System Level Design, Performance, Cost and Economic Assessment – San Francisco Tidal In-Stream Power Plant

Report: EPRI – TP - 006 - SF CA
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1. Introduction and Summary

The narrow passage under the Golden Gate Bridge, which connects the San Francisco bay to the Pacific Ocean is home to some of the most energetic currents in North America. In average 237MW of power is embodied in the tidal stream, of which about 35MW could be extracted without any negative impact on the environment. A plant of that scale could reach an electrical output of about 100MW at peak.

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 in San Francisco. The primary purpose of this design study was to identify and quantify the risks and benefits of using TISEC technology at the San Francisco Golden Gate bridge 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 San Francisco stakeholders and EPRI decided to work with three TISEC device developers: Lunar Energy, Marine Current Turbines (MCT) and Verdant Power. 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. Verdant's 5 m diameter water turbine was judged to be too small for this application and our ability to scale up their design with high confidence of accurate weight and cost estimates was viewed to be unrealistic.

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 intend to compare the two device developers nor 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.

It became clear during the study that a TISEC array would have to be placed directly below the navigation channel under the Golden Gate Bridge. As such only fully submersible technology could be used at the site, which is the RTT2000 and MCTs second generation technology. However, only MCTs surface piercing first-generation SeaGen offered sufficiently solid engineering specifications at this time (January through March 2006) to perform an independent cost assessment. SeaGen was therefore used to establish relevant performance and cost estimates. Given the similar scale and technology used on MCT's fully submersed technology it is likely that cost and performance will be similar to the surface piercing SeaGen. In order to extract a meaningful amount of energy at the Golden Gate site, a technology needs to be sufficiently large in scale to extract a meaningful amount of energy and be completely submersed to avoid interference with shipping traffic. Both MCTs second generation technology and Lunar Energy's RTT2000 satisfy these criteria. It is unlikely that MCTs second generation technology could be ready for commercial pilot demonstration in the next two years as a proof of high reliability of the SeaGen is a prerequisite.

A pilot consisting of a single SeaGen unit would cost \$5.1M to build and would produce an estimated 3,232 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. While the potential to harness energy at the site is limited to about 15% to assure that the system produces no significant or noticeable ecological or environmental effects, it became clear during this design study that the combination of the shortness of the length of the constricted zone at the site (i.e., high velocity flow) and the current technology would further limit the amount of energy that could be extracted at the site to about 7%. This is based on conservative assumptions and further detailed study of required device spacing, increasing rotor size, developing stackable rotor structures and detailed resource modeling could reveal that as much as 15% could be recovered. Based on these conservative assumptions, the yearly electrical energy produced and delivered to bus bar is estimated to be 129,278 MWh/year for an array consisting of 40 dual-rotor MCT turbines. These turbines have a combined installed capacity of 44.5MW, and on average extract 17.3 MW of kinetic power from the tidal stream, which is roughly 7.3% 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 = $95.5 million
- Annual O&M Cost = $3.57 million
- UG Levelized Cost of Electricity (COE) = 6.6 (Real) – 7.6 (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) = 4.9 (Real) – 5.6 (Nominal) cents/kWh with renewable financial incentives equal to that the government provides for renewable wind energy technology
- Nun Utility Generator (Independent Power Producer) Internal Rate of Return of net cash-flows after tax is 21%

It is encouraging that a commercial plant at the Golden Gate site can potentially have a cost of electricity that is below California avoided cost levels. 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 consenting 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 and 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 need to be addressed. Some of these uncertainties include:

- Technological uncertainties
- 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 recommends that stakeholders build collaboration within California 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. Additional, EPRI encourages the stakeholders to support related R&D activities at a state and federal level and at universities in the region. This would 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 potential 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

The San Francisco California stakeholders selected the Golden Gate area for an assessment of in stream tidal power. The Golden Gate Bridge spans over a narrow passage which connects the San Francisco Bay to the Pacific Ocean. The tidal difference between the San Francisco Bay and the open ocean forces the water through this narrow channel, creating high current velocities potentially suitable for economically operating TISEC devices. The site selection was determined by the following primary considerations:

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

The Golden Gate satisfies these considerations. Of the seven North American sites analyzed by EPRI in this study, the Golden Gate is the second largest tidal in stream energy resource (after Minas Passage in Nova Scotia).

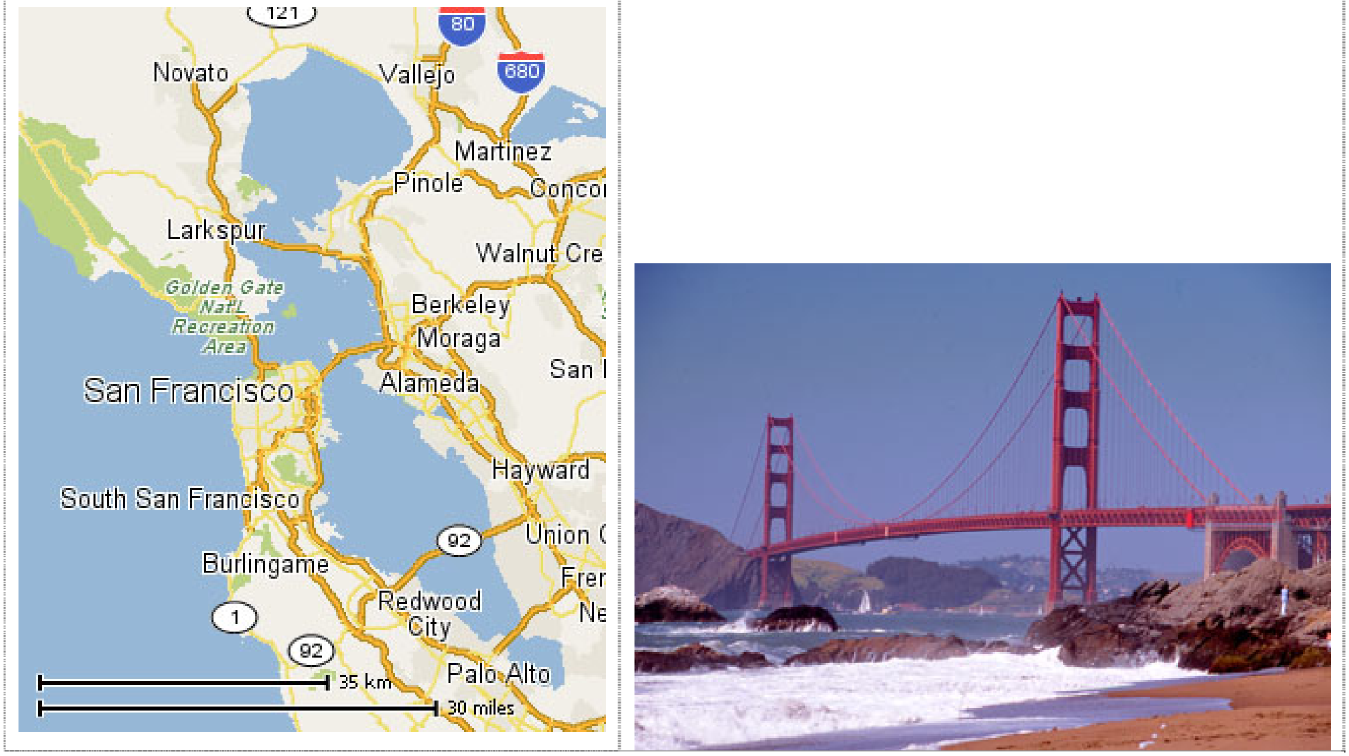


Figure 1 - Bay Area overview map (left), Golden Gate Bridge from Baker Beach

Assembly, installation, operation and maintenance would be performed out of Hunter's Point. Grid interconnection would be to a distribution line at the south foot of the Bridge for the pilot demonstration plant and to a PG&E substation near the Ferry Building for a commercial scale plant. Figure 2 shows a site overview map.

Figure 2 - Site Overview map

Figure 3 shows a nautical chart of the deployment site. The channel where high velocities are expected is relatively short and the red rectangular area shows where the likely boundaries are suitable for TISEC device deployments. East and west of the deployment site, the channel widens significantly leading to lower tidal current velocities.

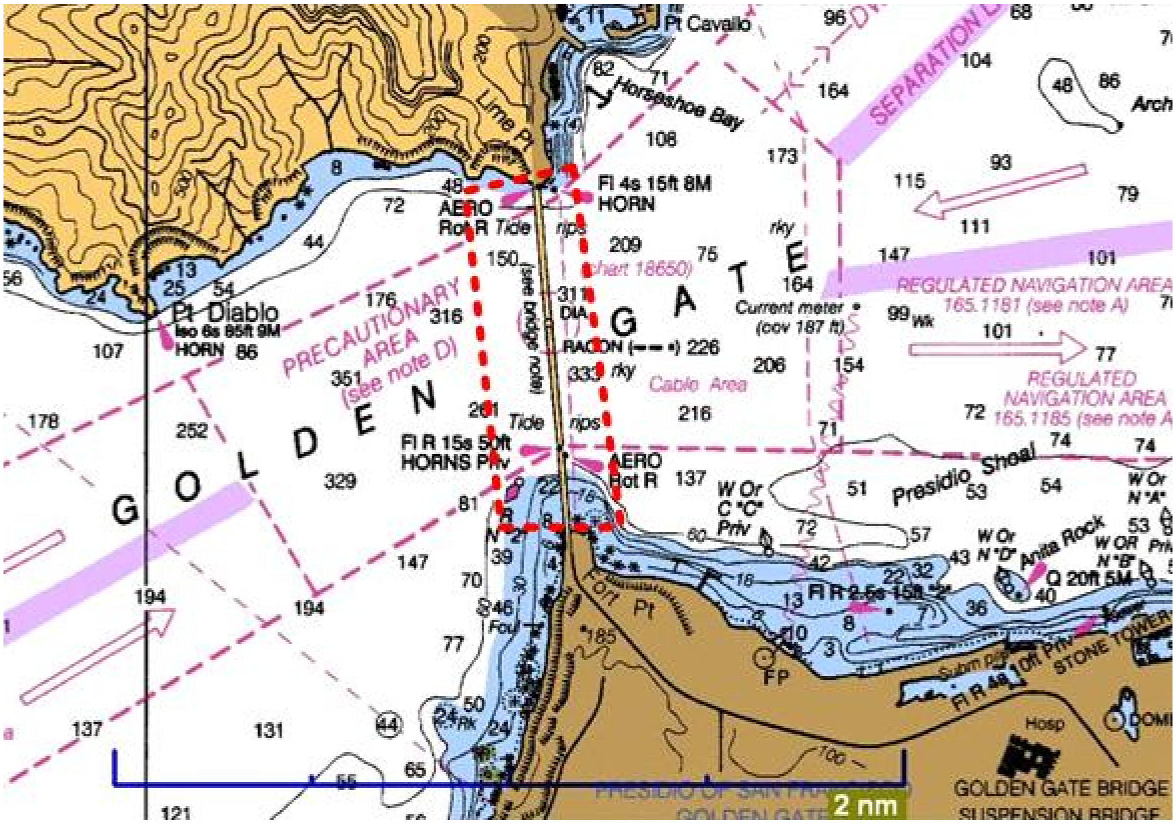
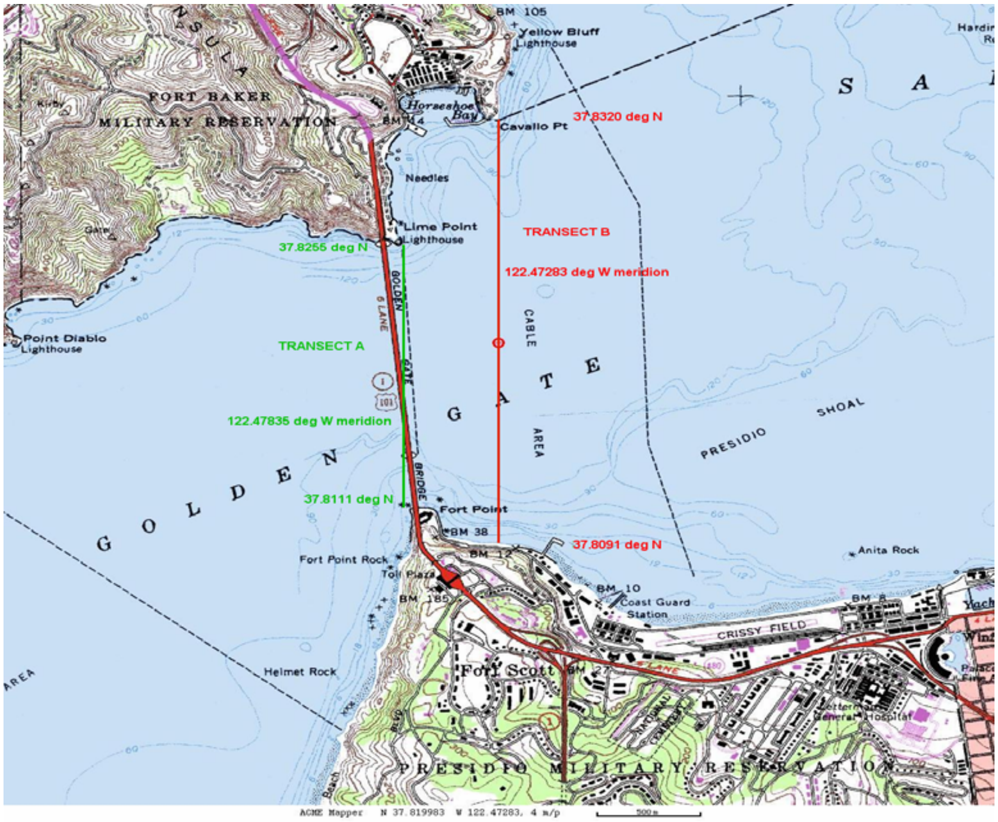


Figure 3 - Nautical Chart of the Golden Gate Bridge (water depth in feet)

Tidal Energy Resource

Tidal velocities at a tidal in stream deployment location are of high importance as the power in a stream increases to the cube power of its velocity. As a result, even small velocity differences can have a major impact on the actual performance of a TISEC device. The methodology to extrapolate actual tidal current data is described in Reference 1 (001 Report).



Ref Station: at Transect B
Location: 500m east of bridge
Latitude: 37^{o} 17 09’ N
Longitude: 122^{o} 32’ 40’ W
Extrapolated velocity profile to from B to A

Transect A Width:	1,380 m
Transect A Mean Depth:	54 m
Transect B Width	2,190 m
Transect B Mean Depth	64 m
Area Ratio of B to A	1.87

Figure 4 - Golden Gate Bridge Cross Section

In order to determine the velocities at the targeted deployment site located directly under the Golden Gate Bridge, measurement data from a NOAA measurement station located about 500m east of the bridge was used (red dot in figure 4). A simplified conservation of mass model was used to scale the water velocity profile from transect B (red) to the TISEC deployment site at transect A. According to the conservation of mass, the same amount of fluid would need to pass through both cross sections and as a result fluid velocities would increase inversely to the two cross-sectional areas. As non-linear effects were ignored, more detailed resource assessments will likely need to be carried out in a detailed design phase. The cross section at Transect A, which is relevant for the calculation of the cross sectional area and tidal flux data was extrapolated from a digital bathymetry set provided by the USGS office in Menlo Park.

Figure 4 and Table 1 shows the depth-averaged velocity distributions at the narrowest transect. This data is later used to calculate the annual performance of the device at the site.

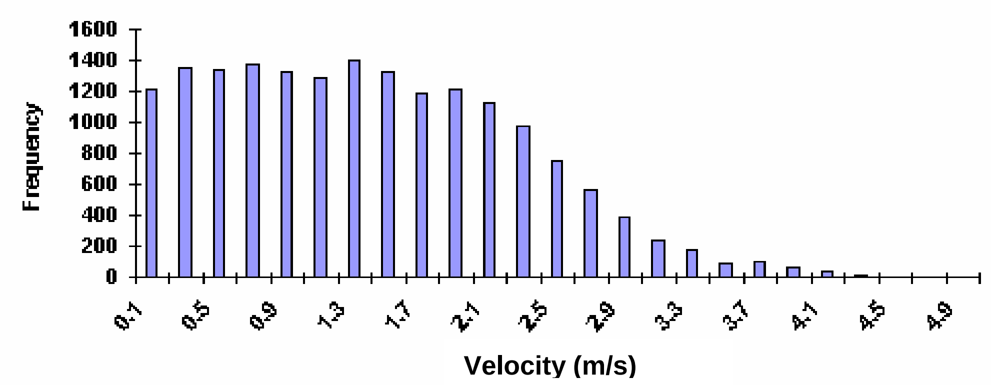


Figure 4 - Depth averaged velocity distribution at the target site. Velocity shown is in m/s

Table 1 - Depth averaged velocity distribution and average resource calculation

Speed (m/sec)	Tidal Stream Power Density (kW/m^2)	Number of Cases	Proportion of Cases	Number of Hours	Tidal Stream Energy Density (kW/m^2)
0.1	0.0	1216	6.94%	608.0	0.0
0.3	0.0	1354	7.73%	677.0	0.0
0.5	0.1	1336	7.63%	668.0	0.0
0.7	0.2	1370	7.82%	685.0	0.1
0.9	0.4	1329	7.59%	664.5	0.2
1.1	0.7	1282	7.32%	641.0	0.4
1.3	1.1	1396	7.97%	698.0	0.8
1.5	1.7	1321	7.54%	660.5	1.1
1.7	2.5	1189	6.79%	594.5	1.5
1.9	3.5	1218	6.95%	609.0	2.1
2.1	4.7	1119	6.39%	559.5	2.7
2.3	6.2	976	5.57%	488.0	3.0
2.5	8.0	753	4.30%	376.5	3.0
2.7	10.1	565	3.22%	282.5	2.8
2.9	12.5	391	2.23%	195.5	2.4
3.1	15.3	243	1.39%	121.5	1.9
3.3	18.4	176	1.00%	88.0	1.6
3.5	22.0	93	0.53%	46.5	1.0
3.7	26.0	97	0.55%	48.5	1.3
3.9	30.4	57	0.33%	28.5	0.9
4.1	35.3	32	0.18%	16.0	0.6
4.3	40.7	7	0.04%	3.5	0.1
4.5	46.7	0	0.00%	0.0	0.0
4.7	53.2	0	0.00%	0.0	0.0
4.9	60.3	0	0.00%	0.0	0.0
		17520	**100.00%**	**8760**	**27.8**
Average Power Density (kW/m^2)					**3.2**
Channel Cross Sectional Area (m^2)					**74,700.0**
Total average resource base (MW)					**236.7**

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.

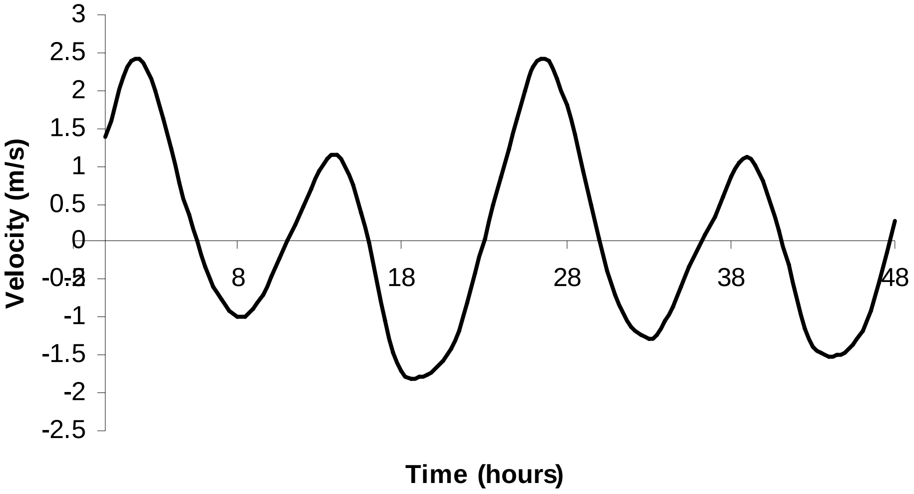


Figure 5 - Typical depth-averaged velocity profile over a 48 hour period

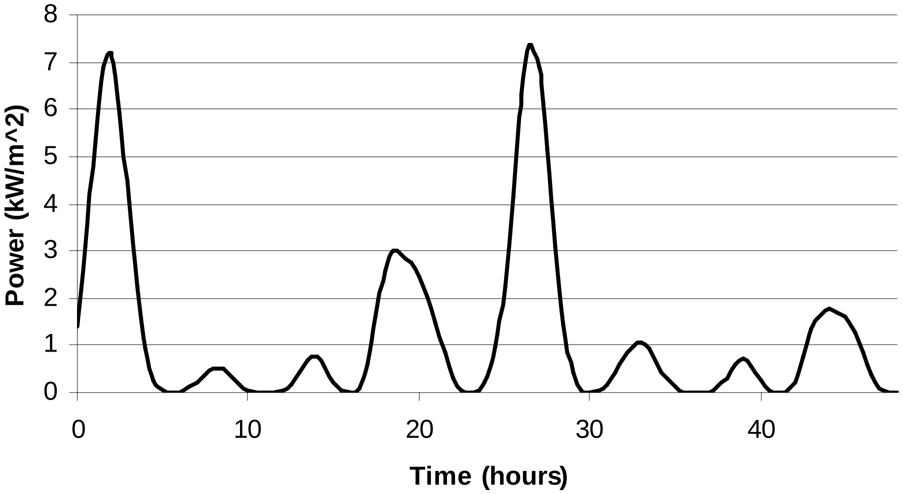


Figure 6 - Typical depth-averaged power variation over a 48-hour period

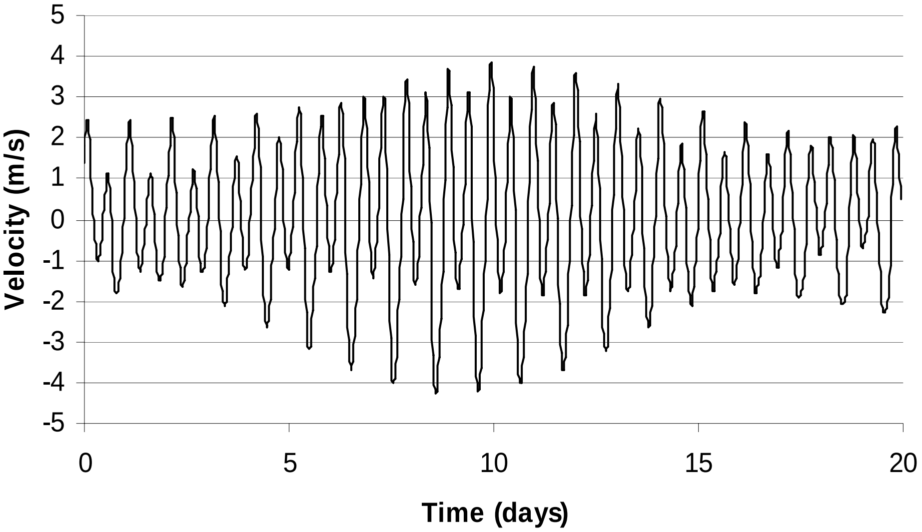


Figure 7 - Velocity profile over a 20 day period covering more then a full lunar cycle

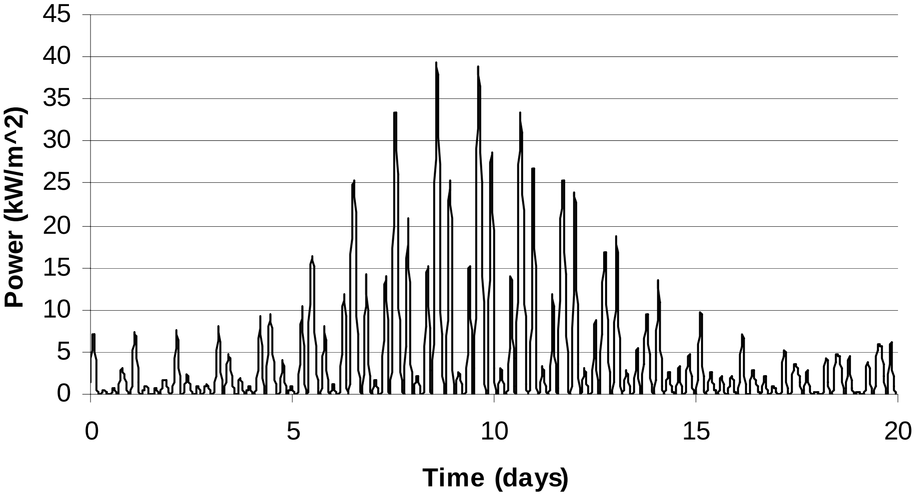


Figure 8 - Power variation of a 20-day period

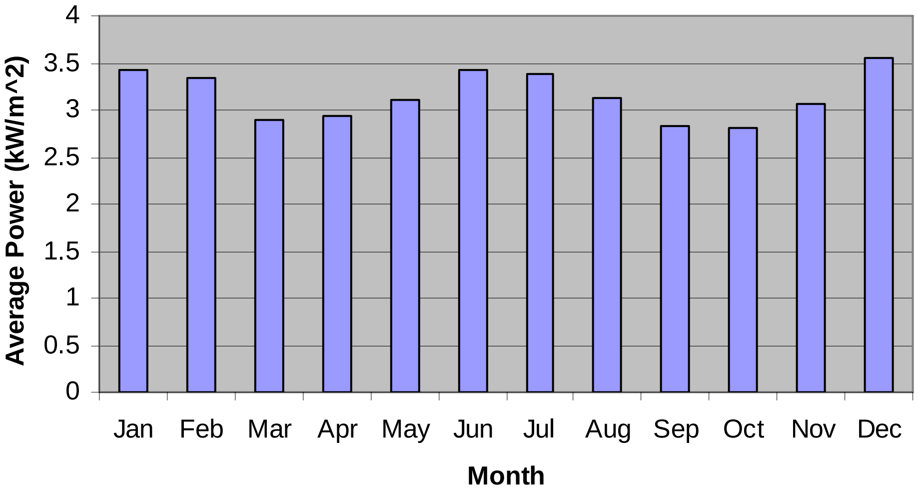


Figure 9 - Annual monthly relative power variation

Grid Interconnection options

While the north-side of the city does not have strong grid interconnection points in close proximity to the actual deployment site, a demonstration-scale tidal power plant could be interconnected at a 12.5kV interconnection point in close proximity to the toll-booth at the south entrance of the Golden Gate Bridge. It is unclear what the feed-in limit at this location would be as no detailed interconnection study was done for that location but at this voltage level it would typically accommodate between 2 and 8 MW. For a commercial sized plant, an interconnection would need to be done at the Embarcadero substation, which is located in close proximity to the Ferry terminal. Bringing additional power through the city would likely require an underground power line which would come at significant additional costs (10's of millions of $) and is therefore not a favorable option. Through consultations with PG&E, the lowest cost option would be to bring a dedicated sub sea cable from the Golden Gate bridge to a landing site in proximity to the Ferry terminal. From there, the power could be fed into an existing circuit close to shore or a dedicated power line could be installed to the Embarcadero substation, which is only a few blocks from the Ferry terminal.

Nearby port facilities

Although the SF Bay Area is not a place where low-cost manufacturing can be located, it offers plenty of facilities to carry out final assembly (staging) and operational activities of TISEC devices. Examples are the port of Oakland in the East Bay and the Hunters Point Naval Shipyard, which is undergoing economic development. For the purpose of this report, it was assumed, that the devices would be launched from the Hunters Point Shipyard and towed to the deployment site. Figure 7 shows an aerial view of Hunters Point Shipyard.

Figure 7 - Hunters Point Naval Shipyard

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, while respecting large containership and oil tanker ship draft clearance of 15m. This drives site selection towards deeper water sites. Given our understanding that the citizens of the city of San Francisco will require that no device elements be surface piercing, ship draft and resulting minimum installation depth for MCT and Lunar turbines are shown in the following figure.

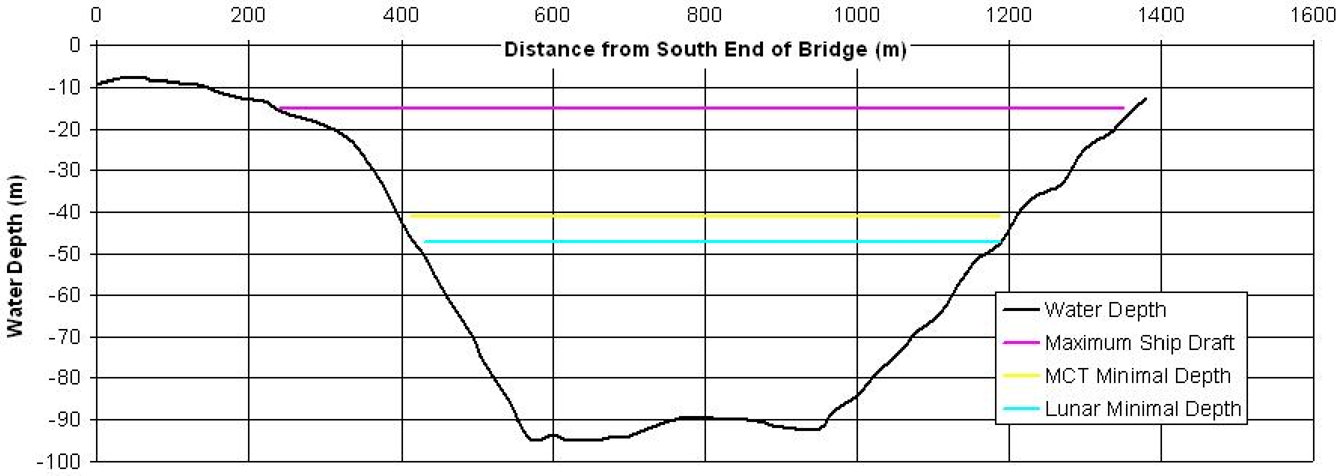


Figure 10 - Cross Sectional Area under the Golden Gate bridge

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). Figure 11 shows that the deployment site will likely have bedrock with some sediment overburden on the south side of the channel. There seems to be less sedimentation on the north side of the channel, which suggests that velocities might be higher on that side.

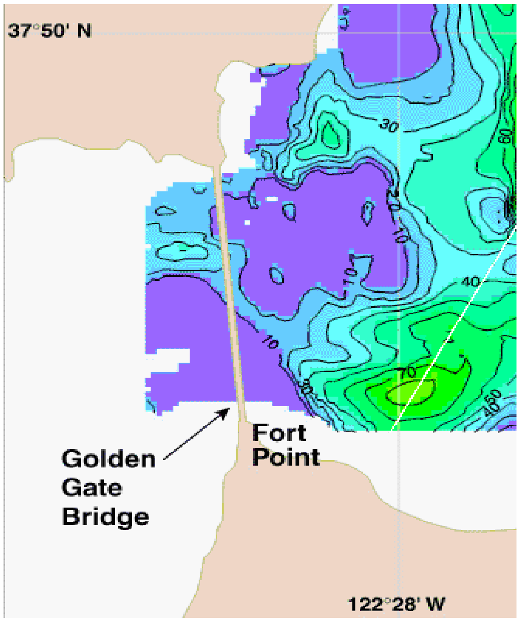


Figure 11 - Sedimentation thickness at the deployment location. Blue shows 0m, purple shows 10m sediment overburden. (Source: USGS Menlo Park)

Navigational Clearances

Vessels entering through the Golden Gate Bridge to access ports in the SF bay area have a draft of up to 15m. Shipping traffic is passing under the Golden Gate Bridge between the north caisson and the south caisson and the shipping channel is covering the whole width of the channel.

Other Site Considerations

San Francisco is a city with an environmentally conscious population and government. The City has set aggressive goals to facilitate the supply of more of its municipal and non-municipal energy from renewable energy sources as outlined in the 2002 Electricity Resource Plan (ERP) (50 MW by 2012). At the same time given the limited landmass and high population density there is little space to develop renewable energy sources within the city boundaries. With an average extractable tidal energy resource potential of 35MW the City could make significant progress towards attaining the ERP renewable energy goals. As a matter of fact the cities peak power consumption is over 950 MW (combined municipal and non-municipal load), with an estimated average of 570MW. Therefore more then 6% of the City's energy needs could potentially come from tidal energy. A second consideration is the fact that the State of California has some of the highest avoided cost levels in the nation, making tidal energy a potentially economic alternative to other generation sources. The California Renewable Portfolio goals are 20% by the year 2017 – as applicable to investor owned utilities. Should the City of San Francisco become a Community Choice Aggregator (CCA) and supply electricity to non-municipal customers, the City could possibly be subject to renewable energy standards goals as specified by California Public Utilities Commission.

Relevant Site Data

For the purpose of establishing point designs for both a demonstration and commercial system, the following data points are relevant. Cost data was estimated after consultation with PG&E, identifying grid interconnection options.

Table 3 - Relevant Site Design Parameters

Site	
Channel Width	1,380 m
Average Depth (from MLLW)	54 m
Deepest Point	96 m
Tidal Range	2 m
Seabed Type	Bedrock with up to 10m sediment overburden
Tidal Energy Statistics	
Depth Averaged Power Density	3.2 kW/m^2
Average Power Available	237 MW
Average Power Extractable (15%)	35.5 MW
# Homes equivalent (1.3 kW/home)	27,300
Peak Velocity at Site	4.83 m/s
Grid Interconnection Demo	
Subsea Cable Length	100m
Cable Landing	Landing over existing bridge structure possible
Overland Interconnection Upgrade cost	$200,000
Infrastructure Upgrade Cost	None assumed
Grid Interconnection Commercial	
Subsea Cable Length	10 km
Cable Landing	Directional Drilling required
Overland Interconnection Upgrade cost	Estimated at $500,000
Infrastructure Upgrade Cost	None assumed. Substation 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 12, 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.

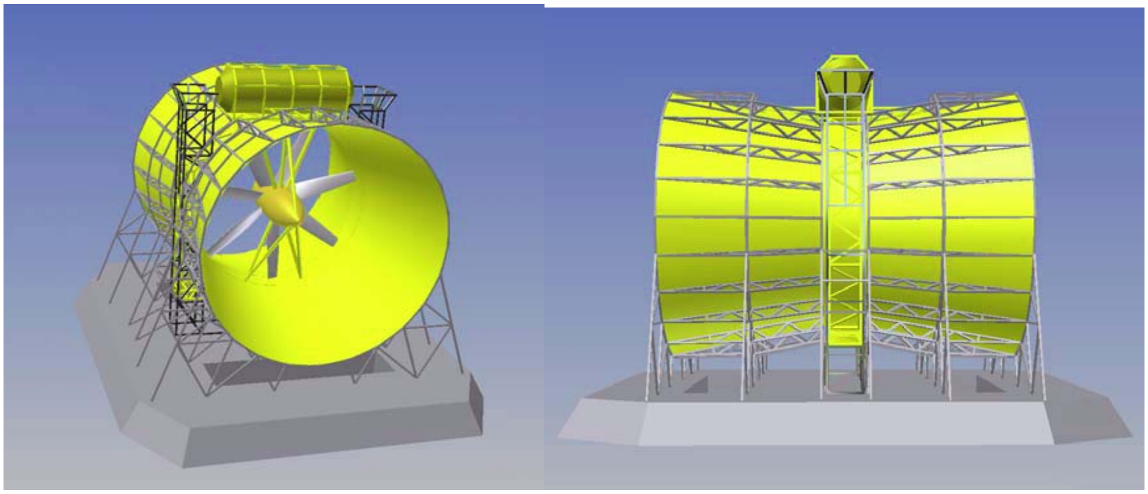


Figure 12 - Lunar Energy Mark I Prototype design

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.

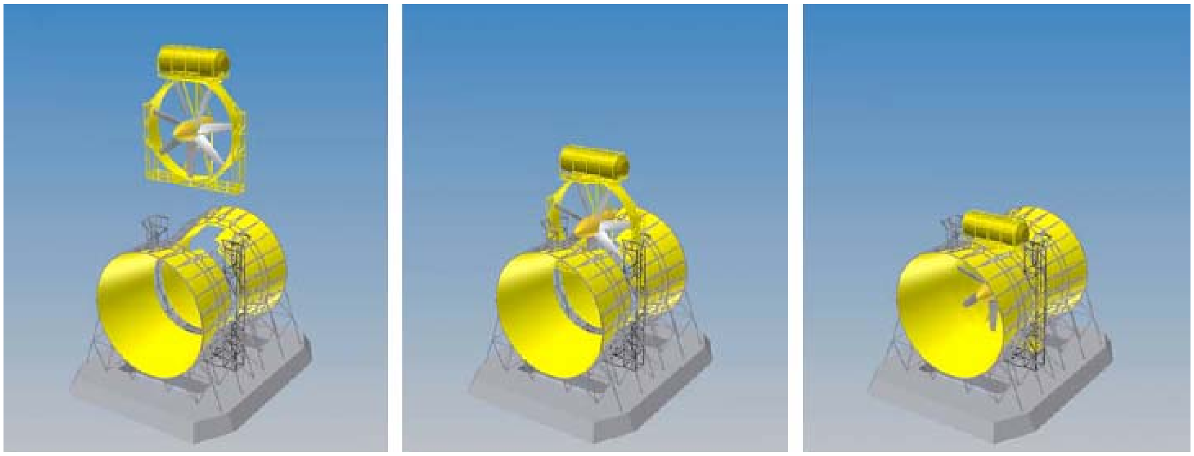


Figure 13 - Insertion and removal of cassette

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 2 - RTT2000 Mark II Specifications optimized for San Francisco 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	1,085 tons
Ballast	1,299 tons
Total installed dry-weight	2,383 tons
Power	
Cut-in speed	0.7 m/s
Rated speed	2.7 m/s
Rated Power	1,284kW
Capacity Factor	21%
Availability	95%
Transmission losses	2%
Net annual generation at bus bar at site	2,389MWh

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.

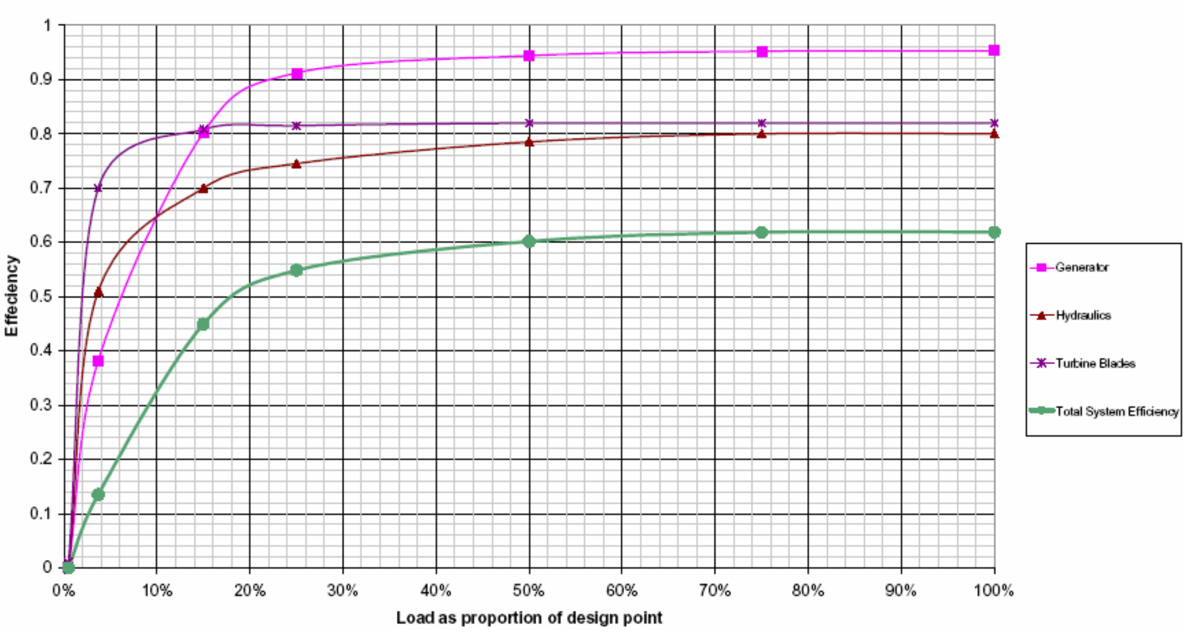


Figure 14 - Efficiency curves of Power Conversion System

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 3 – 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	6.45%	0.0%	0.00	0	33%	0%	0
0.26	6.95%	0.1%	0.01	3	33%	1%	0
0.44	6.80%	0.4%	0.04	15	34%	2%	0
0.62	6.56%	1.2%	0.12	42	36%	6%	0
0.79	7.53%	2.5%	0.25	88	39%	12%	4
0.97	7.17%	4.6%	0.47	161	42%	22%	15
1.14	6.27%	7.6%	0.77	266	45%	35%	42
1.32	7.02%	11.7%	1.18	409	47%	48%	93
1.50	7.01%	17.0%	1.72	595	48%	60%	169
1.67	6.22%	23.8%	2.40	831	48%	67%	268
1.85	6.29%	32.1%	3.24	1122	48%	71%	385
2.03	5.85%	42.2%	4.26	1474	48%	73%	520
2.20	5.33%	54.2%	5.47	1893	48%	74%	678
2.38	4.12%	68.3%	6.88	2385	48%	75%	863
2.55	3.19%	84.6%	8.53	2955	48%	76%	1081
2.73	2.47%	100.0%	10.42	3609	48%	76%	1284
2.91	1.42%	100.0%	12.57	4354	48%	76%	1284
3.08	1.10%	100.0%	15.00	5194	48%	76%	1284
3.26	0.78%	100.0%	17.72	6137	48%	76%	1284
3.43	0.49%	100.0%	20.75	7187	48%	76%	1284
3.61	0.50%	100.0%	24.11	8350	48%	76%	1284
3.79	0.29%	100.0%	27.81	9632	48%	76%	1284
3.96	0.17%	100.0%	31.87	11040	48%	76%	1284
4.14	0.06%	100.0%	36.32	12578	48%	76%	1284
4.49	0.00%	100.0%	46.40	16071	48%	76%	1284
4.67	0.00%						
Avg.			2.88	996			293

Comparison of flow power to electric power generated is shown in Figure 15. Note particularly the cut-in speed (below which no power is generated) and rated speed (above which the power generated is constant).

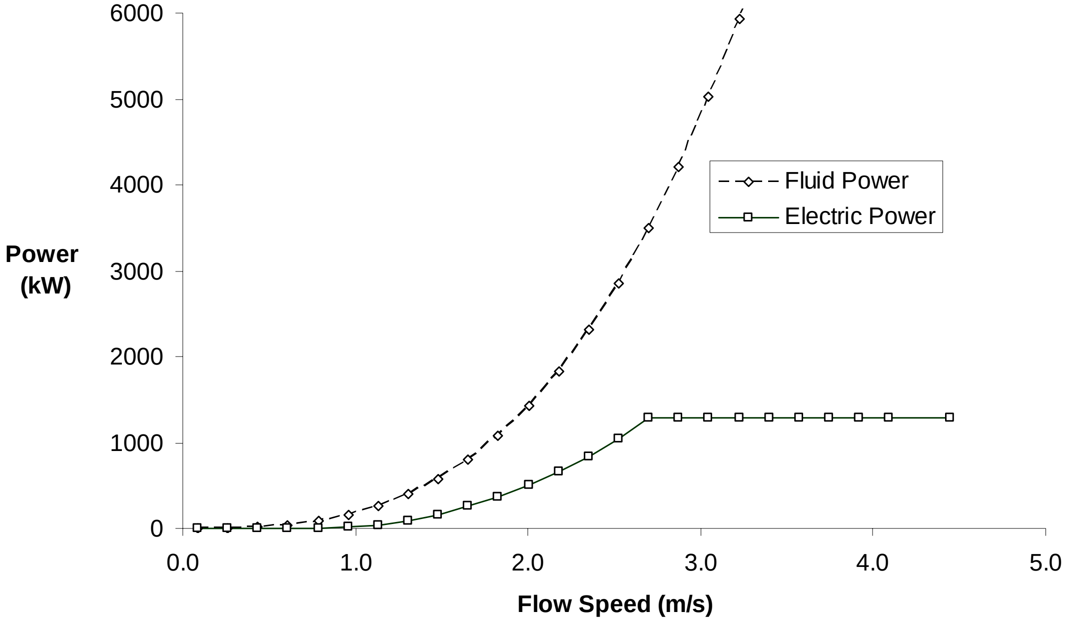


Figure 15 – Comparison of water current speed and electrical power output

The electrical output of the turbine compared to the fluid power crossing the swept area of the rotor is given in Figure 16, for a representative day. The effect of truncating turbine output at rated conditions is obvious.

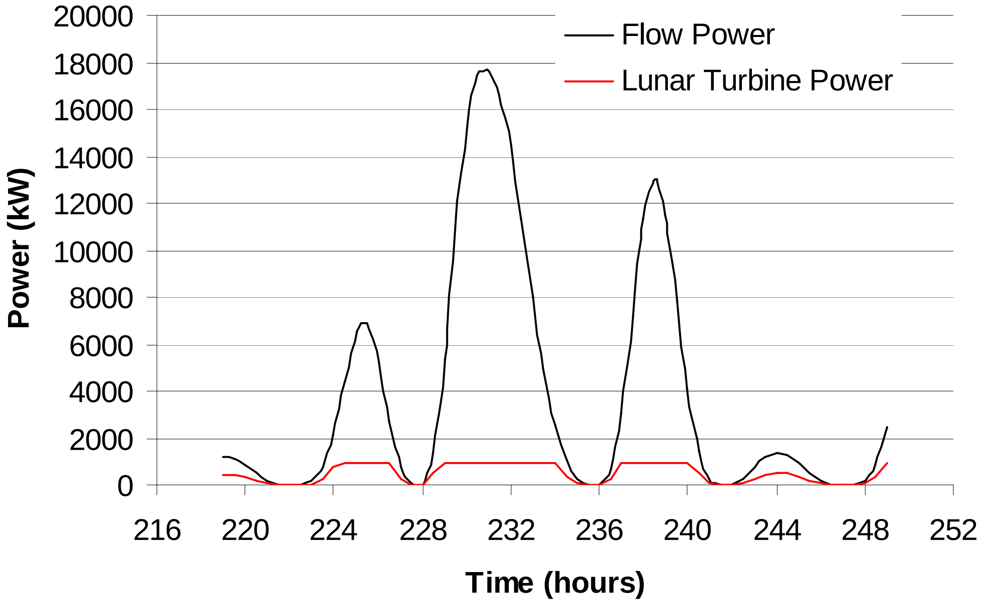


Figure 16 – Variation of flow power and electrical power output at the site

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.

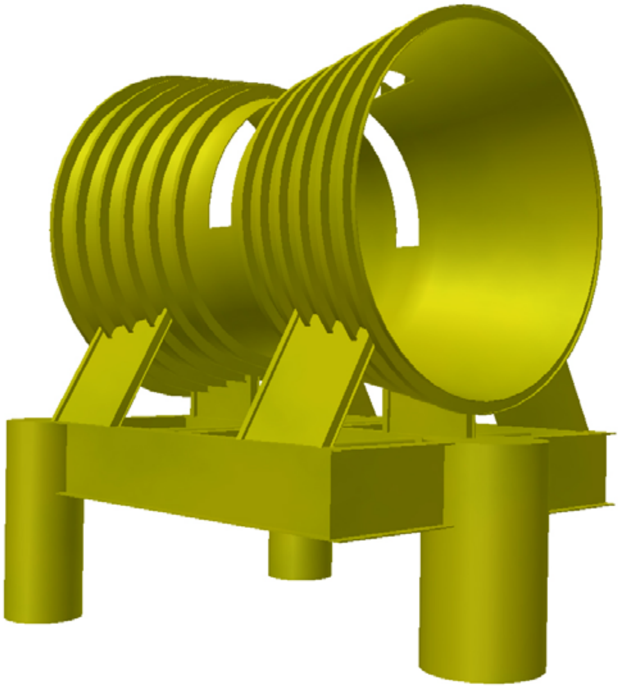


Figure 17 - RTT 2000 Mark II structural design

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 18 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 18 - 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.

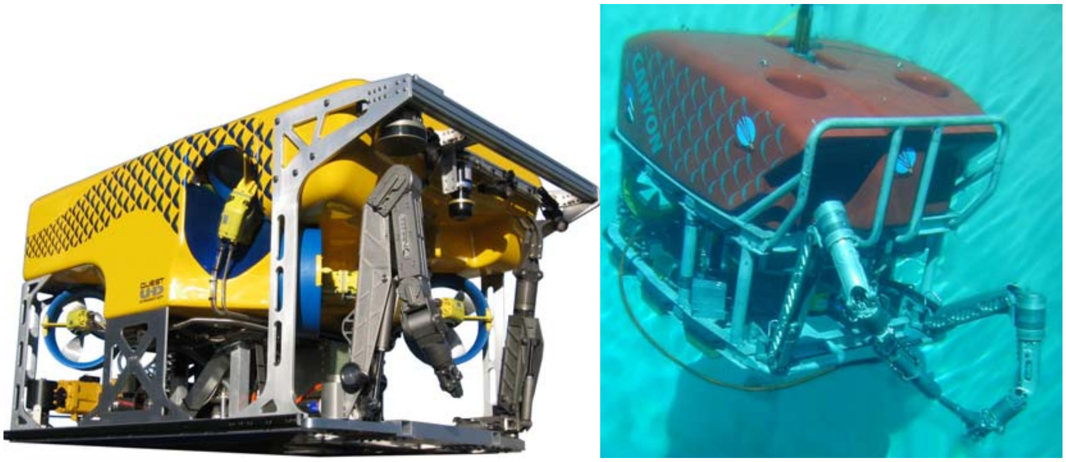


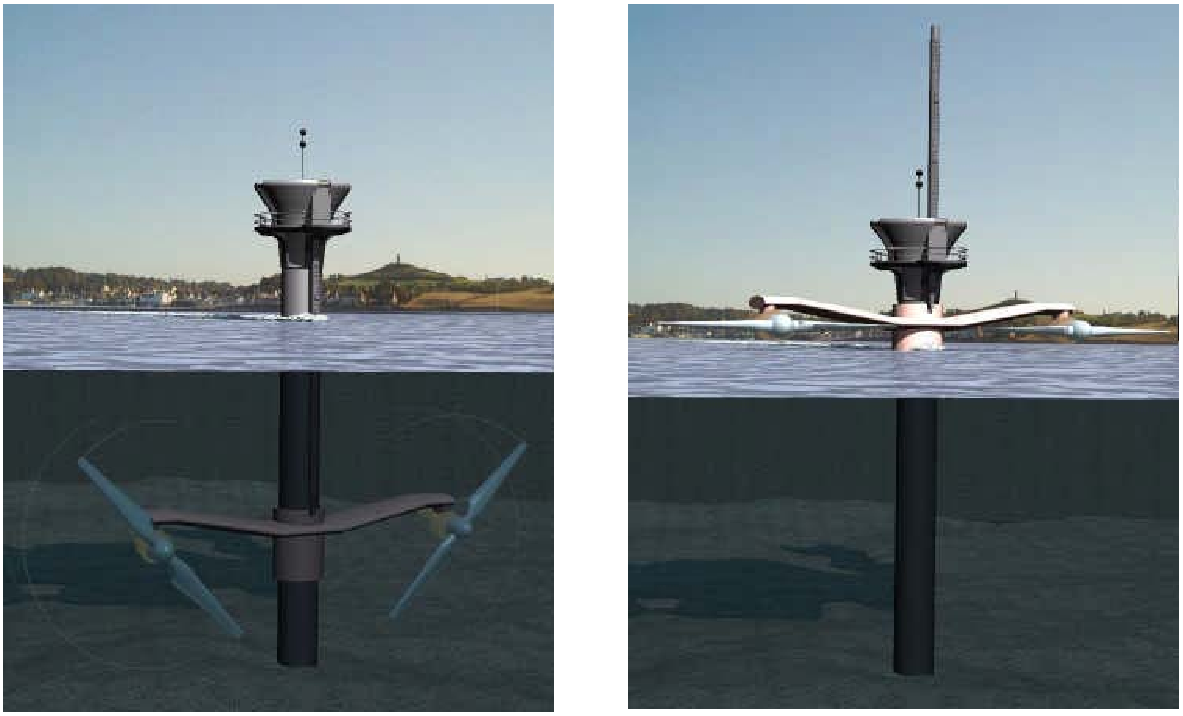
Figure 29 – Remotely Operated Vehicle (ROV) – (courtesy of Schilling Robotics www.ssalliance.com)

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. 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 19.

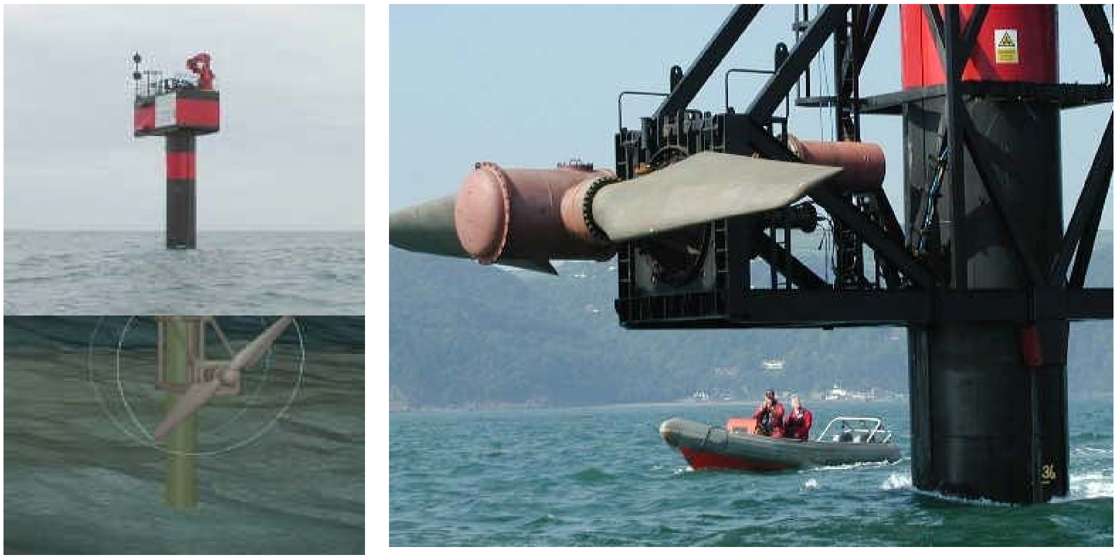


Operation Maintenance

Figure 19 – MCT SeaGen (courtesy of MCT)

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 20), 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 20 – MCT SeaFlow Test Unit (courtesy of MCT)

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 4. Average values can be found in the last row of the table.

Table 4 – Device Performance

Fluid Speed m/s	% of Cases	% Load	Pfluid kW/m^2	Pfluid kW	Pextracted kW	Power Train %	Pelectric kW
0.09	6.45%	0.0%	0.00	0	0	9.27%	0
0.26	6.95%	0.2%	0.01	5	0	13.36%	0
0.43	6.80%	0.8%	0.04	21	0	26.84%	0
0.61	6.56%	2.2%	0.11	58	0	48.35%	0
0.78	7.53%	4.7%	0.24	123	55	68.66%	38
0.95	7.17%	8.5%	0.44	224	101	80.28%	81
1.12	6.27%	14.1%	0.73	370	166	84.47%	141
1.30	7.02%	21.6%	1.12	568	256	86.00%	220
1.47	7.01%	31.4%	1.62	827	372	87.30%	325
1.64	6.22%	43.9%	2.27	1154	519	88.92%	462
1.82	6.29%	59.3%	3.06	1559	701	90.94%	638
1.99	5.85%	77.9%	4.02	2048	921	93.46%	861
2.16	5.33%	100.0%	5.17	2630	1183	94.08%	1113
2.33	4.12%	100.0%	6.51	3313	1183	94.08%	1113
2.51	3.19%	100.0%	8.06	4105	1183	94.08%	1113
2.68	2.47%	100.0%	9.85	5014	1183	94.08%	1113
2.85	1.42%	100.0%	11.88	6048	1183	94.08%	1113
3.03	1.10%	100.0%	14.18	7216	1183	94.08%	1113
3.20	0.78%	100.0%	16.75	8525	1183	94.08%	1113
3.37	0.49%	100.0%	19.62	9983	1183	94.08%	1113
3.54	0.50%	100.0%	22.79	11599	1183	94.08%	1113
3.72	0.29%	100.0%	26.29	13381	1183	94.08%	1113
3.89	0.17%	100.0%	30.13	15336	1183	94.08%	1113
4.06	0.06%	100.0%	34.33	17473	1183	94.08%	1113
4.24	0.00%	100.0%	38.90	19800	1183	94.08%	1113
4.41	0.00%	100.0%	43.87	22325	1183	94.08%	1113
4.58	0.00%	100.0%	49.23	25055	1183	94.08%	1113
Avg.			2.72	1383	431		396

comparison of flow power to electric power generated is shown in Figure 21. Note particularly the cut-in speed (below which no power is generated) and rated speed (above which the power generated is constant).

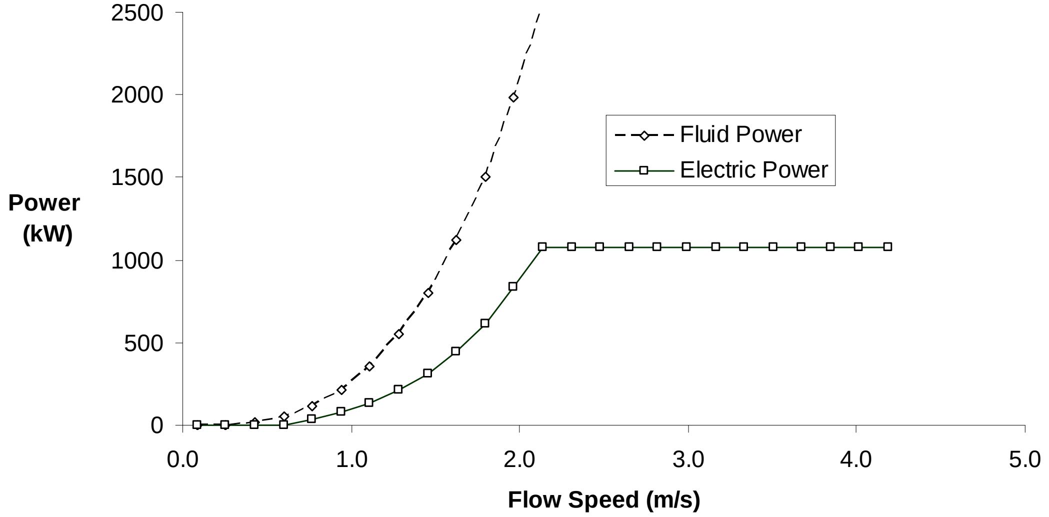


Figure 21 – Comparison of water current speed and electrical power output

The electrical output of the turbine compared to the fluid power crossing the swept area of the rotor is given in Figure 22, for a representative day. The effect of truncating turbine output at rated conditions is obvious.

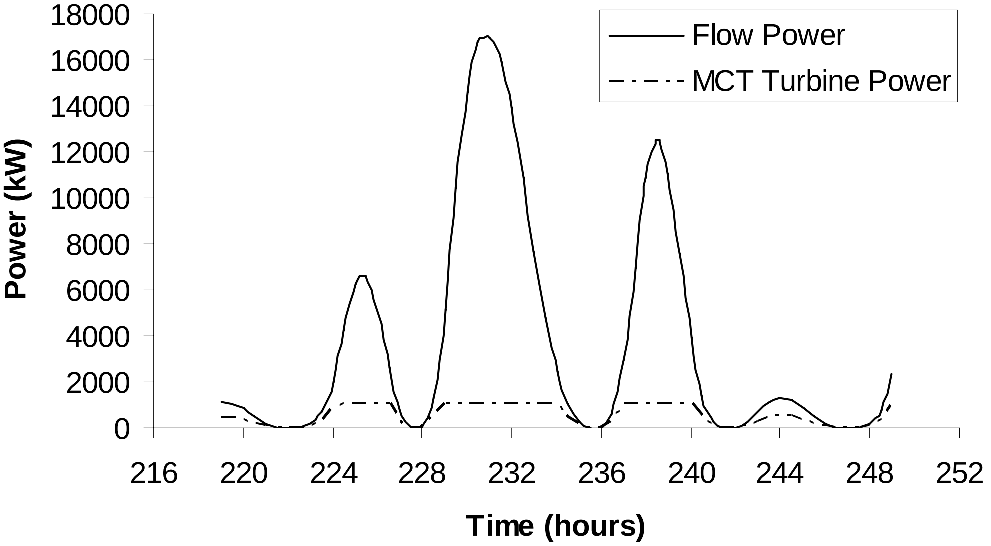


Figure 22 – Variation of flow power and electrical power output at the site

Device Specification

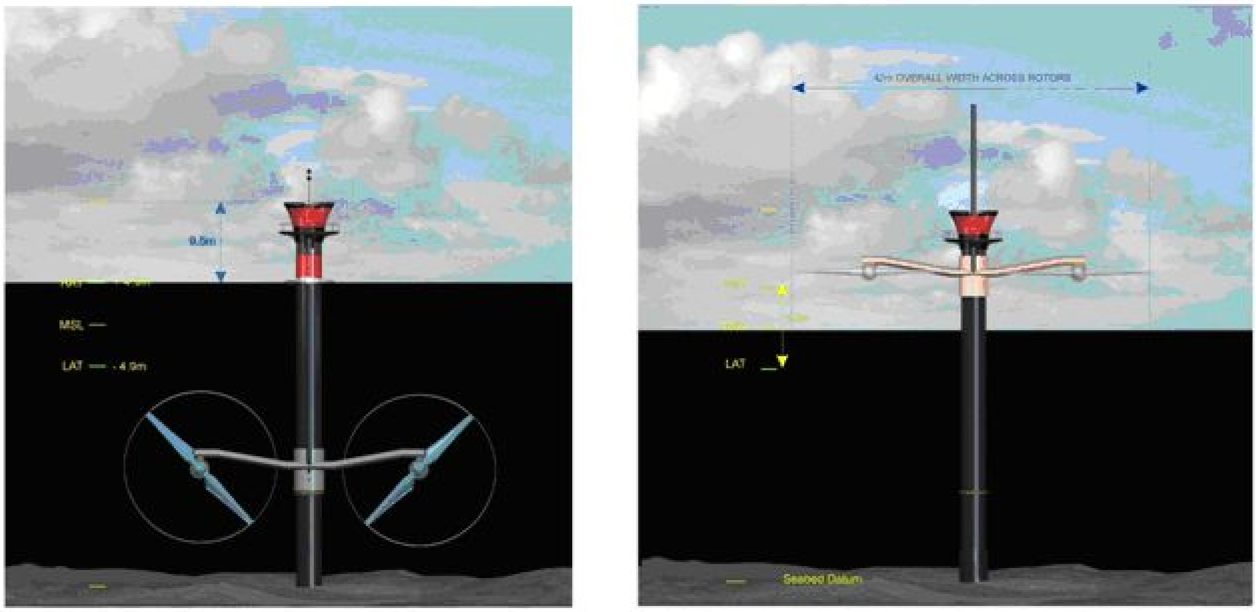
While in principle SeaGen is scalable and adaptable to different site conditions in various ways, EPRI used the 18m dual rotor version and optimized the system to local site conditions to estimate device cost parameters. The following provides specifications which are later used to estimate device cost. 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 5 – SeaGen Device Specification optimized for the San Francisco 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	73m
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	278 tons
Cross Arm	90 tons
Total steel weight	368 tons
Performance	
Cut-in speed	0.7 m/s
Rated speed (optimized to site)	2.14 m/s
Rated Electric Power	1,113 kW
Capacity Factor	33%
Availability	95%
Transmission efficiency	98%
Net annual generation at bus bar	3,232 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 23.



Operation

Maintenance

Figure 23 – 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 24 shows a conceptual illustration of such a design.

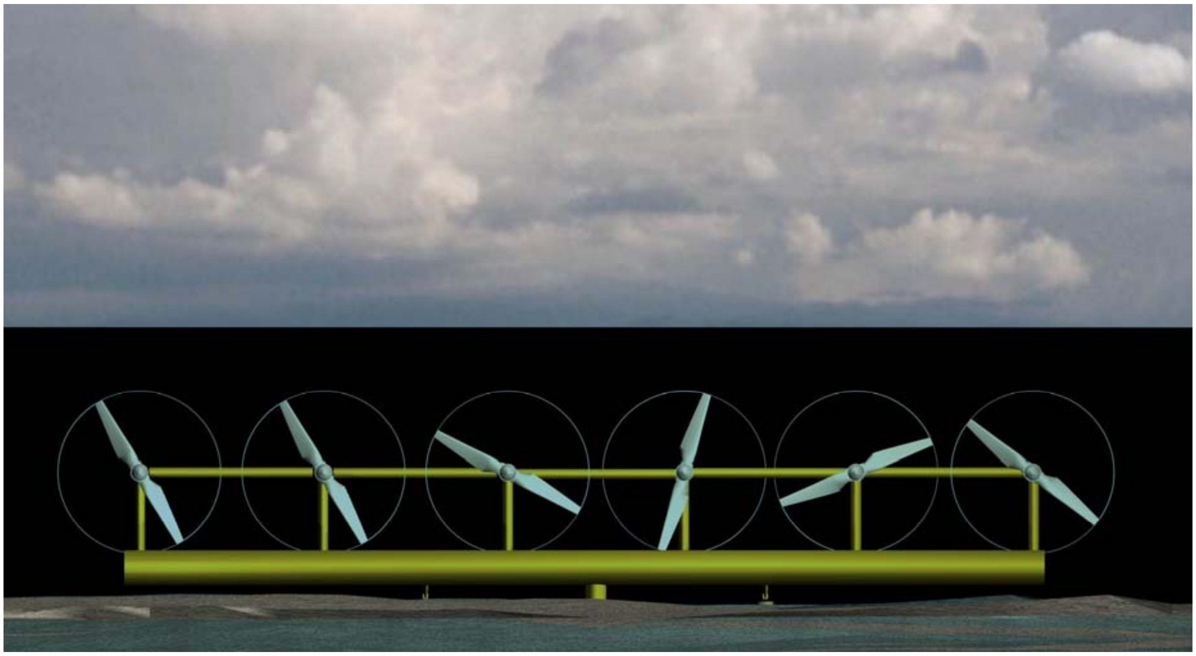


Figure 24 - MCT next generation conceptual illustration

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 25 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.

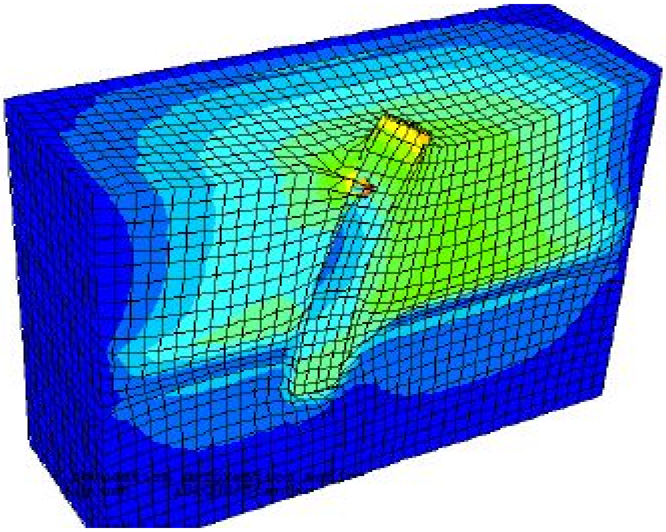


Figure 25 - Simulation of pile-soil interaction subject to lateral load (Source: Danish Geotechnical Institute)

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 San Francisco, the seabed is modeled as bedrock with 10m of sediment overburden.

Figure 26 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.

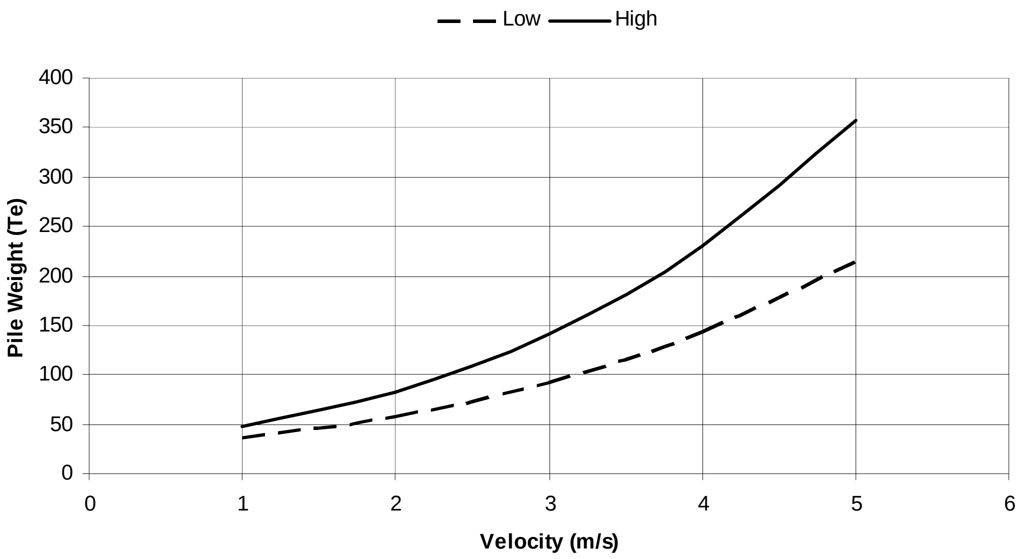


Figure 26 - Pile Weight as a function of design velocity for different sediment types

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.

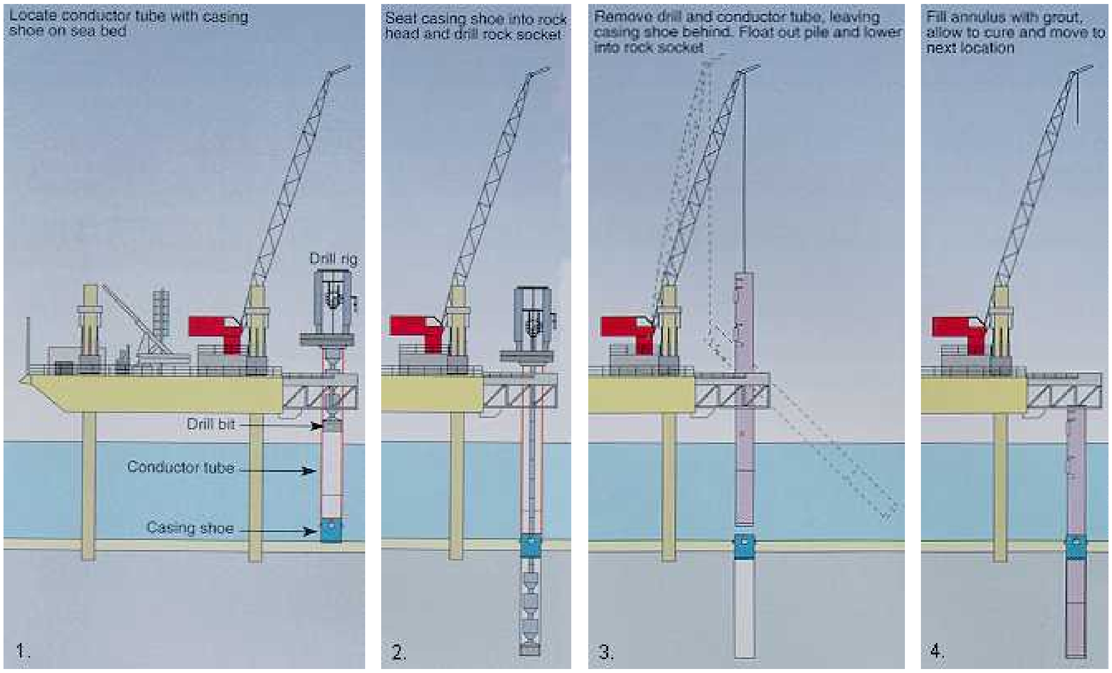


Figure 27 – Pile Installed in Bedrock (Seacore)

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 28 - 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 29: 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 cable 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 30 shows the cross-sections of armored XLPE insulated submersible cables.

Figure 30 – 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 Golden Gate, 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.

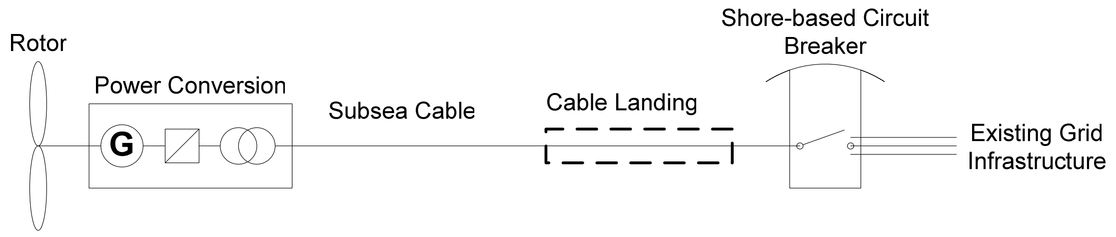


Figure 31 - Conceptual Electrical Design for a single TISEC Unit

Pilot power collection and grid interconnection details are summarized in Table 6 – 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 6 – Pilot Grid Interconnection

Grid Interconnection Demo	
Grid Interconnection Point	12.5 kV distribution line on south side of Golden Gate
Subsea Cable Length	1000m
Subsea Trench Length	500m
Sediment type along cable route	Sedimentation
Cable Landing	Over existing bridge structure
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 under the Golden Gate Bridge on its south end. This will reduce cabling length required to interconnect the system to the nearby 12kV line, which is in close proximity to the toll booth on the south end of the bridge.

The footprint of the pilot plant is quite small and should have little impact on recreation or shipping activities by the Golden Gate Bridge. It is likely that a pilot unit could be deployed in close proximity to the south caisson of the bridge in which case much of the underwater trenching operation could be eliminated or replaced by directional drilling. This could potentially reduce a pilot project by more then $1million.

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 either MCT's next generation multi-rotor machine or Lunar Energy's RTT2000 would be installed at the site. Both of these designs are completely submersed and do not directly interfere with any shipping activities when in operation. Only installation and O&M activities will interfere directly with surface based activities. It is reasonable that such activities can be coordinated so as not to conflict with other uses of the sea space. 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.

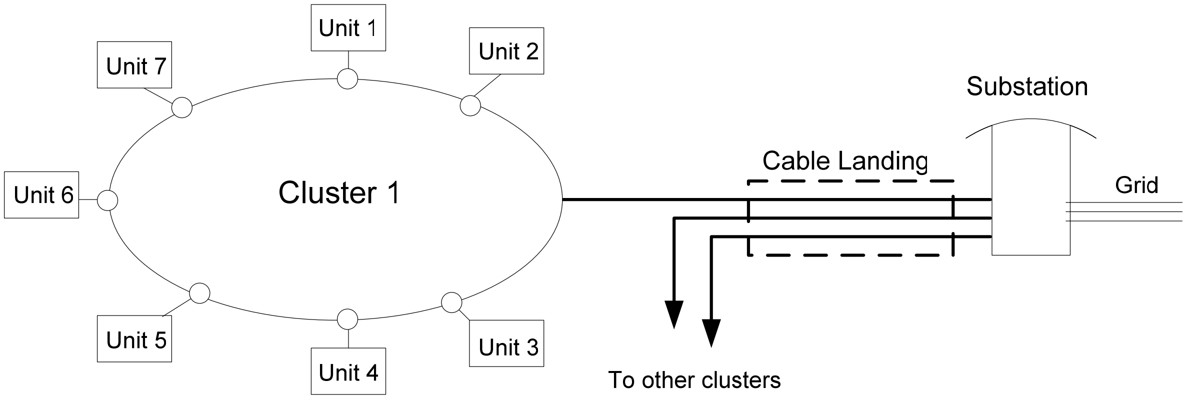


Figure 32 - Electrical Power Collection and Grid Interconnection for commercial plant

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 33 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.

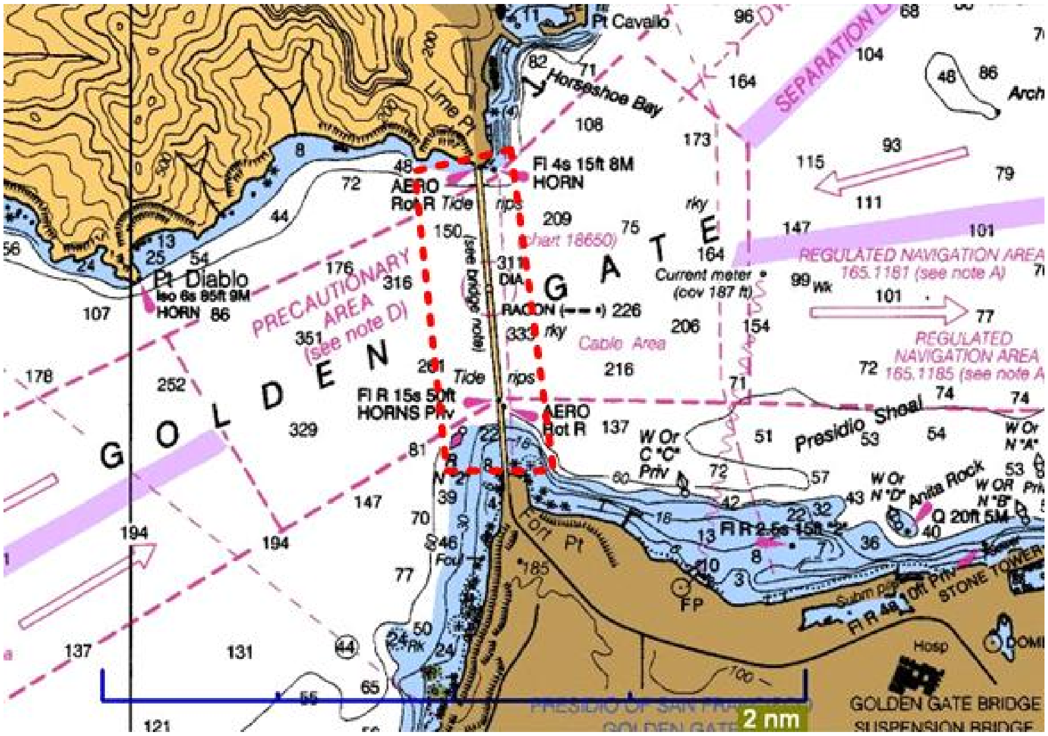


Figure 33 - SF Deployment Site. Water depth shown in feet

Since the deployment site is directly in the San Francisco navigation channel used by large containerships and oil tankers, a navigation clearance of 15m (below LAT) is required. The following illustration shows the cross section of the channel and the turbine height for MCT's machine with a rotor diameter of 18m and a total height from seafloor of 26m and Lunar energy's turbine with a rotor diameter of 21m and a total height from the seafloor of 31m. Adding a 15m navigation clearance to these turbine heights, only water depths of more then 41m (for MCT), respectively 46m (for Lunar's RTT2000) are suitable. The following 2 figures show the turbine size and spacing assumptions for both turbines.

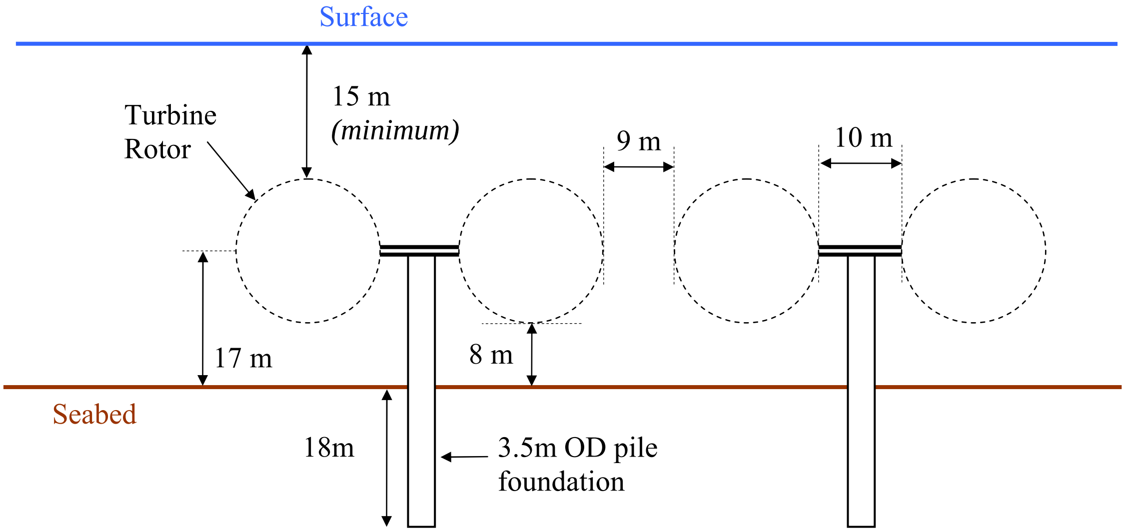


Figure 34 – MCT SeaGen Turbine Spacing Assumptions

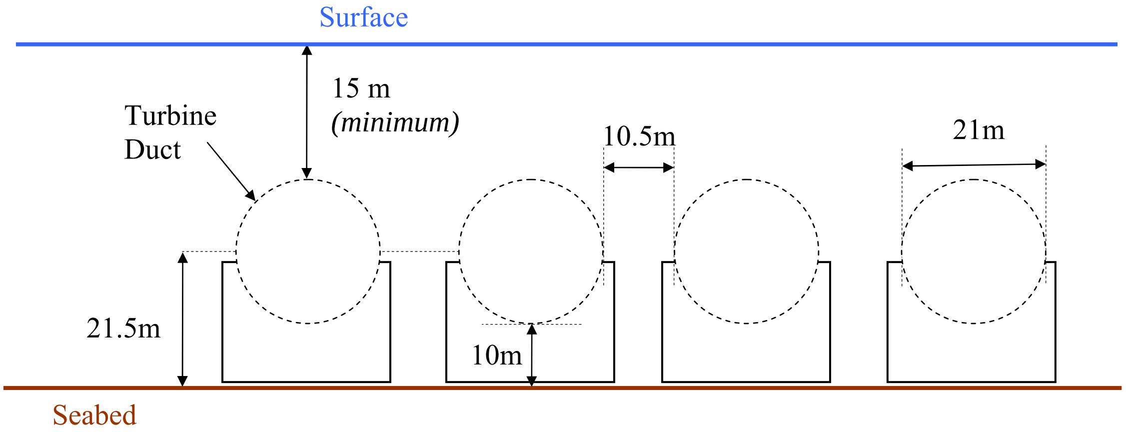


Figure 35 - Lunar RTT 2000 Spacing Assumptions

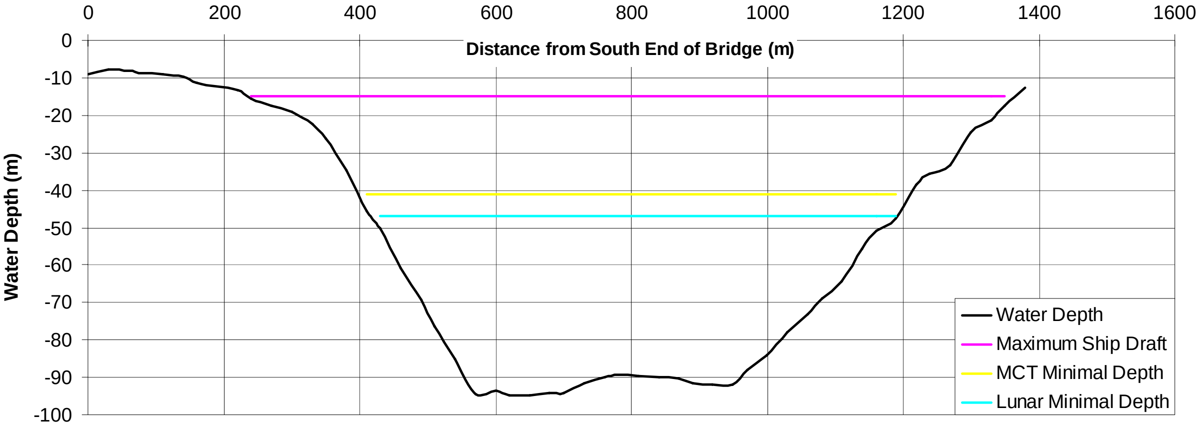


Figure 36 - Channel Cross section at Golden Gate Bridge

Based on this cross section, the useable channel width that accommodates sufficient water depth is 790m. The section length within which high fluid velocities are available is about 400m (See Figure 33). 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 7 - 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	400m	400m
Useful Channel Width	790m	790m
# of Turbines per Row	14	25
# of Rows	3	2
Total # of Turbines deployable	40	50
Average Power Extracted per Turbine	369kW	273kW
15% Extraction Limit	35.5MW	35.5MW
Technology Specific Extraction Limit	15.5MW	13.6MW

The above table shows that the extraction is technology limited. Both technologies looked at show similar extraction limits. The critical assumption taken is that the spacing between two rows of turbines needs to be 10x the device inlet cross-section. This spacing is required so the second row of turbines is placed outside of the wake of the first row. New research by the Carbon Trust however indicates that the spacing requirement could be as low as 3-4 times the turbine diameter. If this holds true, it would increase the extractable potential at the site by about a factor of 2 making it possible to extract almost 15% of the resource.

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 8 - Capital Cost breakdown of MCT Pilot plant

	$/kW	$/Turbine	in %
Power Conversion System	$1,428	$1,589,000	28.1%
Structural Steel Elements	$746	$831,000	14.8%
Subsea Cable Cost	$103	$115,000	2.0%
Turbine Installation	$1,295	$1,442,000	25.7%
Subsea Cable Installation	$1,295	$1,430,000	25.7%
Onshore Electric Grid Interconection	$180	$200,000	3.6%
Total Installed Cost	$5,048	$5,619,000	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 subsea cable installation cost could be potentially reduced by up to $1 million by careful siting of the prototype and use of directional drilling instead of trenching.

It is also 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 40 turbines are installed at the site each one with a rated capacity of 1113 kW and a capacity factor of 33%.

Table 9 – MCT commercial plant capital cost breakdown

	$/kW	$/Turbine	$/Farm	in %	Ref
Power Conversion System	$718	$799,712	$31,988,000	35%	1
Structural Elements	$671	$747,281	$29,891,000	33%	2
Subsea Cable Cost	$67	$74,592	$2,984,000	3%	3
Turbine Installation	$322	$358,862	$14,354,000	16%	4
Subsea Cable Installation	$236	$262,299	$10,492,000	12%	5
Onshore Electric Grid Interconection	$11	$12,500	$500,000	1%	6
Total Installed Cost	**$2,026**	**$2,255,246**	**$90,209,000**	**100%**	
O&M Cost	$50	$55,316	$2,212,644	62%	7
Annual Insurance Cost	$30	$33,829	$1,353,174	38%	8
Total annual O&M cost	**$80**	**$89,145**	**$3,565,792**	**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 money.

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 renewable generation options, a case can be made for pursuing the development of tidal flow energy conversion technology. If, however, even with the most optimistic assumptions, the economics of a commercial size tidal flow power plant is not favorable and cannot economically compete with the alternatives, a case can be made for not pursuing tidal flow energy conversion technology development.

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

The yearly electrical energy produced and delivered to bus bar is estimated to be 129,278 MWh/year for an array consisting of 40 dual-rotor MCT turbines. These turbines have a combined installed capacity of 44.5MW, and on average extract 17.3 MW of kinetic power from the tidal stream, which is roughly 7.3% 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 = $95.5 million
- Annual O&M Cost = $3.57 million
- UG Levelized Cost of Electricity (COE) = 6.6 (Real) – 7.6 (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) = 4.9 (Real) – 5.6 (Nominal) cents/kWh with renewable financial incentives equal to that the government provides for renewable wind energy technology
- Nun Utility Generator (Independent Power Producer) Internal Rate of Return on net cash flows after tax is 21 %

It is encouraging that a commercial plant at the Golden Gate site can potentially have a cost of electricity that is below California avoided cost levels. While being limited in size, this resource should be tapped strategically as it will contribute to a balanced energy supply system.

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

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 **Error! Reference source not found.** 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 10 - COE for Alternative Energy Technologies: 2010

	Capacity Factor (%)	**Capital Cost[1] (\$/kW)**	**COE (cents/kWh)**	**CO2 (lbs per MWh)**
Tidal In Stream	29-33	2,000	5-8	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]
Nuclear Evolutionary (ABWR)	85-90	1,660	4.7-5.0	None

Notes:

1. Costs in 2005\$;
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 11 - 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	CA 8.84-	MACRS	65/300	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	6/58/4.5	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	6/58/4.5	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	6/58/4.5	2
NGCC$^{(3)}$ Advanced (@ \$7/MM Btu)	30/20	35	6.5	ACRS	45/30/00	11.5/13/N/A	55/70/100	6/58/4.5	2
Nuclear First of a kind (Gen IV)	30/20	35	6.5	ACRS	45/30/0	11.5/13/N/A	55/70/100	6/58/4.5	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. Sensitivity plots are given only for the Marine Current Turbine (MCT) array as mature design data was not available for Lunar turbines in the time period of this study (Jan-Mar, 2006).

Array Size

This sensitivity has already been implicitly shown in the unit capital cost differences for pilot turbine versus commercial scale array. Figure 37 shows the sensitivity of cost of energy (COE) to the number of turbines installed.

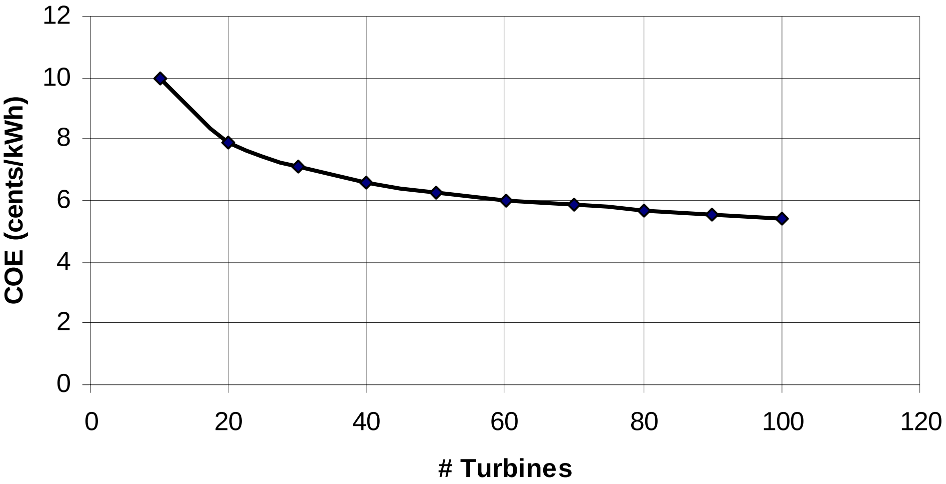


Figure 37 – Sensitivity of COE to number of turbines installed

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 38.

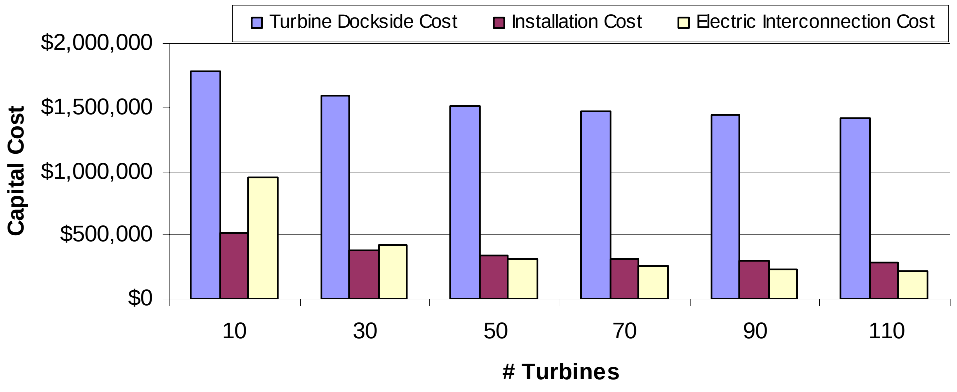


Figure 38 – Sensitivity of capital cost elements to number of installed turbines

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 39.

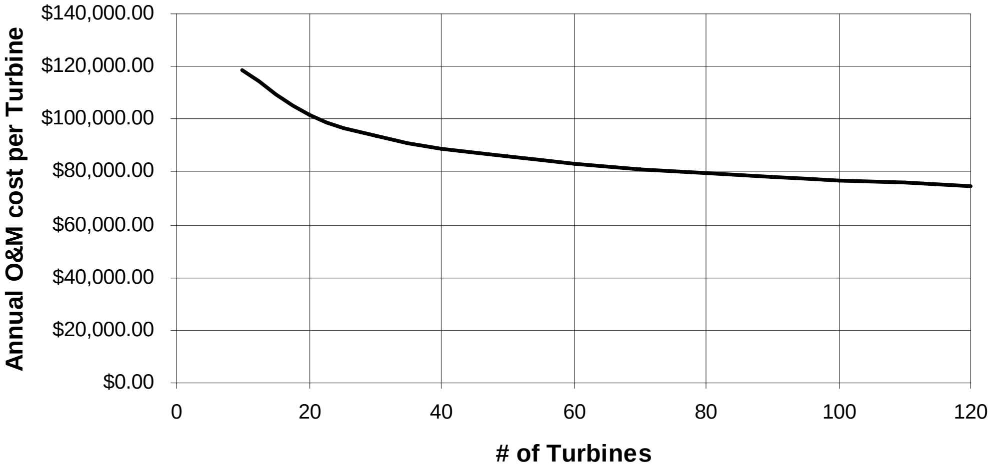


Figure 39 – Sensitivity of annual O&M cost to number of installed turbines

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 40, where all parameters aside from availability are held constant for the commercial array design.

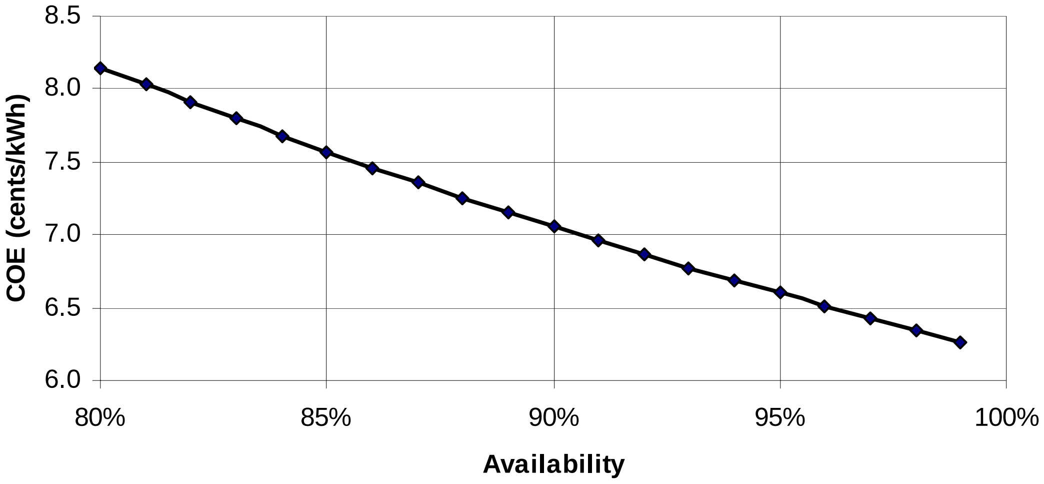


Figure 40 – Sensitivity of COE to array availability

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 41 and Figure 42, 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.

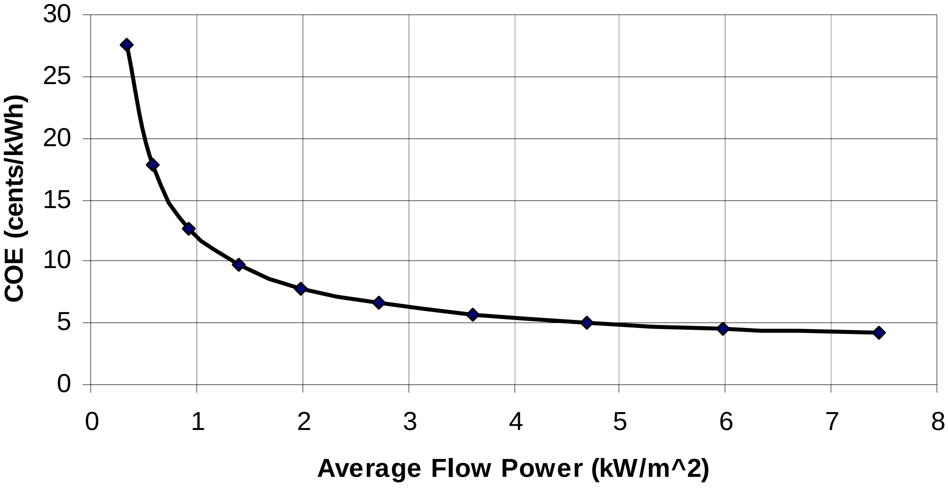


Figure 41 – Sensitivity of COE to average flow power in kW/m^2

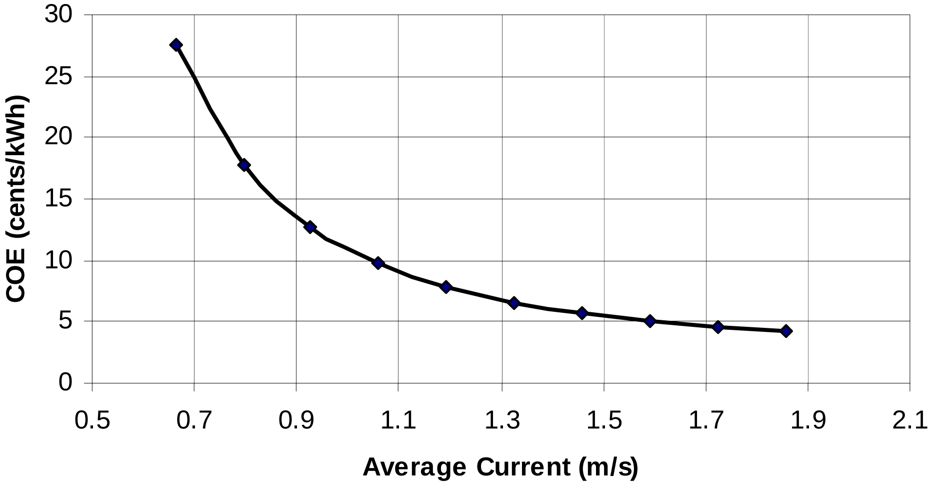


Figure 42 – Sensitivity of COE to average current speed (m/s)

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 43 shows the effect on the real cost of energy by lowering the design speed.

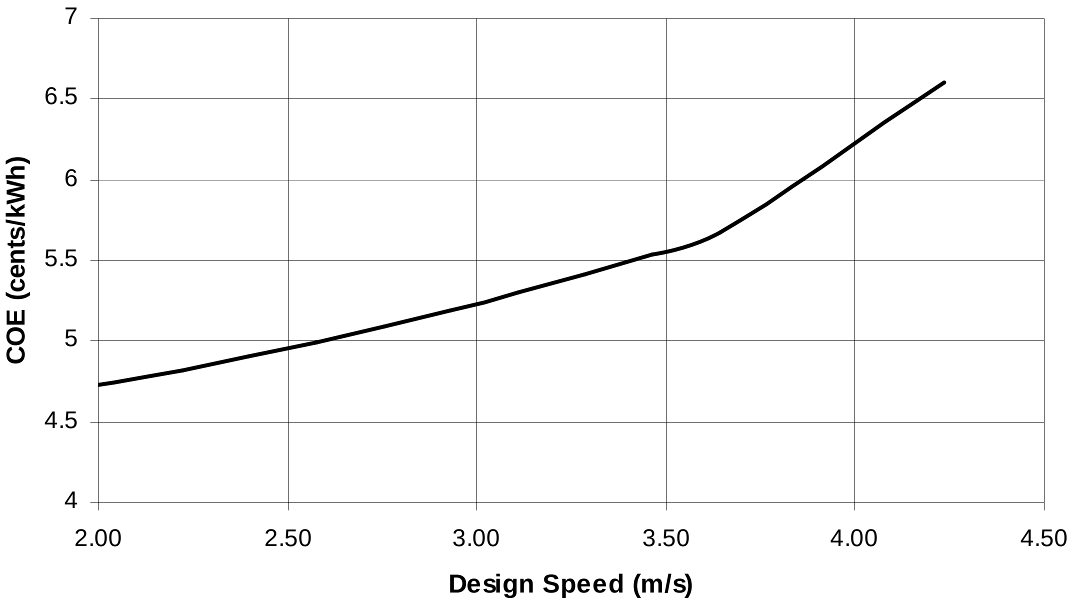


Figure 43 – Sensitivity of COE to design speed

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.

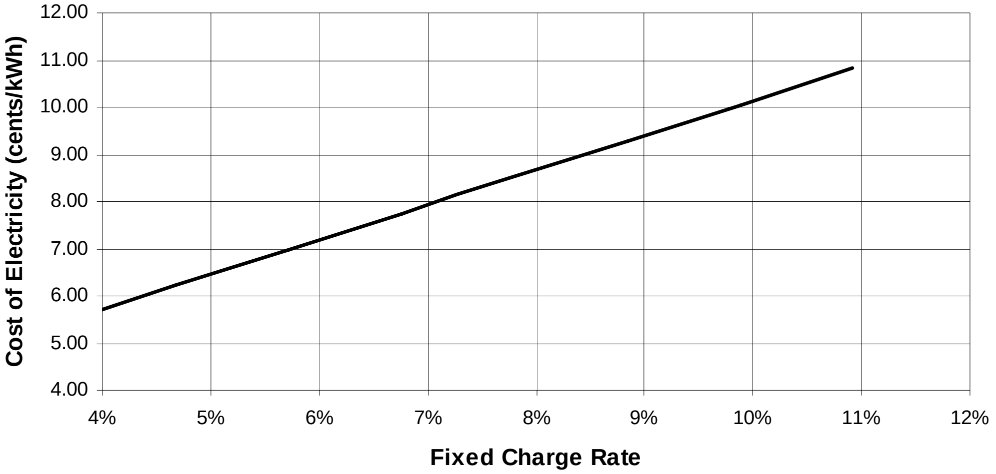


Figure 44 – Sensitivity of COE to Fixed Charge Rate

If a project is deemed ineligible for renewable production credits, or funds for such credits are not fully budgeted, COE increases substantially. Figure 45 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.

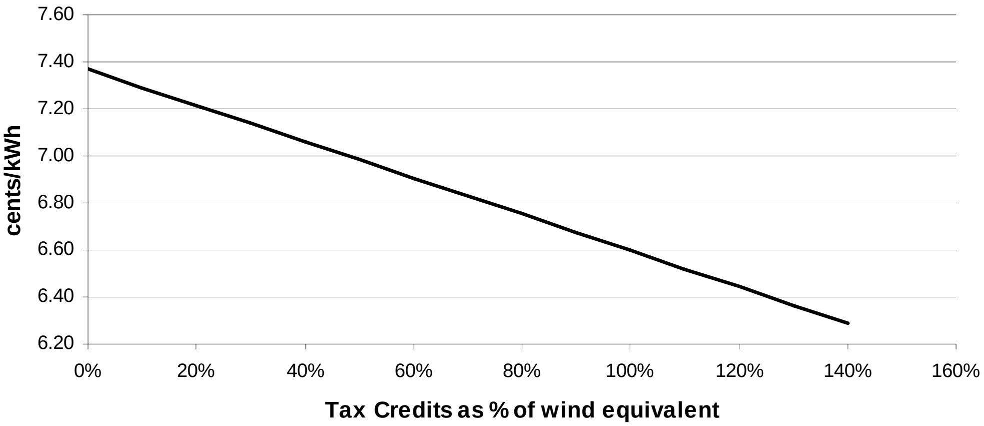


Figure 45 – Sensitivity of COE to production credits

12. Conclusions

Pilot In-Stream Tidal Power Plant

For the single turbine pilot installation, the south side of the Golden Gate bridge offers good potential sites. The predicted resource is strong, interconnection is easily managed, and the site is served by a major port facility in close proximity. All of the sites however are located below the shipping channel and therefore require fully submersible technology. Both manufacturers Lunar Energy and Marine Current Turbines have technology that could be deployed fully submersed. 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. The technology gap to be covered by both Lunar Energy and MCT in order to get to the point where a full-scale, fully-submersed TISEC pilot could be deployed is relatively small and it is reasonable to expect that such a deployment could occur within 2-years given a firm local commitment to move forward with this project.

Commercial In-Stream Tidal Power Plant

San Francisco is a strong candidate site for the installation of a commercial tidal in-stream power plant. Among the sites investigated in this collaborative study, it shows the second largest energy potential and predicted cost of energy from harnessing this resource is low compared to other local generation alternatives. Multiple turbine clusters could be installed under the Golden Gate Bridge. Grid interconnection could be accomplished at the Embarcadero substation in the city of San Francisco and the plant could serve the local load in the city. Given technology evaluated in this study, the resource extraction is technically limited to about 7% of the total kinetic energy at the site. However larger scale turbines and different turbine arrangements could fundamentally change these limitations. For safety reasons, it may be necessary to set up a recreation (e.g. diving) exclusion zone within this area.

Since the commercial array design incorporates features that are largely conceptual, there is significant economic and technical uncertainty in the deployment of a commercial array in San Francisco. If, as MCT expects, the cost and performance of a fully submerged design is in-line with SeaGen, then the results of this study show that an in-stream tidal power plant may provide favorable economics in comparison to other locally available renewable energy production options. With other words, this is a renewable energy resource option worth pursuing.

As a new and emerging technology, in-stream tidal power has essentially no production experience and therefore its costs, uncertainties and risks are relatively high compared to existing commercially available technologies such as wind power with a cumulative production experience of about 40,000 MW installed. Given the technological uncertainty, it would make most sense that the technology companies carry technological and implementation risks and ideally are the owners of the generation assets. Local government can stimulate the implementation by addressing environmental and consenting issues, providing the manufacturers with a framework within which they can operate and if required provide financial incentives such as per kWh subsidies. Technological uncertainties also represent risks in that it is unclear at present which technology is best suited for the site and most manufacturers involved in TISEC are small companies that may or may not be around a few years from now. As such it is important that the resource is being developed as a strategic asset without locking into a single technology path or committing to a single company.

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.

Sensitivities also show that the cost of energy is sensitive to the number of turbines installed, since for larger arrays fixed mobilization costs are spread over a greater number of turbines. Therefore, a phased installation of the array (e.g. 10 turbines/year for 6 years) would substantially increase the cost of energy for the entire project. A regulatory approach that requires a long-term phased installation plan to study the impact of turbine deployment should be discouraged if the project will not be compensated for the increased cost.

General Conclusions

In-stream tidal current energy shows significant promise for San Francisco and represents a way to make sustainable use of a local renewable resource without the visual distractions that delay so many other energy projects. The installation of a TISEC array in San Francisco would provide valuable benefits to the local economy and further reduce its dependence on environmentally problematic fossil energy resources.

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 San Francisco:

- 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 should be evaluated for adding to San Francisco'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 San Francisco 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 competitive compared to other options for expanding and balancing the region's supply portfolio

Recommendations

EPRI makes the following recommendations to the San Francisco Electricity stakeholders:

General

To continue building 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 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 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 San Francisco, 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
- Political and public outreach
- Implementation planning Construction and Operations
- Financing/incentive requirements study

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-004-NA Survey and Characterization of TISEC Devices

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

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

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

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

8 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/

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

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

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

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

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

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

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

16 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 46.

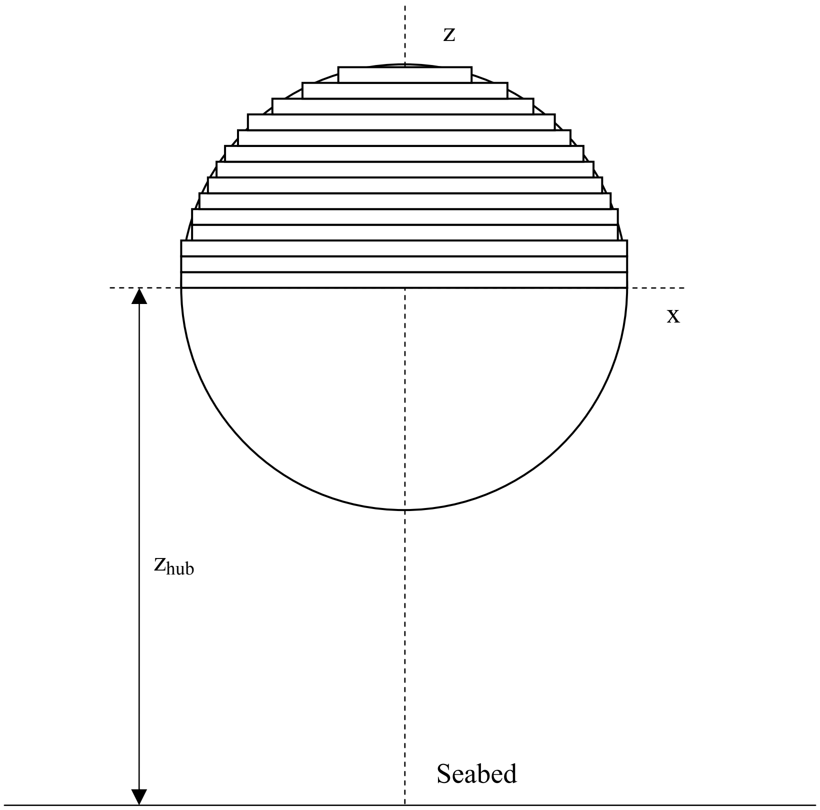


Figure 46 – Representative Numerical Integration

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 $\Delta P/P_{\text{hub height}}$) is tabulated in Table 10.

Table 10 – 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$

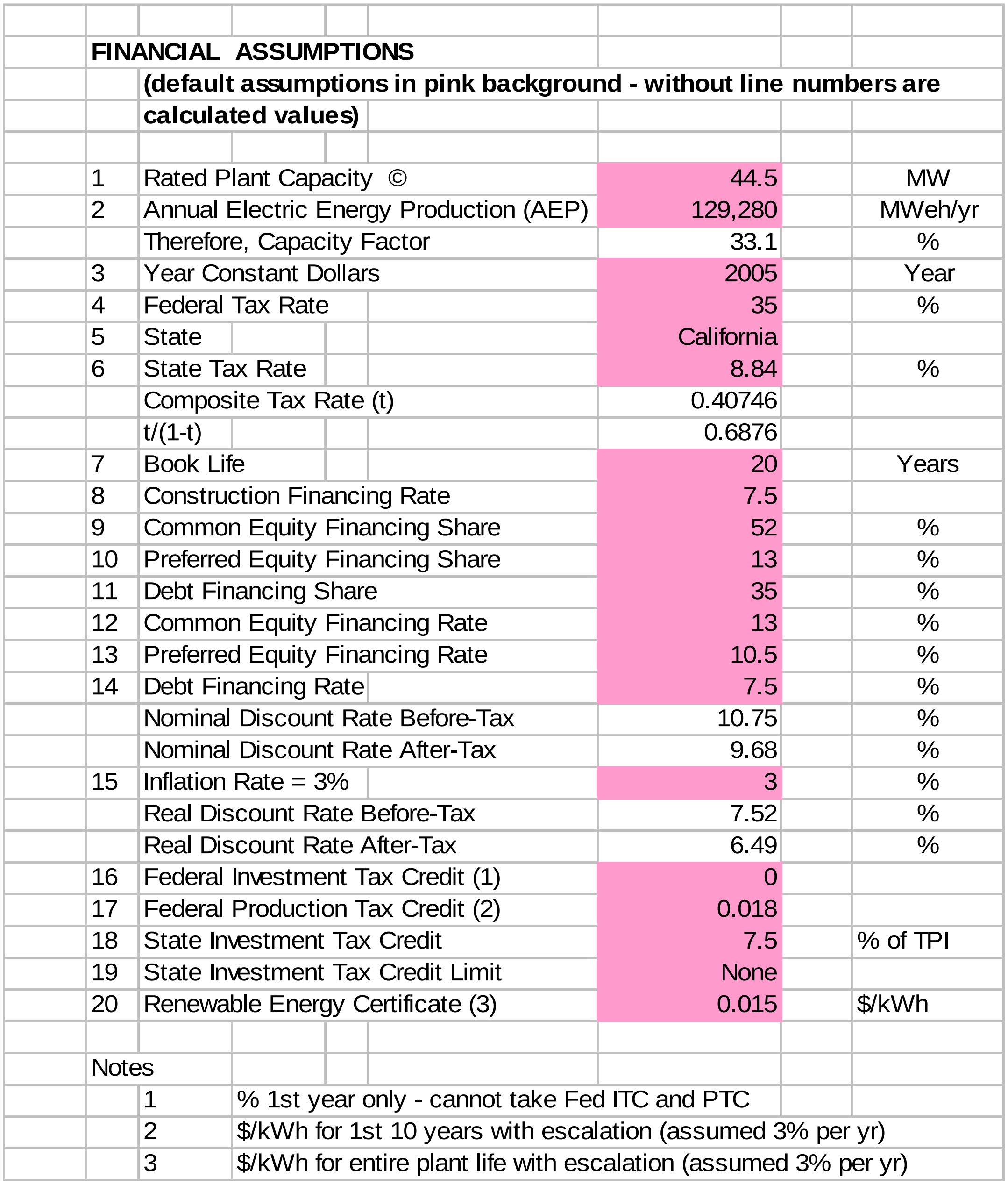
TPC Component	Unit	Unit Cost	Total Cost (2005$)	
Procurement				
Power Conversion System	40	$799,712	$31,988,480	
Structural Elements	40	$747,281	$29,891,240	
Subsea Cables	Lot	$2,984,000	$2,984,000	
Turbine Installation	40	$358,862	$14,354,480	
Subsea Cable Installation	Lot	$10,492,000	$10,492,000	
Onshore Grid Interconnection	Lot	$500,000	$500,000	
TOTAL			$90,210,200	

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	$45,105,100	$3,382,883	$2,758,033	$47,863,133
2008	$45,105,100	$3,382,883	$2,490,323	$47,595,423
Total	$90,210,200	$6,765,765	$5,248,356	$95,458,556

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

Costs	Yrly Cost	Amount	
Labor and Parts	$2,212,644	$2,212,644	
Insurance (1.5% of TPC)	$1,353,153	$1,353,153	
Total		$3,565,797	



FINANCIAL ASSUMPTIONS

(default assumptions in pink background - without line numbers are calculated values)

1	Rated Plant Capacity ©	44.5	MW
2	Annual Electric Energy Production (AEP)	129,280	MWeh/yr
	Therefore, Capacity Factor	33.1	%
3	Year Constant Dollars	2005	Year
4	Federal Tax Rate	35	%
5	State	California	
6	State Tax Rate	8.84	%
	Composite Tax Rate (t)	0.40746	
	t/(1-t)	0.6876	
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	9.68	%
15	Inflation Rate = 3%	3	%
	Real Discount Rate Before-Tax	7.52	%
	Real Discount Rate After-Tax	6.49	%
16	Federal Investment Tax Credit (1)	0	
17	Federal Production Tax Credit (2)	0.018	
18	State Investment Tax Credit	7.5	% of TPI
19	State Investment Tax Credit Limit	None	
20	Renewable Energy Certificate (3)	0.015	$/kWh

Notes

1 % 1st year only - cannot take Fed ITC and PTC

2 $/kWh for 1st 10 years with escalation (assumed 3% per yr)

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

NET PRESENT VALUE (NPV) - 2005 $

TPI = $95,458,556

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	**95,458,556**					**95,458,556**
2009	95,458,556	4,772,928	4,772,928	0.2000	5,834,331	84,851,297
2010	95,458,556	4,772,928	9,545,856	0.3200	10,501,797	69,576,572
2011	95,458,556	4,772,928	14,318,783	0.1920	5,523,167	59,280,477
2012	95,458,556	4,772,928	19,091,711	0.1152	2,535,989	51,971,560
2013	95,458,556	4,772,928	23,864,639	0.1152	2,535,989	44,662,643
2014	95,458,556	4,772,928	28,637,567	0.0576	295,606	39,594,109
2015	95,458,556	4,772,928	33,410,495	0.0000	-1,944,777	36,765,958
2016	95,458,556	4,772,928	38,183,422	0.0000	-1,944,777	33,937,808
2017	95,458,556	4,772,928	42,956,350	0.0000	-1,944,777	31,109,657
2018	95,458,556	4,772,928	47,729,278	0.0000	-1,944,777	28,281,506
2019	95,458,556	4,772,928	52,502,206	0.0000	-1,944,777	25,453,356
2020	95,458,556	4,772,928	57,275,134	0.0000	-1,944,777	22,625,205
2021	95,458,556	4,772,928	62,048,061	0.0000	-1,944,777	19,797,054
2022	95,458,556	4,772,928	66,820,989	0.0000	-1,944,777	16,968,904
2023	95,458,556	4,772,928	71,593,917	0.0000	-1,944,777	14,140,753
2024	95,458,556	4,772,928	76,366,845	0.0000	-1,944,777	11,312,603
2025	95,458,556	4,772,928	81,139,773	0.0000	-1,944,777	8,484,452
2036	95,458,556	4,772,928	85,912,700	0.0000	-1,944,777	5,656,301
2027	95,458,556	4,772,928	90,685,628	0.0000	-1,944,777	2,828,151
2028	95,458,556	4,772,928	95,458,556	0.0000	-1,944,777	0

CAPITAL REVENUE REQUIREMENTS 2005$

TPI : $95,458,556

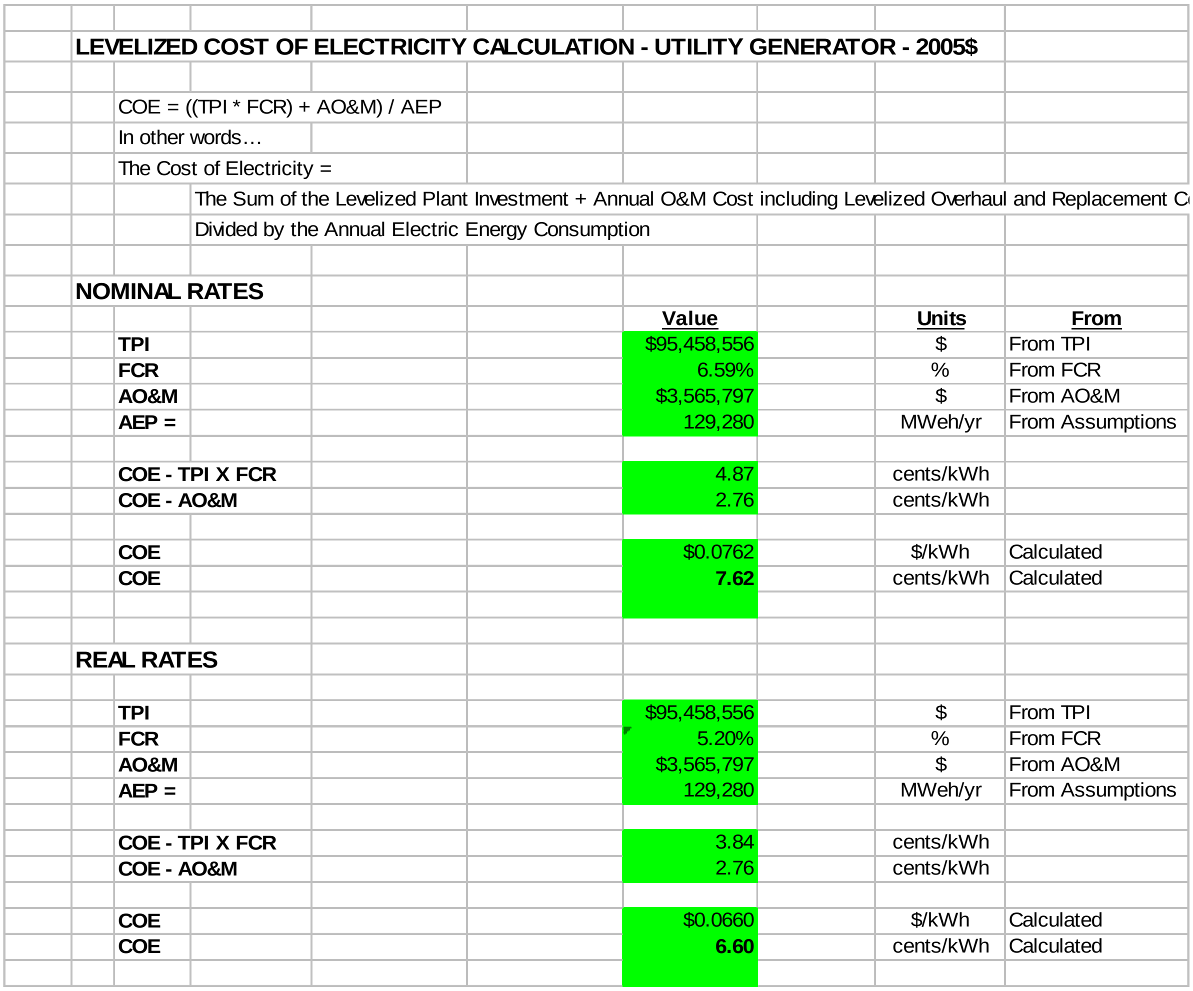
End of Year	Net Book A	Returns to Equity Common B	Returns to Equity Pref C	Interest on Debt D	Book Dep E	Income Tax on Equity Return F	Fed PTC and REC H	Capital Revenue Req'ts I
2009	84,851,297	5,735,948	1,158,220	2,227,347	4,772,928	7,221,115	4,266,240	16,849,318
2010	69,576,572	4,703,376	949,720	1,826,385	4,772,928	9,852,995	4,266,240	17,839,165
2011	59,280,477	4,007,360	809,179	1,556,113	4,772,928	6,040,036	4,266,240	12,919,375
2012	51,971,560	3,513,277	709,412	1,364,253	4,772,928	3,709,475	4,266,240	9,803,106
2013	44,662,643	3,019,195	609,645	1,172,394	4,772,928	3,433,047	4,266,240	8,740,969
2014	39,594,109	2,676,562	540,460	1,039,345	4,772,928	1,700,752	4,266,240	6,463,806
2015	36,765,958	2,485,379	501,855	965,106	4,772,928	53,190	4,266,240	4,512,218
2016	33,937,808	2,294,196	463,251	890,867	4,772,928	-53,773	4,266,240	4,101,229
2017	31,109,657	2,103,013	424,647	816,628	4,772,928	-160,735	4,266,240	3,690,241
2018	28,281,506	1,911,830	386,043	742,390	4,772,928	-267,698	4,266,240	3,279,252
2019	25,453,356	1,720,647	347,438	668,151	4,772,928	-374,661	1,939,200	5,195,303
2020	22,625,205	1,529,464	308,834	593,912	4,772,928	-481,624	1,939,200	4,784,314
2021	19,797,054	1,338,281	270,230	519,673	4,772,928	-588,586	1,939,200	4,373,325
2022	16,968,904	1,147,098	231,626	445,434	4,772,928	-695,549	1,939,200	3,962,336
2023	14,140,753	955,915	193,021	371,195	4,772,928	-802,512	1,939,200	3,551,347
2024	11,312,603	764,732	154,417	296,956	4,772,928	-909,475	1,939,200	3,140,358
2025	8,484,452	573,549	115,813	222,717	4,772,928	-1,016,437	1,939,200	2,729,369
2026	5,656,301	382,366	77,209	148,478	4,772,928	-1,123,400	1,939,200	2,318,380
2027	2,828,151	191,183	38,604	74,239	4,772,928	-1,230,363	1,939,200	1,907,391
2028	0	0	0	0	4,772,928	-1,337,326	1,939,200	1,496,402
Sum of Annual Capital Revenue Requirements								121,657,203

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

TPI = $95,458,556

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	16,849,318	0.6910	11,643,028	14,970,400	0.7777	11,643,028
2010	17,839,165	0.6300	11,239,035	15,388,220	0.7304	11,239,035
2011	12,919,375	0.5744	7,421,077	10,819,773	0.6859	7,421,077
2012	9,803,106	0.5237	5,134,049	7,970,822	0.6441	5,134,049
2013	8,740,969	0.4775	4,173,754	6,900,201	0.6049	4,173,754
2014	6,463,806	0.4353	2,814,016	4,953,969	0.5680	2,814,016
2015	4,512,218	0.3969	1,791,015	3,357,514	0.5334	1,791,015
2016	4,101,229	0.3619	1,484,205	2,962,815	0.5009	1,484,205
2017	3,690,241	0.3300	1,217,603	2,588,260	0.4704	1,217,603
2018	3,279,252	0.3008	986,499	2,233,011	0.4418	986,499
2019	5,195,303	0.2743	1,424,963	3,434,707	0.4149	1,424,963
2020	4,784,314	0.2501	1,196,419	3,070,869	0.3896	1,196,419
2021	4,373,325	0.2280	997,117	2,725,311	0.3659	997,117
2022	3,962,336	0.2079	823,676	2,397,278	0.3436	823,676
2023	3,551,347	0.1895	673,084	2,086,042	0.3227	673,084
2024	3,140,358	0.1728	542,658	1,790,902	0.3030	542,658
2025	2,729,369	0.1575	430,012	1,511,185	0.2846	430,012
2026	2,318,380	0.1436	333,023	1,246,244	0.2672	333,023
2027	1,907,391	0.1310	249,804	995,453	0.2509	249,804
2028	1,496,402	0.1194	178,681	758,215	0.2357	178,681
	121,657,203		54,753,718	92,161,195		54,753,718

	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	54,753,718		54,753,718
2. Escalation Rate	3%		3%
3. After Tax Discount Rate = i	9.68%		6.49%
4. Capital recovery factor value = $i(1+i)^n/(1+i)^n-1$ where book life = n and discount rate = i	0.1149079		0.090654358
5. The levelized annual charges (end of year) = Present Value (Item 1) * Capital Recovery Factor (Item 4)	6,291,635		4,963,663
6. Booked Cost	95,458,556		95,458,556
7. The levelized annual fixed charge rate (levelized annual charges divided by the booked cost)	**0.0659**		**0.0520**



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	$95,458,556	$	From TPI
FCR	6.59%	%	From FCR
AO&M	$3,565,797	$	From AO&M
AEP =	129,280	MWeh/yr	From Assumptions
COE - TPI X FCR	4.87	cents/kWh	
COE - AO&M	2.76	cents/kWh	
COE	$0.0762	$/kWh	Calculated
COE	**7.62**	cents/kWh	Calculated

REAL RATES

TPI	$95,458,556	$	From TPI
FCR	5.20%	%	From FCR
AO&M	$3,565,797	$	From AO&M
AEP =	129,280	MWeh/yr	From Assumptions
COE - TPI X FCR	3.84	cents/kWh	
COE - AO&M	2.76	cents/kWh	
COE	$0.0660	$/kWh	Calculated
COE	**6.60**	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		
▨		Indicates Input Cell (either input or use default values)
☐		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	40	$799,712	$31,988,480	
Structural Elements	40	$747,281	$29,891,240	
Subsea Cables	Lot	$2,984,000	$2,984,000	
Turbine Installation	40	$358,862	$14,354,480	
Subsea Cable Installation	Lot	$10,492,000	$10,492,000	
Onshore Grid Interconnection	Lot	$500,000	$500,000	
TOTAL			$90,210,200	

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	$45,105,100	$4,059,459	$3,312,630	$48,417,730
2007	$45,105,100	$4,059,459	$2,992,439	$48,097,539
Total	$90,210,200	$8,118,918	$6,305,069	$96,515,269

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

Costs	Yrly Cost	Amount	
Labor and Parts	$2,212,644	$2,212,644	
Insurance (1.5% of TPC)	$1,353,153	$1,353,153	
Total		$3,565,797	

	FINANCIAL ASSUMPTIONS			
▨	**(default assumptions in pink background - without line numbers are**			
☐	**calculated values)**			
1	Rated Plant Capacity ©	44.5		MW
2	Annual Electric Energy Production (AEP)	129,280		MWeh/yr
	Therefore, Capacity Factor	33.14		%
3	Year Constant Dollars	2005		Year
4	Federal Tax Rate	35		%
5	State	California		
6	State Tax Rate	8.84		%
	Composite Tax Rate (t)	0.40746		%
	t/(1-t)	0.6876		
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	8.42		%
15	Inflation rate	3		%
16	Federal Investment Tax Credit	0		Assumed take PTC
17	Federal Production Tax Credit inc 3% escalation	0.018		$/kWh for 1st 10 yrs
18	State Investment Tax Credit	7.5		%
19	State Production Tax Credit			
20	Wholesale electricity price - 2005$	$0		$/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	0.0150		$/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**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
REVENUES																				
Energy Payments	11,029,802	11,199,379	11,371,564	11,546,396	11,978,729	12,427,250	12,892,565	13,375,303	13,876,116	14,395,681	14,934,700	15,493,901	16,074,041	16,675,903	17,300,301	17,948,078	18,620,110	19,317,305	20,040,605	20,790,987
REC income	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200	1,939,200
State ITC	17,373																			
Federal ITC	0																			
Fedaral PTC	2,327,040	2,396,851	2,468,757	2,542,819	2,619,104	2,697,677	2,778,607	2,861,966	2,947,825	3,036,259										
TOTAL REVENUES	12,986,375	13,138,579	13,310,764	13,485,596	13,917,929	14,366,450	14,831,765	15,314,503	15,815,316	16,334,881	16,873,900	17,433,101	18,013,241	18,615,103	19,239,501	19,887,278	20,559,310	21,256,505	21,979,805	22,730,187
AVG $/KWH	0.100	0.102	0.103	0.104	0.108	0.111	0.115	0.118	0.122	0.126	0.131	0.135	0.139	0.144	0.149	0.154	0.159	0.164	0.170	0.176
OPERATING COSTS																				
Scheduled and Unscheduled O&M	3,565,797	3,672,771	3,782,954	3,896,443	4,013,336	4,133,736	4,257,748	4,385,481	4,517,045	4,652,556	4,792,133	4,935,897	5,083,974	5,236,493	5,393,588	5,555,396	5,722,057	5,893,719	6,070,531	6,252,647
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	3,565,797	3,672,771	3,782,954	3,896,443	4,013,336	4,133,736	4,257,748	4,385,481	4,517,045	4,652,556	4,792,133	4,935,897	5,083,974	5,236,493	5,393,588	5,555,396	5,722,057	5,893,719	6,070,531	6,252,647
EBITDA	9,420,578	9,465,809	9,527,810	9,589,154	9,904,593	10,232,714	10,574,017	10,929,022	11,298,271	11,682,324	12,081,767	12,497,204	12,929,267	13,378,610	13,845,913	14,331,883	14,837,253	15,362,786	15,909,274	16,477,541
Tax Depreciation	19,303,054	30,884,886	18,530,932	11,118,559	11,118,559	1,447,729	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Interest Paid	5,404,855	5,286,747	5,159,190	5,021,429	4,872,647	4,711,962	4,538,423	4,351,000	4,148,584	3,929,974	3,693,876	3,438,889	3,163,504	2,866,088	2,544,879	2,197,973	1,823,314	1,418,683	981,681	509,719
TAXABLE EARNINGS	-15,287,331	-26,705,825	-14,162,312	-6,550,834	-6,086,613	4,073,023	6,035,594	6,578,022	7,149,687	7,752,350	8,387,891	9,058,315	9,765,763	10,512,522	11,301,034	12,133,910	13,013,939	13,944,103	14,927,593	15,967,822
State Tax	-1,351,400	-2,360,795	-1,251,948	-579,094	-538,057	360,055	533,547	581,497	632,032	685,308	741,490	800,755	863,293	929,307	999,011	1,072,638	1,150,432	1,232,659	1,319,599	1,411,555
Federal Tax	-4,877,576	-8,520,760	-4,518,627	-2,090,109	-1,941,995	1,299,539	1,925,717	2,098,784	2,281,179	2,473,465	2,676,240	2,890,146	3,115,864	3,354,125	3,605,708	3,871,445	4,152,227	4,449,006	4,762,798	5,094,693
TOTAL TAX OBLIGATIONS	-6,228,976	-10,881,555	-5,770,576	-2,669,203	-2,480,051	1,659,594	2,459,263	2,680,281	2,913,211	3,158,773	3,417,730	3,690,901	3,979,158	4,283,432	4,604,719	4,944,083	5,302,659	5,681,664	6,082,397	6,506,249

CASH FLOW STATEMENT

Description/Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
EBITDA			9,420,578	9,465,809	9,527,810	9,589,154	9,904,593
Taxes Paid			-6,228,976	-10,881,555	-5,770,576	-2,669,203	-2,480,051
CASH FLOW FROM OPS			15,649,554	20,347,364	15,298,386	12,258,357	12,384,645
Debt Service			-6,881,205	-6,881,205	-6,881,205	-6,881,205	-6,881,205
NET CASH FLOW AFTER TAX		-28,954,581	8,768,348	13,466,158	8,417,180	5,377,151	5,503,439
CUM NET CASH FLOW		-28,954,581	-20,186,232	-6,720,074	1,697,106	7,074,258	12,577,697

Description/Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
EBITDA	10,232,714	10,574,017	10,929,022	11,298,271	11,682,324	12,081,767	12,497,204	12,929,267
Taxes Paid	1,659,594	2,459,263	2,680,281	2,913,211	3,158,773	3,417,730	3,690,901	3,979,158
CASH FLOW FROM OPS	8,573,120	8,114,754	8,248,742	8,385,059	8,523,552	8,664,037	8,806,303	8,950,110
Debt Service	-6,881,205	-6,881,205	-6,881,205	-6,881,205	-6,881,205	-6,881,205	-6,881,205	-6,881,205
NET CASH FLOW AFTER TAX	1,691,915	1,233,549	1,367,536	1,503,854	1,642,347	1,782,831	1,925,098	2,068,904
CUM NET CASH FLOW	14,269,612	15,503,161	16,870,697	18,374,551	20,016,898	21,799,729	23,724,827	25,793,731

Description/Year	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
EBITDA	13,378,610	13,845,913	14,331,883	14,837,253	15,362,786	15,909,274	16,477,541
Taxes Paid	4,283,432	4,604,719	4,944,083	5,302,659	5,681,664	6,082,397	6,506,249
CASH FLOW FROM OPS	9,095,178	9,241,194	9,387,800	9,534,593	9,681,121	9,826,877	9,971,292
Debt Service	-6,881,205	-6,881,205	-6,881,205	-6,881,205	-6,881,205	-6,881,205	-6,881,205
NET CASH FLOW AFTER TAX	2,213,973	2,359,988	2,506,594	2,653,388	2,799,916	2,945,672	3,090,087
CUM NET CASH FLOW	28,007,704	30,367,692	32,874,287	35,527,675	38,327,591	41,273,262	44,363,349

IRR ON NET CASH FLOW AFTER TAX 20.8%

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	40	$799,712	$31,988,480
Structural Elements	40	$747,281	$29,891,240
Subsea Cables	Lot	$2,984,000	$2,984,000
Turbine Installation	40	$358,862	$14,354,480
Subsea Cable Installation	Lot	$10,492,000	$10,492,000
Onshore Grid Interconnection	Lot	$500,000	$500,000
TOTAL			$90,210,200

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	$45,105,100	$2,255,255	$2,045,583	$47,150,683
2008	$45,105,100	$2,255,255	$1,948,174	$47,053,274
Total	$90,210,200	$4,510,510	$3,993,757	$94,203,957

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

Costs	Yrly Cost	Amount
Labor and Parts	$2,212,644	$2,212,644
Insurance (1.5% of TPC)	$1,353,153	$1,353,153
Total		$3,565,797

FINANCIAL ASSUMPTIONS

(default assumptions in pink background - without line numbers are calculated values)

1	Rated Plant Capacity ©	44.5	MW
2	Annual Electric Energy Production (AEP)	129,280	MWeh/yr
	Therefore, Capacity Factor	33.1	%
3	Year Constant Dollars	2005	Year
4	Federal Tax Rate	0	%
5	State	California	
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	0	% of TPI
19	State Investment Production Tax Credit	$0	Credit - 1st y
			$10M plant
20	Renewable Energy Certificate (2)	0.015	$/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	1.30%	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	1.10%	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 = $94,203,957

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	**94,203,957**					**94,203,957**
2009	94,203,957	4,710,198	4,710,198	0	0	89,493,759
2010	94,203,957	4,710,198	9,420,396	0	0	84,783,561
2011	94,203,957	4,710,198	14,130,594	0	0	80,073,363
2012	94,203,957	4,710,198	18,840,791	0	0	75,363,165
2013	94,203,957	4,710,198	23,550,989	0	0	70,652,968
2014	94,203,957	4,710,198	28,261,187	0	0	65,942,770
2015	94,203,957	4,710,198	32,971,385	0	0	61,232,572
2016	94,203,957	4,710,198	37,681,583	0	0	56,522,374
2017	94,203,957	4,710,198	42,391,781	0	0	51,812,176
2018	94,203,957	4,710,198	47,101,978	0	0	47,101,978
2019	94,203,957	4,710,198	51,812,176	0	0	42,391,781
2020	94,203,957	4,710,198	56,522,374	0	0	37,681,583
2021	94,203,957	4,710,198	61,232,572	0	0	32,971,385
2022	94,203,957	4,710,198	65,942,770	0	0	28,261,187
2023	94,203,957	4,710,198	70,652,968	0	0	23,550,989
2024	94,203,957	4,710,198	75,363,165	0	0	18,840,791
2025	94,203,957	4,710,198	80,073,363	0	0	14,130,594
2036	94,203,957	4,710,198	84,783,561	0	0	9,420,396
2027	94,203,957	4,710,198	89,493,759	0	0	4,710,198
2028	94,203,957	4,710,198	94,203,957	0	0	0

CAPITAL REVENUE REQUIREMENTS - 2005$

TPI : $94,203,957

End of Year	Net Book A	Returns to Equity Common B	Returns to Equity Pref C	Interest on Debt D	Book Dep E	Income Tax on Equity Return F	REPI H	Capital Revenue Req'ts I
2009	89,493,759	0	0	4,474,688	4,710,198	0	3,878,400	5,306,486
2010	84,783,561	0	0	4,239,178	4,710,198	0	3,878,400	5,070,976
2011	80,073,363	0	0	4,003,668	4,710,198	0	3,878,400	4,835,466
2012	75,363,165	0	0	3,768,158	4,710,198	0	3,878,400	4,599,956
2013	70,652,968	0	0	3,532,648	4,710,198	0	3,878,400	4,364,446
2014	65,942,770	0	0	3,297,138	4,710,198	0	3,878,400	4,128,936
2015	61,232,572	0	0	3,061,629	4,710,198	0	3,878,400	3,893,426
2016	56,522,374	0	0	2,826,119	4,710,198	0	3,878,400	3,657,917
2017	51,812,176	0	0	2,590,609	4,710,198	0	3,878,400	3,422,407
2018	47,101,978	0	0	2,355,099	4,710,198	0	3,878,400	3,186,897
2019	42,391,781	0	0	2,119,589	4,710,198	0	1,939,200	4,890,587
2020	37,681,583	0	0	1,884,079	4,710,198	0	1,939,200	4,655,077
2021	32,971,385	0	0	1,648,569	4,710,198	0	1,939,200	4,419,567
2022	28,261,187	0	0	1,413,059	4,710,198	0	1,939,200	4,184,057
2023	23,550,989	0	0	1,177,549	4,710,198	0	1,939,200	3,948,547
2024	18,840,791	0	0	942,040	4,710,198	0	1,939,200	3,713,037
2025	14,130,594	0	0	706,530	4,710,198	0	1,939,200	3,477,528
2026	9,420,396	0	0	471,020	4,710,198	0	1,939,200	3,242,018
2027	4,710,198	0	0	235,510	4,710,198	0	1,939,200	3,006,508
2028	0	0	0	0	4,710,198	0	1,939,200	2,770,998
Sum of Annual Capital Revenue Requirements								80,774,836

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

TPI = $94,203,957

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	5,306,486	0.8227	4,365,659	4,714,744	0.9260	4,365,659
2010	5,070,976	0.7835	3,973,242	4,374,268	0.9083	3,973,242
2011	4,835,466	0.7462	3,608,299	4,049,627	0.8910	3,608,299
2012	4,599,956	0.7107	3,269,103	3,740,185	0.8740	3,269,103
2013	4,364,446	0.6768	2,954,029	3,445,334	0.8574	2,954,029
2014	4,128,936	0.6446	2,661,549	3,164,486	0.8411	2,661,549
2015	3,893,426	0.6139	2,390,226	2,897,075	0.8250	2,390,226
2016	3,657,917	0.5847	2,138,708	2,642,557	0.8093	2,138,708
2017	3,422,407	0.5568	1,905,724	2,400,407	0.7939	1,905,724
2018	3,186,897	0.5303	1,690,079	2,170,122	0.7788	1,690,079
2019	4,890,587	0.5051	2,470,079	3,233,254	0.7640	2,470,079
2020	4,655,077	0.4810	2,239,172	2,987,917	0.7494	2,239,172
2021	4,419,567	0.4581	2,024,655	2,754,128	0.7351	2,024,655
2022	4,184,057	0.4363	1,825,490	2,531,423	0.7211	1,825,490
2023	3,948,547	0.4155	1,640,703	2,319,355	0.7074	1,640,703
2024	3,713,037	0.3957	1,469,375	2,117,493	0.6939	1,469,375
2025	3,477,528	0.3769	1,310,644	1,925,423	0.6807	1,310,644
2026	3,242,018	0.3589	1,163,697	1,742,744	0.6677	1,163,697
2027	3,006,508	0.3418	1,027,774	1,569,074	0.6550	1,027,774
2028	2,770,998	0.3256	902,157	1,404,042	0.6425	902,157
	80,774,836		45,030,365	56,183,658		45,030,365

	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	45,030,365		45,030,365
2. Escalation Rate	3%		3%
3. Discount Rate = i	5.00%		1.94%
4. Capital recovery factor value = $i(1+i)^n/(1+i)^n-1$ 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)	3,613,353		2,738,452
6. Booked Cost	94,203,957		94,203,957
7. The levelized annual fixed charge rate (levelized annual charges divided by the booked cost)	**0.0384**		**0.0291**

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	$94,203,957	$	From TPI
FCR	3.84%	%	From FCR
AO&M	$3,565,797	$	From AO&M
AEP =	129,280	MWeh/yr	From Assumptions
COE - TPI X FCR	2.79	cents/kWh	
COE - AO&M	2.76	cents/kWh	
COE	$0.0555	$/kWh	Calculated
COE	**5.55**	cents/kWh	Calculated

REAL RATES

	Value	Units	From
TPI	$94,203,957	$	From TPI
FCR	2.91%	%	From FCR
AO&M	$3,565,797	$	From AO&M
AEP =	129,280	MWeh/yr	From Assumptions
COE - TPI X FCR	2.12	cents/kWh	
COE - AO&M	2.76	cents/kWh	
COE	$0.0488	$/kWh	Calculated
COE	**4.88**	cents/kWh	Calculated