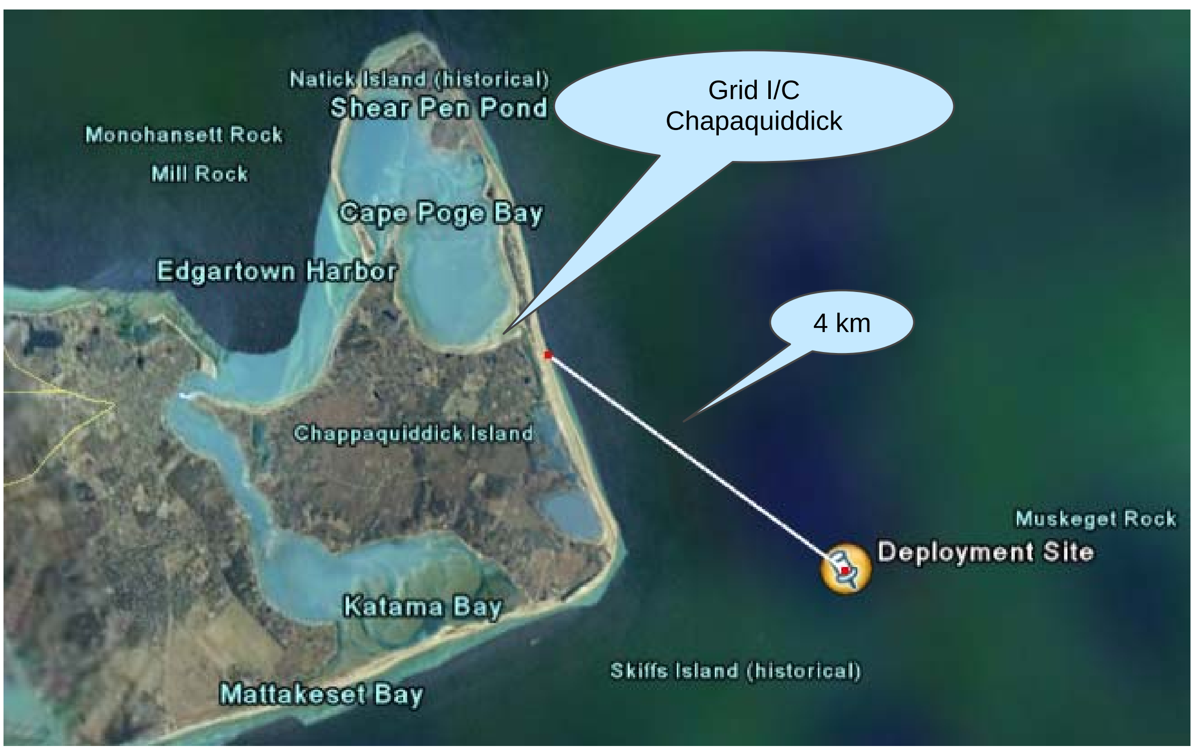


Figure 10 - Grid Interconnection location

A detailed grid-interconnection study would need to be carried out before any project would go ahead at the particular location to identify the limitations and costs.

Nearby port facilities

There are two harbors on Martha's Vineyard that could provide shoreside support for servicing a TISEC project in Muskeget Channel.

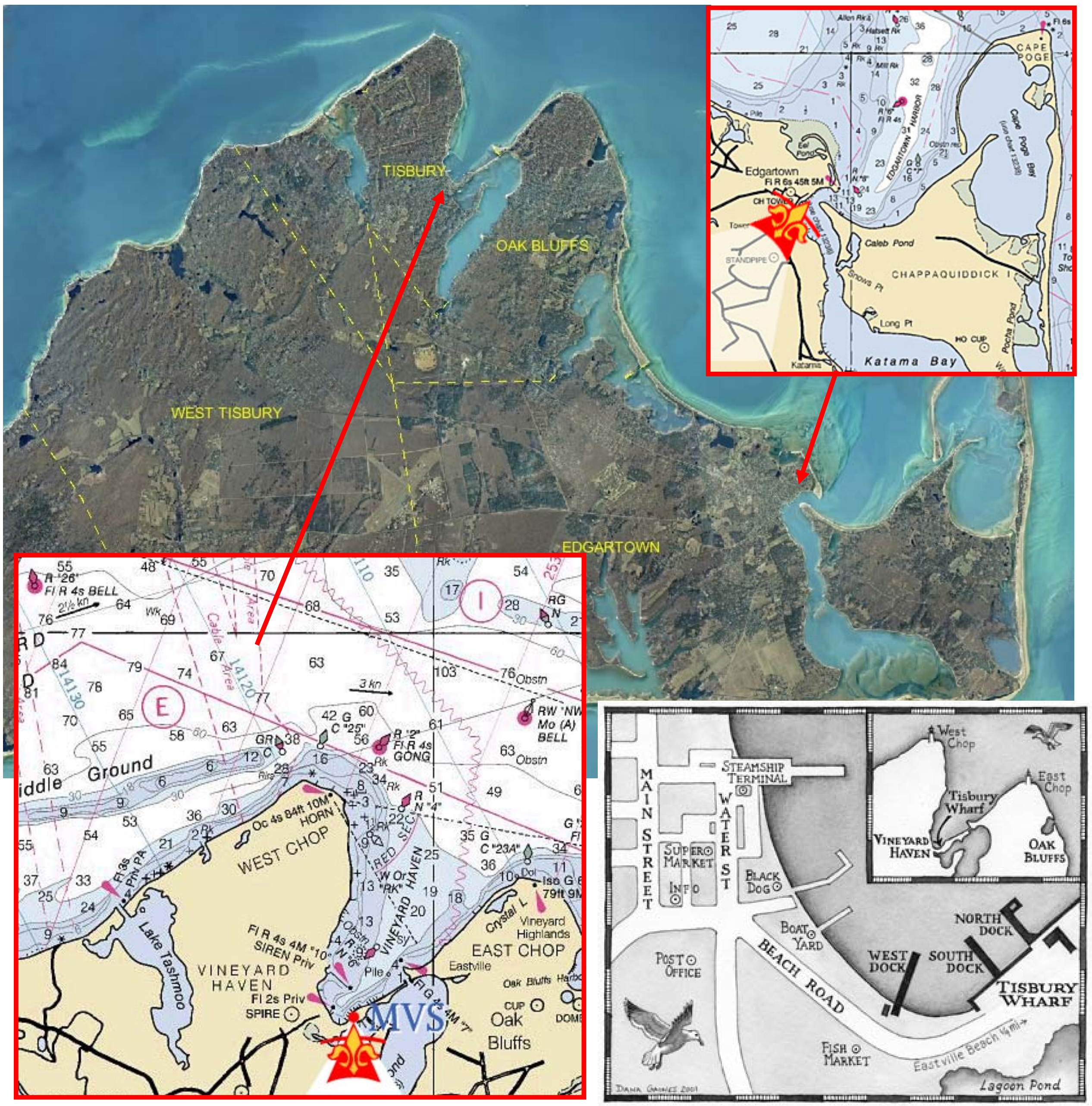


Figure 11 – Support Harbors on Martha's Vineyard

Edgartown is located closer to the deployment site, but Vineyard Haven is wider and deeper and has a better developed maritime infrastructure. The depth alongside the town wharf at Edgartown is 25 feet. Depths at the other wharves are about 11 feet. The boatyard operated by Martha's Vineyard Shipyard has a marine lift that can handle craft to 9 tons for hull and engine repairs and dry open or covered storage. Gasoline, diesel fuel, water, ice, marine supplies, moorings, and launch service to moored craft are all available from the marina. Edgartown Marine, Inc., advertises a mobile lift with hauling capacity to 25 tons (http://www.edgartownmarine.com/).

Edgartown Harbor is normally closed by ice during January and February. The Chappaquiddick ferry channel is usually kept open. The tidal currents keep the inner harbor here open year-round except for a few days at a time during severe winters.

Vineyard Haven Harbor is a funnel-shaped bight about 1.4 miles long and 1.3 miles wide at its entrance, located on the north end of Martha's Vineyard between East Chop and West Chop. This is the most important harbor of refuge between Provincetown, MA and Narragansett Bay, RI. Depths range from 35 to 45 feet at the bight's entrance, and channel depths of 16 feet or more are available to the ferry wharf.

One significant disadvantage of Vineyard Haven is its exposure to winds out of the northeast, common during winter storms that move up the eastern seaboard from the Carolina Capes. Well anchored vessels with good ground tackle can ride out most blows, but there is danger of being struck or fouled by other vessels poorly anchored or with weak ground tackle, which might drag anchor and possibly break free during northeast gales.

Martha's Vineyard Shipyard is open year-round in Vineyard Haven and during the summers in Edgartown, offering a full range of boatyard services, with a mobile lift capable of hauling up to 20 tons for below-the-waterline repairs and storage services, both inside and outside. Details are available at http://www.mvshipyard.com/services.html. Tisbury Wharf Company also offers a full range of marina services and has a 50-ton marine railway (http://www.tisburywharf.com).Maciel Marine (http://www.macielmarine.com) is another large, full-service marina in Vineyard Haven.

Bathymetry

The bathymetry (the ocean equivalent to land topography) is an important determinant in the siting of tidal turbines. In shallow water, there may be insufficient surface and seabed clearance for the turbine rotor. This drives site selection towards deeper water sites. However, installation and maintenance costs increase with water depth. These two competing desires result in a range of depth for each site suitable for deployment of tidal turbines

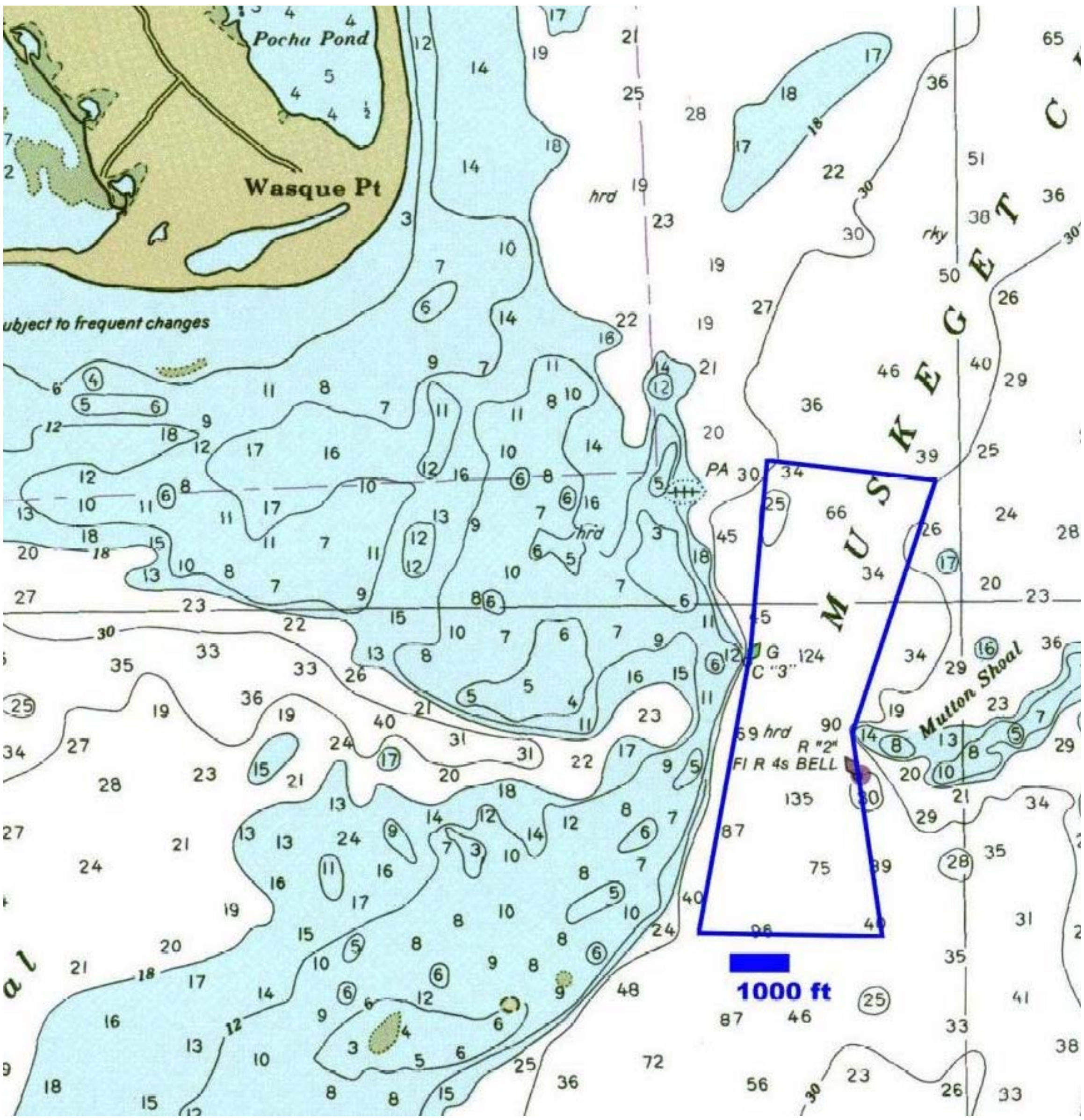


Figure 12 - Muskeget Channel bathymetry

This diagram below indicates a channel width of 2,000 ft and an average channel depth of 75 ft at the location of the NOAA secondary tidal current prediction station. This gives a tidal stream cross-sectional area of 150,000 ft^2 or 14,000 m^2.

It should be noted, however, that over the shoals on either side of Muskeget Channel, there is considerable water exchange between Nantucket Sound and Atlantic continental shelf waters to the south. Therefore, it is likely that this site can support a larger TISEC project than estimated from just the deep-water cross-section, and still have minimal environmental impact.

Seabed Composition

Sedimentation at a tidal energy deployment site is an important consideration for foundation design and has an impact on the type of foundation used, installation methods and scour protection methods (if required). The seabed composition in the Muskeget Channel is sand, gravel and gravelly sediment and bedrock seabed.

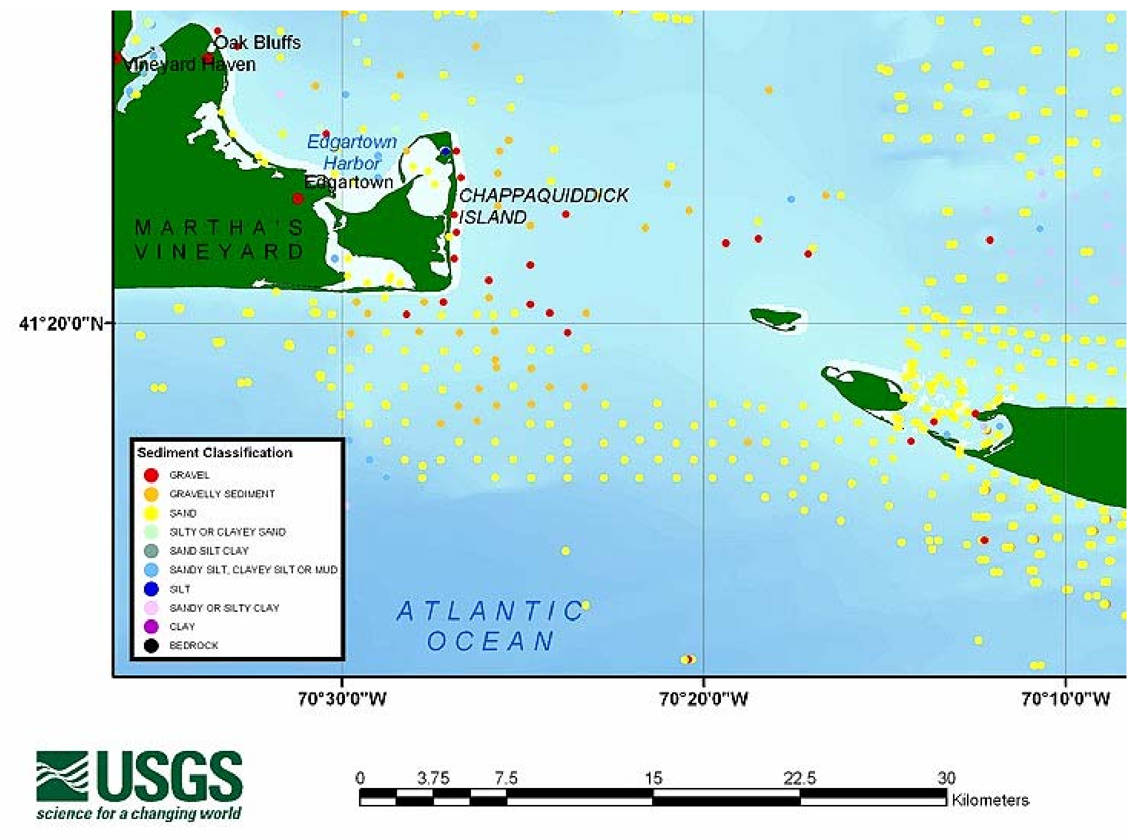


Figure 13 - Seabed Composition as Muskeget channel

Muskeget and Tuckernuck Islands were originally formed by the terminal moraine of the last glacial episode, and the surficial geology of this region consists of sand, gravel, and gravelly sediments heavily reworked by wave and current action. As shown in the figure below, the depth of bedrock beneath the sediments of Muskeget Channel ranges from 300 to 600 meters. Finer sediments may be located beneath the surface layers of sand and gravel. Bottom cores are needed for detailed foundation design.

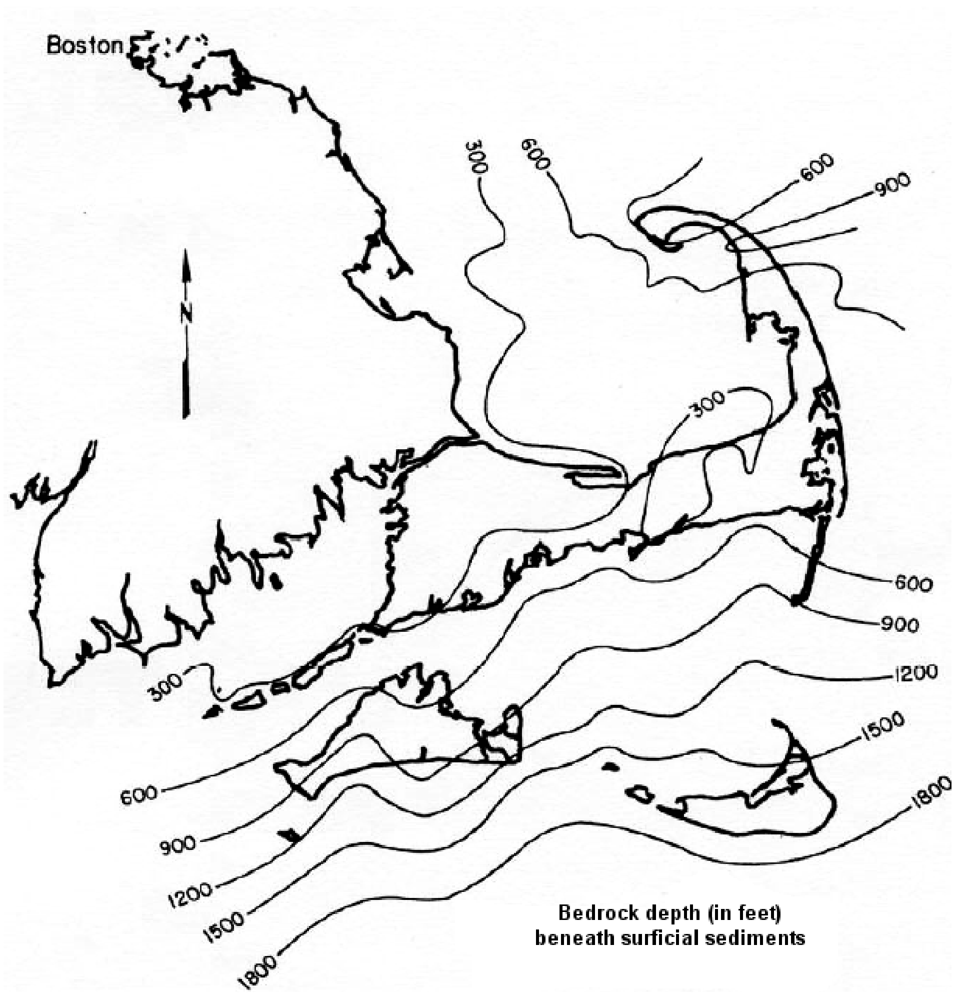


Figure 14 - Depth of bedrock beneath Cape Cod, Martha’s Vineyard, and Nantucket Island.

Navigational Clearances

The Muskeget channel is not used by large freight ships because of it's currents and shifting shoals. Only commercial vessels and recreational vessels pass through the channel. There is sufficient space within the channels boundaries to accommodate competing uses. As a matter of fact, surface piercing SeaGen devices could be used as channel markers to increase shipping safety.

Relevant Site Data

For the purpose of establishing point designs for both a demonstration and commercial system, the following data points are relevant.

Table 2: Relevant Site Design Parameters

Site	
Channel Width	1,000 m
Average Depth (from MLLW)	25 m
Deepest Point	45 m
Seabed Type	Sediments
Tidal Energy Statistics	
Depth Averaged Power Density	0.95 kW/m^2
Average Power Available	13.3 MW
Average Power Extractable (15%)	2 MW
# Homes equivalent (1.3 kW/home)	1,500
Peak Velocity at Site	2.3 m/s
Grid Interconnection Demo	
Subsea Cable Length	4000 m
Sediment type along cable route	Soft Sediments (Sand Gravel)
Cable Landing	Directional drilling
Overland Interconnection Upgrade cost	$200,000
Infrastructure Upgrade Cost	None assumed
Grid Interconnection Commercial	
Subsea Cable Length	4000 m
Cable Landing	Directional Drilling required
Overland Interconnection Upgrade cost	Estimated at $200,000
Infrastructure Upgrade Cost	None assumed. Significant upgrades may be required.

3. Lunar Energy Device

Device Description

The Lunar Energy technology, known as the Rotech Tidal Turbine (RTT) and illustrated in Figure 15, is a horizontal axis turbine located in a symmetrical duct. Unique features of the

RTT are the use of a fixed duct, a patent pending blade design and the use of a hydraulic speed increaser. The full-scale prototype is designed to produce 1 MW of electricity while the initial commercial unit, the RTT 2000, is designed to produce 2 MW from a 7.2 knot (surface current) tidal stream. While no detailed cost analysis was carried out for this device, EPRI used the geometry of the RTT2000 to establish parameters for this project to address critical engineering issues. Ballast and structural reinforcements were scaled to meet load conditions at the site based on the maximum tidal current speed. Where required scour protection and other measures were assessed which are likely to impact the design at a particular site. The gravity foundation is provided by a concrete base, which can be provided with additional ballast to meet the required stability in high currents. The duct consists of steel plates which are supported by a steel tubular frame.

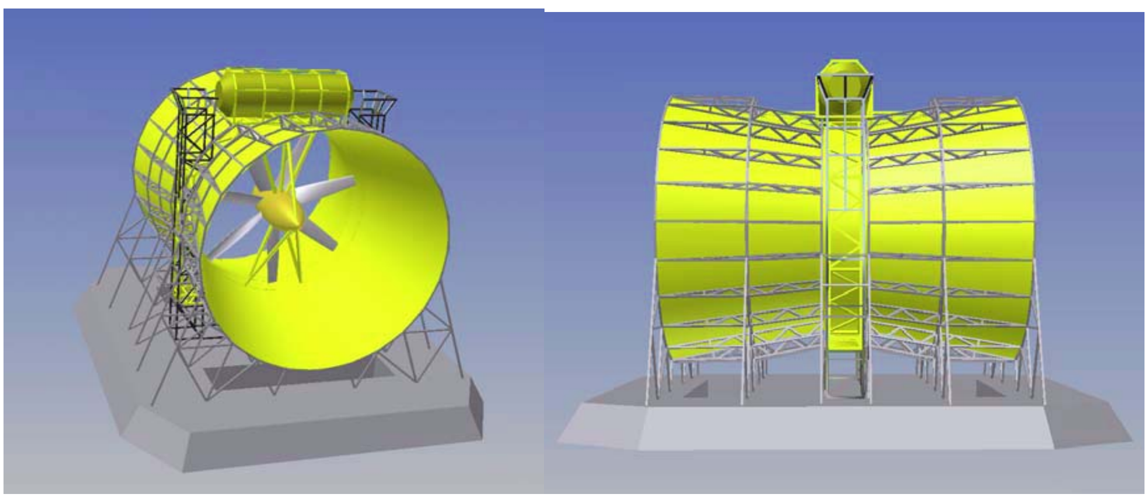


Figure 15 - Lunar Energy Mark I Prototype design

A cassette with the complete power take off, including rotor, hydraulic power conversion, electrical generation and grid synchronization is inserted as a module into the duct. This arrangement allows for relatively simple removal and replacement of the power conversion system and simplifies O&M procedures.

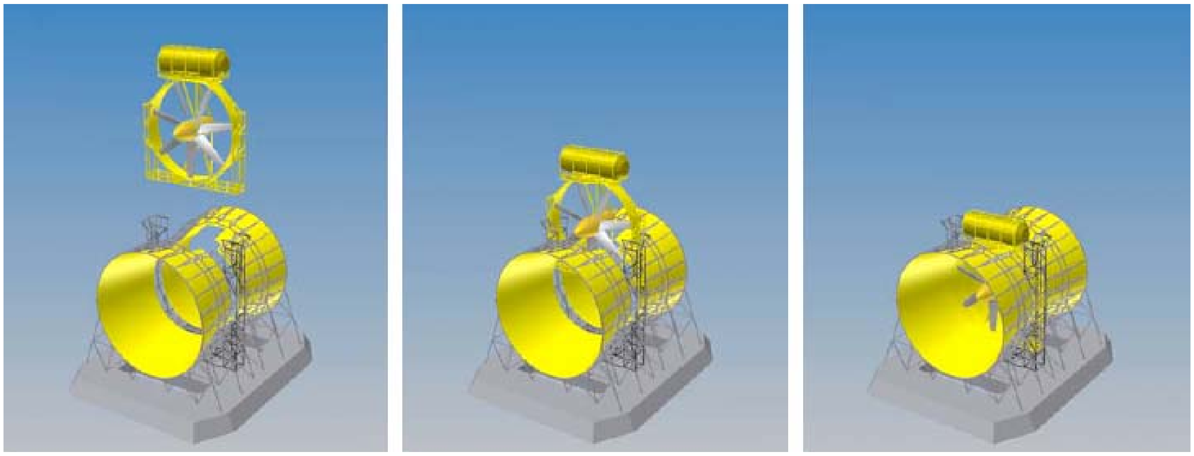


Figure 16 - Insertion and removal of cassette

Based on the site design velocity (maximum occurring velocity) the basic design's weight breakdown was scaled to ensure structural integrity and device stability. The following table contains the key properties for this site-design.

Table 3 - RTT2000 Mark II Specifications optimized for Muskeget channel Site conditions

Generic Device Specs	
Power Conversion	Hydraulic
Electrical Output	Synchronized with Grid
Foundation	Gravity Base
Dimensions	
Duct Inlet Diameter	21m
Duct Length	27m
Duct Clearance to Seafloor	10m
Duct Inlet Area	$346m^2$
Hub Height above Seafloor	20.5m
Weight Breakdown	
Structural Steel	277 tons
Ballast	332 tons
Total installed dry-weight	609 tons
Power	
Cut-in speed	0.7 m/s
Rated speed	1.57 m/s
Rated Power	252 kW
Capacity Factor	22%
Availability	95%
Transmission losses	2%
Net annual generation at bus bar at site	635 MWh

Device Performance

Given a velocity distribution for a site, the calculation of extracted and electrical power is discussed in [1]. Site surface velocity distributions have been adjusted to hub height velocity assuming a 1/10th power law.

The overall efficiency of the Lunar Energy RTT2000 is the product of rotor efficiency, gearbox efficiency and generator efficiency. The following chart shows the efficiency of the various elements as a function of rated speed as provided by Lunar Energy. In order to get to obtain the relative efficiency of the device, the numbers below should be multiplied by the Betz limit which is 0.593.

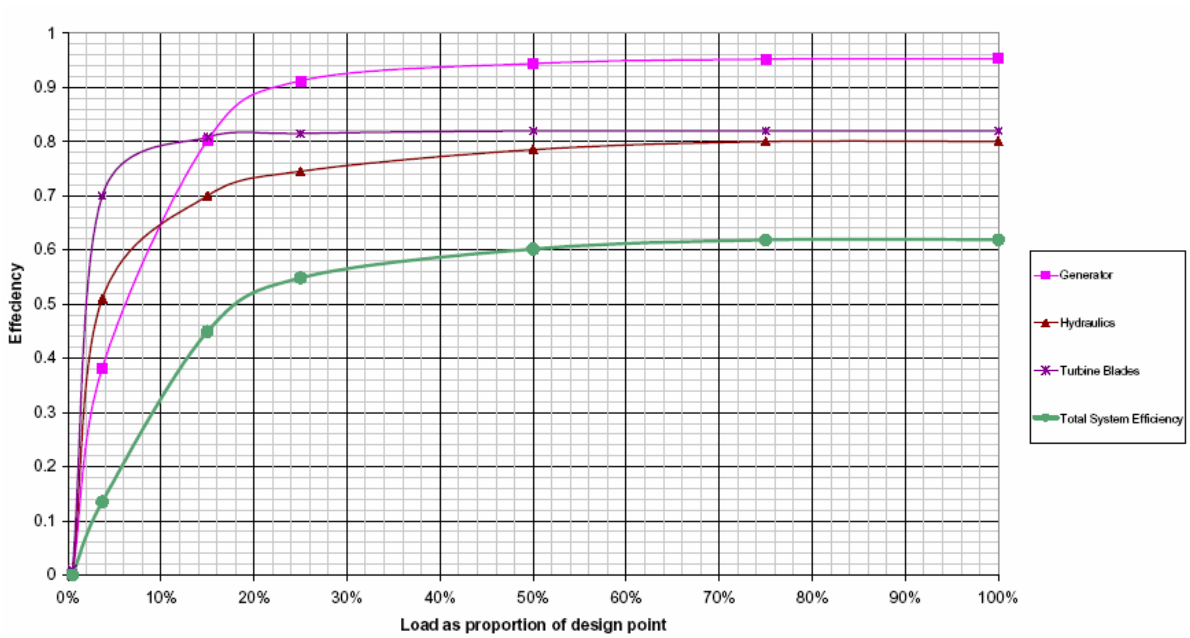


Figure 17 - Efficiency curves of Power Conversion System

Based on this efficiency chain and the exposed duct inlet area the device performance in a given site can be obtained. The following table shows the energy calculations at the Golden Gate site. The following definitions may help the reader understand:

- Flow velocities are depth adjusted using a 1/10 power law and represent the bin midpoint of the fluid speed at hub-height of the TISEC device.
- % Cases represents the percentage of time the flow at the site is at the flow velocity
- % Load represents the electrical output as a percentage of rated output of the device
- Power flux shows the incident power per square meter at the referenced velocity

- Flow power is the power passing through the cross sectional area of the device
- Extracted Power shows the amount of absorbed power

Average values can be found in the last column of the table.

Table 4 – Device Performance at deployment site (depth adjusted)

Fluid Speed m/s	% of Cases	% Load	Pfluid kW/m^2	Pfluid kW	Rotor Eff %	PCS Eff. %	Pelectric kW
0.09	5.37%	0.0%	0.00	0	33%	0%	0
0.27	8.71%	0.5%	0.01	3	34%	3%	0
0.45	9.15%	2.3%	0.05	16	39%	11%	0
0.63	9.58%	6.4%	0.13	44	44%	30%	0
0.81	10.76%	13.7%	0.27	94	47%	53%	24
0.99	13.45%	24.9%	0.49	171	48%	68%	56
1.17	17.04%	41.1%	0.82	282	48%	73%	99
1.35	13.53%	63.2%	1.25	434	48%	75%	156
1.53	7.87%	92.0%	1.82	631	48%	76%	232
1.71	3.09%	100.0%	2.54	881	48%	76%	252
1.89	1.26%	100.0%	3.44	1190	48%	76%	252
2.07	0.18%	100.0%	4.51	1563	48%	76%	252
2.25	0.00%	100.0%	5.80	2008	48%	76%	252
2.43	0.00%	100.0%	7.30	2529	48%	76%	252
2.60	0.00%	100.0%	9.05	3134	48%	76%	252
2.78	0.00%	100.0%	11.05	3828	48%	76%	252
2.96	0.00%	100.0%	13.33	4618	48%	76%	252
3.14	0.00%	100.0%	15.91	5509	48%	76%	252
3.32	0.00%	100.0%	18.79	6509	48%	76%	252
3.50	0.00%	100.0%	22.01	7622	48%	76%	252
3.68	0.00%	100.0%	25.57	8856	48%	76%	252
3.86	0.00%	100.0%	29.50	10216	48%	76%	252
4.04	0.00%	100.0%	33.81	11709	48%	76%	252
4.22	0.00%	100.0%	38.52	13341	48%	76%	252
4.58	0.00%	100.0%	49.21	17045	48%	76%	252
4.76	0.00%						
Average Values			0.69	241			78

Comparison of flow power to electric power generated is shown in Figure 18. Note particularly the cut-in speed (below which no power is generated) and rated speed (above which the power generated is constant).

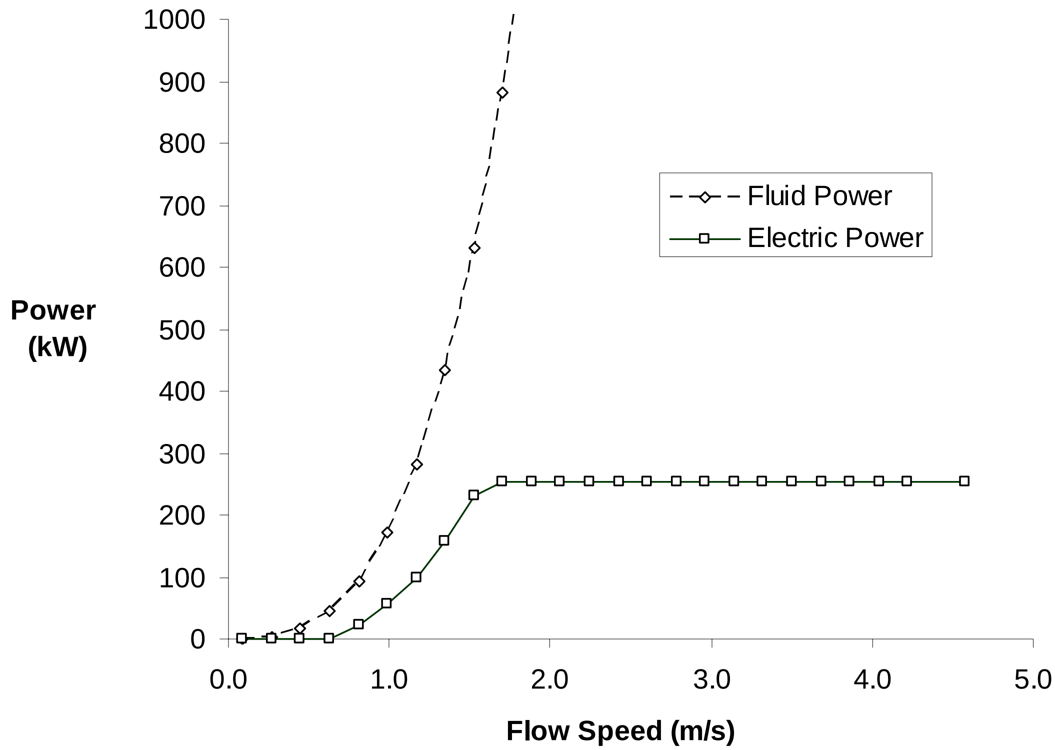


Figure 18 – Comparison of water current speed and electrical power output

The electrical output of the turbine compared to the fluid power crossing the swept area of the rotor is given in Figure 19, for a representative day. The effect of truncating turbine output at rated conditions is obvious.

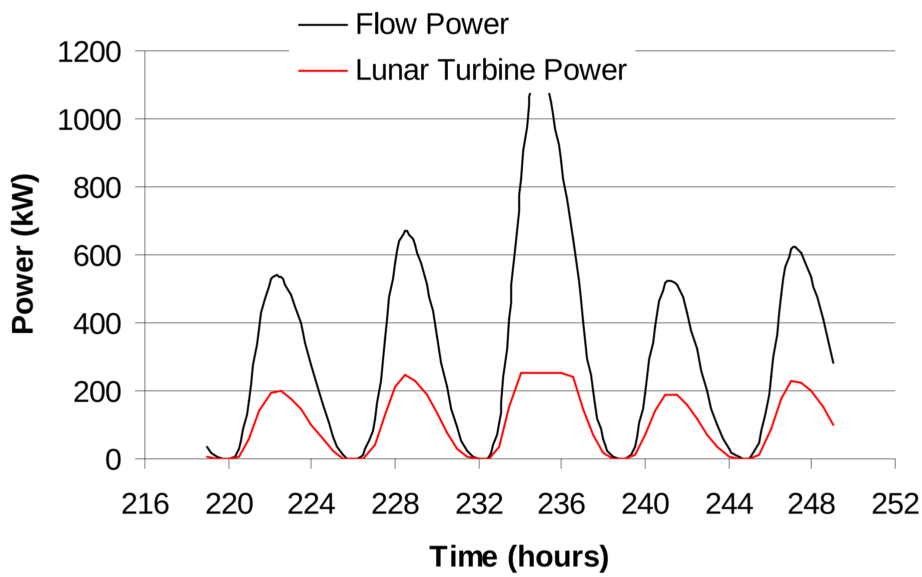


Figure 19 - Flow Power vs. Turbine Power at Site over 48-hour period

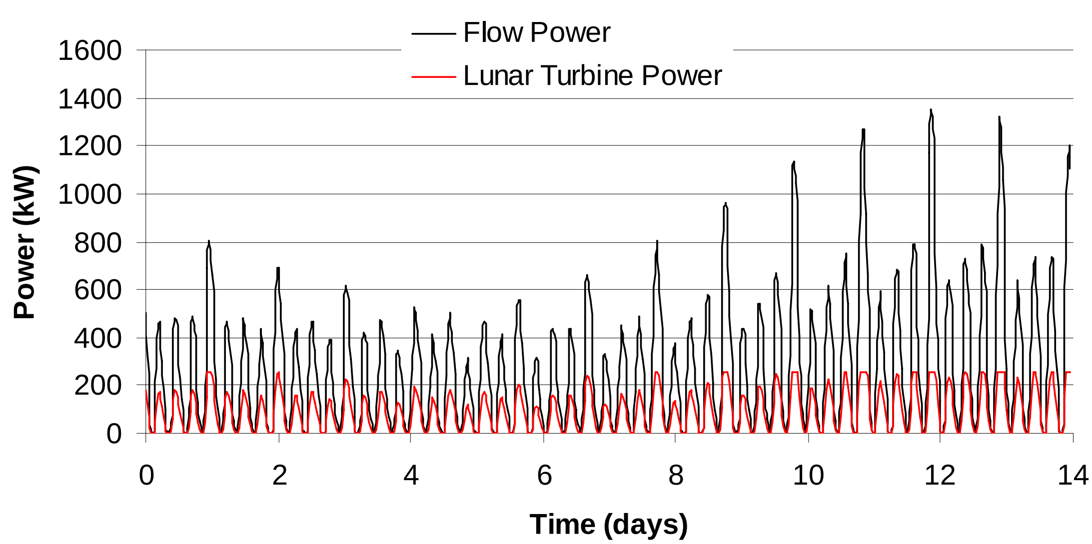


Figure 20 - Variation of flow power and electrical power output at the site over Lunar cycle

Lunar Device Evolution

Current design efforts carried out by Lunar Energy is focused on value engineering. Whereas the prototype design is in its final phase, the commercial units are expected to benefit from several potential areas of improvements, including:

1. Device Streamlining: Improving the overall design envelope to yield less drag, will reduce the stresses on the structure and result in savings on structural elements, foundation cost and weight.

2. Use of different materials: Replacing steel with concrete and composites could significantly reduce overall capital cost of the device.

3. Improving power train reliability: Improving the reliability of the power conversion system will result in less maintenance and could prove to provide significant savings. In particular replacing existing hydraulic elements with a direct induction generator could cut the number of interventions required over the devices design life by more then 50%.

4. Improving power train efficiency: The currently used hydraulic power conversion system shows an efficiency of about 76% at rated capacity. This is low as compared to other power train alternatives having efficiencies of up to 95%.

It is important to understand that none of the above measures would require novel technology and most of the measures could be implemented by means of simple value-engineering. Discussions with Lunar Energy showed that many of these improvements are already under consideration.

In March 2006, Lunar Energy provided EPRI with information on their redesigned prototype the RTT 2000 Mark II. The systems overall structural design was simplified by replacing the concrete base with 3 ‘steel-can’ legs. These steel pipes can be filled with ballast to provide stability against sliding in heavy currents. The duct-steelwork was also streamlined by making the duct a load-carrying element and eliminating the structural frame. While the overall redesign increased the steel-weight slightly, it reduced manufacturing complexities and associated cost.

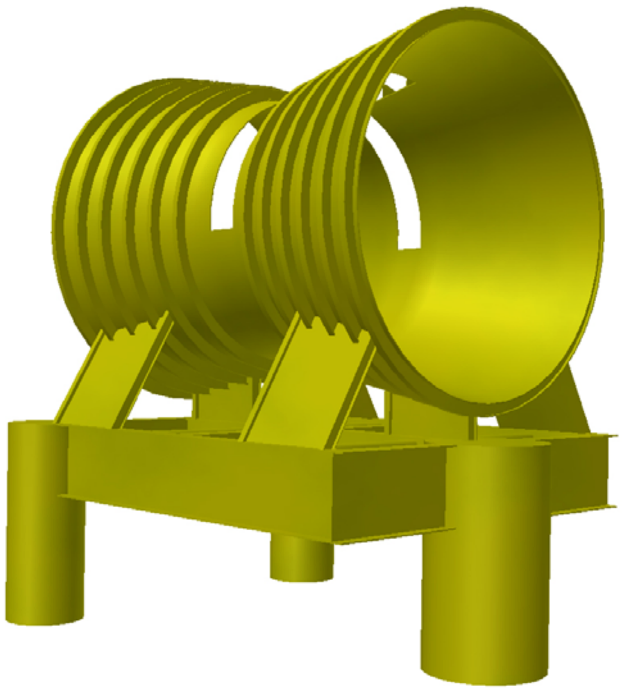


Figure 21 - RTT 2000 Mark II structural design

Installation of Lunar Module

The largest crane barges on the US west coast have capacities of up to 600 tons. With over 2000 tons, Lunar Energy's RTT2000 total system weight is well beyond of what any available crane-barge could handle and one of the big questions that needed to be answered was how this system was to be deployed, recovered and maintained. As a result, a detailed outline was developed of how the deployment and recovery of the device could be accomplished at reasonable cost. For the purpose of this outline we assumed that the device is deployed in two pieces, the concrete base and the duct. The text below outlines the deployment procedure.

The concrete base is constructed on a casting barge in calm, protected waters. The casting barge is then outfitted with four vertical pontoons (3m long), which are attached to each corner of the barge deck to provide stability during barge submersion. After the base is complete, the barge is ballasted until the deck is about 1.5m below the water level. This will allow the completed base shell to float free with a draft of about 1.2m. Once the base is floated off the barge it is sunk to the bottom in a water depth of at least 8m. Riser pipes are used to control the decent. A transport barge is floated over the base and preinstalled strand jacks are used to lift the base from the seabed until it is directly underneath the barge. The base is then filled with ballast and made ready for deployment. Finally, the barge is towed to it's deployment location and the same strand jacks are used to lower the base to it's prepared seabed.

Both the duct as well as the cassette unit are guided into final position using pre-installed guide wires extending vertically from the base structure to beams extending out in front of a derrick barge. The derrick barge places the duct onto a frame attached to the front of the barge. The duct is then attached to the guide wires and the guide wires are tensioned. Finally the duct is lowered onto the base using strand-jacks and guide wires. After set down, a ROV will disconnect strand jacks and guide wires from the base and duct.

The same procedure can be used to deploy and recover the cassette. The only difference is that the cassette weighs less and as a result a smaller (and less costly) derrick barge can be used.

Scour protection (if required) can be provided by either using concrete infill below the base or by placing articulated concrete mats onto the seabed. Both of these approaches have been successfully used in a number of North American projects.

Most installation and maintenance activities can be carried out from a derrick barge. These barges are in operation all over North and Central America and are used for a large variety of construction projects. Figure 22 shows Manson Construction's 600 ton derrick barge WOTAN doing construction work on an offshore drilling rig. Two tug boats are used for positioning the derrick barge and set moorings if required.

Figure 22 - Manson Construction 600 ton Derrick Barge WOTAN operating offshore

In heavy currents these barges use a mooring spread that allows them to keep on station and accurately reposition themselves continuously using hydraulic winches controlled by the operator.

A second piece of equipment that becomes really important for subsea installations is the remote operated vehicle (ROV). These systems increasingly replace divers and are used to monitor the subsea operation, visual inspections and carrying out various manipulation tasks such as connecting and disconnecting of guide wires, unplugging electrical cables etc. Technological advances have made these submersibles increasingly capable, in many instances eliminating the need to send down divers. This in turn reduces cost while increasing safety. A typical dual manipulator arm ROV making an underwater electrical connection is shown in Figure 23.

Operational Activities Lunar Energy

The O&M philosophy of Lunar Energy's RTT 2000 is to provide a reliable design that would require a minimal amount of intervention over its lifetime. In order to accomplish this Lunar Energy decided early on to use highly reliable and proven components even if that meant lower power conversion efficiency and performance as a result

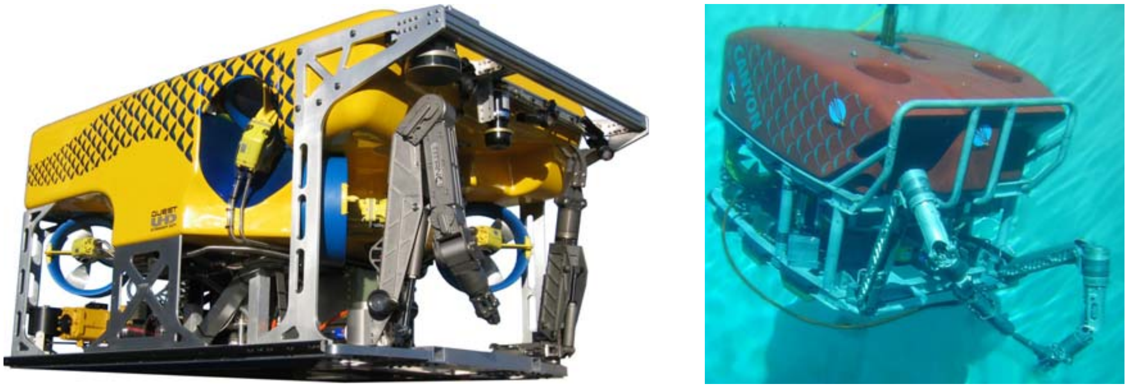
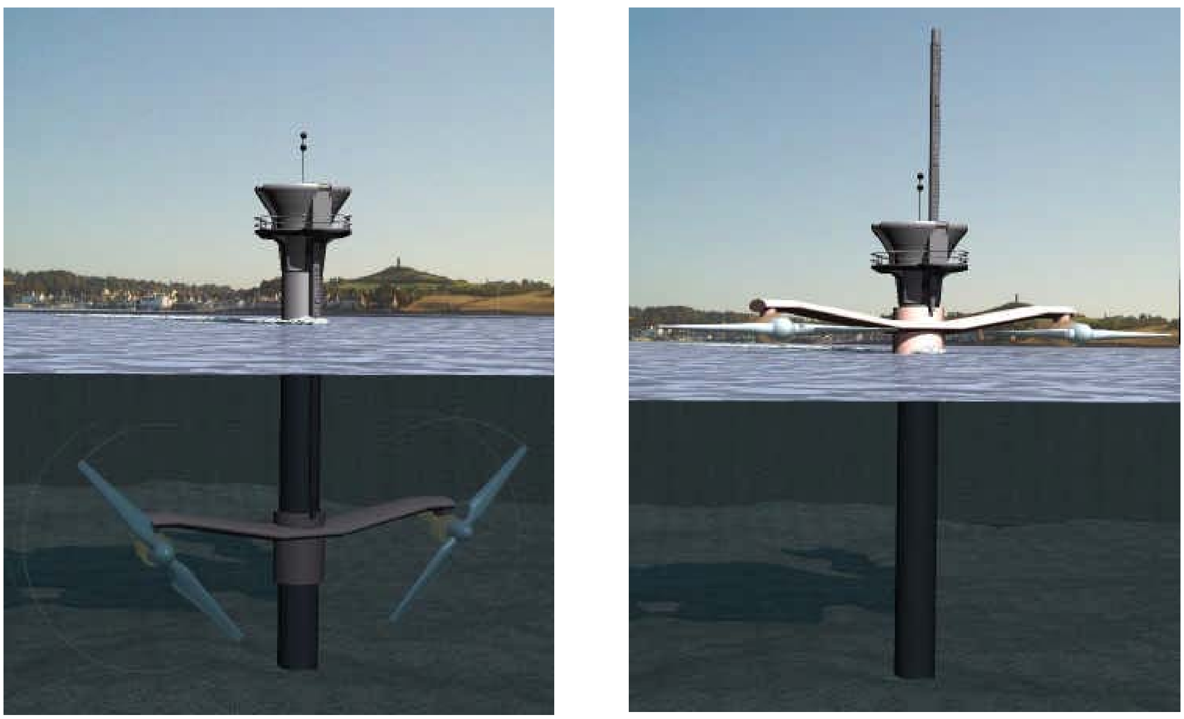


Figure 23 – Remotely Operated Vehicle (ROV) – ROV making electrical connection (courtesy of Schilling_Robotics - www.ssaalliance.com)

All of the power conversion equipment of the RTT 2000 is mounted on a cassette, which can be removed from the duct and brought into a port to carry out operation and maintenance activities. The fact that the device is completely submersed makes its operation very dependent on attaining claimed reliability as each repair requires the recovery of the duct which requires specialized equipment. Lunar Energy has addressed this issue by optimizing its operation and maintenance strategy for minimal intervention. It is expected that the cassette is swapped out every 4 years and undergoes a complete overhaul after which it is ready to operate for another 4 years. The critical components prone to failure in the power conversion system are the hydraulic power conversion system. Given the high cost for maintenance intervention, reliability of the system becomes a critical attribute of the system, which will need to be proven on a prototype system. The L90 life of a component specifies after how much time 10% of components will fail (i.e. 90% of the components are still in good order therefore the term L90). The most critical hydraulic component of the RTT2000 has a L90 life of 5 years (meaning that after 5 years 90% of all devices are still operating without any issues). Given a typical Weibull failure distribution it was deemed that a 4-year service interval as proposed by the company is a sensitive approach.

4. Marine Current Turbines

The Marine Current Turbine (MCT) SeaGen free flow water power conversion device has twin open axial flow rotors (propeller type) mounted on “wings” either side of a monopile support structure which is installed in the seabed. Rotors have full span pitch control and drive induction generators at variable speed through three stage gearboxes. Gearboxes and generators are submersible devices the casings of which are exposed directly to the passing sea water for efficient cooling. A patented and important feature of the technology is that the entire wing together with the rotors can be raised up the pile above the water surface for maintenance. Blade pitch is rotated 180^{o} at slack water to accommodate bi-directional tides without requiring a separate yaw control mechanism. This device is illustrated in Figure 24.



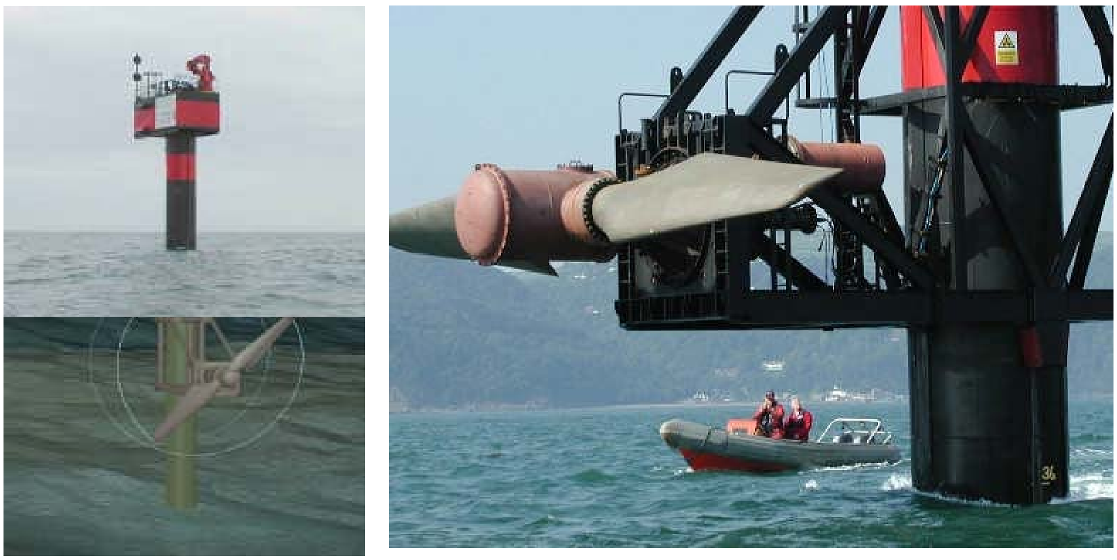
Operation Maintenance

Figure 24 – MCT SeaGen (courtesy of MCT)

(This photo prints upside down courtesy of either Microsoft or our lack of MS Word skills)

A 1.2 MW prototype SeaGen is presently being built and is scheduled for UK deployment in the fall of 2006. SeaGen is intended as a commercial prototype (not proof of concept) – and incorporates important learnings from SeaFlow, a 300kW single rotor test rig (Figure

25), which has been in operation for about 3 years. SeaFlow tested many of the features of SeaGen and has informed the design process by providing large amounts of data. The photo shows the rotor raised out of the water for maintenance – the submersible gearbox and generator are clearly visible. The rotor diameter is 11m and the pile diameter is 2.1m.



Operation Maintenance

Figure 25 – MCT SeaFlow Test Unit (courtesy of MCT)
(This photo prints upside down courtesy of either Microsoft or our lack of MS Word skills)

Device Performance

Given a velocity distribution for a site, the calculation of extracted and electrical power is discussed in [1]. Site surface velocity distributions have been adjusted to hub height velocity assuming a 1/10th power law.

The overall efficiency of the MCT SeaGen is the product of:

- Rotor: constant efficiency = 45%
- Gearbox: efficiency at rated power = 96%
- Generator: maximum efficiency = 98%

The efficiency of the gearbox and generator is expressed as a function of the load on the turbine (% load). Balance of system efficiency (BOS) is assumed to follow the same form as for a conventional wind turbine drivetrain – which can be approximated by the following function:

$$\eta_{BOS} = 0.8337e^{0.1467(\%\,\text{Load})} - 0.7426e^{-33.89(\%\,\text{Load})}$$

The performance of a single turbine deployed at the site is shown in Table 5. Average values can be found in the last row of the table.

Table 5 – Device Performance

Fluid Speed m/s	% of Cases	% Load	Pfluid kW/m^2	Pfluid kW	Pextracted kW	PCS %	Pelectric kW
0.09	6.80%	0.0%	0.00	0	0	9.62%	0
0.28	7.28%	0.5%	0.01	6	0	21.80%	0
0.47	7.27%	2.5%	0.05	27	0	52.33%	0
0.66	7.73%	7.0%	0.15	75	0	77.26%	0
0.85	8.89%	14.8%	0.31	160	72	84.72%	61
1.04	9.74%	27.1%	0.57	292	132	86.74%	114
1.23	13.53%	44.7%	0.95	483	217	89.02%	193
1.42	15.04%	68.7%	1.46	742	334	92.21%	308
1.61	12.92%	100.0%	2.12	1080	486	94.08%	457
1.80	7.36%	100.0%	2.96	1507	486	94.08%	457
1.98	3.11%	100.0%	4.00	2035	486	94.08%	457
2.17	0.34%	100.0%	5.25	2674	486	94.08%	457
2.36	0.00%	100.0%	6.75	3434	486	94.08%	457
2.55	0.00%	100.0%	8.50	4325	486	94.08%	457
2.74	0.00%	100.0%	10.53	5360	486	94.08%	457
2.93	0.00%	100.0%	12.86	6547	486	94.08%	457
3.12	0.00%	100.0%	15.52	7897	486	94.08%	457
3.31	0.00%	100.0%	18.51	9422	486	94.08%	457
3.50	0.00%	100.0%	21.87	11131	486	94.08%	457
3.68	0.00%	100.0%	25.61	13035	486	94.08%	457
3.87	0.00%	100.0%	29.76	15146	486	94.08%	457
4.06	0.00%	100.0%	34.33	17472	486	94.08%	457
4.25	0.00%	100.0%	39.35	20025	486	94.08%	457
4.44	0.00%	100.0%	44.83	22815	486	94.08%	457
4.63	0.00%	100.0%	50.80	25854	486	94.08%	457
4.82	0.00%	100.0%	57.28	29150	486	94.08%	457
5.01	0.00%	100.0%	64.28	32716	486	94.08%	457
Average Values			1.08	551	214		197

comparison of flow power to electric power generated is shown in Figure 26. Note particularly the cut-in speed (below which no power is generated) and rated speed (above which the power generated is constant).

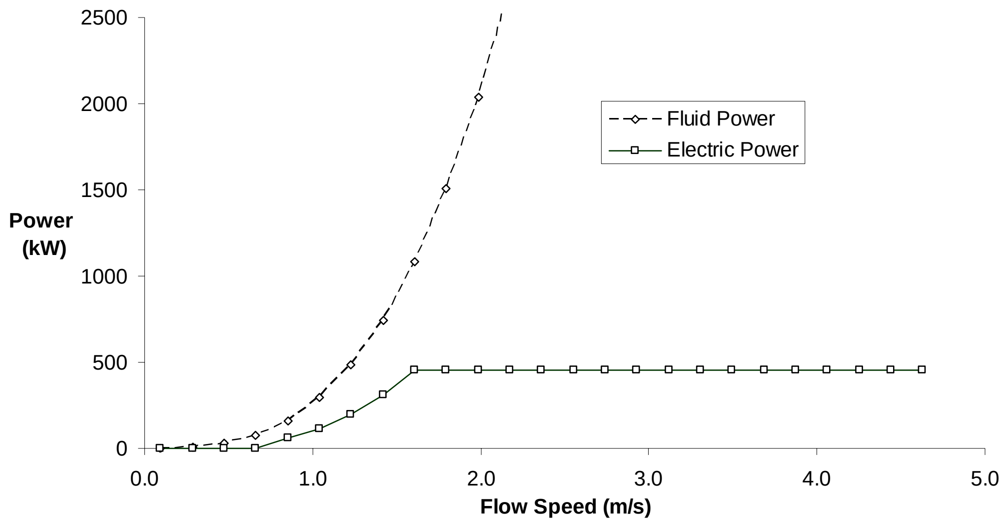


Figure 26 – Comparison of water current speed and electrical power output

The electrical output of the turbine compared to the fluid power crossing the swept area of the rotor is given in Figure 27, for a representative day. The effect of truncating turbine output at rated conditions is obvious.

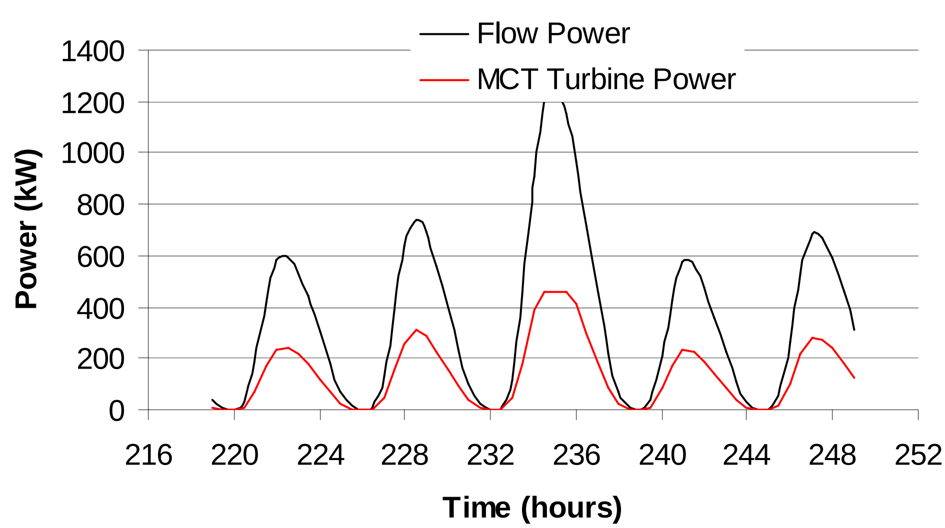


Figure 27 – Variation of flow power and electrical power output at the site

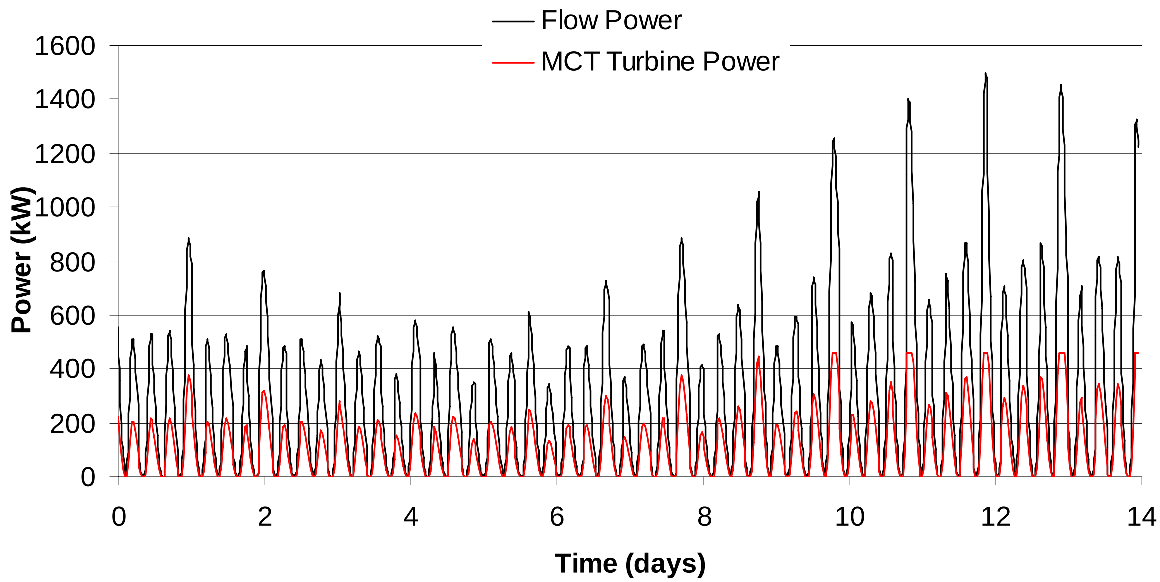


Figure 28 - Turbine power vs. Flow Power at site over lunar cycle

Device Specification

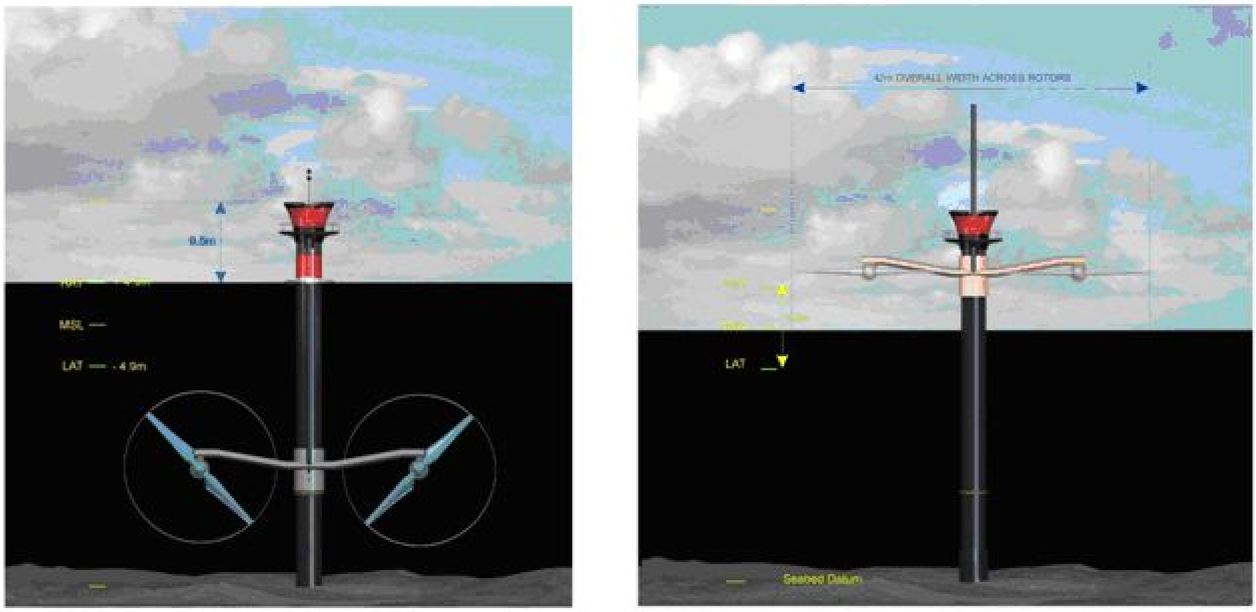
While in principle SeaGen is scalable and adaptable to different site conditions in various ways, EPRI used the 18m dual rotor version and optimized the system to local site conditions to estimate device cost parameters. The following provides specifications which are later used to estimate device cost. Since MCT's second generation completely submersed concept is not yet designed for manufacturing, EPRI was not able to do an independent cost analysis or it. Therefore the costing model represents an installation depth of 30m (which is representative of MCTs SeaGen technology). Based on discussions with MCT it is reasonable to expect that subsequent generation devices will have similar capital cost.

Table 6 – SeaGen Device Specification optimized for the Muskeget channel site

Generic Device Specs	
Speed Increaser	Planetary gear box
Electrical Output	Synchronized to grid
Foundation	Monopile drilled and grouted into bedrock
Average Deployment Water Depth	30m
Dimensions	
Pile Length	68m
Pile Diameter	3.5m
Rotor Diameter	18m
# Rotors per SeaGen	2
Rotor Tip to Tip spacing	46m
Hub Height above Seafloor	17m
Weight Breakdown	
Monopile	115 tons
Cross Arm	55 tons
Total steel weight	170 tons
Performance	
Cut-in speed	0.7 m/s
Rated speed (optimized to site)	1.61 m/s
Rated Electric Power	457 kW
Capacity Factor	40%
Availability	95%
Transmission efficiency	98%
Net annual generation at bus bar	1,610 MWh

MCT Device Evolution

MCTs first commercial unit, the SeaGen has been designed for a target water depth of less then 50m using a surface piercing monopile, which will allow low cost access to the devices critical components such as the rotor, power conversion system, gearbox etc. This configuration is shown in Figure 29.



Operation Maintenance

Figure 29 – MCT SeaGen (courtesy of MCT)

This configuration is not necessarily suitable for all sites for two reasons. First, deployment in deep water would be difficult and expensive. Second, surface piercing turbines are incompatible in some channels due to interference with shipping traffic. Since a number of sites prospective sites in North American are located in deeper water or in shipping channels, MCT has revealed a conceptual design for a deep-water, non-surface piercing turbine. It is based on MCTs existing turbine technology with an arrangement to raise the whole system to the surface where it can be accessed easily for operation and maintenance purposes. A preliminary review suggests that capital and operational costs are likely going to be in a similar range then for the SeaGen unit for which detailed cost models were built to evaluate the technology's economics in selected sites in North America.

Since a number of prospective sites in North American are located in deeper water or in shipping channels, MCT is considering a number of conceptual designs for deep-water, non-surface piercing installations. These next-generation devices would use the same power train as the SeaGen, but attached to a different support structure. Figure 30 shows a conceptual illustration of such a design.

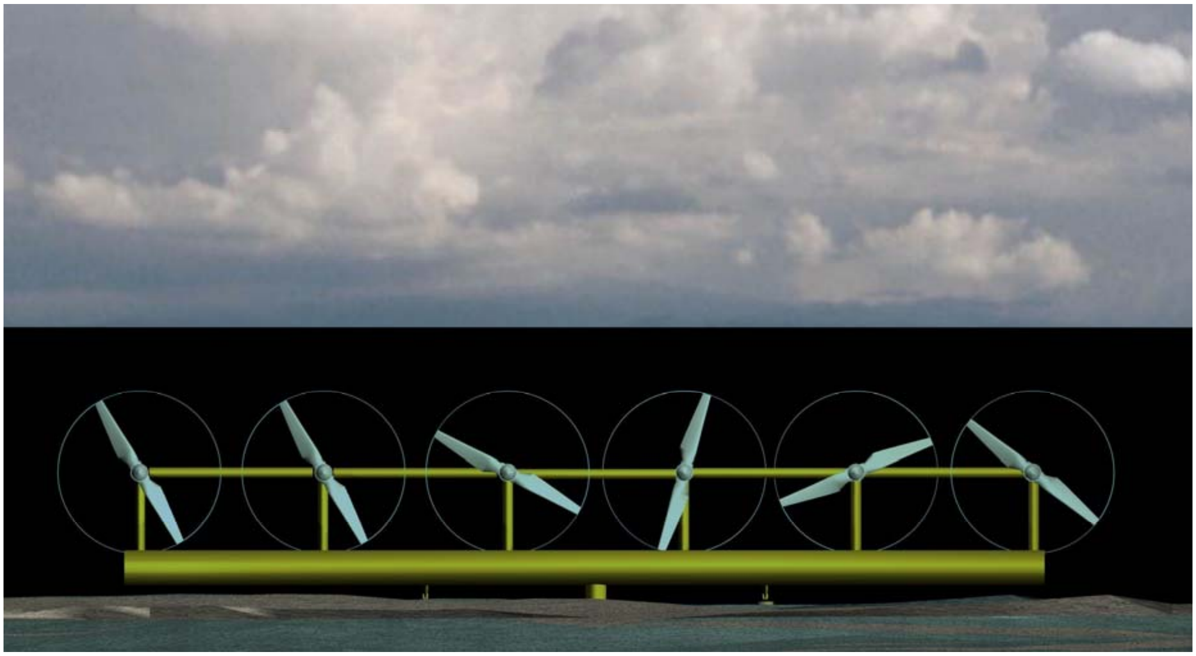


Figure 30 - MCT next generation conceptual illustration

A lifting mechanism (type to be determined) to surface the array for maintenance and repair without the use of specialized craft remains an integral part of MCT's design philosophy and would be present in any next-generation design. MCT is also investigating the use of gravity foundations instead of monopiles for certain sites.

MCT anticipates that maintenance of a completely submerged turbine will be more complicated than for a surface piercing structure. As a result, deployment of completely submerged turbines is contingent upon proving the reliability of the SeaGen power train.

Monopile Foundations

The MCT SeaGen is secured to the seabed using monopile foundation. Figure 31 shows a representative simulation of seabed/pile interaction. Near the surface the seabed yields due to stresses on the pile, but deforms elastically below a certain depth.

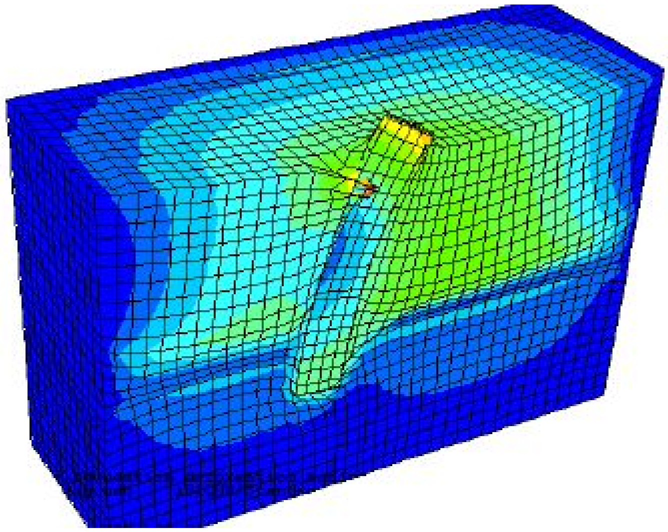


Figure 31 - Simulation of pile-soil interaction subject to lateral load (Source: Danish Geotechnical Institute)

Simulations such as the one shown above require detailed knowledge of the local soil conditions. Because this study did not perform any detailed geophysical assessment, three different types of soil conditions were chosen to model the pile thickness based on a simplified mechanical model:

- Bedrock
- Bedrock with 10m of sediment overburden
- Soft sediments

The design criterion was to limit maximum stresses to $120N/mm^2$ and account for corrosion over the pile life. For Muskeget channel, the seabed is modeled as bedrock with 10m of sediment overburden.

Figure 32 shows the range of pile weights as a function of design velocity (the maximum occurring fluid velocity at the site). These curves were then directly used to estimate capital costs of the piles depending on local site conditions. While the model is well suited for a first order estimate, it is important to understand that the detailed design phase may show deviation from EPRI's base model.

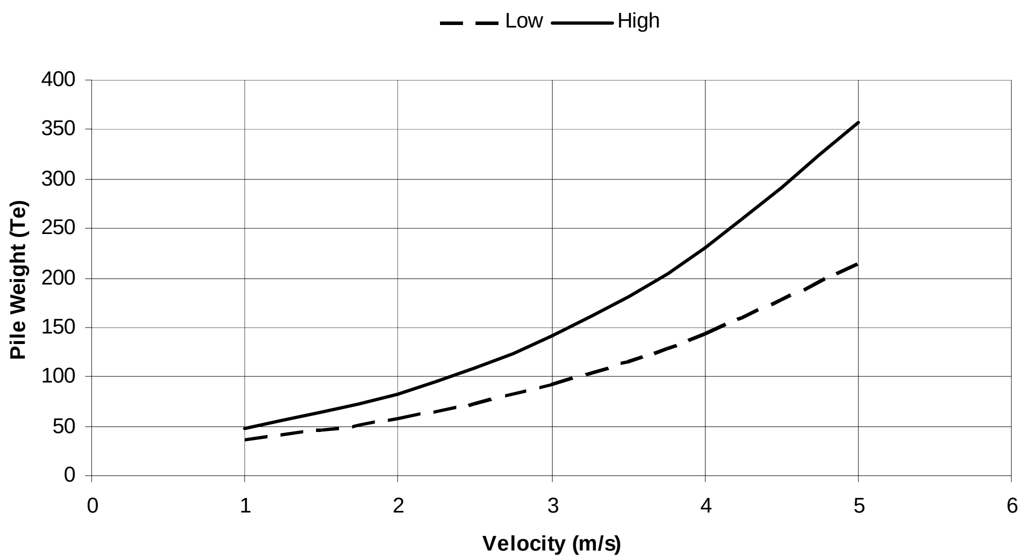


Figure 32 - Pile Weight as a function of design velocity for different sediment types

Pile Installation

MCT proposes to install their large diameter monopiles (3.5m - 4m outer diameter) using a jack-up barge. This is consistent with other European offshore wind projects that have used such barges to deploy offshore wind turbine foundations. While a few operators were found on the east-coast that use jack-up barges, most of them are used in the Gulf of Mexico and no suitable jack-up barge was found on the US west coast. Given the expense of mobilizing marine construction equipment from the Gulf of Mexico, EPRI decided to investigate lower-cost alternatives. The following outline shows the installation of a pile in bedrock from a jack-up barge.

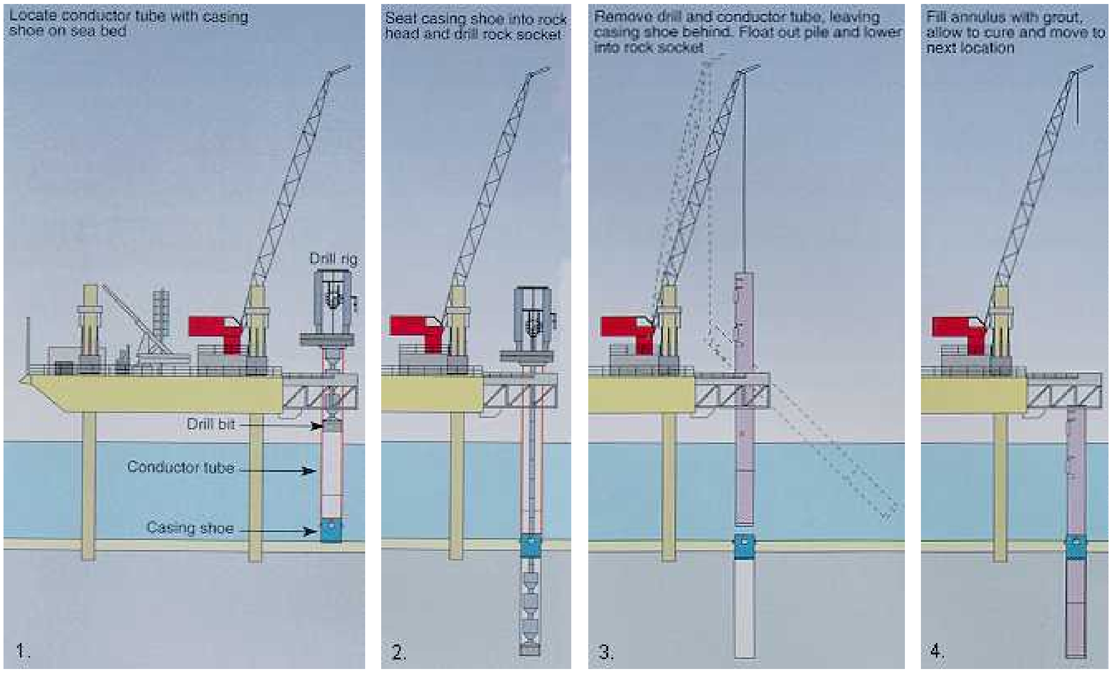


Figure 33 – Pile Installed in Bedrock (Seacore)

While jack-up barges are not commonly available in US waters, there are a significant number of crane barges available from which the installation of theses piles could be carried out. These derrick barges operate on the US west and east coast and are extensively used for construction projects in heavy currents such as rivers. Typical construction projects include the construction of bridges, cofferdams and pile installations. Crane capacities vary with some of the largest derrick barges being able to lift up to 600 tons. To carry out the installation of these relatively large 3.5m diameter piles, it was determined that a crane capacity of about 400 tons or more would be adequate to handle the piles, drilling bits and other installation equipment. Figure 27 shows Manson Construction's 600 ton derrick barge WOTAN doing construction work on an offshore drilling rig. Two tug boats are used for positioning the derrick barge and set moorings if required.

Figure 34 - 600 ton Derrick Barge WOTAN operating offshore (Manson Construction)

In heavy currents these barges use a mooring spread that allows them to keep on station and accurately reposition themselves continuously using hydraulic winches controlled by the operator.

Working from a barge, rather then from a jack-up platform does not set hard limits on the water depth in which piles can be installed. Some preliminary studies suggest that type of pile required for the MCT SeaGen device could be installed in water depths of as much as 90m. However such a configuration may not be cost effective due to high cost. In the offshore industry, piles are oftentimes used as mooring points for offshore structures. Installation of driven piles in water depths of more then 300m is not uncommon. It is, however, clear that pile installation in deeper waters becomes more costly and presents a limiting factor to their viability. Several options exist for installing piles, but it is important to stress that few marine construction companies in the US have experience with the installation of large piles in high current waters. Potential construction methods include:

- Driving piles using a hydraulic hammer

- Combination of water jetting and vibratory hammer
- Drill and socket a sleeve, then grout pile in place

Each of these methods has advantages and disadvantages. A drilled pile installation would involve drilling into the consolidated sediments and stabilizing the walls of the drill hole with a metal sleeve (follower). Once the hole has been drilled to a suitable depth, the pile is inserted and grouted into place. This method of installation is preferred by MCT to limit excessive pile fatigue during the installation process and drilling is required in most locations because of bedrock that would need to be penetrated.

Operational and Maintenance Activities

The guiding philosophy behind the MCT design is to provide low cost access to critical turbine systems. Since an integrated lifting mechanism on the pile (or level arm for the next generation design) can lift the rotor and all subsystems out of the water, general maintenance activities do not require specialized ships or personnel (e.g. divers). The overall design philosophy appears to be that the risks associated with long-term underwater operation are best offset by simplifying scheduled and unscheduled maintenance tasks. The only activity that could require use of divers or ROVs would be repairs to the lifting mechanism or inspection of the monopile, none of which are likely to be required over the project life.

Annual inspection and maintenance activities are carried out using a small crew of 2-3 technicians on the device itself. Tasks involved in this annual maintenance cycle include activities such as; replacement of gearbox oil, applying bearing grease and changing oil filters. In addition, all electrical equipment can be checked during this inspection cycle and repairs carried out if required. Access to the main structure can be carried out safely using a small craft such as a RIB (Rigid Inflatable Boat) in most sea conditions.

Figure 35: Typical Rigid Inflatable Boat (RIB)

For repairs on larger subsystems such as the gearbox, the individual components can be hoisted out with a crane or winch and placed onto a motorized barge. The barge can then convey the systems ashore for overhaul, repair or replacement. For the purpose of estimating the likely O&M cost, the mean time to failure was estimated for each component to determine the resulting annual operational and replacement cost. Based on wind-turbine data, the most critical component is the gearbox which shows an average mean time to failure of 10.8 years.

For the next generation design for a completely submerged turbine (assumed for commercial plant) major intervention could require the use of a crane barge to dismount the power train from the support structure. Since the lifting mechanism would also be subsurface, a failsafe retrieval method (e.g. retrieval hook) would be required in the case of a failure of the lifting mechanism. MCT does not anticipate the added complexity of full submergence to greatly increase maintenance costs, because deployment of a fully submerged device is contingent on proving that the chosen power train requires limited maintenance intervention.

5. Electrical Interconnection

Each TISEC device houses a step-up transformer to increase the voltage from generator voltage to a suitable array interconnection voltage. The choice of the voltage level of this energy collector system is driven by the grid interconnection requirements and the array electrical interconnection design but is typically between 12kV and 40kV. For the pilot scale, 12kV systems are anticipated – depending on local interconnection voltages. This will allow the device interconnection on the distribution level. For commercial scale arrays, voltage levels of 33kV are used. This allows the interconnection of an array with a rated capacity of up to about 40MW on a single cable.

A fiber core is used to establish reliable communication between the devices and a shore-based supervisory system. Remote diagnostic and device management features are important from an O&M stand-point as it allows to pin-point specific issues or failures on each unit, reducing the physical intervention requirements on the device and optimizing operational activities. Operational activities offshore are expensive and minimizing such interventions is a critical component of any operational strategy in this harsh environment.

The Surface piercing MCT SeaGen device has all it's electrical components located inside the monopile, where it is well protected and easily accessible for operation and maintenance activities. In other words, sub sea connectors or junction boxes are not required to interconnect the device to the electrical grid.

The completely submersed Lunar Energy Device houses all the generation equipment and step-up transformer in cylindrical watertight container mounted on the cassette, which needs to be recovered to the surface for servicing. Interconnection is envisioned to be accomplished using a pressure compensated junction box that allows a single device to be connected to a device cluster. The cassette can be interconnected by either using sub sea wet-mate able connectors or using a flexible cable that is attached to the cassette so that it can be connected and disconnected on the surface.

Subsea Cabling

Umbilical cables to connect turbines to shore are being used in the offshore oil & gas industry and for the inter-connection of different locations or entire islands. With other words, it is well established technology with a long track-record. In order to make these cables suitable for in-ocean use, they are equipped with water-tight insulation and additional armor, which protects the cables from the harsh ocean environment and the high stress levels experienced during the cable laying operation. Submersible power cables are vulnerable to damage and need to be buried into soft sediments on the ocean floor. While traditionally, sub-sea cables have been oil-insulated, recent offshore wind projects in Europe, showed that the environmental risks prohibit the use of such cables in the sensitive coastal environment. XLPE insulations have proven to be an excellent alternative, having no such potential hazards associated with its operation. Figure 36 shows the cross-sections of armored XLPE insulated submersible cables.

Figure 36 – Armored submarine cables

For this project, 3 phase cables with double armor and a fiber core are being used. The fiber core allows data transmission between the units and an operator station on shore. In order to protect the cable properly from damage such as an anchor of a fishing boat, the cable is buried into soft sediments along a predetermined route. There are different technologies available to bury the cable along the cable route. All of them require the creation of a trench in which the cable can be laid. In order to protect the cable, this channel is then back-filled with rocks. Various trenching technologies exist such as the use of a plough in soft sediments, use of a subsea rock-saw in rock (if going through hard-rock) or the use of water jets. All of these cable laying operations can be carried out from a derrick barge that is properly outfitted for the particular job. The choice of technology best suited for getting the job done depends largely on the outcome of detailed geophysical assessments along the cable route. For this study, the EPRI team assessed both the use of a trenching rock saw as well as a plough.

An important part of bringing power back to shore is the cable landing. Existing easements should be used wherever possible to drive down costs and avoid permitting issues. If they do not exist, directional drilling is the method with the least impact on the environment. Directional drilling is a well established method to land such cables from the shoreline into the ocean and has been used quite extensively to land fiber optic cables on shore. Given some of the deployment location proximity to shore, detailed engineering might even reveal that directional drilling directly to the deployment site is possible. This would reduce environmental construction impacts at the site, while reducing overall cost.

Onshore Cabling and Grid Interconnection

Traditional overland transmission is used to transmit power from the shoreline to a suitable grid interconnection point. Grid interconnection requirements are driven by local utility requirements. At the very least, breaker circuits need to be installed to protect the grid infrastructure from system faults. VAR compensation voltage step-up and other measures might be introduced based on particular local requirements.

6. System Design – Pilot Plant

The purpose of a pilot plant is first, and foremost, to demonstrate the viability of a particular technology. Pilot plants are, in general, not expected to produce cost competitive electricity and often incorporate instrumentation absent from a commercial device.

For the pilot TISEC plant, the following should be successfully demonstrated prior to installation of a commercial array:

- Turbine output meets predictions for site
- Installation according to design plan with no significant problems
- Turbine operates reliably, without excessive maintenance intervention
- No significant environmental impacts for both installation as well as operational aspects.

For the pilot plant at Muskeget Channel, the following issues deserve particular attention and should be an integral part of the pilot testing plan:

- Large marine mammal and fish interaction with turbine. This will require instrumentation for fish monitoring.
- Bio-accumulation on turbine and support structure over course of demonstration.

The following illustration shows how a single TISEC device is connected to the electric grid.

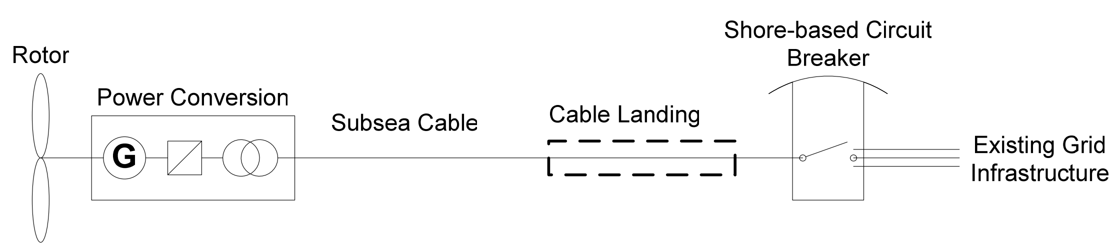


Figure 37 - Conceptual Electrical Design for a single TISEC Unit

Pilot power collection and grid interconnection details are summarized in Table 7 – Pilot Grid Interconnection. The cost for overland interconnection is for routing the power take-off cable from the beach to distribution line. Infrastructure upgrade costs are expected to be minor since power is being fed into an existing distribution line.

Table 7 – Pilot Grid Interconnection

Grid Interconnection Demo	
Grid Interconnection Point	4 kV distribution line on eastside of Chappaquiddick island
Subsea Cable Length	4000m
Subsea Trench Length	4000m
Sediment type along cable route	Sediments
Cable Landing	Directional Drilling
Overland Interconnection Cost	Estimated at $200,000
Infrastructure Upgrade Cost	None

The deployment location for a single unit is described in the site selection section and turbine performance is outlined in the performance section. A demonstration unit is likely to be deployed in the narrowest cross section in the Muskeget channel.

The footprint of the pilot plant is quite small and should have little impact on recreation or shipping activities.

7. System Design - Commercial TISEC Power Plant

The purpose of a commercial tidal plant is to generate cost competitive electricity for the grid without causing unacceptable environmental impacts. The single largest impact on the cost of electricity for a TISEC farm is the current velocity profile. The reason is that structural loads (and corresponding structural cost) increase to the second power of velocity, while the power generated increase to the 3rd power of the velocity. In a channel the fluid velocity will increase in narrow passages. So the channel transect with the lowest cross-sectional area will generally prove to be the most economic one.

Other factors considered in the design of this commercial tidal power plant are:

- Install turbines only in waters sufficiently deep to meet shipping clearance requirements
- Turbines are not to extract more then 15% of the total estimated resource
- Locate the plant in close proximity to a grid interconnection point to reduce costs

For purposes of establishing a conceptual design point, we assumed that MCT's surface piercing SeaGen would be installed at the site. Alternatively deep water fully submersed technology could be used at the site. Since the plant is not interfering with freight transport, only with recreational and commercial shipping, it is thought that the two uses could co-exist nicely in the area. For design and cost estimate purposes we assumed that the commercial MCT design use the same rotor diameter and clearance requirements as the surface piercing SeaGen device.

Electrical Interconnection

In order to interconnect a large number of turbines to the electric grid, a power collection network needs to be set up. In order to maximize availability and stay within reasonable limits on the amount of electrical power fed back to shore per single cable, devices are arranged in clusters. Each cluster connects back to shore using a single cable. This allows a cluster of devices to be isolated if required.

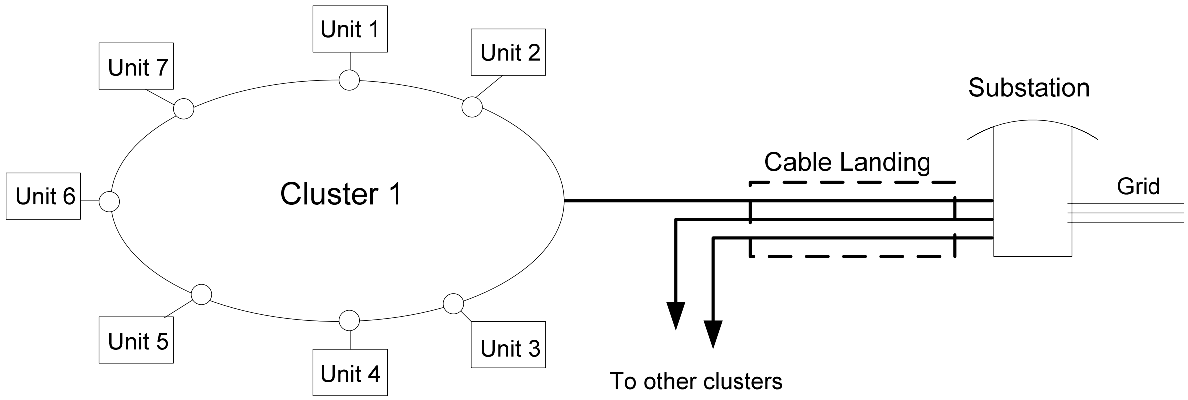


Figure 38 - Electrical Power Collection and Grid Interconnection for commercial plant

Physical Layout

In order to extract 15% of the resource at the site, a significant portion of the cross-sectional area needs to be intersected. With existing prototype device rotor diameters and non stackable structures, this can only be achieved by arranging the turbines in rows across the channel width in areas with sufficient depth. In addition, it might require the rows of turbines to be installed at different depths behind each other with sufficient spacing in order to avoid the wake of the previous row of turbines to affect subsequent rows. The narrowest transect where we can expect high velocities is very narrow. The rectangular area in Figure 39 shows the length and width of interest for turbine deployment. Detailed modeling of the resource could reveal hot-spots and provide more information as to where such turbines should be located. However in absence of such models, the outline shown below shows reasonable boundaries within which devices could be deployed.

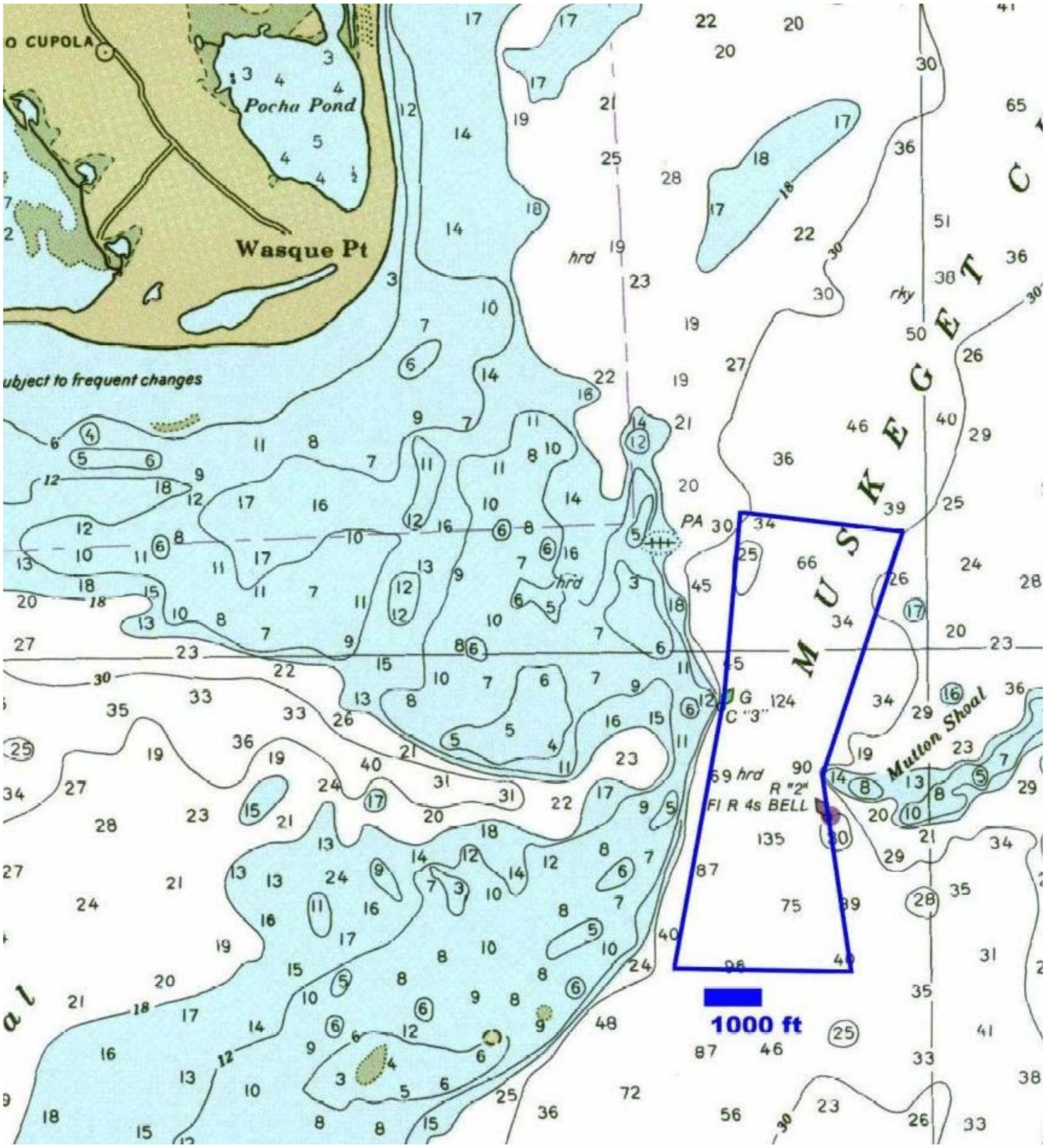


Figure 39 - SF Deployment Site. Water depth shown in feet

The following 2 figures show the turbine size and spacing assumptions for both turbines. Downstream spacing to avoid the wake of previous turbines are assumed to be 10x the turbine diameter. These spacing assumptions are critical in determining how many turbines can be fit within a given high-velocity channel.

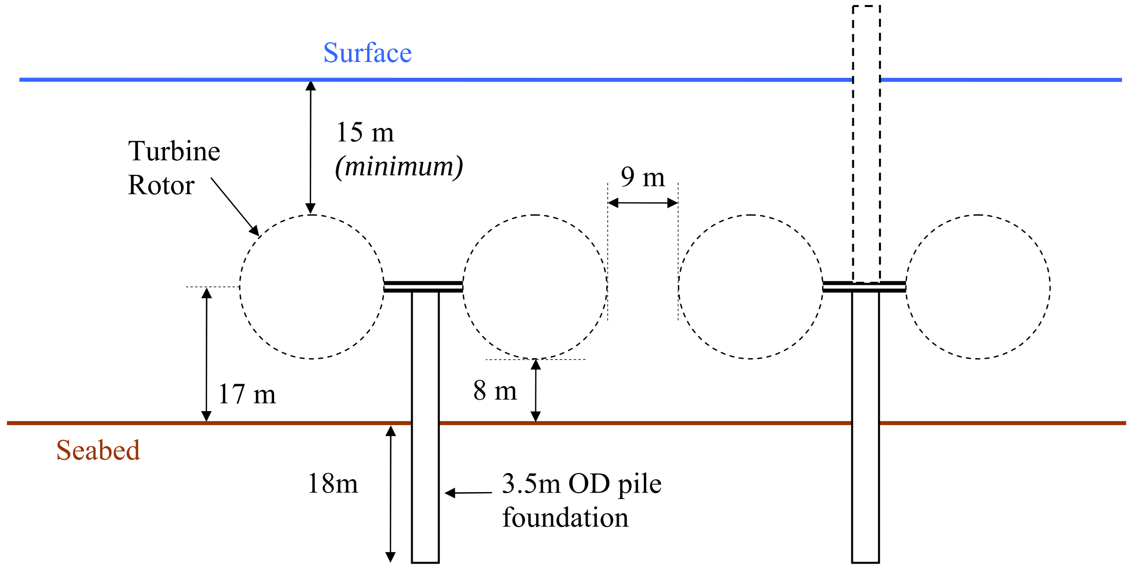


Figure 40 – MCT SeaGen Turbine Spacing Assumptions (surface and non-surface piercing)

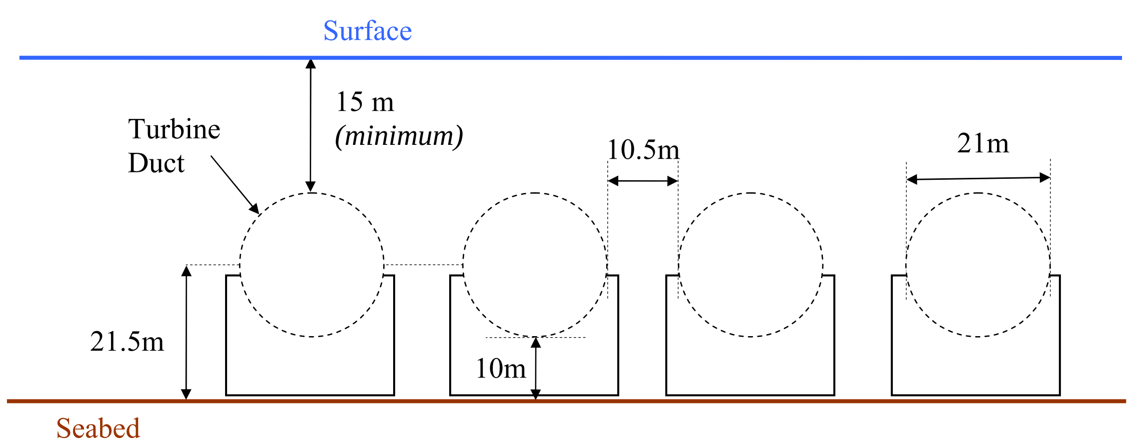


Figure 41 - Lunar RTT 2000 Spacing Assumptions

Based on this cross section, the useable channel width that accommodates sufficient water depth is 1000m. The section length within which high fluid velocities are available is about 2000m (See Figure 39). Based on this data the following table summarizes the critical assumptions leading to the likely number of turbines that could be deployed at the site.

Table 8 - Physical Layout Properties

	MCT	Lunar
Turbine Diameter	2 x 18m	21m
Device Width	46m	21m
Device Spacing	9m	10.5m
Channel width per device	55m	31.5m
Downstream Spacing	185m	235m
Useful Channel Length	2000m	2000m
Useful Channel Width	1000m	1000m
# of Turbines per Row	18	31
# of Rows	10	8
Total # of Turbines deployable	180	248
Average Power Extracted per Turbine	214kW	155kW
15% Extraction Limit	2 MW	2 MW
Technology Specific Extraction Limit	38 MW	38 MW

The above table shows that the extraction is limited by the amount that is environmentally sensible to extract at the site to about 2MW average. It also shows that there is plenty of space available at the site to deploy more turbines. Only 9 MCT SeaGen devices or 12 Lunar energy RTT2000 would need to be deployed at the site to meet the given extraction limit of 2MW. This provides some flexibility as to where exactly such turbines are placed to extract energy from the resource and provides space to accommodate competing users of the space (such as pleasure and commercial boating). If surface piercing SeaGen units are deployed, they could be used as channel markers at the site.

8. Cost Assessment – Demonstration Plant

The cost assessment of the pilot demonstration plant was carried out by taking manufacturer specifications for their devices, assessing principal loads on the structure and scaling the devices to the design velocity at the deployment site. The MCT cost model was developed internally, MCT provided data and support to calibrate the model, which was an important step to come up with a meaningful model. Installation and operational costs were evaluated by creating detailed cost build-ups for these aspects taking into considerations equipment availability and North American rates. A high-level capital cost breakdown relevant to the deployment site is shown in the table below.

Table 9 - Capital Cost breakdown of MCT Pilot plant

	$/kW	$/Turbine	in %
Power Conversion System	$1,428	$653,000	28.1%
Structural Steel Elements	$887	$406,000	14.8%
Subsea Cable Cost	$473	$216,000	2.0%
Turbine Installation	$3,155	$1,442,000	25.7%
Subsea Cable Installation	$5,847	$2,672,000	25.7%
Onshore Electric Grid Interconection	$438	$200,000	3.6%
Total Installed Cost	$12,227	$5,588,000	100.0%

A single unit will cost significantly more then subsequent units installed at the site. This is apparent by an increase in capital and installation cost. Installation costs are dominated by mobilization charges and the fact that the first unit will always be more expensive then subsequent ones. Capital costs are higher as well for similar reasons. The assessment of operational and maintenance cost was not part of the scope of this study. It is important to understand that the purpose of the pilot plant is not to provide low cost electricity, but to reduce risks associated with a full-blown commercial scheme. Risks include technological risks such as device performance, operation & maintenance requirements and validation of structural integrity as well as environmental risks associated with the interaction between the natural habitat and the TISEC device.

9. Cost Assessment – Commercial Plant

Costs for the commercial plant are, as for most renewable energy generating technologies, heavily weighted towards up-front capital. In order to determine the major cost centers of the commercial plant, detailed cost build-ups were created in order to assess them properly in the context of the given site conditions. There are a few major influences impacting the relative economic cost at a particular site which are discussed below:

Design Current Speed: The design current speed is the maximum velocity of the water expected to occur at the site. Structural loads (and related structural cost) on a structure increase to the second power of the fluid velocity. Given the velocity distribution at the site, the design velocity can be well above the velocity at which it is economically useful to extract power. In other words, the design velocity can have a major influence on the cost of the structural elements. During normal operating conditions, the loads on the structure will peak near the rated turbine velocity and decrease thereafter as the turbine blades are pitched to maintain constant power output, decreasing the thrust coefficient on the rotor blades. For conservatism, the design velocity is set to the site peak, rather than device rating, in order to simulate the loads experienced during runaway operation in the event of pitch control failure.

Velocity Distribution: The velocity distribution at the site is outlined in chapter 2 of this report. It shows the tidal current velocities at which there is a useful number of reoccurrence to pay for the capital cost which is needed to tap into this velocity bin. Rather then trying to make assumptions on where the appropriate rated velocity of the TISEC device should be, an iterative approach was chosen to determine which rated speed of the machine will yield the lowest cost of electricity at the particular site. This in turn resulted in different machine capacity factors as rated speed of the machine was adjusted for lowest cost of electricity.

Seabed Composition: The seabed composition at the site has a major impact on the foundation design of the TISEC device. For a monopile foundation the seabed composition determines the installation procedure (i.e. drilling and grouting or pile driving). The soil-type will also impact the cost of the monopile. Typically soft soils yield higher monopile cost then rock foundations. For a bottom standing device there is a cost impact on the installation for seabed preparation, scour protection and assuring device stability in weak soils.

Number of installed units: The number of TISEC devices deployed has a major influence on the resulting cost of energy. In general a larger number of units will result in lower cost of electricity. There are several reasons for this which are outlined below:

- Infrastructure cost required to interconnect the devices to the electric grid can be shared and therefore their cost per unit of electricity produced is lower.

- Installation cost per turbine is lower because mobilization cost can be shared between multiple devices. It is also apparent that the installation of the first unit is more expensive then subsequent units as the installation contractor is able to increase their operational efficiency.

- Capital cost per turbine is lower because manufacturing of multiple devices will result in reduction of cost. The cost of manufactured steel as an example is very labor intensive. The cost of hot rolled steel plates as of July 2005 was $650 per ton. The final product can however cost as much as $4500 per manufactured ton of steel. With other words there is significant potential to reduce capital cost by introducing more efficient manufacturing processes and engineering a structure in such a way that it can be manufactured cost effectively. The capital cost for all other equipment and parts is very similar.

Device Reliability and O&M procedures: The device component reliability directly impacts the operation and maintenance cost of a device. It is important to understand that it is not only the component that needs to be replaced, but that the actual operation required to recover the component can dominate the cost. Additional cost of the failure is incurred by the downtime of the device and its inability to generate revenues by producing electricity. In order to determine these operational costs, the failure rate on a per component basis was estimated. Then operational procedures were outlined to replace these components and carry out routine maintenance such as changing the oil. The access arrangement plays a critical role in determining what kind of maintenance strategy is pursued and the resulting total operation cost.

Insurance cost: The insurance cost can vary greatly depending on what the project risks are. While this is an area of uncertainty, especially considering the novelty of the technologies used and the likely lack of specific standards, it was assumed that a commercial farm will incur insurance costs similar to mature an offshore project which is typically at about 1.5% of installed cost.

The following table shows a cost breakdown of a commercial TISEC farm at the deployment site. It was assumed that a total of 9 turbines are installed at the site each one with a rated capacity of 457 kW and a capacity factor of 40% delivering a combined 14,492 MWh per year of electrical output.

Table 10 – MCT commercial plant capital cost breakdown

	$/kW	$/Turbine	$/Farm	in %	Ref
Power Conversion System	$943	$431,051	$3,879,000	23.8%	1
Structural Elements	$724	$330,983	$2,979,000	18.3%	2
Subsea Cable Cost	$130	$59,220	$533,000	3.3%	3
Turbine Installation	$1,174	$536,721	$4,830,000	29.6%	4
Subsea Cable Installation	$944	$431,404	$3,883,000	23.8%	5
Onshore Electric Grid Interconnection	$49	$22,222	$200,000	1.2%	6
Total Installed Cost	**3,963**	**1,811,601**	**$16,304,000**	**100%**	
O&M Cost	$77	$35,158	$316,420	56.4%	7
Annual Insurance Cost	$59	$27,174	$244,566	43.6%	8
Total annual O&M cost	**$136**	**$62,332**	**$560,986**	**100%**	

1. Power conversion system cost includes all elements required to go from fluid power to electrical power suitable to interconnect to the TISEC farm electrical collector system. As such it includes rotor blades, speed increaser, generator, grid synchronization and step-up transformer. The cost is based on a drive-train cost

study by NREL [12] with necessary adjustments made such as marinization, gearing-ratio, rotational speed and turbine blade length. Manufacturing cost progress ratio's were used to scale to different production volumes.

2. Structural steel elements include all elements required to hold the turbine in place. In the case of MCT, it includes the monopile and the cross arm. For the Lunar turbine it includes all the structural members, the duct as well as ballast. In order to determine the amount of steel required, the manufacturer's data was scaled based on the estimated loads on the structure. Only principal loads based on the fluid velocity were considered and it was assumed that they are the driving factor. While this approach is well suited for a conceptual study, it needs to be stressed that other loading conditions such as wave loads or resonance conditions can potentially dominate and will need to be taken into consideration in a detailed design phase.

3. Sub sea cable cost includes the cable cost to collect the electricity from the turbines and bring the electricity to shore at a suitable location.

4. Turbine installation cost includes all cost components to install the turbines. Detailed models were developed to outline the deployment procedures using heavy offshore equipment such as crane barges, tugs, supply vessels drilling equipment, mobilization charges and crew cost. Discussions with experienced contractors and offshore engineers were used to solidify costs.

5. Subsea cable installation cost includes, trenching, cable laying and trench back-fill using a derrick barge. It also includes cable landing costs. If existing easements such as pipes or existing pier or bridge structures are in place, the cable can be landed on shore using these easements. If not, it was assumed that directional drilling is used to bring the cable to shore.

6. Onshore electrical grid interconnection includes all cost components required to bring the power to the selected substation. Cost components required to build-out the capabilities of the substation or upgrade the transmission capacity of the electric

grid were excluded. Under FERC regulations, such cost is covered by 'wires' charges and is not considered to be a part of the levelized busbar plant cost of electricity (COE).

10. Cost of Electricity Assessments

To evaluate the economics of tidal in-stream power plants, three standard economic assessment methodologies have been used:

a. Utility Generator (UG),
b. Municipal Generator (MG)
c. Non-Utility Generator (NUG) or Independent Power Producer (IPP).

Taxable regulated utilities (independently owned utilities) are permitted to set electricity rates (i.e., collect revenue) that will cover operating costs and provide an opportunity to earn a reasonable rate of return on the property devoted to the business. This return must enable the UG to maintain its financial credit as well as to attract whatever capital may be required in the future for replacement, expansion and technological innovation and must be comparable to that earned by other businesses with corresponding risk.

Non taxable municipal utilities also set electricity rates that will cover operating costs, however, utility projects are financed by issuing tax-exempt bonds, enabling local governments to access some of the lowest interest rates available

Because the risks associated with private ownership are generally considered to be greater than utility ownership, the return on equity must be potentially higher in order to justify the investment. However, it is important to understand that there is no single right method to model an independently owned and operated NUG or IPP renewable power plant. Considerations such as an organization's access to capital, project risks, and power purchase and contract terms determine project risks and therefore the cost of financing.

This regulated UG and MG methodologies are based on a levelized cost approach using real (or constant) dollars with 2005 as the reference year and a 20-year book life. The purpose of this standard methodology is to provide a consistent, verifiable and replicable basis for computing the cost of electricity (COE) of a tidal energy generation project (i.e., a project to engineer, permit, procure, construct, operate and maintain a tidal energy power plant).

The NUG methodology is based on a cash flow analysis and projections of market electricity prices. This allows a NUG to estimate how quickly an initial investment is recovered and how returns change over time.

The results of this economic evaluation will help government policy makers determine the public benefit of investing public funds into building the experience base of tidal energy to transform the market to the point where private investment will take over and sustain the market. Such technology support is typically done through funding R&D and through incentives for the deployment of targeted renewable technologies.

If the economics of the notional commercial scale tidal in-stream power plant is favorable with respect to alternative generation options, a case can be made for pursuing the development of tidal flow energy conversion technology. If, even with optimistic assumptions, it turns out that the economics of a commercial size tidal flow power plant is not favorable with the alternatives, a case can therefore be made for not pursuing the development of tidal flow energy conversion technology.

The methodology is described in detail in Reference [2].

The yearly electrical energy produced and delivered to bus bar is estimated to be 1,610 MWh/year for an array consisting of 9 dual-rotor MCT turbines. These turbines have a combined installed capacity of 4.1MW, and on average extract 1.93 MW of kinetic power from the tidal stream, which is roughly 15% of the total kinetic energy at the site. The elements of cost and economics (in 2005$) for MCT's SeaGen are:

- Utility Generator (UG) Total Plant Investment = $16.9 million
- Annual O&M Cost = $0.57 million

- UG Levelized Cost of Electricity (COE) = 8.6 (Real) – 9.9 (Nominal) cents/kWh with renewable financial incentives equal to that the government provides for renewable wind energy technology
- Municipal Generator (MG) Levelized Cost of Electricity (COE) = 6.0 (Real) – 6.7 (Nominal) cents/kWh with renewable financial incentives equal to that the government provides for renewable wind energy technology
- Non Utility Generator (Independent Power Producer) does not obtain an Internal Rate of Return

The detailed worksheets including financial assumptions used to calculate COE and IRR are contained in the Appendix.

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

Except for the Minas Passage in Nova Scotia which clearly has the size to be considered central power, all other sites studied in the U.S. and Canada fall in between the 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 and nuclear 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, in collaboration with DOER, NJBPU and CEC, and funded by NASEO, is studying political and financial mechanisms for win-win DG/DR solutions for both the distribution utility and the end user.

Economic assessments of a commercial scale tidal power plant and other renewable and non renewable energy systems were made.

The current comparative costs of several different central power generation technologies are given in Table 11 - COE for Alternative Energy Technologies: 2010 for 2010. Capital costs are given in $/kW. They have wide ranges that depend on the size of the plant and other conditions such as environmental controls for coal and quality of the resource for geothermal. We are using generally accepted average numbers and ranges from EPRI sources.

Table 11 - COE for Alternative Energy Technologies: 2010

	Capacity Factor (%)	Capital Cost[1] ($/kW)	COE (cents/kWh)	CO2 (lbs per MWh)
Tidal In Stream	40	1,800	6 - 10	None
Wind (Class 3-6)	30-42	1,150	4.7-6.5	None
Solar Thermal Trough	33	3,300	18	None
Coal PC USC (2)	80	1,275	4.2	1760
NGCC[3] @ $7/MM BTU)	80	480	6.4	860
IGCC[2] with CO2 capture	80	1,850	6.1	344[4]

Notes:
1. Costs in 2005 U.S. $;
2. 600 MW capacity; Pittsburgh#8 coal
3. Based on GE 7F machine or equivalent by other vendors
4. Based on 85% removal

The fuel cost for coal and natural gas (NG) is the price of fuel (in $ per Mbtu), times the heat rate (BTUs needed to generate a kWh of electricity – 10,000 for PC Coal, 9,000 for IGCC, 12,000 for Gas CT and 7,000 for NG CC), divided by 10,000.

Table 13 - Assumptions forming the Basis for COE for Alternative Energy Technologies

	Book Life/ Tax life)	Fed Tax Rate	State Tax Rate	Dep Sch	% Equity UG/ NUG/ Public	Equity Disc't Rate (Real) UG/NUG	% Debt UG/ NUG/ Public	Debt Disc't Rate (Real) UG/NUG/ Public	Inflation Rate
Tidal In Stream	20/20	35	9.5	MACRS	65/ 30 0	13/ 17/ 5	35/ 70/ 100	7.5/ 8/ 5	3
Wind	30/ 20	35	6.5	MACRS	45/ 30/ 0	11.5/ 13/ N/A	55/ 70/ 100	6/5 8/ 4.5	2
Coal(2) PC First of a Kind USC	30/ 20	35	6.5	ACRS	45/ 30/ 0	11.5/ 13/ N/A	55/ 70/ 100	6/5 8/ 4.5	2
IGCC(2) GE Quench W/O CO2 capture	30/ 20	35	6.5	ACRS	45/ 30/ 00	11.5/ 13/ N/A	55/ 70/ 100	6/5 8/ 4.5	2
NGCC(3) Advanced (@ $7/MM Btu)	30/ 20	35	6.5	ACRS	45/ 30/ 00	11.5/ 13/ N/A	55/ 70/ 100	6/5 8/ 4.5	2
NGCC(3) Advanced @ $5/MM Btu)	30/ 20	35	6.5	ACRS	45/ 30/ 0	11.5/ 13/ N/A	55/ 70/ 100	6/5 8/ 4.5	2

11. Sensitivity Studies

The results reported thus far are for a single design case. Certain key parameters can have a significant impact on the cost of energy from a TISEC array. Among these are:

- Array size – economies of scale with larger arrays
- Plant system Availability – deployment of maturing technology
- Current velocities at site
- Financial assumptions – financing rates, renewable energy production credits

Cost of energy numbers presented are real costs for a UG generator with assumptions discussed in Chapter 9. All costs are in 2005 USD.

Array Size

This sensitivity has already been implicitly shown in the unit capital cost differences for pilot turbine versus commercial scale array. Figure 42 shows the sensitivity of cost of energy (COE) to the number of turbines installed.

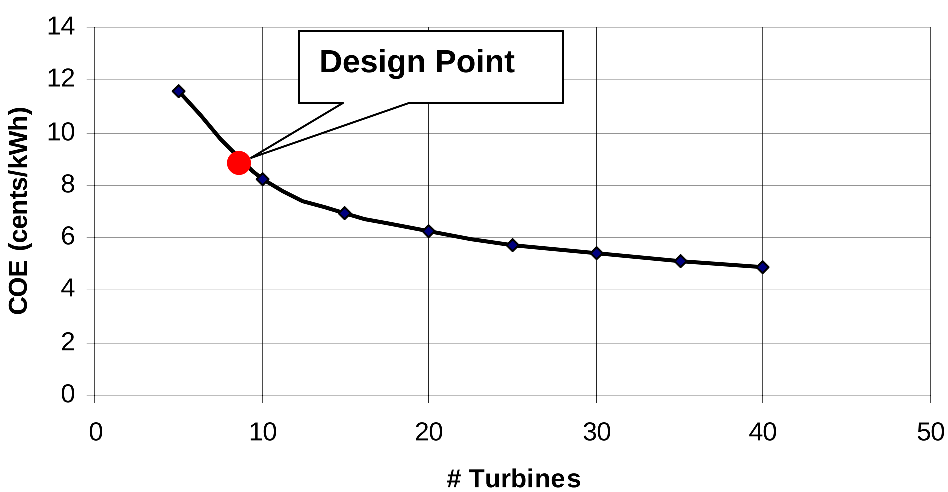


Figure 42 – Sensitivity of COE to number of turbines installed

Due to economies of scale (mobilization costs, increased manufacturing efficiency), the capital and operating costs for the array decrease with the number of installed turbines. The sensitivity of the different elements of capital cost to the number of turbines installed is given in Figure 43.

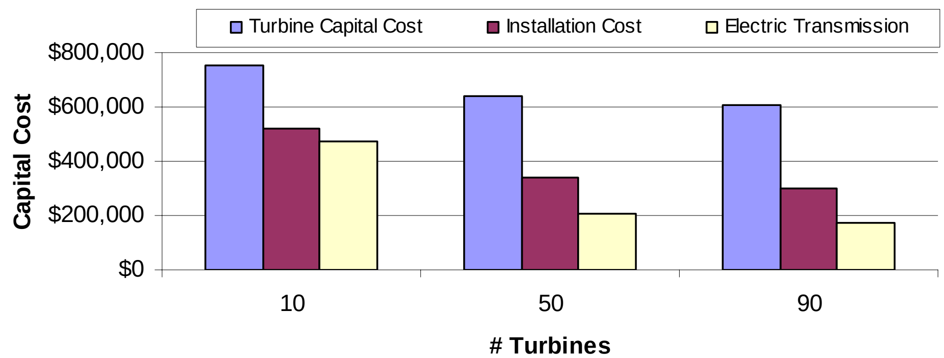


Figure 43 – Sensitivity of capital cost elements to number of installed turbines

Economies of scale due to decreasing capital cost occur in equipment, installation, and electrical interconnection. Installation and electrical transmission costs are near identical. Cost of energy decreases are not driven exclusively by scale in one particular area. Note that equipment costs dominate in all cases. Annual O&M costs also decrease due to economies of scale (e.g. maintenance mobilization costs spread out over more turbines). The sensitivity of annual O&M costs to number of installed turbines is given in Figure 44.

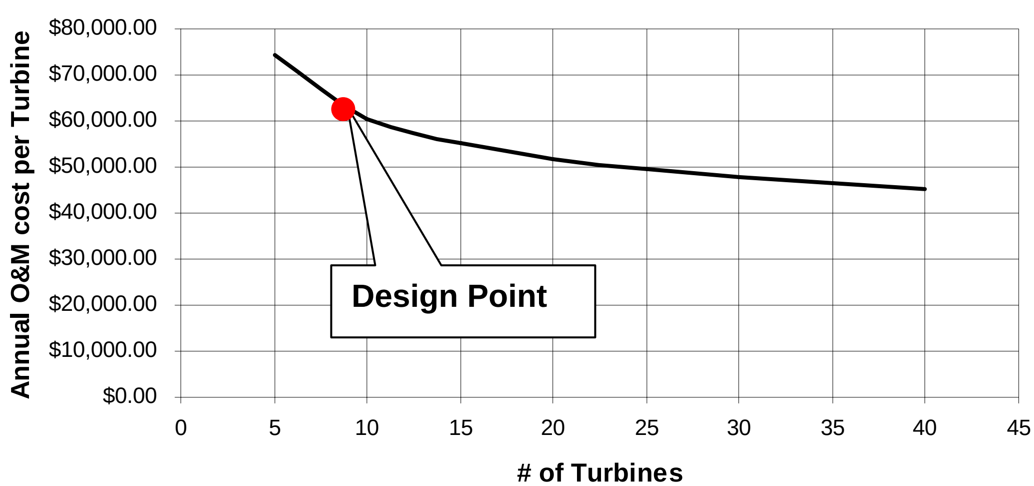


Figure 44 – Sensitivity of annual O&M cost to number of installed turbines

Power Plant System Availability

Given that tidal in-stream energy is an emerging industry and limited testing has been done to validate component reliability, the impact of the plant system availability on cost of energy is key. If the availability is lower than anticipated, array output will be lower, but costs will be the same. This is shown in Figure 45, where all parameters aside from availability are held constant for the commercial array design.

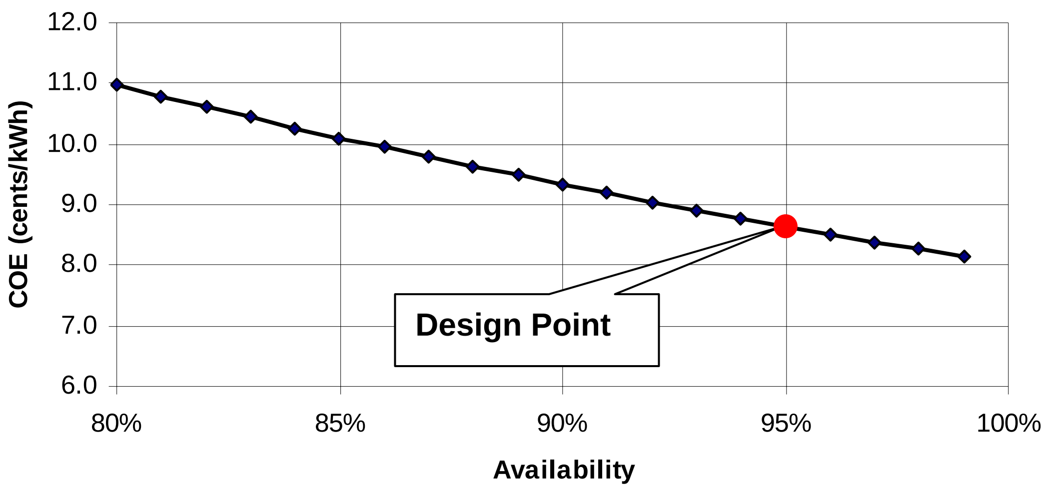


Figure 45 – Sensitivity of COE to array availability

If system availability is as low at 80%, the cost of energy with increase by a bit more than 1.5 cents/kWh (20% increase) compared to the assumed availability of 95%. This is a substantial increase and highlights the need of developers to verify expected component lifetimes and service schedules.

Current Velocity

One of the greatest unknowns in the array design is current velocity over the region of array deployment. The sensitivity of cost of energy to average current and power flux is shown in Figure 46 and Figure 47, where most other parameters are held constant for the commercial array design. Current velocity is modified by multiplying each velocity 'bin' by a constant value (e.g. 0.7). As a result, the shape of the velocity histogram is unchanged, only the mean value. As the velocity changes, the rated speed of the turbine is allowed to vary to maintain the lowest possible cost of energy. Note that average current velocity and power flux are not independent variables, the design point average current velocity corresponds to the design point average power flux.

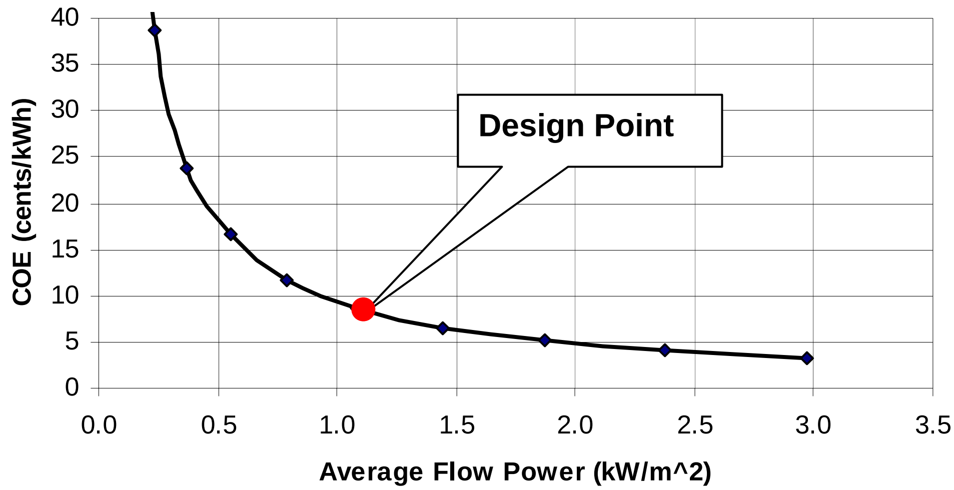


Figure 46 – Sensitivity of COE to average flow power in kW/m^2

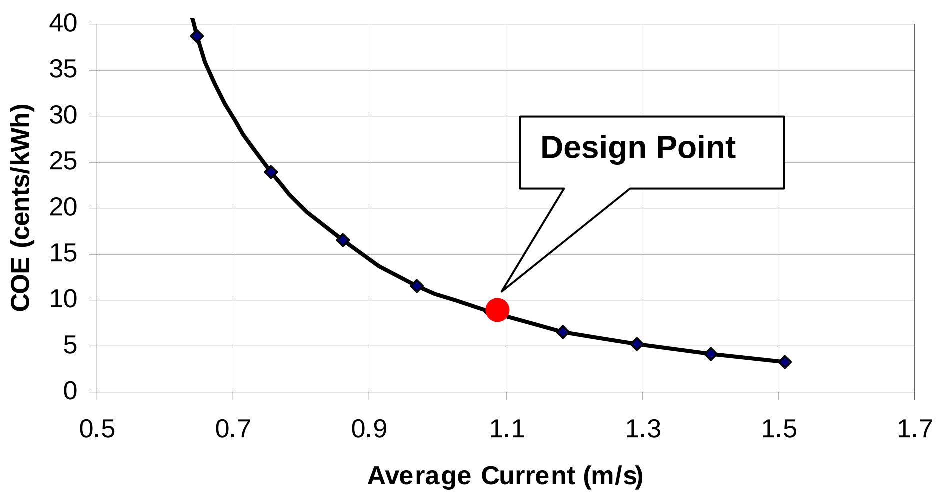


Figure 47 – Sensitivity of COE to average current speed (m/s)

Clearly, the average velocity at the site has a significant effect on cost of energy, particularly if average current speeds are lower than expected. Note that these results are dependent on the shape of the velocity distribution histogram and therefore, we can not broadly draw conclusions about the cost of energy at other sites from this analysis (though one would expect the general direction of the results to be comparable for all west coast sites).

Design Velocity

As discussed in Chapter 3, the design velocity for the turbine has been chosen to approximate "runaway" conditions – a pitch control failure in the maximum current existing at the site. However, since the most significant design load is the thrust on the rotors – which is maximized near rated conditions – this represents a potential system overdesign. If manufacturers are able to achieve sufficient operating experiences with their turbines to ensure that turbines will never operate in a "runaway" mode, then the design velocity could be set much closer to the rated velocity. Similar functionality is used in large wind-turbines to reduce loading conditions. Figure 48 shows the effect on the real cost of energy by lowering the design speed.

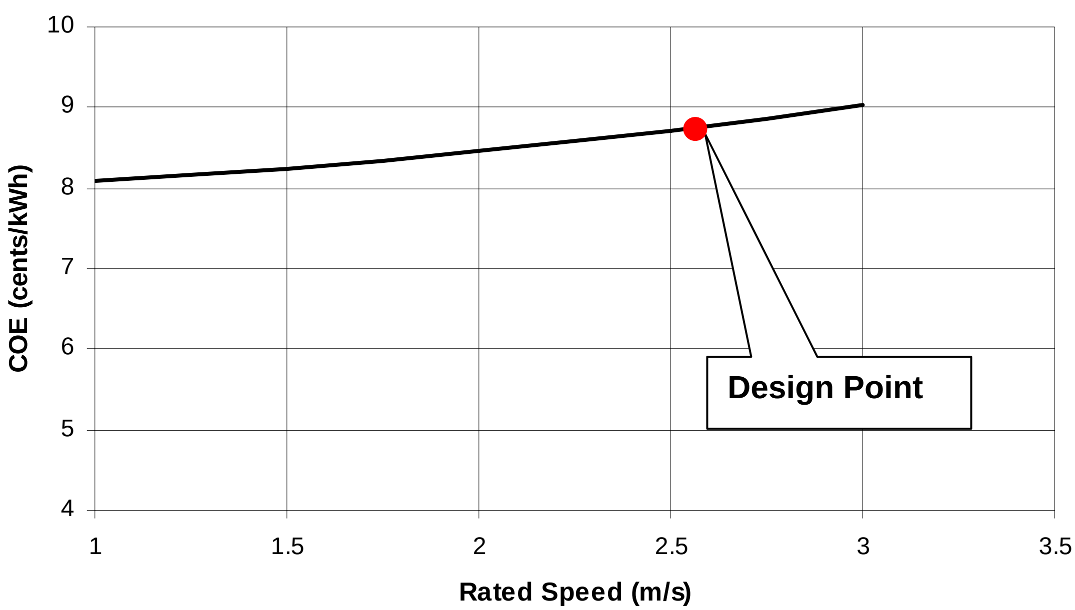


Figure 48 – Sensitivity of COE to design speed

Financial Assumptions

The effect of varying the cost of capital to finance the project is shown in the following figure. The fixed charge rate represents a single indicator of the cost of capital and is used here (see Reference 2 for a detailed explanation). It includes effects of interest rates, return of capital, taxation and production tax credits.

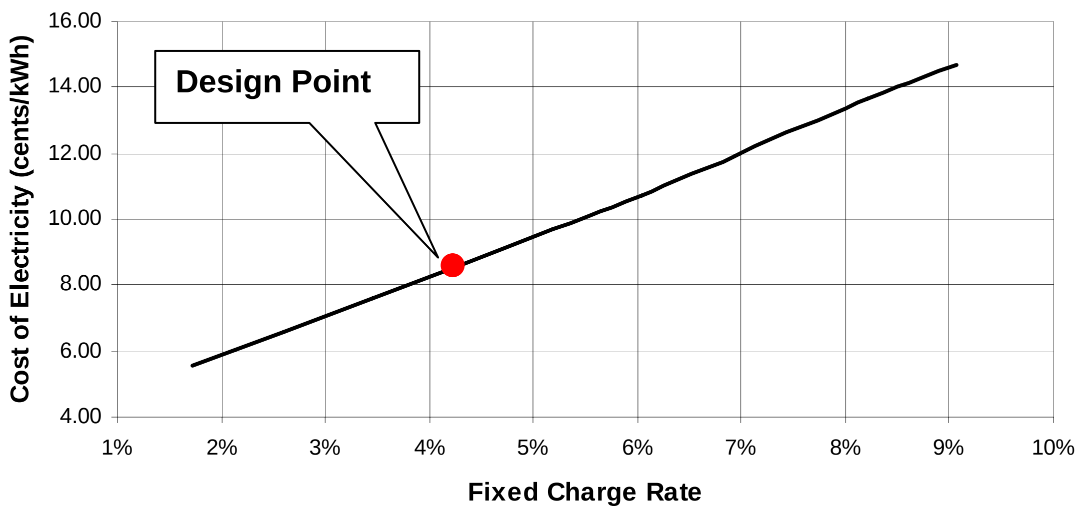


Figure 49 – Sensitivity of COE to Fixed Charge Rate

If a project is deemed ineligible for renewable production credits, or funds for such credits are not fully budgeted, COE increases substantially. Figure 50 shows the sensitivity of COE to production credits, with credits varied from 0% (no credits) to more credits than are currently assumed in the financial analysis, 100% being the design value used in our financing assumptions.

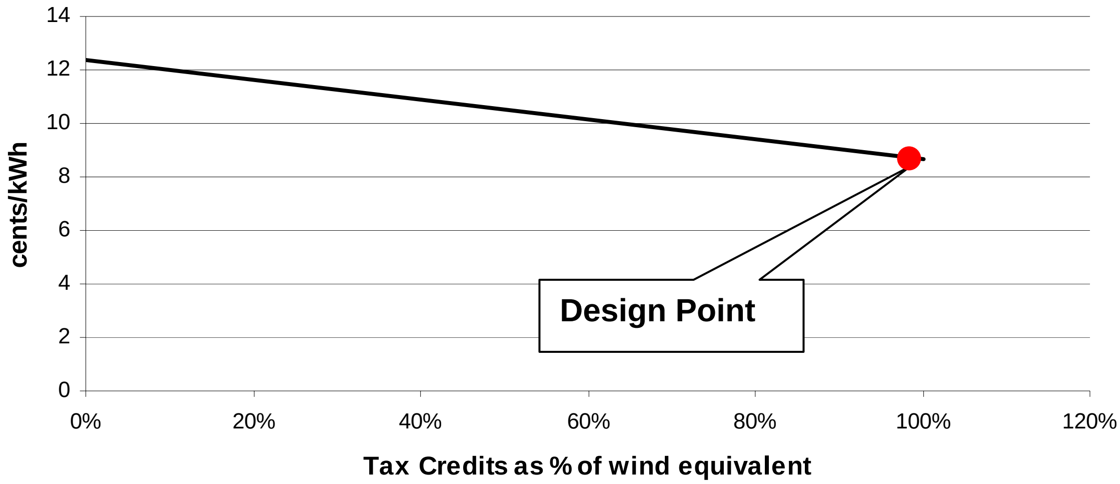


Figure 50 – Sensitivity of COE to production credits

12. Conclusions

Pilot In-Stream Tidal Power Plant

For the single turbine pilot installation, the Muskeget Channel offers a good potential site. The predicted resource is decent, interconnection is manageable, and the site is served by a major port facility in close proximity. There is ample space to deploy surface piercing SeaGen technology in the channel or completely submersed technology could be deployed alternatively. A pilot system is an important intermediary step before proceeding to a commercial installation and should use similar technology and units that are of similar scale as the full-scale devices. The purpose of the pilot is to demonstrate the potential for a commercial array, verify low environmental impact, and generally build towards regulatory acceptance of an array of similar devices. It is important to understand that many design requirements are unique to the site and the manufacturers will need to take local site conditions into consideration when adapting their technology to meet these requirements.

Commercial In-Stream Tidal Power Plant

Muskeget Channel is only a moderate site for the installation of a commercial tidal in-stream power plant. Only about 9 SeaGen units would meet the extraction limit at the site making it a typical distributed renewable energy development that is relatively small in scale. Grid interconnection could be accomplished on the east side of Chappaquiddick Island and the plant could serve the local load on the island. Grid interconnection remains an issue that needs to be addressed for capacities going beyond 500kW at the site. For safety reasons, it may be necessary to set up a recreation (e.g. diving) exclusion zone within this area.

The site can likely accommodate SeaGen first generation technology, which could be deployed without significant further technology development and site adaptations.

Techno-economic Challenges

The cost for the first tidal plant leverages the learnings gained from wind energy. Therefore, the cost of future plants will not follow a learning curve based on the first plant. Rather than seeing a sharp reduction in unit cost for the next 10 MW or so plant, a substantial decrease might require another 40,000 MW of installed capacity (double the end of 2004 wind production volume). Device manufacturers are pursuing novel approaches to array-scale installations. The economic analysis presented in this report is based on first-generation device economics. The assumption contingent in this analysis is that while next-generation devices will enable turbine deployment at a wider range of sites (e.g. deep water) and with greater versatility (e.g. integrated lift without surface piercing pile) the cost of installing and operating next-generation turbines will be similar to first-generation devices. O&M costs are particularly uncertain since no tidal current turbine has been in service for extended periods of time. Assumptions regarding intervention frequencies, refit costs, and component lifetimes will not be completely borne out for at least a decade.

Sensitivities show that the cost of energy is highly dependent on the currents (and power flux) at the deployment site. Furthermore, sensitivity analysis indicates the manufacturers are best served by designing turbines which experience their design loads close to rated device speed.

General Conclusions

The installation of a TISEC array at Muskeget Channel in Massachusetts might provide valuable distributed generation-type benefits to the local economy and further reduce its dependence on environmentally problematic fossil energy resources. Further study is required to investigate this DG potential

In-stream tidal energy electricity generation is a new and emerging technology. Many important questions about the application of in stream tidal energy to electricity generation remain to be answered, such as:

- There is not a single in-stream power technology. There is a wide range of in stream tidal power technologies and power conversion machines which are currently under development. It is unclear at present what type of technology will yield optimal economics. Not all devices are equally suitable for deployment in all depths and currents.
- It is also unclear at present at which size these technologies will yield optimal economics. Tidal power devices are typically optimized to prevailing conditions at the deployment site. Wind turbines for example have grown in size from less then 100kW per unit to over 3MW in order to drive down cost.
- Will the predictability of in stream energy earn capacity payments for its ability to be dispatched for electricity generation?
- How soon will developers be ready to offer large-scale, fully submerged, deep water devices?
- Will the installed cost of in-stream tidal energy conversion devices realize their potential of being much less expensive than solar or wind (because a tidal machine is converting a much more concentrated form of energy than a solar or wind machine)?
- Will the O&M cost of in-stream tidal energy conversion devices be as high as predicted in this study and remain much higher than the O&M cost of solar or wind (because of the more remote and harsher environment in which it operates and must be maintained)?
- Will the performance, reliability and cost projections be realized in practice once in stream tidal energy devices are deployed and tested?

And in particular for Muskeget channel:

- Detailed velocity measurements and 3 dimensional flow simulations will be necessary prior to the deployment of even a pilot plant. Will the actual power flux experienced at the site meet the predictions made in this study? Sensitivity analysis clearly shows that the power flux has a substantial impact on the cost of electricity.

- Are assumptions related to turbine spacing (both laterally and downstream) reasonable? Could the array be packed even closer together (further reducing its footprint) without degrading individual turbine performance?
- Is extracting 15% of the kinetic energy resource a reasonable target? Could more of the resource be extracted without degrading the marine environment? If so, the cost of energy for the project could be further reduced by increasing the size of the array.

In-stream tidal energy is a potentially important energy source and could be used to diversify Massachusetts's energy supply portfolio. A balanced and diversified portfolio of energy supply options is the foundation of a reliable and robust electric grid. TISEC offers an opportunity for Massachusetts to expand its supply portfolio with a resource that is:

- Local – providing long-term energy security and keeping development dollars in the region
- Sustainable and green-house gas emission free
- Cost that are only a few cents per kWh more than natural gas options for expanding and balancing the region's supply portfolio and which provide a hedge against increasing natural gas prices in the future

Recommendations

EPRI makes the following recommendations to the Massachusetts Electricity stakeholders:

General

Build collaboration with other states and the Federal Government with common goals. In order to accelerate the growth and development of an ocean energy industry in the United States and to address and answer the many techno-economic challenges, a technology roadmap is needed which can most effectively be accomplished through leadership at the national level. The development of ocean energy technology and the deployment of this clean renewable energy technology would be greatly accelerated if the Federal Government was financially committed to supporting the development.

Join a working group to be established by EPRI (to be called "OceanFleet") for existing and potential owners, buyers and developers of tidal in stream energy including the development of a permanent in stream tidal energy testing facility in the U.S. For this group EPRI will track and regularly report on:

- Potential funding sources
- In-stream tidal energy test and evaluation projects overseas (primarily in the UK) and in the U.S (Verdant RITE project, etc)
- Status and efforts of the permitting process for new in stream tidal projects
- Newly announced in-stream tidal energy devices

Encourage R&D at universities - potentially in partnership with pilot plant device developer.

Encourage State and Federal government support of RD&D

- Implement a national ocean tidal energy program at DOE
- Promote development of industry standards
- Continue membership in the IEA Ocean Energy Program
- Clarify and streamline federal permitting processes
- Study provisions for tax incentives and subsidies
- Ensure that the public receives a fair return from the use of ocean tidal energy resources
- Ensure that development rights in state waters are allocated through a fair and transparent process that takes into account state, local, and public concerns

Pilot Demonstration

In order to proceed with a pilot plant in the Muskeget channel, remaining technology, consenting and environmental issues will need to be resolved. This includes:

- Detailed velocity profiling survey and 3-dimensional flow simulations. Computational fluid dynamic (CFD) modeling of tidal flows under the Golden

Gate Bridge could help focus this work on the most promising areas, as well as identifying turbulent eddies which could degrade turbine performance.

- High resolution bottom bathymetry survey
- Geotechnical seabed survey
- Detailed design using above data
- Environmental impact assessments
- Public outreach
- Implementation planning for Phase III – Construction
- Financing/incentive requirements study four Phase III and IV (Operation)

13. References

1 EPRI TP-001-NA Guidelines for Preliminary Estimation of Power Production

2 EPRI TP-002-NA Economic Assessment Methodology

3 EPRI TP-003-MA Massachusetts Tidal Site Survey and Characterization

4 EPRI TP-004-NA Survey and Characterization of TISEC Devices

5 EPRI TP-005-NA Methodology for Conceptual Level Design of TISEC Plant

6 Google Maps. http://maps.google.com/

7 NOAA Tidal Current Predictions 2005. http://www.tidesandcurrents.noaa.gov/

8 NOAA Tidal Range Predictions 2005. http://www.tidesandcurrents.noaa.gov/

9 Bywaters G, John V, Lynch J, Mattila P, Norton G, Stowell J, Salata M, Labath O, Chertok A, Hablanian D. Northern Power Systems WindPACT Drive Train Alternative Design Study Report. 2005. Available through: http://www.osti.gov/

10 Gerwick, B. Construction of Marine and Offshore Structures. CRC Press, Boca Raton, FL. 2000.

11 Dawson, T. Simplified Analysis of Offshore Piles Under Cyclic Lateral Loads. *Ocean Engineering* 7;553-562. 1980.

12 Myers L, Bahaj A. Simulated electrical power potential harnessed by marine current turbine arrays in the Alderney Race, *Renewable Energy* 30:11;1713-1731.

13 Poore R, Lettenmeier T, Wind Pact Advanced Drive Trains Design Study, NREL 2003

14 Dayton A. Griffin, Wind PACT Turbine Design Scaling Studies Technical Area 1 – Composite Blades for 80- to 120-Meter Rotor

15 API American Petroleum Institute. Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms Working Stress Design. API-RP2A-WSD, 21st edition, December 2000

16 Kellezi L, Hansen P, Static and dynamic analysis of an offshore mono-pile windmill foundation, Danish Geotechnical Institute, Lyngby, Denmark

17 Generic Design Framework Pile foundations (fixed steel structures), Offshore Technology Report 2000/99

14. Appendix

Irrelevance of Flow Decay Concerns

A concern established by some other researchers, particularly Bahaj and Myers [11] is that the power available in a tidal stream is reduced for each subsequent transect of turbines. Their results point to a substantial reduction in flow power, and degraded array performance, for arrays with more than a few transects.

This analysis is, however, in error as it violates mass conservation for tidal channels by assuming that the cross-sectional area of the channel is constant along the entire array. If the velocity of the flow is decreasing over each transect, then the area of the channel would have to increase to maintain conservation of mass.

However, the fuller picture is considerably more counter-intuitive. The total power in a tidal stream is the summation of the kinetic energy due to its velocity and the potential energy due to its height. For representative tidal channels, if the height of the water was to increase to satisfy mass conservation, the potential energy of the stream would also increase. In fact, this increase in potential energy would actually exceed the decrease of kinetic energy due to the presence of turbines and the total power in the channel would increase after each transect. Since this rationale violates conservation of energy it is also, clearly, incorrect. In order to satisfy both conservation of mass and energy, after each transect the height of the water decreases and velocity *increases*. The net effect is a decrease in channel power, but from a kinetic energy standpoint, the presence of upstream turbines actually should improve the performance of those downstream. This effect is described in detail for an ideal channel in Bryden and Couch.

However, without detailed information about cross-channel flow both upstream and downstream of the proposed turbine array it is not possible to model the potential performance enhancement. As a result, any such transect-to-transect enhancement is omitted from the model. However, it would appear that concerns related to flow degradation have little scientific basis.

Hub-height Velocity Approximation

In order to simplify calculations, it has been assumed that the power flux over the swept area of the turbine may be approximated by the power flux at the hub height. Assuming the velocity profile in the channel varies with a 1/10th power law, the average power flux over the area of the turbine is given by the following integral:

$$\overline{P} = \frac{\int_0^{2\pi}\int_0^{R} \frac{1}{2}\rho u_o^3 \left(\frac{r\sin\theta + z_{hub}}{z_o}\right)^{3/10} r\,dr\,d\theta}{\int_0^{2\pi}\int_0^{R} r\,dr\,d\theta}$$

where P is the average power flux, R is the radius of the turbine, u_o is the surface current velocity, z_o is the depth of the water, and z_{hub} is the hub height.

This integral is not readily evaluated by analytical methods, but may be approached numerically. This is done by approximating the rotor as a series of rectangles with height Δz and width Δx. The power flux for the rectangles is calculated, and an area-weighted average taken to find the average power flux over the rotor. A representation of this method is shown in Figure 51.

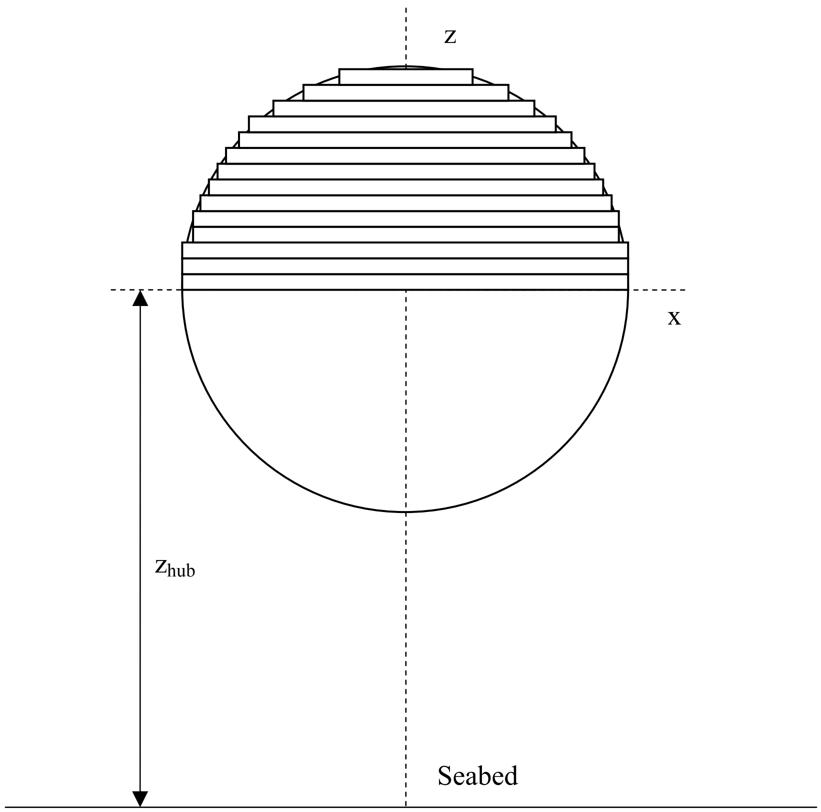


Figure 51 – Representative Numerical Integration

The result of this calculation is independent of water depth and velocity, but is dependent on hub height above the seabed. The variance from midpoint power flux (defined as $\Delta P/P_{hub\ height}$) is tabulated in Table 12.

Table 12 – Approximation Variance as Function of Hub Height

Hub Height (m)	Variance
10	-2.7%
15	-1.0%
20	-0.6%
30	-0.3%

A hub height of 17m (as assumed for the purposes of this feasibility study) introduces an error of -0.8% — that is, the actual power extracted by a turbine when approximating the power flux as the midpoint power flux is approximately 1% less than would be extracted by a turbine operating in water with a 1/10th power velocity profile. For the purposes of a feasibility study, this approximation is reasonable.

Utility Generator Cost of Electricity Worksheet

INSTRUCTIONS		
		Indicates Input Cell (either input or use default values)
		Indicates a Calculated Cell (do not input any values)
Sheet 1.	**TPC/TPI (Total Plant Cost/Total Plant Investment)**	
	a)	Enter Component Unit Cost and No. of Units per System
	b)	Worksheet sums component costs to get TPC
	c)	Adds the value of the construction loan payments to get TPI
	d)	Enter Annual O&M Type including annualized overhaul and refit cost
	c)	Worksheet Calculates insurance cost and Total Annual O&M Cost
Sheet 2.	**Assumptions (Financial)**	
	a)	Enter project and financial assumptions or leave default values
Sheet 3.	**NPV (Net Present Value)**	
	A	Gross Book Value = TPI
	B	Annual Book Depreciation = Gross Book Value/Book Life
	C	Cumulative Depreciation
	D	MACRS 5 Year Depreciation Tax Schedule Assumption
	E	Deferred Taxes = (Gross Book Value X MACRS Rate - Annual
		Book Depreciation) X Debt Financing Rate
	F	Net Book Value = Previous Year Net Book Value - Annual Book
		Depreciation - Deferred Tax for that Year
Sheet 4.	**CRR (Capital Revenue Requirements)**	
	A	Net Book Value for Column F of NPV Worksheet
	B	Common Equity = Net Book X Common Equity Financing
		Share X Common Equity Financing Rate
	C	Preferred Equity = Net Book X Preferred Equity Financing
		Share X Preferred Equity Financing Rate
	D	Debt = Net Book X Debt Financing Share X Debt Financing Rate
	E	Annual Book Depreciation = Gross Book Value/Book Life
	F	Income Taxes = (Return on Common Equity + Return of Preferred Equity -
		Interest on Debt + Deferred Taxes) X (Comp Tax Rate/(1-Comp Tax Rate
	G	Property Taxes and Insurance Expense =
	H	Calculates Investment and Production Tax Credit Revenues
	I	Capital Revenue Req'ts = Sum of Columns B through G
Sheet 5.	**FCR (Fixed Charge Rate)**	
	A	Nominal Rates Capital Revenue Req'ts from Columnn H of Previous Worksheet
	B	Nominal Rate Present Worth Factor = 1 / (1 + After Tax Discount Rate)
	C	Nominal Rate Product of Columns A and B = A * B
	D	Real Rates Capital Revenue Req'ts from Columnn H of Previous Worksheet
	E	Real Rates Present Worth Factor = 1 / (1 + After Tax Discount Rate - Inflation Rate)
	F	Real Rates Product of Columns A and B = A * B
Sheet 6.	**Calculates COE (Cost of Electricity)**	
	COE = ((TPI * FCR) + AO&M) / AEP	
	In other words…The Cost of Electricity =	
		The Sum of the Levelized Plant Investment + Annual O&M Cost including Levelized
		Overhaul and Replacement Cost Divided by the Annual Electric Energy Consumption

TOTAL PLANT COST (TPC) - 2005$

TPC Component	Unit	Unit Cost	Total Cost (2005$)
Procurement			
Power Conversion System	9	$431,051	$3,879,461
Structural Elements	9	$330,983	$2,978,851
Subsea Cables	Lot	$532,980	$532,980
Turbine Installation	9	$536,721	$4,830,487
Subsea Cable Installation	Lot	$3,882,633	$3,882,633
Onshore Grid Interconnection	Lot	$200,000	$200,000
TOTAL			$16,304,412

TOTAL PLANT INVESTMENT (TPI) - 2005 $

End of Year	Total Cash Expended TPC (2005$)	Before Tax Construction Loan Cost at Debt Financing Rate	2005 Value of Construction Loan Payments	TOTAL PLANT INVESTMENT 2005$
2007	$8,152,206	$611,415	$498,481	$8,650,687
2008	$8,152,206	$611,415	$450,096	$8,602,302
Total	$16,304,412	$1,222,831	$948,577	$17,252,989

ANNUAL OPERATING AND MAINTENANCE COST (AO&M) - 2005$

Costs	Yrly Cost	Amount
Labor and Parts	$316,420	$316,420
Insurance (1.5% of TPC)	$244,566	$244,566
Total		$560,986

	FINANCIAL ASSUMPTIONS		
	(default assumptions in pink background - without line numbers are calculated values)		
1	Rated Plant Capacity ©	4.1	MW
2	Annual Electric Energy Production (AEP)	14,492	MWeh/yr
	Therefore, Capacity Factor	40.3	%
3	Year Constant Dollars	2005	Year
4	Federal Tax Rate	35	%
5	State	Massachusetts	
6	State Tax Rate	9.5	%
	Composite Tax Rate (t)	0.41175	
	t/(1-t)	0.7000	
7	Book Life	20	Years
8	Construction Financing Rate	7.5	
9	Common Equity Financing Share	52	%
10	Preferred Equity Financing Share	13	%
11	Debt Financing Share	35	%
12	Common Equity Financing Rate	13	%
13	Preferred Equity Financing Rate	10.5	%
14	Debt Financing Rate	7.5	%
	Nominal Discount Rate Before-Tax	10.75	%
	Nominal Discount Rate After-Tax	9.67	%
15	Inflation Rate = 3%	3	%
	Real Discount Rate Before-Tax	7.52	%
	Real Discount Rate After-Tax	6.47	%
16	Federal Investment Tax Credit (1)	0	
17	Federal Production Tax Credit (2)	0.018	$/kWh
18	State Investment Tax Credit (3)	8,913,120	$
19	State Investment Tax Credit Limit	None	
20	Renewable Energy Certificate (3)	0.05	$/kWh

NET PRESENT VALUE (NPV) - 2005 $						
TPI =	$17,252,989					
Year End	**Gross Book Value**	**Book Depreciation Annual**	**Book Depreciation Accumulated**	**Renewable Resource MACRS Tax Depreciation Schedule**	**Deferred Taxes**	**Net Book Value**
	A	**B**	**C**	**D**	**E**	**F**
2008	**17,252,989**					**17,252,989**
2009	17,252,989	862,649	862,649	0.2000	1,065,588	15,324,752
2010	17,252,989	862,649	1,725,299	0.3200	1,918,058	12,544,044
2011	17,252,989	862,649	2,587,948	0.1920	1,008,756	10,672,639
2012	17,252,989	862,649	3,450,598	0.1152	463,175	9,346,814
2013	17,252,989	862,649	4,313,247	0.1152	463,175	8,020,989
2014	17,252,989	862,649	5,175,897	0.0576	53,990	7,104,350
2015	17,252,989	862,649	6,038,546	0.0000	-355,196	6,596,896
2016	17,252,989	862,649	6,901,196	0.0000	-355,196	6,089,442
2017	17,252,989	862,649	7,763,845	0.0000	-355,196	5,581,989
2018	17,252,989	862,649	8,626,495	0.0000	-355,196	5,074,535
2019	17,252,989	862,649	9,489,144	0.0000	-355,196	4,567,082
2020	17,252,989	862,649	10,351,793	0.0000	-355,196	4,059,628
2021	17,252,989	862,649	11,214,443	0.0000	-355,196	3,552,175
2022	17,252,989	862,649	12,077,092	0.0000	-355,196	3,044,721
2023	17,252,989	862,649	12,939,742	0.0000	-355,196	2,537,268
2024	17,252,989	862,649	13,802,391	0.0000	-355,196	2,029,814
2025	17,252,989	862,649	14,665,041	0.0000	-355,196	1,522,361
2036	17,252,989	862,649	15,527,690	0.0000	-355,196	1,014,907
2027	17,252,989	862,649	16,390,340	0.0000	-355,196	507,454
2028	17,252,989	862,649	17,252,989	0.0000	-355,196	0

CAPITAL REVENUE REQUIREMENTS 2005$								
TPI :	$17,252,989							
End of Year	Net Book	Returns to Equity Common	Returns to Equity Pref	Interest on Debt	Book Dep	Income Tax on Equity Return	Fed PTC and REC	Capital Revenue Req'ts
	A	B	C	D	E	F	H	I
2009	15,324,752	1,035,953	209,183	402,275	862,649	1,335,833	1,832,202	2,013,691
2010	12,544,044	847,977	171,226	329,281	862,649	1,825,475	985,456	3,051,154
2011	10,672,639	721,470	145,682	280,157	862,649	1,116,958	985,456	2,141,460
2012	9,346,814	631,845	127,584	245,354	862,649	684,034	985,456	1,566,010
2013	8,020,989	542,219	109,486	210,551	862,649	632,992	985,456	1,372,442
2014	7,104,350	480,254	96,974	186,489	862,649	311,291	985,456	952,202
2015	6,596,896	445,950	90,048	173,169	862,649	5,343	985,456	591,703
2016	6,089,442	411,646	83,121	159,848	862,649	-14,193	985,456	517,616
2017	5,581,989	377,342	76,194	146,527	862,649	-33,729	985,456	443,529
2018	5,074,535	343,039	69,267	133,207	862,649	-53,264	985,456	369,442
2019	4,567,082	308,735	62,341	119,886	862,649	-72,800	724,600	556,211
2020	4,059,628	274,431	55,414	106,565	862,649	-92,336	724,600	482,124
2021	3,552,175	240,127	48,487	93,245	862,649	-111,872	724,600	408,037
2022	3,044,721	205,823	41,560	79,924	862,649	-131,407	724,600	333,950
2023	2,537,268	171,519	34,634	66,603	862,649	-150,943	724,600	259,863
2024	2,029,814	137,215	27,707	53,283	862,649	-170,479	724,600	185,776
2025	1,522,361	102,912	20,780	39,962	862,649	-190,015	724,600	111,688
2026	1,014,907	68,608	13,853	26,641	862,649	-209,550	724,600	37,601
2027	507,454	34,304	6,927	13,321	862,649	-229,086	724,600	-36,486
2028	0	0	0	0	862,649	-248,622	724,600	-110,573
Sum of Annual Capital Revenue Requirements								15,247,439

FIXED CHARGE RATE (FCR) - NOMINAL AND REAL LEVELIZED - 2005$

TPI = $17,252,989

End of Year	Capital Revenue Req'ts Nominal A	Present Worth Factor Nominal B	Product of Columns A and B C	Capital Revenue Req'ts Real D	Present Worth Factor Real E	Product of Columns D and E F
2009	2,013,691	0.6913	1,392,050	1,789,138	0.7781	1,392,050
2010	3,051,154	0.6303	1,923,276	2,631,952	0.7307	1,923,276
2011	2,141,460	0.5748	1,230,844	1,793,439	0.6863	1,230,844
2012	1,566,010	0.5241	820,735	1,273,309	0.6446	820,735
2013	1,372,442	0.4779	655,870	1,083,419	0.6054	655,870
2014	952,202	0.4358	414,924	729,784	0.5686	414,924
2015	591,703	0.3973	235,103	440,282	0.5340	235,103
2016	517,616	0.3623	187,533	373,937	0.5015	187,533
2017	443,529	0.3304	146,524	311,082	0.4710	146,524
2018	369,442	0.3012	111,288	251,572	0.4424	111,288
2019	556,211	0.2747	152,776	367,721	0.4155	152,776
2020	482,124	0.2505	120,751	309,457	0.3902	120,751
2021	408,037	0.2284	93,185	254,275	0.3665	93,185
2022	333,950	0.2082	69,542	202,045	0.3442	69,542
2023	259,863	0.1899	49,343	152,642	0.3233	49,343
2024	185,776	0.1731	32,165	105,945	0.3036	32,165
2025	111,688	0.1579	17,633	61,839	0.2851	17,633
2026	37,601	0.1440	5,413	20,213	0.2678	5,413
2027	-36,486	0.1313	-4,789	-19,042	0.2515	-4,789
2028	-110,573	0.1197	-13,234	-56,026	0.2362	-13,234
	15,247,439		7,640,931	12,076,983		7,640,931

	Nominal $		Real $
1. The present value is at the beginning of 2006 and results from the sum of the products of the annual present value factors times the annual requirements	7,640,931		7,640,931
2. Escalation Rate	3%		3%
3. After Tax Discount Rate = i	9.67%		6.47%
4. Capital recovery factor value = $i(1+i)^n/(1+i)^n-1$ where book life = n and discount rate = i	0.11481837		0.090575595
5. The levelized annual charges (end of year) = Present Value (Item 1) * Capital Recovery Factor (Item 4)	877,319		692,082
6. Booked Cost	17,252,989		17,252,989
7. The levelized annual fixed charge rate (levelized annual charges divided by the booked cost)	**0.0509**		**0.0401**

LEVELIZED COST OF ELECTRICITY CALCULATION - UTILITY GENERATOR - 2005$

COE = ((TPI * FCR) + AO&M) / AEP

In other words…

The Cost of Electricity =

The Sum of the Levelized Plant Investment + Annual O&M Cost including Levelized Overhaul and Replacement C

Divided by the Annual Electric Energy Consumption

NOMINAL RATES

	Value	Units	From
TPI	$17,252,989	$	From TPI
FCR	5.09%	%	From FCR
AO&M	$560,986	$	From AO&M
AEP =	14,492	MWeh/yr	From Assumptions
COE - TPI X FCR	6.05	cents/kWh	
COE - AO&M	3.87	cents/kWh	
COE	$0.0992	$/kWh	Calculated
COE	**9.92**	cents/kWh	Calculated

REAL RATES

	Value	Units	From
TPI	$17,252,989	$	From TPI
FCR	4.01%	%	From FCR
AO&M	$560,986	$	From AO&M
AEP =	14,492	MWeh/yr	From Assumptions
COE - TPI X FCR	4.78	cents/kWh	
COE - AO&M	3.87	cents/kWh	
COE	$0.0865	$/kWh	Calculated
COE	**8.65**	cents/kWh	Calculated

Non Utility Generator Internal Rate of Return Worksheet

INSTRUCTIONS		
Fill in first four worksheets (or use default values) - the last two worksheets are automatically calculated. Refer to EPRI Economic Methodology Report 002		
(pink cell)		Indicates Input Cell (either input or use default values)
(outlined cell)		Indicates a Calculated Cell (do not input any values)
Sheet 1.	**Total Plant Cost/Total Plant Investment (TPC/TPI) - 2005$**	
	1	Enter Component Unit Cost and No. of Units per System
	2	Worksheet sums component costs to get TPC
	3	Worksheet adds the value of the construction loan payments to get TPI
Sheet 2.	**AO&M (Annual Operation and Maintenance Cost) - 2005$**	
	1	Enter Labor Hrs and Cost by O&M Type)
	2	Enter Parts and Supplies Cost by O&M Type)
	3	Worksheet Calculates Total Annual O&M Cost
Sheet 3.	**O&R (Overhaul and Replacement Cost) - 2005$**	
	1	Enter Year of Cost and O&R Cost per Item
	2	Worksheet calculates inflation to the year of the cost of the O&R
Sheet 4.	**Assumptions (Project, Financial and Others)**	
	1	Enter project, financial and other assumptions or leave default values
Sheet 5.	**Income Statement - Assuming no capacity factor income - Current $**	
	1	2008 1st Year Energy payments = AEP X 2005 wholesale price X 97.18% (to adjust price from 2005 to 2008 (an 2.82% decline) X Inflation from 2005 to 2008
		2009-2011 Energy payments = AEP X Previous Year Elec Price X Annual Price de-escalation of -1.42% X Inflation
		2012-2025 Energy payments = AEP X Previous Year Elec Price X 0.72% Price escalation X Inflation
	2	Calculates State Investment and Prodution tax credit
	3	Calculates Federal Investment and Production Tax Credit
	4	Scheduled O&M from TPC worksheet with inflation
	5	Scheduled O&R from TPC worksheet with inflation
	8	Earnings before EBITDA = total revenues less total operating costs
	9	Tax Depreciation = Assumed MACRS rate X TPI
	10	Interest paid = Annual interest given assumed debt interest rate and life of loan
	11	Taxable earnings = Tax Depreciation + Interest Paid
	12	State Tax = Taxable Earnings x state tax rate
	13	Federal Tax = (Taxable earnings - State Tax) X Federal tax rate
	14	Total Tax Obligation = Total State + Federal Tax
Sheet 6.	**Cash Flow Statement - Current $**	
	1	EBITDA
	2	Taxes Paid
	3	Cash Flow From Operations = EBITDA - Taxes Paid
	4	Debt Service = Principal + Interest paid on the debt loan
	5	Net Cash Flow after Tax
		Year of Start of Ops minus 1 = Equity amount
		Year of Start of Ops = Cash flow from ops - debt service
		Year of Start of Ops Plus 1 to N = Cash flow from ops - debt service
	6	Cum Net Cash Flow After Taxes = previous year net cash flow + current year net cash flow
	7	Cum IRR on net cash Flow After Taxes = discount rate that sets the present worth of the net cash flows over the book life equal to the equity investment at the commercial operations

TOTAL PLANT COST (TPC) - 2005$

TPC Component	Unit	Unit Cost	Total Cost (2005$)	Notes and Assumptions
Procurement				
Power Conversion System	9	$431,051	$3,879,459	
Structural Elements	9	$330,983	$2,978,847	
Subsea Cables	Lot	$532,980	$532,980	
Turbine Installation	9	$536,721	$4,830,489	
Subsea Cable Installation	Lot	$3,882,633	$3,882,633	
Onshore Grid Interconnection	Lot	$200,000	$200,000	
TOTAL			$16,304,408	

TOTAL PLANT INVESTMENT (TPI) - 2005 $

End of Year	Total Cash Expended TPC ($2005)	Before Tax Construction Loan Cost at Debt Financing Rate	2005 Value of Construction Loan Payments	TOTAL PLANT INVESTMENT (TPC + Loan Value) ($2005)
2006	$8,152,204	$733,698	$598,718	$8,750,922
2007	$8,152,204	$733,698	$540,847	$8,693,051
Total	$16,304,408	$1,467,397	$1,139,565	$17,443,973

ANNUAL OPERATING AND MAINTENANCE COST (AO&M) - 2005$

Costs	Yrly Cost	Amount	
Labor and Parts	$316,420	$316,420	
Insurance (1.5% of TPC)	$244,566	$244,566	
Total		$560,986	

	FINANCIAL ASSUMPTIONS		
	(default assumptions in pink background - without line numbers are calculated values)		
1	Rated Plant Capacity ©	4.1	MW
2	Annual Electric Energy Production (AEP)	14,422	MWeh/yr
	Therefore, Capacity Factor	40.13	%
3	Year Constant Dollars	2005	Year
4	Federal Tax Rate	35	%
5	State	Massachusetts	
6	State Tax Rate	9.5	%
	Composite Tax Rate (t)	0.41175	%
	t/(1-t)	0.7000	
7	Book Life	20	Years
8	Construction Financing Rate	9	
9	Common Equity Financing Share	30	%
10	Preferred Equity Financing Share	0	%
11	Debt Financing Share	70	%
12	Common Equity Financing Rate	17	%
13	Preferred Equity Financing Rate	0	%
14	Debt Financing Rate	8	%
	Current $ Discount Rate Before-Tax	10.7	%
	Current $ Discount Rate After-Tax	8.39	%
15	Inflation rate	3	%
16	Federal Investment Tax Credit	0	Assumed take PTC
17	Federal Production Tax Credit inc 3% escalation	0.018	$/kWh for 1st 10 yrs
18	State Investment Tax Credit	8,913,489	$
19	State Production Tax Credit		
20	Wholesale electricity price - 2005$	$0.0520	$/kWh
21	Decline in wholesale elec. price from 2005 to 2008	4.20	%
22	Annual decline in wholesale price, 2009 - 2011	1.42	%
23	Annual increase in wholesale price, 2012 - 2025	0.72	%
24	Yearly Unscheduled O&M	5	% of Sch O&M cost
25	MACRS Year 1	0.2000	
26	MACRS Year 2	0.3200	
27	MACRS Year 3	0.1920	
28	MACRS Year 4	0.1152	
29	MACRS Year 5	0.1152	
30	MACRS Year 6	0.0576	
31	REC Rate	0.0500	$/kWh for Project Life

Electricity Price Forecast Area

The electricity price forecast from the EIA (Doc 002, Reference 8):

"Average U.S. electricity prices, in real 2003 dollars, are expected to decline by 11% from 7.4 cents/kWh in 2003 to 6.6 cents in 2011, then rise to 7.3 cents/kWh in 2025."

	2003	7.4	7.4	
	2004		7.29	
Base	2005		7.19	
	2006		7.09	
	2007		6.99	
	2008		6.89	-4.20% Decline (2005 - 2008)
	2009		6.79	
	2010		6.7	
	2011	6.6	6.6	-1.42% Annual Decline (2009 - 2011)
	2012		6.65	
	2013		6.7	
	2014		6.74	
	2015		6.79	
	2016		6.84	
	2017		6.89	
	2018		6.94	
	2019		6.99	
	2020		7.04	
	2021		7.09	
	2022		7.14	
	2023		7.2	
	2024		7.25	
	2025	7.3	7.3	0.72% Annual Increase (2012 - 2025)

INCOME STATEMENT ($)		CURRENT DOLLARS							
Description/Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
REVENUES									
Energy Payments	785,069	797,139	809,394	821,838	852,610	884,535	917,655	952,014	987,661
REC income	811,604	835,953	861,031	886,862	913,468	940,872	969,098	998,171	1,028,116
State ITC	846,781								
Federal ITC	0								
Fedaral PTC	259,596	267,384	275,405	283,668	292,178	300,943	309,971	319,270	328,848
TOTAL REVENUES	2,443,454	1,633,091	1,670,425	1,708,700	1,766,078	1,825,407	1,886,753	1,950,185	2,015,777
AVG $/KWH	0.169	0.113	0.116	0.118	0.122	0.127	0.131	0.135	0.140
OPERATING COSTS									
Scheduled and Unscheduled O&M	569,814	586,908	604,515	622,651	641,330	660,570	680,387	700,799	721,823
Other	0	0	0	0	0	0	0	0	0
TOTAL	569,814	586,908	604,515	622,651	641,330	660,570	680,387	700,799	721,823
EBITDA	1,873,641	1,046,183	1,065,910	1,086,049	1,124,748	1,164,836	1,206,365	1,249,386	1,293,954
Tax Depreciation	3,614,723	5,783,557	3,470,134	2,082,081	2,082,081	903,681	0	0	0
Interest Paid	1,012,123	990,005	966,119	940,322	912,460	882,370	849,873	814,776	776,871
TAXABLE EARNINGS	-2,753,205	-5,727,380	-3,370,343	-1,936,353	-1,869,793	-621,215	356,492	434,611	517,083
State Tax	-261,554	-544,101	-320,183	-183,954	-177,630	-59,015	33,867	41,288	49,123
Federal Tax	-872,078	-1,814,147	-1,067,556	-613,340	-592,257	-196,770	112,919	137,663	163,786
TOTAL TAX OBLIGATIONS	-1,133,632	-2,358,249	-1,387,739	-797,293	-769,887	-255,785	146,786	178,951	212,909

Description/Year	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
REVENUES											
Energy Payments	1,024,642	1,063,008	1,102,810	1,144,103	1,186,941	1,231,384	1,277,491	1,325,324	1,374,948	1,426,431	1,479,841
REC income	1,058,960	1,090,728	1,123,450	1,157,154	1,191,868	1,227,624	1,264,453	1,302,387	1,341,458	1,381,702	1,423,153
State ITC											
Federal ITC											
Fedaral PTC	338,714										
TOTAL REVENUES	2,083,602	2,153,736	2,226,260	2,301,256	2,378,810	2,459,009	2,541,944	2,627,711	2,716,407	2,808,133	2,902,994
AVG $/KWH	0.144	0.149	0.154	0.160	0.165	0.171	0.176	0.182	0.188	0.195	0.201
OPERATING COSTS											
Scheduled and Unscheduled O&M	743,478	765,782	788,756	812,418	836,791	861,894	887,751	914,384	941,815	970,070	999,172
Other	0	0	0	0	0	0	0	0	0	0	0
TOTAL	743,478	765,782	788,756	812,418	836,791	861,894	887,751	914,384	941,815	970,070	999,172
EBITDA	1,340,124	1,387,954	1,437,505	1,488,838	1,542,019	1,597,114	1,654,193	1,713,327	1,774,592	1,838,063	1,903,822
Tax Depreciation	0	0	0	0	0	0	0	0	0	0	0
Interest Paid	735,934	691,722	643,972	592,403	536,709	476,558	411,596	341,437	265,665	183,831	95,451
TAXABLE EARNINGS	604,190	696,232	793,532	896,435	1,005,310	1,120,556	1,242,597	1,371,890	1,508,927	1,654,232	1,808,371
State Tax	57,398	66,142	75,386	85,161	95,504	106,453	118,047	130,330	143,348	157,152	171,795
Federal Tax	191,377	220,532	251,351	283,946	318,432	354,936	393,593	434,546	477,952	523,978	572,802
TOTAL TAX OBLIGATIONS	248,775	286,674	326,737	369,107	413,937	461,389	511,639	564,876	621,301	681,130	744,597

CASH FLOW STATEMENT							
Description/Year	2007	2008	2009	2010	2011	2012	2013
EBITDA			1,873,641	1,046,183	1,065,910	1,086,049	1,124,748
Taxes Paid			-1,133,632	-2,358,249	-1,387,739	-797,293	-769,887
CASH FLOW FROM OPS			3,007,273	3,404,431	2,453,649	1,883,343	1,894,635
Debt Service			-1,288,586	-1,288,586	-1,288,586	-1,288,586	-1,288,586
NET CASH FLOW AFTER TAX		-5,422,085	1,718,686	2,115,845	1,165,062	594,756	606,049
CUM NET CASH FLOW		-5,422,085	-3,703,398	-1,587,553	-422,491	172,265	778,314

2014	2015	2016	2017	2018	2019	2020	2021
1,164,836	1,206,365	1,249,386	1,293,954	1,340,124	1,387,954	1,437,505	1,488,838
-255,785	146,786	178,951	212,909	248,775	286,674	326,737	369,107
1,420,622	1,059,580	1,070,435	1,081,045	1,091,349	1,101,280	1,110,768	1,119,731
-1,288,586	-1,288,586	-1,288,586	-1,288,586	-1,288,586	-1,288,586	-1,288,586	-1,288,586
132,035	-229,007	-218,151	-207,541	-197,238	-187,306	-177,819	-168,855
910,349	681,342	463,191	255,650	58,412	-128,894	-306,713	-475,568

2022	2023	2024	2025	2026	2027	2028
1,542,019	1,597,114	1,654,193	1,713,327	1,774,592	1,838,063	1,903,822
413,937	461,389	511,639	564,876	621,301	681,130	744,597
1,128,082	1,135,725	1,142,554	1,148,451	1,153,291	1,156,933	1,159,225
-1,288,586	-1,288,586	-1,288,586	-1,288,586	-1,288,586	-1,288,586	-1,288,586
-160,504	-152,861	-146,033	-140,135	-135,295	-131,653	-129,361
-636,072	-788,933	-934,966	-1,075,101	-1,210,396	-1,342,049	-1,471,410
			IRR ON NET CASH FLOW AFTER TAX			#NUM!

Municipal Generator Cost of Electricity Worksheet

INSTRUCTIONS			
			Indicates Input Cell (either input or use default values)
			Indicates a Calculated Cell (do not input any values)
Sheet 1.	**TPC/TPI (Total Plant Cost/Total Plant Investment)**		
		a)	Enter Component Unit Cost and No. of Units per System
		b)	Worksheet sums component costs to get TPC
		c)	Adds the value of the construction loan payments to get TPI
		a)	Enter Labor Hrs and and Parts Cost by O&M inc overhaul and refit
		c)	Worksheet Calculates Insurance and Total Annual O&M Cost
Sheet 3.	**O&R (Overhaul and Replacement Cost)**		
		a)	Enter Year of Cost and O&R Cost per Item
		b)	Worksheets calculates the present value of the O&R costs
Sheet 4.	**Assumptions (Financial)**		
		a)	Enter project and financial assumptions or leave default values
Sheet 5.	**NPV (Net Present Value)**		
		A	Gross Book Value = TPI
		B	Annual Book Depreciation = Gross Book Value/Book Life
		C	Cumulative Depreciation
		D	~~MACRS 5 Year Depreciation Tax Schedule Assumption~~
		E	~~Deferred Taxes = (Gross Book Value X MACRS Rate - Annual~~
			~~Book Depreciation) X Debt Financing Rate~~
		F	Net Book Value = Previous Year Net Book Value - Annual Book
			Depreciation - Deferred Tax for that Year
Sheet 6.	**CRR (Capital Revenue Requirements)**		
		A	Net Book Value for Column F of NPV Worksheet
		B	Common Equity = Net Book X Common Equity Financing
			Share X Common Equity Financing Rate
		C	Preferred Equity = Net Book X Preferred Equity Financing
			Share X Preferred Equity Financing Rate
		D	Debt = Net Book X Debt Financing Share X Debt Financing Rate
		E	Annual Book Depreciation = Gross Book Value/Book Life
		F	~~Income Taxes = (Return on Common Equity + Return of Preferred Equity -~~
			~~Interest on Debt + Deferred Taxes) X (Comp Tax Rate/(1-Comp Tax Rate))~~
		G	Property Taxes and Insurance Expense =
		H	Calculates Investment and ~~Production Tax Credit Revenues~~
		I	Capital Revenue Req'ts = Sum of Columns B through G
Sheet 7.	**FCR (Fixed Charge Rate)**		
		A	Nominal Rates Capital Revenue Req'ts from Columnn H of Previous Worksheet
		B	Nominal Rate Present Worth Factor = 1 / (1 + After Tax Discount Rate)
		C	Nominal Rate Product of Columns A and B = A * B
		D	Real Rates Capital Revenue Req'ts from Columnn H of Previous Worksheet
		E	Real Rates Present Worth Factor = 1 / (1 + After Tax Discount Rate - Inflation Rate)
		F	Real Rates Product of Columns A and B = A * B
Sheet 8.	**Calculates COE (Cost of Electricity)**		
		COE = ((TPI * FCR) + AO&M + LO&R) / AEP	
		In other words…The Cost of Electricity =	
			The Sum of the Levelized Plant Investment + Annual O&M Cost including Levelized
			Overhaul and Replacement Cost Divided by the Annual Electric Energy Consumption

TOTAL PLANT COST (TPC) - 2005$

TPC Component	Unit	Unit Cost	Total Cost (2004$)
Procurement			
Power Conversion System	9	$431,051	$3,879,459
Structural Elements	9	$330,983	$2,978,847
Subsea Cables	Lot	$532,980	$532,980
Turbine Installation	9	$536,721	$4,830,489
Subsea Cable Installation	Lot	$3,882,633	$3,882,633
Onshore Grid Interconnection	Lot	$200,000	$200,000
TOTAL			$16,304,408

TOTAL PLANT INVESTMENT (TPI) - 2005 $

End of Year	Total Cash Expended TPC (2005$)	Before Tax Construction Loan Cost at Debt Financing Rate	2005 Value of Construction Loan Payments	TOTAL PLANT INVESTMENT 2005$
2007	$8,152,204	$407,610	$369,714	$8,521,918
2008	$8,152,204	$407,610	$352,109	$8,504,313
Total	$16,304,408	$815,220	$721,823	$17,026,231

ANNUAL OPERATING AND MAINTENANCE COST (AO&M) - 2005$

Costs	Yrly Cost	Amount
Labor and Parts	$316,420	$316,420
Insurance (1.5% of TPC)	$244,566	$244,566
Total		$560,986

	FINANCIAL ASSUMPTIONS		
	(default assumptions in pink background - without line numbers are calculated values)		
1	Rated Plant Capacity ©	4.1	MW
2	Annual Electric Energy Production (AEP)	14,422	MWeh/yr
	Therefore, Capacity Factor	40.1	%
3	Year Constant Dollars	2005	Year
4	Federal Tax Rate	0	%
5	State	Massachusetts	
6	State Tax Rate	0	%
	Composite Tax Rate (t)	0	
	t/(1-t)	0.0000	
7	Book Life	20	Years
8	Construction Financing Rate	5	
9	Common Equity Financing Share	0	%
10	Preferred Equity Financing Share	0	%
11	Debt Financing Share	100	%
12	Common Equity Financing Rate	0	%
13	Preferred Equity Financing Rate	0	%
14	Debt Financing Rate	5	%
	Nominal Discount Rate Before-Tax	5.00	%
	Nominal Discount Rate After-Tax	5.00	%
15	Inflation Rate = 3%	3	%
	Real Discount Rate Before-Tax	1.94	%
	Real Discount Rate After-Tax	1.94	%
16	Federal Investment Tax Credit	0	
17	Federal REPI (1)	0.015	$/kWh
18	State Investment Tax Credit	8,913,489	$
19	State Investment Production Tax Credit	$0	None
20	Renewable Energy Certificate (2)	0.05	$/kWh
21	State Tax Depreciation	0	Installation Cos

Notes

1 $/kWh for 1st 10 years with escalation (assumed 3% per yr)

2 $/kWh for entire plant life with escalation (assumed 3% per yr)

PPI Change in inflation

http://www.gpec.org/InfoCenter/Topics/Economy/USInflation.html

			REPI incentive	
		1993	1.50	cents/kWh
1994	130%	1994	1.52	cents/kWh
1995	3.60%	1995	1.57	cents/kWh
1996	2.40%	1996	1.61	cents/kWh
1997	-0.10%	1997	1.61	cents/kWh
1998	-2.50%	1998	1.57	cents/kWh
1999	0.90%	1999	1.58	cents/kWh
2000	5.70%	2000	1.67	cents/kWh
2001	110%	2001	1.69	cents/kWh
2002	-2.30%	2002	1.65	cents/kWh
2003	5.30%	2003	1.74	cents/kWh
2004	-0.70%	2004	1.73	cents/kWh

Post 2004, assume inflation rate of line 15

NET PRESENT VALUE (NPV) - 2005 $						
TPI =	$17,026,231					
Year End	Gross Book Value	Book Depreciation Annual	Accumulated	Renewable Resource MACRS Tax Depreciation Schedule	Deferred Taxes	Net Book Value
	A	B	C	D	E	F
2008	**17,026,231**					**17,026,231**
2009	17,026,231	851,312	851,312	0	0	16,174,920
2010	17,026,231	851,312	1,702,623	0	0	15,323,608
2011	17,026,231	851,312	2,553,935	0	0	14,472,297
2012	17,026,231	851,312	3,405,246	0	0	13,620,985
2013	17,026,231	851,312	4,256,558	0	0	12,769,674
2014	17,026,231	851,312	5,107,869	0	0	11,918,362
2015	17,026,231	851,312	5,959,181	0	0	11,067,050
2016	17,026,231	851,312	6,810,493	0	0	10,215,739
2017	17,026,231	851,312	7,661,804	0	0	9,364,427
2018	17,026,231	851,312	8,513,116	0	0	8,513,116
2019	17,026,231	851,312	9,364,427	0	0	7,661,804
2020	17,026,231	851,312	10,215,739	0	0	6,810,493
2021	17,026,231	851,312	11,067,050	0	0	5,959,181
2022	17,026,231	851,312	11,918,362	0	0	5,107,869
2023	17,026,231	851,312	12,769,674	0	0	4,256,558
2024	17,026,231	851,312	13,620,985	0	0	3,405,246
2025	17,026,231	851,312	14,472,297	0	0	2,553,935
2036	17,026,231	851,312	15,323,608	0	0	1,702,623
2027	17,026,231	851,312	16,174,920	0	0	851,312
2028	17,026,231	851,312	17,026,231	0	0	0

CAPITAL REVENUE REQUIREMENTS - 2005$								
TPI :	$17,026,231							
End of Year	Net Book	Returns to Equity Common	Returns to Equity Pref	Interest on Debt	Book Dep	Income Tax on Equity Return	REPI	Capital Revenue Req'ts
	A	B	C	D	E	F	H	I
2009	16,174,920	0	0	808,746	851,312	0	937,430	722,628
2010	15,323,608	0	0	766,180	851,312	0	937,430	680,062
2011	14,472,297	0	0	723,615	851,312	0	937,430	637,496
2012	13,620,985	0	0	681,049	851,312	0	937,430	594,931
2013	12,769,674	0	0	638,484	851,312	0	937,430	552,365
2014	11,918,362	0	0	595,918	851,312	0	937,430	509,800
2015	11,067,050	0	0	553,353	851,312	0	937,430	467,234
2016	10,215,739	0	0	510,787	851,312	0	937,430	424,669
2017	9,364,427	0	0	468,221	851,312	0	937,430	382,103
2018	8,513,116	0	0	425,656	851,312	0	937,430	339,537
2019	7,661,804	0	0	383,090	851,312	0	721,100	513,302
2020	6,810,493	0	0	340,525	851,312	0	721,100	470,736
2021	5,959,181	0	0	297,959	851,312	0	721,100	428,171
2022	5,107,869	0	0	255,393	851,312	0	721,100	385,605
2023	4,256,558	0	0	212,828	851,312	0	721,100	343,039
2024	3,405,246	0	0	170,262	851,312	0	721,100	300,474
2025	2,553,935	0	0	127,697	851,312	0	721,100	257,908
2026	1,702,623	0	0	85,131	851,312	0	721,100	215,343
2027	851,312	0	0	42,566	851,312	0	721,100	172,777
2028	0	0	0	0	851,312	0	721,100	130,212
Sum of Annual Capital Revenue Requirements								8,528,391

FIXED CHARGE RATE (FCR) - NOMINAL AND REAL LEVELIZED - 2005$

TPI = $17,026,231

End of Year	Capital Revenue Req'ts Nominal A	Present Worth Factor Nominal B	Product of Columns A and B C	Capital Revenue Req'ts Real D	Present Worth Factor Real E	Product of Columns D and E F
2009	722,628	0.8227	594,507	642,045	0.9260	594,507
2010	680,062	0.7835	532,846	586,627	0.9083	532,846
2011	637,496	0.7462	475,710	533,893	0.8910	475,710
2012	594,931	0.7107	422,806	483,733	0.8740	422,806
2013	552,365	0.6768	373,863	436,042	0.8574	373,863
2014	509,800	0.6446	328,621	390,719	0.8411	328,621
2015	467,234	0.6139	286,841	347,666	0.8250	286,841
2016	424,669	0.5847	248,295	306,790	0.8093	248,295
2017	382,103	0.5568	212,769	267,999	0.7939	212,769
2018	339,537	0.5303	180,064	231,208	0.7788	180,064
2019	513,302	0.5051	259,252	339,353	0.7640	259,252
2020	470,736	0.4810	226,432	302,148	0.7494	226,432
2021	428,171	0.4581	196,150	266,822	0.7351	196,150
2022	385,605	0.4363	168,238	233,297	0.7211	168,238
2023	343,039	0.4155	142,540	201,500	0.7074	142,540
2024	300,474	0.3957	118,908	171,356	0.6939	118,908
2025	257,908	0.3769	97,203	142,798	0.6807	97,203
2026	215,343	0.3589	77,296	115,757	0.6677	77,296
2027	172,777	0.3418	59,064	90,171	0.6550	59,064
2028	130,212	0.3256	42,393	65,977	0.6425	42,393
	8,528,391		5,043,799	6,155,902		5,043,799

	Nominal $		Real $
1. The present value is at the beginning of 2006 and results from the sum of the products of the annual present value factors times the annual requirements	5,043,799		5,043,799
2. Escalation Rate	3%		3%
3. Discount Rate = i	5.00%		1.94%
4. Capital recovery factor value = i(1+i)"/(1+i)"-1 where book life = n and discount rate = i	0.08024259		0.060813464
5. The levelized annual charges (end of year) = Present Value (Item 1) * Capital Recovery Factor (Item 4)	404,727		306,731
6. Booked Cost	17,026,231		17,026,231
7. The levelized annual fixed charge rate (levelized annual charges divided by the booked cost)	**0.0238**		**0.0180**

LEVELIZED COST OF ELECTRICITY CALCULATION - MUNICIPAL GENERATOR - 2005$			
COE = ((TPI * FCR) + AO&M) / AEP			
In other words…			
The Cost of Electricity =			
The Sum of the Levelized Plant Investment + Annual O&M Cost + Levelized Overhaul and Replacement Cost			
Divided by the Annual Electric Energy Consumption			
NOMINAL RATES			
	Value	**Units**	**From**
TPI	$17,026,231	$	From TPI
FCR	2.38%	%	From FCR
AO&M	$560,986	$	From AO&M
AEP =	14,422	MWeh/yr	From Assumptions
COE - TPI X FCR	2.81	cents/kWh	
COE - AO&M	3.89	cents/kWh	
COE	$0.0670	$/kWh	Calculated
COE	**6.70**	cents/kWh	Calculated
REAL RATES			
TPI	$17,026,231	$	From TPI
FCR	1.80%	%	From FCR
AO&M	$560,986	$	From AO&M
AEP =	14,422	MWeh/yr	From Assumptions
COE - TPI X FCR	2.13	cents/kWh	
COE - AO&M	3.89	cents/kWh	
COE	$0.0602	$/kWh	Calculated
COE	**6.02**	cents/kWh	Calculated