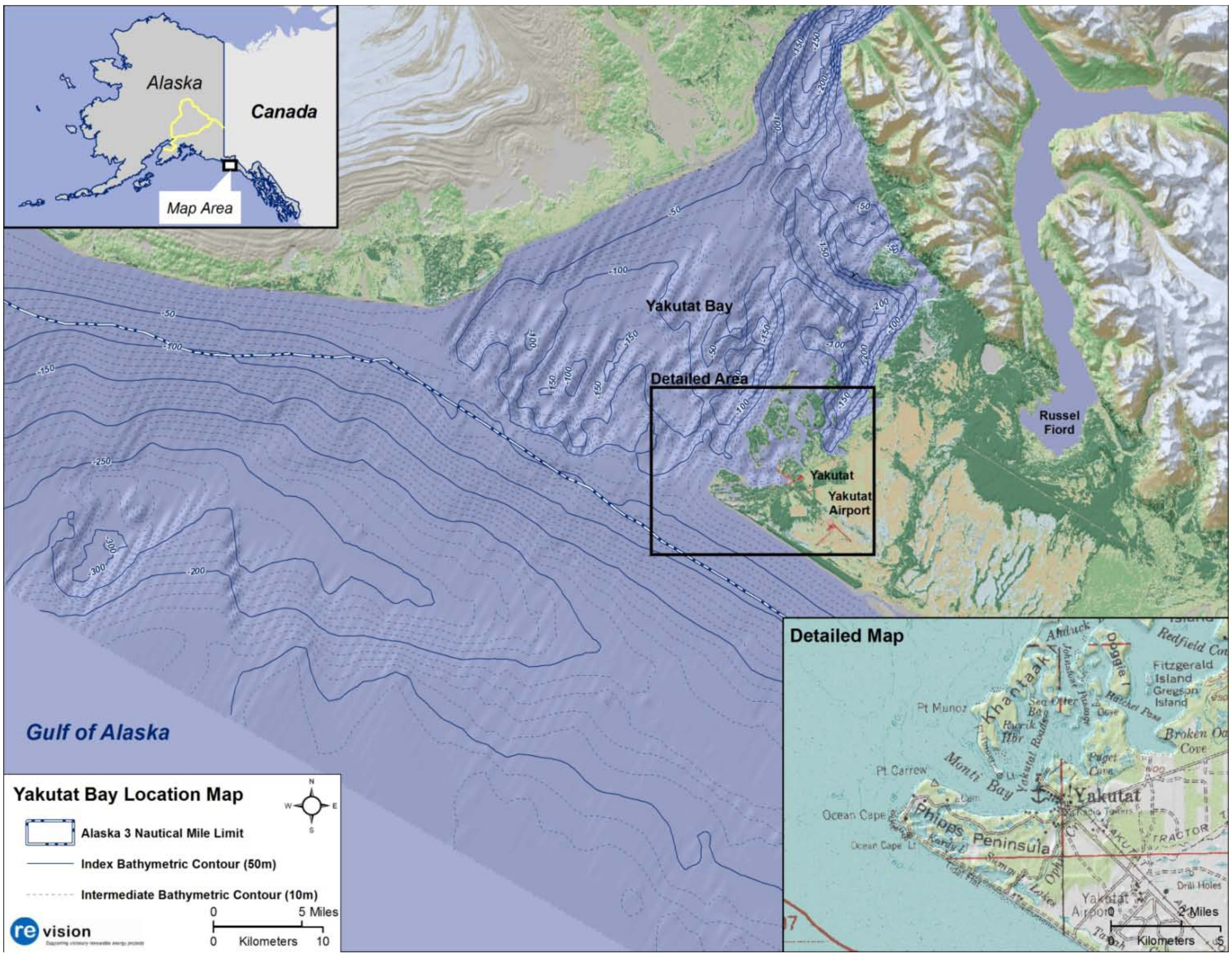
Yakutat Conceptual Design, Performance, Cost and Economic Wave Power Feasibility Study



Project Yakutat Conceptual Wave Power Feasibility Study
Phase Conceptual Design
Report EPRI - WP- 006-Alaska

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Date November 30, 2009

Organization(s) that prepared this document:

Electric Power Research Institute

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1. Introduction and Summary

A Phase I Reconnaissance and Phase II Feasibility Analysis Phase was completed in 2009 by the Electric Power Research Institute (EPRI) under Yakutat Power funding, which assessed the technical, cost and economic viability of a WEC project. This is the final report of this study phase.

An initial high-level scoping study showed that, given Yakutat's 500 kW to 1 MW electricity generation needs, it is unlikely that a deep-water wave power conversion plant would make economic sense. At the small scale proposed, the cost drivers are the subsea cable cost and installation and operation cost, which are dominated by offshore operational considerations. It was therefore decided to apply focus on near-shore technology.

The study scope included: (1) a shallow water wave energy resource assessment, (2) a conceptual design based on the Aquamarine Power Oyster shallow water wave energy conversion technology, (3) a cost assessment (capital and O&M), and (4) an economic analysis. The Aquamarine Oyster was chosen as representative of a shallow water wave energy conversion technology suitable for the deployment site. Oyster is a wave-actuated hydraulic pump that pumps fresh water to shore at a pressure level of about 120 bars, where it is converted into electricity using a conventional hydroelectric system and then returns it to the Oyster in a closed loop. The major project elements include: (1) the Oyster WEC device, (2) a high pressure (120-bar) supply sub sea pipeline and a low pressure (3-bar) return sub sea pipeline, (3) an onshore turbine generator power station, and (4) a distribution line extension to connect the power station to the city electrical grid network. The proposed deployment location and related project elements are shown in the following Figure 1.

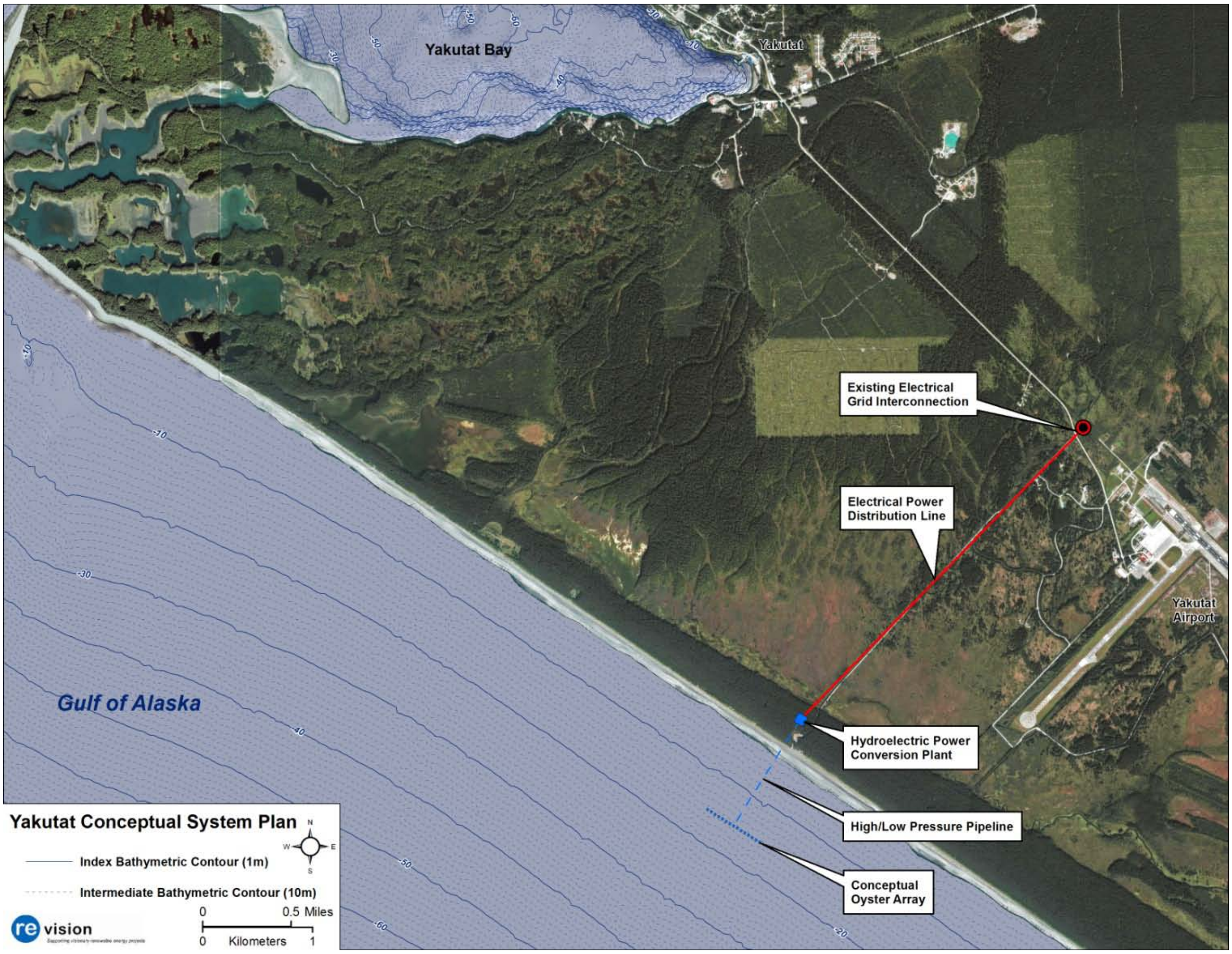

Figure 1 – Oyster II Conceptual Design Layout

Yakutat has an excellent wave climate for wave energy conversion. A shallow water wave transformation model (SWAN) was used to propagate a full year of wave data to the deployment location at 13m water depth. Shallow water power densities at the deployment site of interest were assessed at between 19kW/m and 22kW/m. Based on this wave energy resource data, the resulting capacity factor of the 650kW-rated Oyster machine was assessed at 48%. Cost elements, including: (1) device, (2) sub sea pipeline, (3) on-shore power station, (4) overland distribution line extension, (5) installation, and (6) operation and maintenance were assessed for the plant at four different sizes (1, 2, 4 and 8 units at 650 kW per unit), as summarized in Table 1 below. Cost of electricity was then computed using a Municipal Utility Ownership economic model. Cost of electricity is estimated to be about 45 cents/kWh (in constant Jan 1, 2010 dollars) for a 20-year plant-life. Cost and economic uncertainties at this early stage of project development are still quite substantial; based on EPRI's experience with similar projects at a conceptual stage of development, cost uncertainty is on the order of +/- 30%.

Table 1 - Cost, Performance and Economic Summary

		1 Unit		2 Units		4 Units		8 Units	
Capital Cost		USD	$/kW	USD	$/kW	USD	$/kW	USD	$/kW
	Device Structure	$3,840,000	$4,923	$6,912,000	$4,431	$12,441,600	$3,988	$22,394,880	$3,589
	Water Pipeline	$1,344,000	$1,723	$2,419,200	$1,551	$4,354,560	$1,396	$7,838,208	$1,256
	Power House	$1,359,000	$1,742	$2,478,000	$1,588	$4,716,000	$1,512	$9,192,000	$1,473
	Installation Cost	$2,347,200	$3,009	$3,288,000	$2,108	$4,724,400	$1,514	$6,945,000	$1,113
	Total Cost	$8,890,200	$13,677	$15,097,200	$11,613	$26,236,560	$10,091	$46,370,088	$8,917
Annualized OPEX		$330,000	$508	$510,000	$392	$810,000	$312	$1,400,000	$269
Performance									
	Rated Power	650	kW	1300	kW	2600	kW	5200	kW
	Capacity Factor	48.00%		48.00%		48.00%		48.00%	
	Availability	95%		95%		95%		95%	
	Annual Energy Output	2596	MWh	5193	MWh	10386	MWh	20772	MWh
Cost of electricity (constant $)		45.1	cents/kWh	38.0	cents/kWh	32.3	cents/kWh	28.4	cents/kWh

The cost at this relatively small scale (compared with sizes of utility power plants in the lower 48) is clearly dominated by infrastructure and operational considerations related to the installation of the device in this somewhat remote location. However, present busbar cost of electricity from the existing diesel-based generation facility comes in at about 27 cents/kWh and will only increase in the future. This is comparable to Oyster at an 8 unit scale plant and removes the issue of price volatility of diesel fuel generation. Diesel fuel cost has dramatically increased since the year 2000 and is only temporarily lower at present because the global recession has reduced the demand on fossil fuels, temporarily creating a more attractive pricing structure. In the long term, energy costs are expected to increase, which creates an additional economic burden to small communities like Yakutat that are heavily reliant on diesel fuel.

A key result of the feasibility study is that the level of cost-reduction potential that could come from optimization is substantial. These cost reductions can only be quantified through detailed design and engineering analysis because most cost elements are driven by site-specific considerations. A key part of the proposed next phase, the final design and permitting phase, is to investigate some of the identified alternate design options and detail the “optimal” solution for the site of interest. Many cost reductions could come from improved installation and operational procedures, economies of scale and the potential to locate the plant closer to shore.

2. Site Description

Yakutat is located along the rugged Alaskan Gulf Coast between Sitka and Cordova. Bounded by the Gulf of Alaska on the South, nearly impenetrable mountains to the North and coastal glaciers to the East and West, Yakutat is undeniably remote. There are no roads leading into or out of Yakutat. All commerce and access must occur via air or sea. The City and Borough of Yakutat has a population of 631 and is located at the mouth of Yakutat Bay along the Gulf of Alaska, 225 miles northwest of Juneau and 220 miles southeast of Cordova. Yakutat receives monthly barge service during the winter and more frequent service during summer. Yakutat is equipped with two jet-certified runways and receives jet service daily. The U.S. Forest Service and the National Park Service have offices in Yakutat.

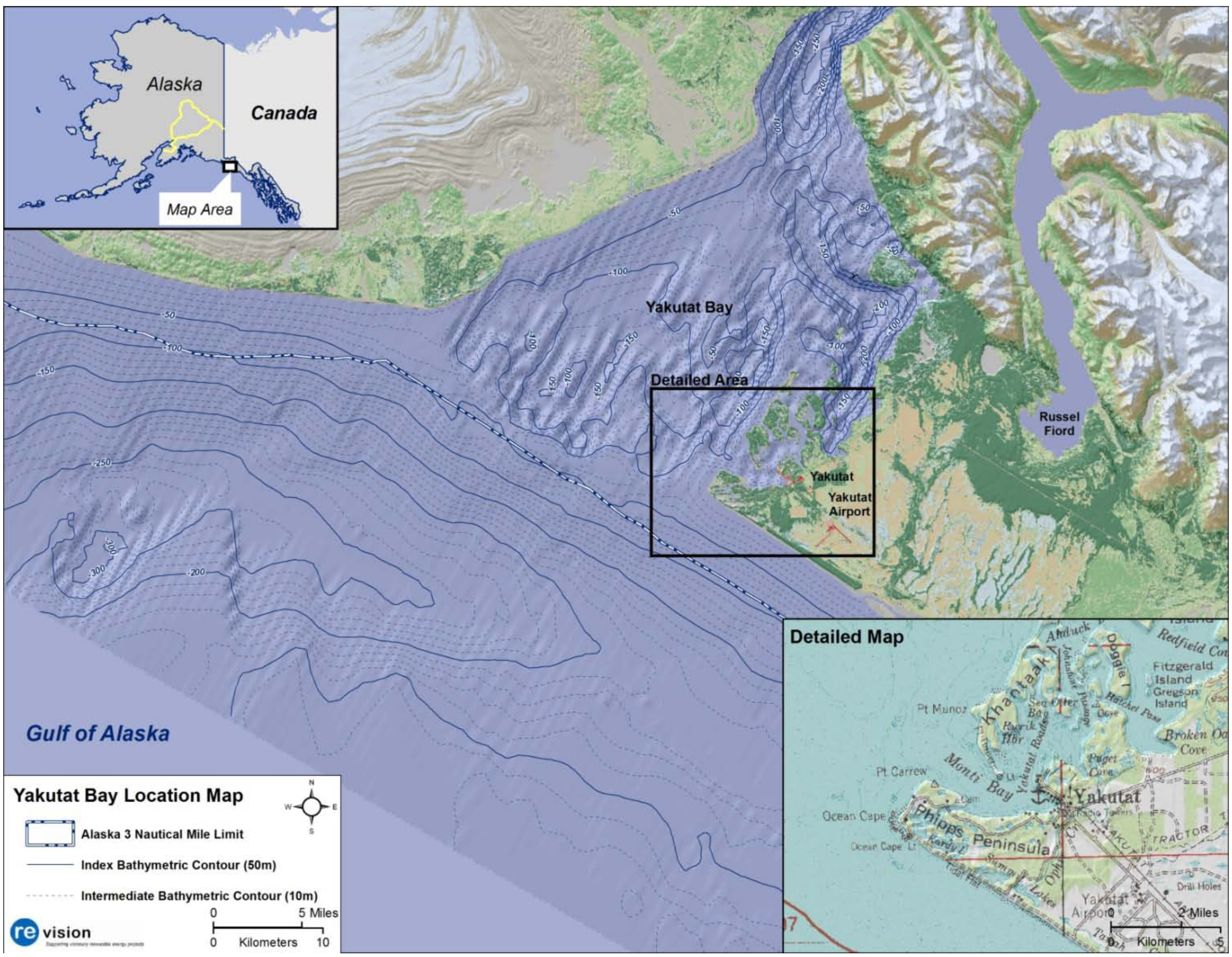

Figure 2 - Yakutat Overview Map

2.1. Bathymetry/Sediments

Little is know as to the exact nature of the sediments in the area. However, initial research indicates no rocky outcrops and a thick, soft sediment layer including sand and mud. The seabed is gently sloping, with the continental shelf extending about 60 miles off the coast. Figure 3 shows the bathymetry near Yakutat. Water depth contour lines are shown in 10m increments with the thicker lines, representing 50m increments.

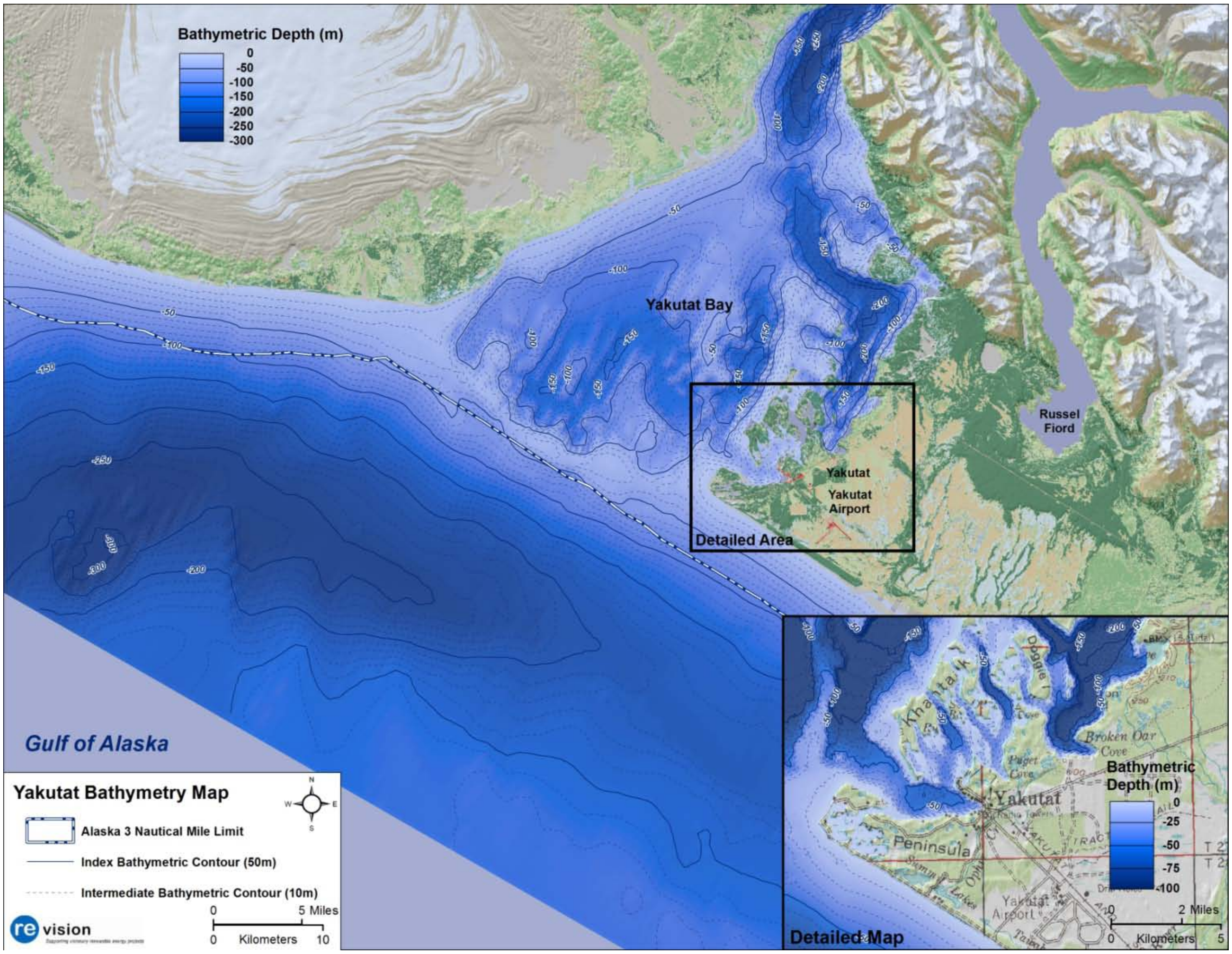

Figure 3 - Bathymetry near Yakutat. Water depth in meters. Thick contour lines in 50m increments.

2.2. Deep Water Wave Energy Resource

Yakutat has an excellent wave energy climate. Archival measurements are available from a number of sources, including National Oceanographic and Atmospheric Administration (NOAA), National Data Buoy Center (NDBC) and other wave measurement buoys. Preliminary analysis based on NDBC data from a prior assessment indicates the average annual deep water wave power density is about 34kW/m near Yakutat. The wave power densities are higher in the winter than in the summer due to seasonal storms, indicating a good match between higher winter electric loads and WEC device power output.

The Fairweather Grounds NOAA measurement buoy NDBC 46083 was chosen as representative of the deep water wave climate near Yakutat, Alaska. This measurement station is located 92Nm southeast of Yakutat in 136m water depth. The following illustration shows an overview map of the measurement buoy location.

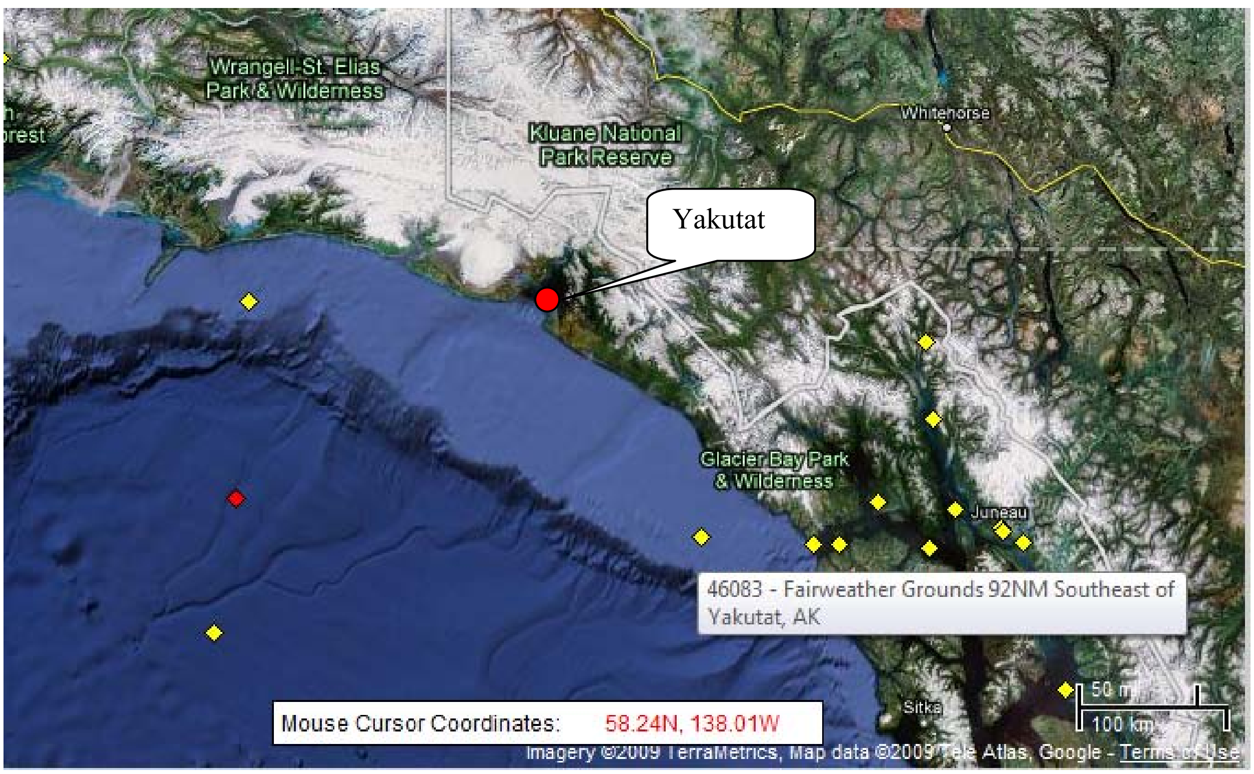

Figure 4 - Location of Deep Water Measurement Buoy used for Analysis.

Monthly average power densities were computed from data of the time period 2001 through 2006. The following illustration shows the seasonal variations at the site of interest.

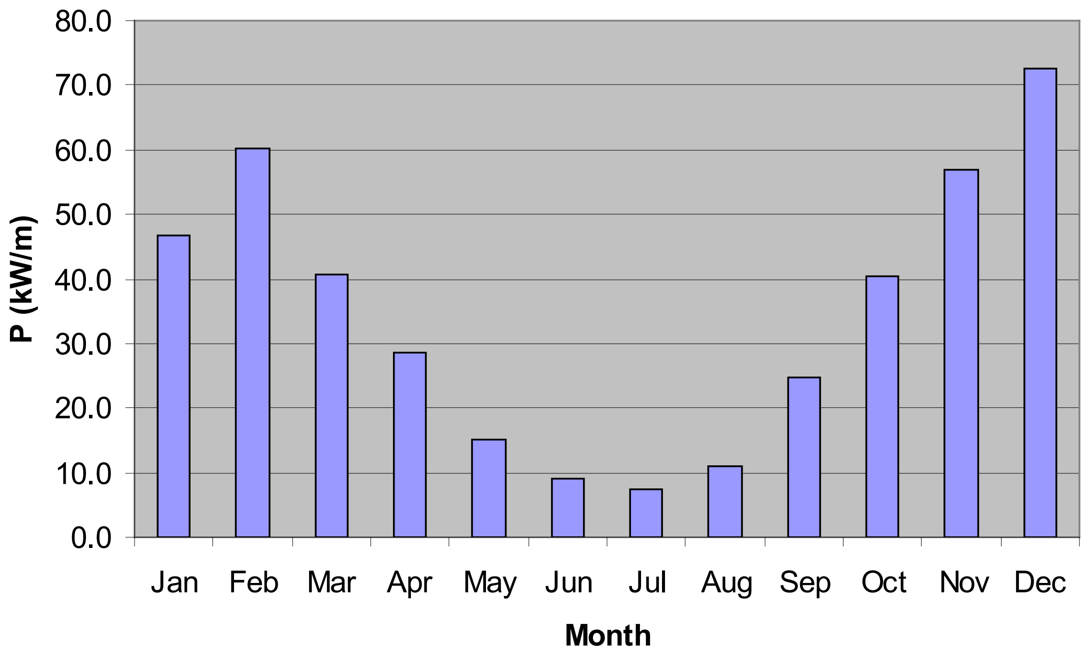

Figure 5 - Monthly Average Power Densities at NDBC 46083

2.3. Shallow Water Wave Energy Resource Assessment

SWAN is a third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. However, SWAN can be used on any scale relevant for wind-generated surface gravity waves. The model is based on the wave action balance equation with sources and sinks. Directional wave data from NOAA Wavewatch III was used to define the deep water offshore wave boundary condition. This boundary was about 50 miles from shore in sufficiently deep water. Bathymetry data obtained from NOAA was used to define the bathymetry. A total of 2920 SWAN runs were completed for the site, by propagating the deep water wave energy resource over the spatial domain in three-hour intervals. This corresponds to a full year of Wavewatch III data. The year 2008 was chosen as reference year.

Figure 6 shows the annual average significant wave height over the computational domain. The significant wave height is a good indicator of power density and hence device performance. A single output point at the potential deployment site in 13m water depth was chosen, and a statistical analysis was carried out to quantify the resource in detail at the site of interest. The modeling indicated an annual average power density of 22kW/m wave front. Aquamarine Power (the developer of the Oyster) carried out an independent analysis processing eight years of data and came to a similar conclusion with about 19kW/m. For a shallow water resource assessment, these results demonstrated excellent agreement, providing confidence in the resource data available. However, it is important to note that both analyses used the same bathymetry data, which may or may not be accurate in such near shore locations. Data coverage is oftentimes sparse in near-shore locations, as it is difficult to operate in that environment with research vessels, and it may be that NOAA simply interpolated depth figures in the near-shore environment.

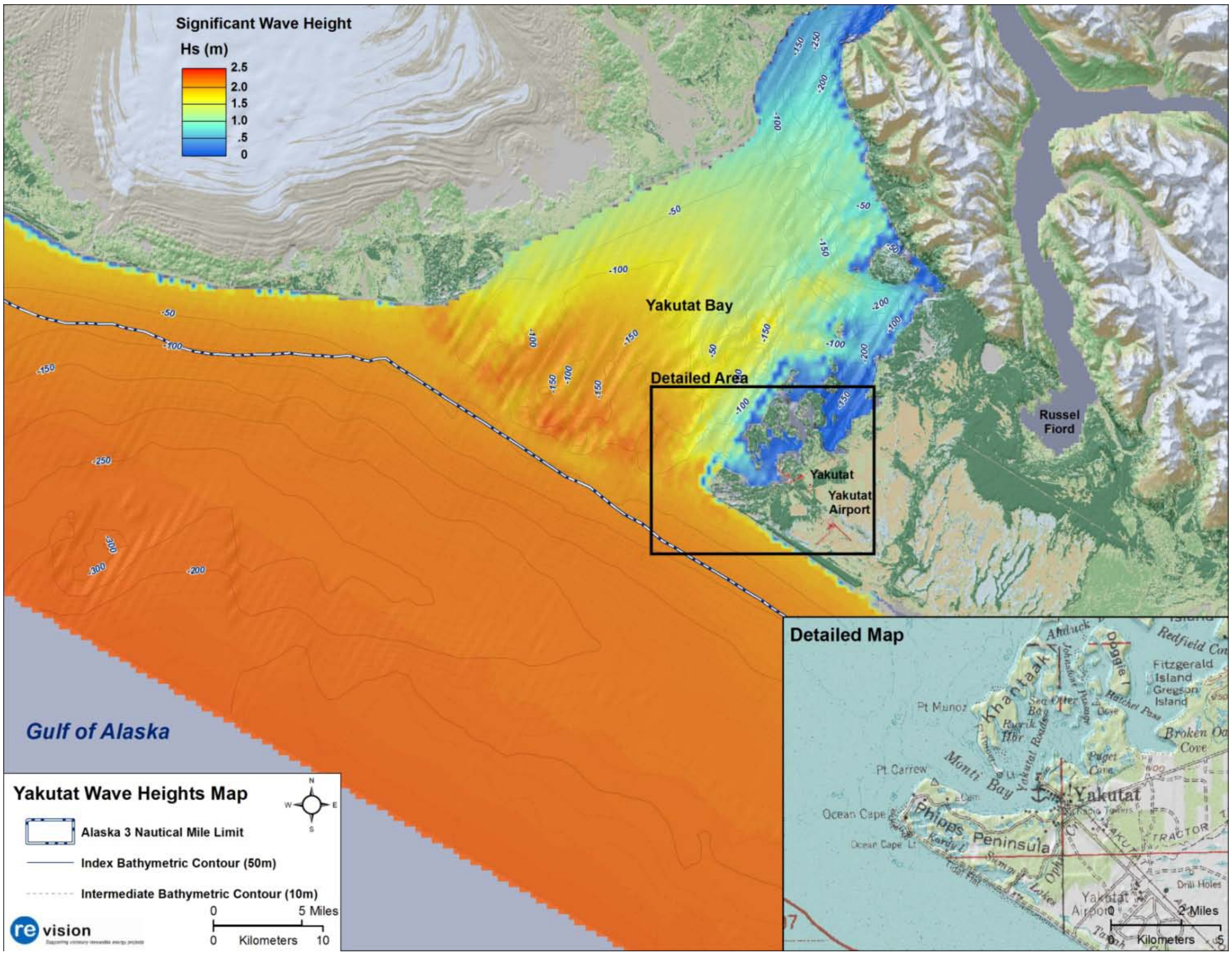

Figure 6 - Average Significant Wave Height (Hs) over the computational domain for the year 2008.

Table 2 shows a frequency distribution of sea-states defined as a function of significant wave height (Hs) and zero crossing period (Tz) at the deployment site.

Table 2 - Frequency Distribution of significant wave height (Hs) versus zero cross period (Tz) at the 13m deep deployment site computed from SWAN model outputs.

	Tz (s)											
Hs (m)	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5
0.25	0	0	3	0	2	1	2	0	0	0	0	0
0.75	14	87	147	98	69	47	23	4	0	2	0	0
1.25	2	120	270	159	92	57	34	15	1	2	3	0
1.75	0	37	224	133	33	37	29	10	10	7	0	0
2.25	0	0	81	177	68	23	22	18	2	7	0	0
2.75	0	0	11	103	110	32	15	7	6	1	1	0
3.25	0	0	0	35	87	62	14	9	5	2	2	0
3.75	0	0	0	1	32	81	19	12	1	1	1	2
4.25	0	0	0	0	0	31	36	6	2	0	0	1
4.75	0	0	0	0	0	0	6	13	5	0	0	0
5.25	0	0	0	0	0	0	0	5	5	2	0	0
5.75	0	0	0	0	0	0	0	0	1	0	0	0

Using the Aquamarine Power Oyster performance table, which specifies the electrical machine output as a function of sea state, the annual energy output for the Oyster was calculated at the deployment site. The results of this performance assessment are shown below.

- Rated Capacity 650kW
- Capacity Factor 48%
- Availability 95%
- Annual Output 2,596 MWh/year

2.4. Existing Generation System

The existing resource is diesel fuel. Fuel is delivered to Yakutat via barge year-round and stored in bulk at the Delta Western tank farm. Fuel is delivered by truck to Yakutat Power, local businesses and residents. Yakutat Power made a major investment in 2007 to replace an antiquated CAT 3412 with the new 3516B, in order to increase the plant's rated kW capacity. A heat recovery system was installed in the early 1990s and provides heat to the Yakutat school complex nearby. Virtually all heating of the school complex is provided by the Yakutat power plant heat recovery system.

The existing Yakutat Power plant generation equipment consists of four diesel generator sets (gensets) with a total generation capacity of 4,000 kW. The generation system is a 4160-volt three-phase system. All generators operate at 1200 RPM.

- Genset #1 a new CAT 3516B rated at 1322 kW
- Genset #2 is a CAT 3512B rated at 880 kW
- Genset #3 is a CAT 3508B rated at 600 kW
- Genset #4 is a CAT 3516 rated at 1200 kW

The new 3516B is the primary genset. The 3512B and 3508B gensets operate on an as-needed basis when the electric load exceeds the 3516B capacity and when the 3516B is down for maintenance. The 3516 is nearing the end of its useful life and is thus used sparingly. The power plant has two separate cooling systems, both with heat recovery capability. The 3516B and 3512B are on one common cooling loop, and the 3508B and the 3516 are on a separate cooling loop. Both cooling loops are 5-inch diameter welded steel piping with flanged butterfly valves, an AMONT valve, plate heat exchanger and a single radiator.

2.5. Existing Demand/Market for Electricity and Cost

Figure 7 shows the daily electrical generation in Yakutat for 2007. The average electrical load during that year was 794kW.

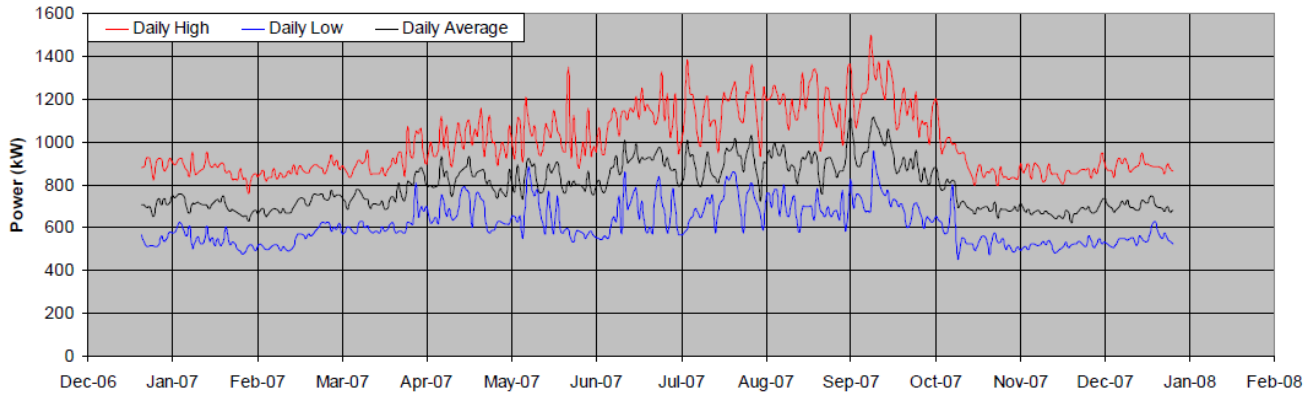

Figure 7 - Daily Average, Low and Peak Load for Yakutat

The amount of electricity that could be displaced is largely dependent on how well the generation matches demand. From the chart above, reporting daily average, low and peak generation, it becomes apparent that short-term storage could greatly increase the renewable capacity that could be added to the electrical system in the village. As daily load profiles for Yakutat were not available, Figure 8 and Figure 9 show examples of daily load fluctuations for other remote villages in Alaska for a winter and a summer month. These are presented as representative of the load profiles expected in Yakutat.

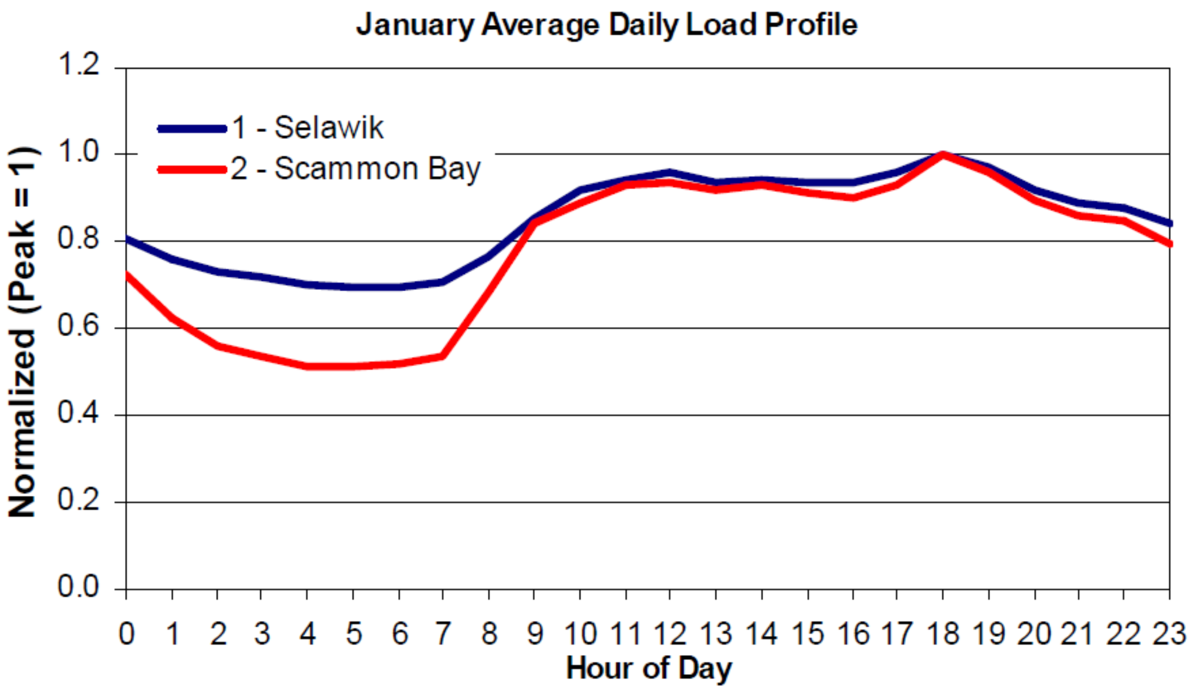

Figure 8 - January Average Load Profile for Selawik and Scammon Bay

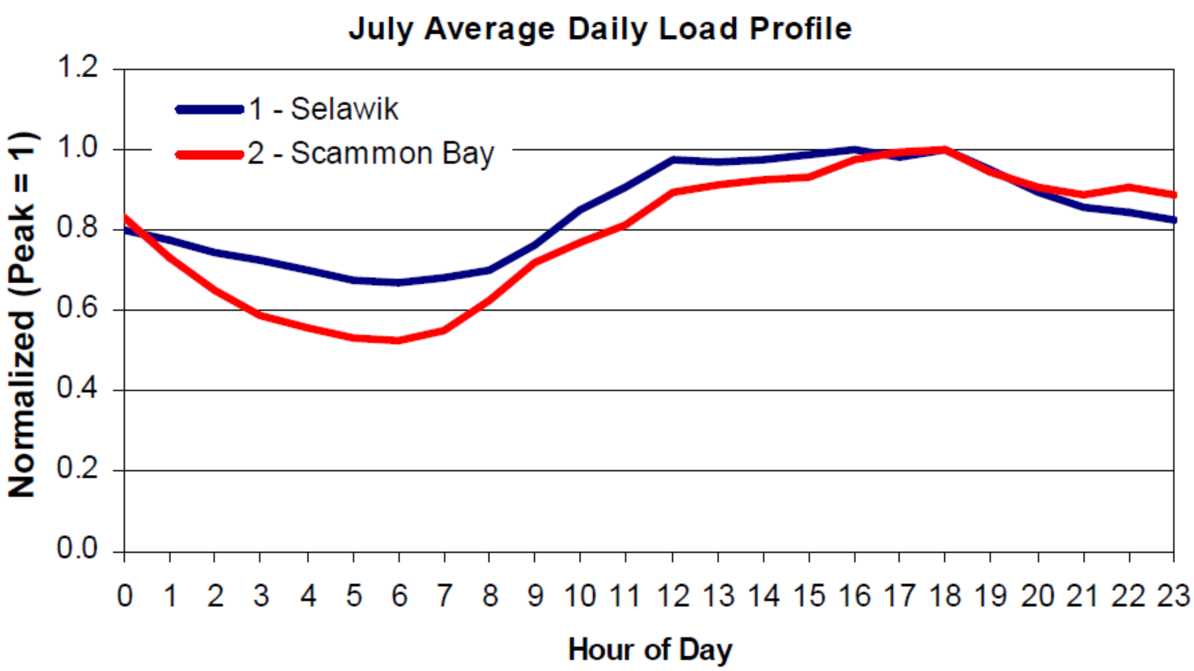

Figure 9 - July Average Daily Load Profile for Selawik and Scammon Bay

The load profile shows that the lowest load during the daily load cycle is almost half of the peak load. If there was no storage in the electrical system, the renewable generation system would have to be sized at a capacity that would not exceed the minimum load. This would insure that none of the electrical energy from a renewable power plant would get wasted. For Yakutat, this lower limit is at about 450kW.

Instead of using fuel for heating, electricity could be used. Because heat can be stored relatively easily using thermal mass, the time of the day during which energy is dissipated in heating elements does not need to directly coincide with the heating needs. To accomplish this, electrical boilers could be placed at the existing power plant and tied into the power plant's heat recovery system. Further, electric boilers could be placed in large commercial/community buildings to absorb peak electric generation when demand is low. Yakutat is presently in the process of upgrading its entire electric distribution system. Potential future space heat electric loads will be considered in the design.

There also appears to be a natural correlation between the heating needs in the night/early morning hours and the lowest electrical energy needs in the village. This is the time during which there may be excess electricity coming from the wave power plant, and this energy could be dissipated in the form of heat. Total heating fuel used in 2007 was 343,000 Gallons. In order to calculate the equivalent number of kWh to meet that heating demand, the following assumptions are made:

- 1 Gallon of heating fuel = 140,000 btu
- Heating efficiency of oil = 80%
- 1kWh = 3,412 btu
- Electrical Heating efficiency = 99%

Based on these assumptions, 1 MWh of electricity could accomplish the same amount of heating as 30.2 gallons of heating fuel. In other words, the 343,000 gallons of heating fuel could be replaced with 11,357 MWh of electricity, which corresponds to an average electrical output of 1.3MW. Meeting all of the heating and electrical needs in the village may be impractical at present and would require additional work to create intelligent loads within the village. However, the total needs will set an upper limit on the potential for renewable generation within Yakutat. The total potential average load is 2.1MW (0.8MW electrical + 1.3MW heating). Given a capacity factor of the wave power plant of 48%, this would require an installed capacity of 4.3MW to meet all of the village electrical and heating needs. If no energy storage was present, the electrical generation from the wave power plant would have to be limited to the lowest electrical load in the system, which was 450kW in 2007. An intelligent grid design and integration with electrical heating has the potential to significantly increase the amount of energy that could come from a renewable (i.e. variable) resource.

A second consideration is the cost of electricity. Over the past decade, fuel prices have continually increased and have led to significant increases in the cost of electricity. The following chart shows the fuel prices between 1999 and 2008.

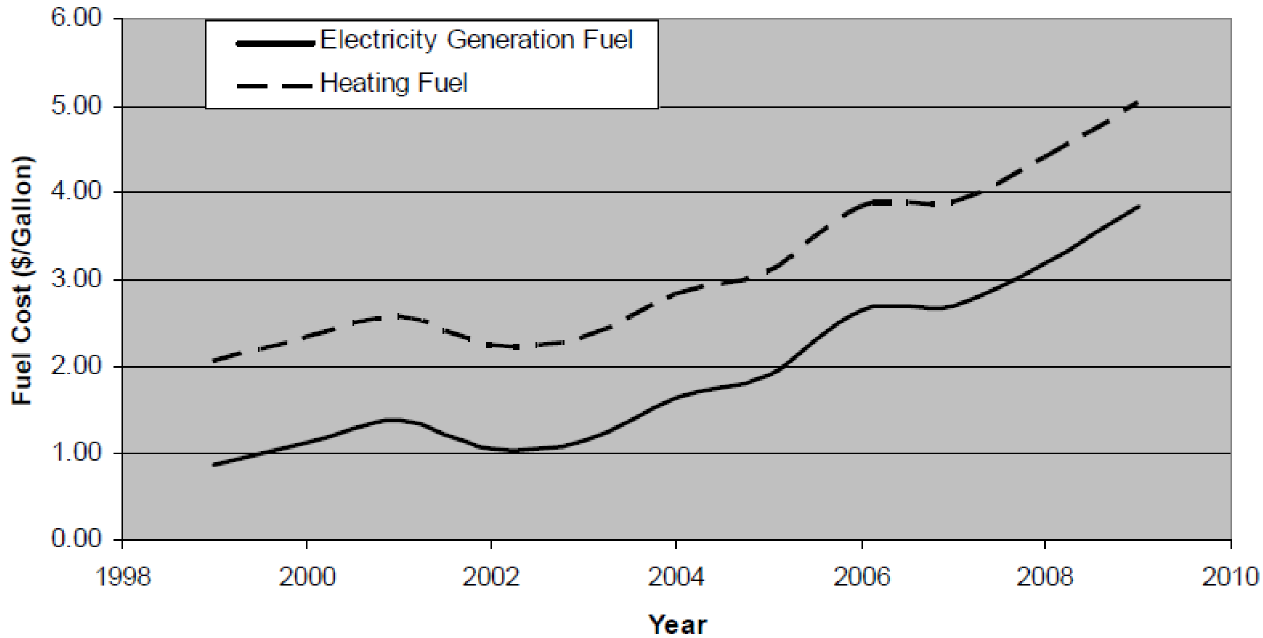

Figure 10 - Diesel and Heating Fuel Cost in Yakutat between 1999 and 2008.

These fuel cost have translated directly into significant electricity cost increases. The following chart shows the electricity cost over the same time frame.

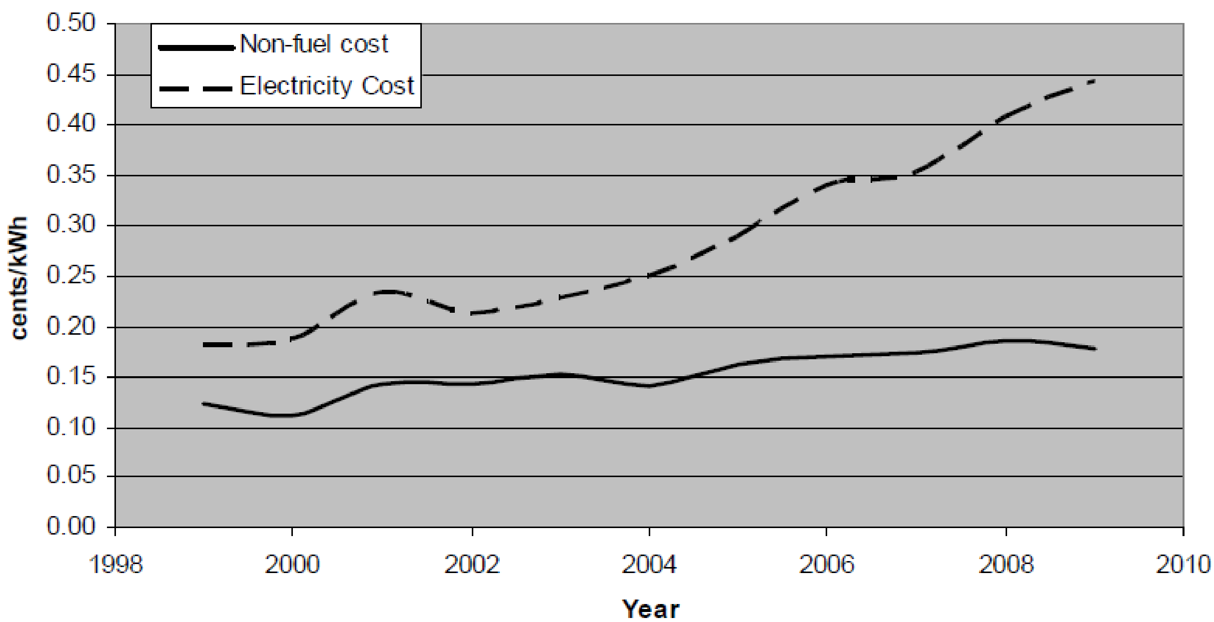

Figure 11 - Electricity Cost between 1999 and 2008

As shown in the above chart, electricity cost increases are largely driven by fuel cost increases. In 2008, the electricity cost in Yakutat reached 44 cents/kW (27 cents/kWh is directly related to fuel cost, and the remaining 17 cents/kWh is related to other cost of the electrical generation system). While fuel prices have lowered in 2009, this adjustment is largely believed to be of a temporary nature and is attributed to the global recession, which reduced pressure on fuel prices globally. In the long term, fuel prices will continue to climb and apply increased economic pressure on this remote community.

Clearly, the value of electricity for heating is not the same as the value for electricity. In addition, diesel generation systems can yield additional benefits such as district heating. Based on a heating fuel cost of $4.7 per gallon, the equivalent electricity value is 18 cents/kWh. In terms of present break-even points, the first 0.8 MW of average electricity (7,000MWh/year) has a value of 44 cents/kWh, while the next 3.5MW (31,000 MWh/year) has a value of 18 cents/kWh. As mentioned earlier, the real value of electricity from wave power would be less then the equivalent from a diesel generation system. However, because of the added value of long-term price stability from renewable resources, the above cost levels are good indicators of the value of electricity in Yakutat at the given generation levels and suggest that wave energy could provide cost-competitive renewable energy to the city.

3. Technology - Aquamarine Power Oyster

The Aquamarine Power Oyster is a near shore wave energy conversion device that was selected as representative of the technology most suitable to the Yakutat application.

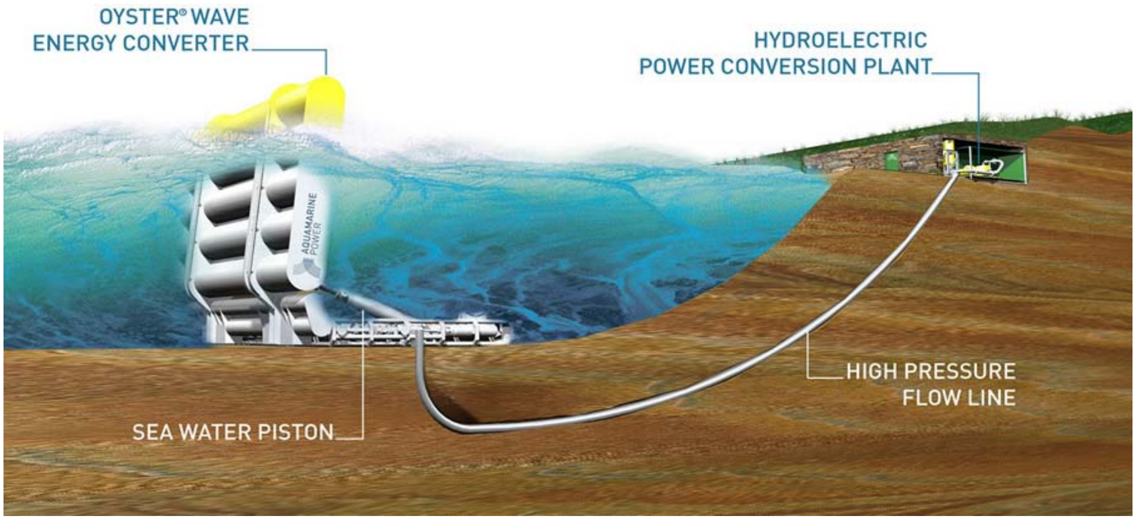

Figure 12 – Oyster 1 prototype illustration

Figure 13 - Oyster Operating at EMEC in the Orkney islands, Scotland

Specifications (Oyster II commercial device)

Water Depth	12-16m typical, 10-20m possible
Flap Width	26m
Flap Depth	13m
Total Weight	about 450T, including foundations
Power Conversion	Water Hydraulics (closed loop)
Generator	3 phase Induction generator
Converter	step up transformer, to 11/33kV
Rated power output	about 700kW (depending on deployment site)
Anchor type	Site-specific, e.g. a novel tension anchor solution has been developed for hard rock substrates; other substrates such as deep sand will use conventional offshore foundation solutions such as suction cans.
Hydraulic fluid	Pressurized fresh water (closed loop system)

Company information

Company Name:	Aquamarine Power Limited
Website:	www.aquamarinepower.com

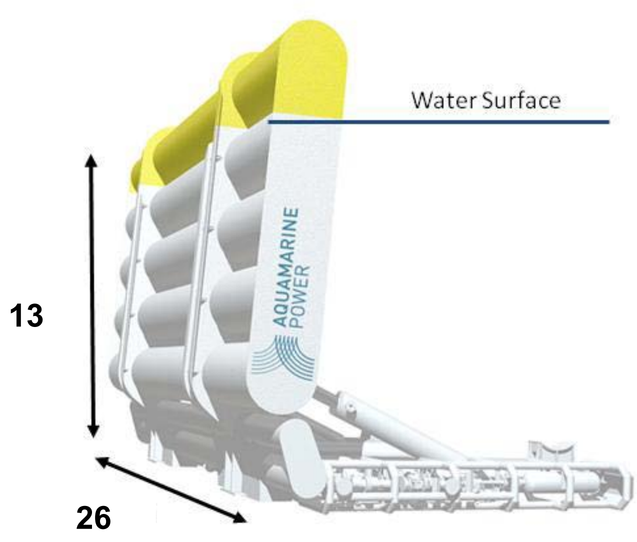

Figure 14 – Oyster II basic dimensions

3.1. Principle of Operation

The Oyster concept is a large buoyant oscillator that completely penetrates the water column from the water surface to the sea bed. It is a near shore device, typically deployed in 10 to 20 meter water depth, designed to capture the amplified surge forces found in these near shore waves. The surge component in the waves forces the bottom-hinged “flap” to oscillate, which in turn compresses and extends two hydraulic cylinders mounted between the flap and the sub-frame, pumping water at high pressure through a pipeline back to the beach.

Onshore is a modified hydro-electric plant consisting of a Pelton wheel turbine driving a variable speed electrical generator coupled to a flywheel. The Pelton turbine is an impulse turbine, commonly used in the hydropower industry. Impulse turbines are known to have high efficiencies at high pressure levels (typically >20 bars) and are considered proven technology. Power flow is regulated onshore using a combination of hydraulic accumulators, an adjustable spear valve, a flywheel in the mechanical power train and rectification and inversion of the electrical output. The low pressure return-water passes back to the device in a closed loop via a second pipeline. A key design philosophy is to keep the offshore components as few and as simple as possible. The Oyster device has no major electrical components or active control functions operating in the offshore environment.

3.2. Device Anchoring & Footprint

The Oyster wave power device differs from all other wave power devices in this project both because it is anchored directly to the sea floor and because it operates in relatively shallow water. An example array including device footprint size, pipeline layout and spacing between devices for a 5MW deployment is shown in Figure 15. An initial foundation concept has been developed for rocky substrates, using tension anchors to provide high friction between the device and the seabed. Other foundation solutions are under development for substrates, including deep sand and sand-over-rock.

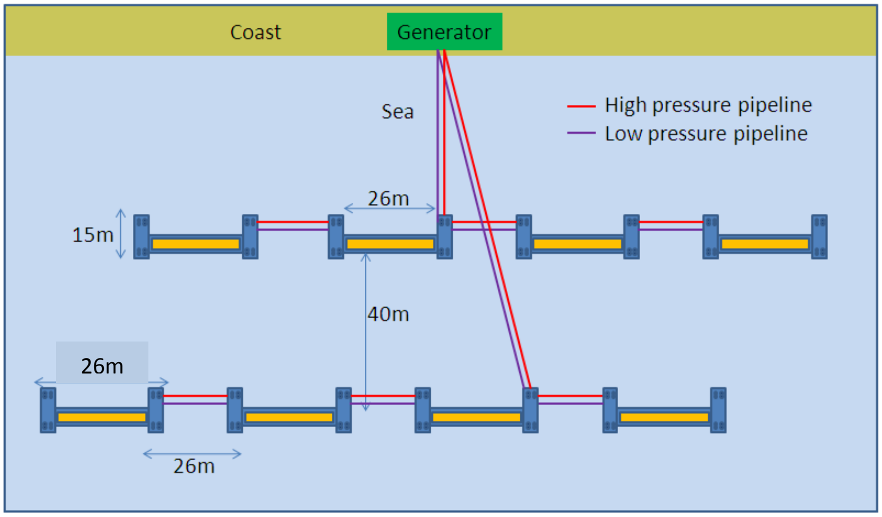

Figure 15 –Indicative device array and pipeline layout for a 5MW (peak) Oyster II farm

3.3. Operation & Maintenance

The offshore device units are designed with a minimal number of moving elements: two hinges, four non-return valves and an accumulator. Each moving part is designed for low-cost modular replacement using non-specialist marine vessels on a five-year preventative maintenance cycle. The fixed steel “flap” structure is designed for an operating lifetime of 20 years in high-energy sea environments, without replacement. This low level of complexity will likely result in extended periods of operation without the need for maintenance and/or repair. The Pelton wheel and turbine are located in a permanent onshore structure, and thus readily accessible on a 24/7 basis, in all weather conditions, for inspection and maintenance purposes.

3.4. Operating Procedures

The following operational activities and time frames are estimated for a deployment at three different scales. In absence of detailed design and engineering studies, the time frames and intervention intervals represent initial estimates and are to be used for illustrative purposes only. Time estimates refer to operational time within the general deployment area and includes mobilization time. Only offshore activities that are directly affecting the marine environment are outlined here to provide the reader with a better understanding of operational impacts on the environment.

The first set of operational activities are outlined for pre-construction activities that are used to support permitting, detailed design and subsequent construction activities at the site. Pre-installation activities will not differ significantly as a function of scale or technology choice.

Table 3 – Pre-installation resources and duration

Activity	Resources	Duration
Survey to map high-resolution bathymetry at deployment site and cable route	Survey vessel	< 1 week
Sub-bottom profiling to identify sedimentation layer thickness at deployment site	Survey vessel	< 1 week
Visual inspection of seabed in deployment area and along cable route. Soil Sampling where required.	Survey vessel ROV or diver	< 1 week
Wave Resource Characterization using ADCP or directional measurement buoy	Survey Vessel or RIB	1 year
Environmental baseline studies	Survey vessel Stand-alone instrumentation	1-2 years

The second set of activities represent project construction activities. These are activities that will have the most significant impacts over the project life and are compressed in a relatively short (one- to two-year) timeframe. While onshore construction and pipeline drilling works can take place during the winter months, offshore construction activities are dependent on weather windows at the site and would occur during times when there is a high likelihood of calm seas. Due to weather considerations, the offshore construction time period is likely constrained to the May through early September time period. It is likely that in reality the type of equipment mobilized would depend on project scale, since for larger projects, operational efficiencies become more important cost drivers in comparison to smaller projects, where mobilization cost tends to dominate. Addressing this equipment choice in detail is beyond the scope of this study.

Table 4 – Installation resources and duration

Activity	Resources	Duration	
		1-Unit	10-Units
Directional drilling to land high-pressure water pipeline to shore	Drill rig	< 2 months	< 2 months
Construction of onshore powerhouse	Standard excavation and construction equipment	< 3 months	< 3 months
Foundation Installation	2 Tugs, Barge, Supply boat	2 weeks (including weather downtime)	3 weeks
Connect High-pressure collector system	Supply boat & Diver	1 week (including weather risk)	2 weeks
Device Deployment and Commissioning	Barge, 2 Tugs, Supply boat	2 weeks (including weather downtime)	3 weeks

Operation and Maintenance activities can be divided into planned and unplanned activities. The majority of operational activities will occur during summer months, when relatively calm weather conditions allow these operations to be carried out safely. Some unplanned maintenance activities may need to be carried out during the winter season, as in the case of a failure that requires immediate attention.

Table 5 – Operational activity, resources and intervention frequency estimates

Activity	Resources	Frequency
Planned maintenance (offshore)	Standard mid-size boat	Every 5 years
Unplanned Maintenance (offshore)	Standard mid-size boat, diver	Every 4-5 years
Visual Inspection of underwater elements	Research Vessel, ROV	Every 2 years
Replacement/Refurbishment/Decommissioning of offshore Power Capture Unit and Foundation	Derrick Barge 2 Tugs Supply Boat	20 years

Decommissioning occurs at the end of the project life (typically 20 years). Decommissioning activities will probably be carried out over one to two summer seasons, depending on the project scale.

Table 6 – Decommissioning, resources and duration

Activity	Resources	1-Unit	10-Units
Recover Devices	Custom Vessel	1 week	2 weeks
Recover Device Foundation	2 x Tug Barge Supply Boat	1 week	2 weeks
Hydraulic Collector System Removal	2 x Tug Barge Supply Boat	1 week	2 weeks

4. Conceptual Design

Aquamarine Power's Oyster is a wave-actuated hydraulic pump that pumps fresh water to shore at a pressure level of about 120 bars, where it is converted into electricity using a conventional hydroelectric system and then returned to the Oyster in a closed loop. The major project elements include: (1) the Oyster WEC device, (2) a high-pressure supply sub sea pipeline and a low-pressure return sub sea pipeline, (3) an onshore turbine generator power station, and (4) a distribution line extension to connect the power station to the city electrical grid network. The proposed deployment location and related project elements are shown in the following figure.

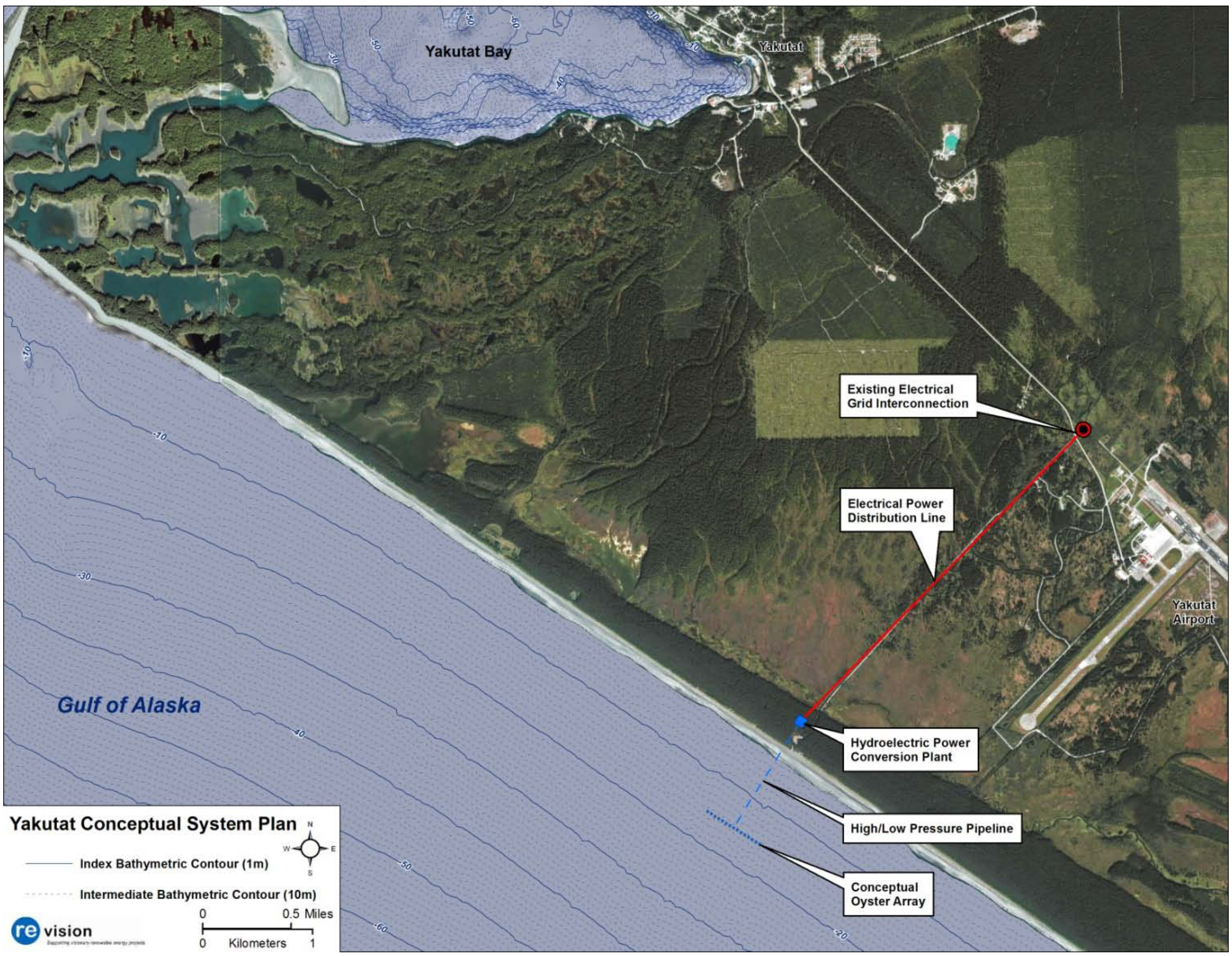

Figure 16 - Proposed Project Location and Design Elements. Thick contour lines in 10m increments.

A critical aspect of the plant design is the need to bring a set of pipelines from the deployment location back to the shore-based hydroelectric power plant. Such pipelines can be installed by directionally drilling from the shore to the site. A key cost reduction measure would entail only drilling for a portion of the distance and simply laying the pipeline onto the seabed for the remainder of the distance. The following illustration shows a cross-sectional profile of the anticipated pipeline path. The elevation profile extracted from a high-resolution GIS data set shows that about 1,150m of subsea pipeline would be needed to connect the offshore plant to the power station on-shore. However, it is likely that the near-shore bathymetry data is not accurate and further measurements should be carried out to properly characterize the bathymetry in the near-shore environment.

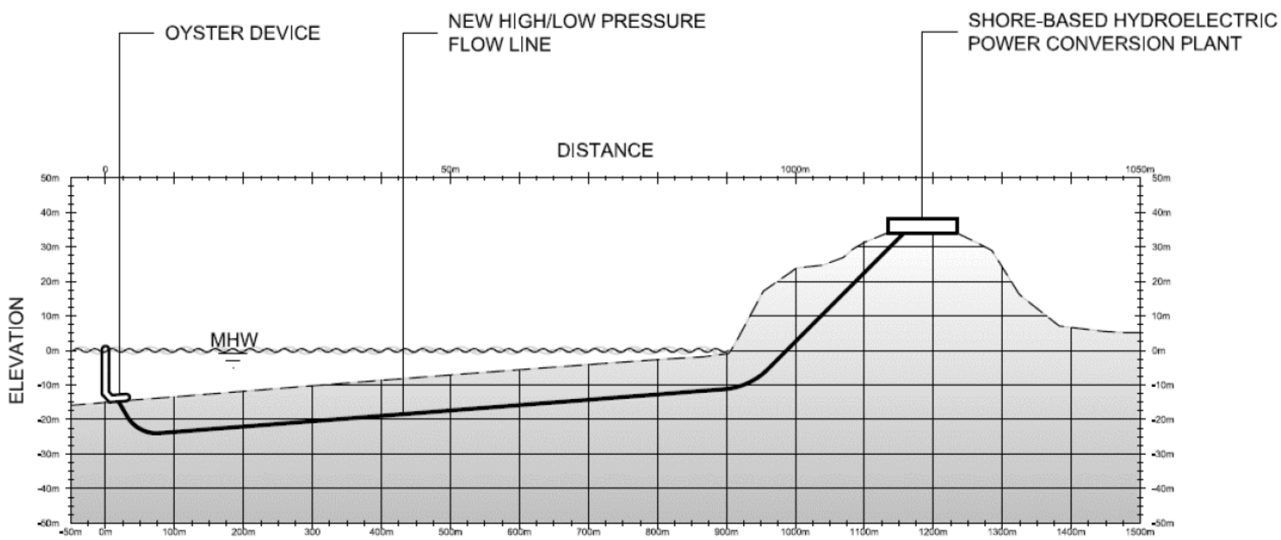

Figure 17 - Likely Pipeline Path at Deployment Site

A distribution line extension would need to be established to connect the powerhouse with the remainder of the electrical network. The planned upgrade of the powerhouse and related facilities would allow incorporating important changes to the electrical supply system in order to accommodate and integrate a wave power plant. Some of the key issues identified during the conceptual design phase that should be addressed during a detailed design study phase include:

Uncertainty in Bathymetry Accuracy – The bathymetry drives shallow water wave processes and therefore has a direct impact on the energy production from Oyster. It will also affect the placement location of the device, which has a key impact on the total cost of the system.

Directional Drilling Feasibility – A geotechnical assessment will be required to determine the feasibility of installing the subsea pipeline by means of directional drilling (or alternate method). Directional drilling cost is highly sensitive to the type of material that is being drilled through. Further, the cost in this conceptual feasibility study was calculated assuming that the pipeline would be placed by directional drilling for the whole distance of >1100m. Alternative placement methods for the outer subsea portion of the pipeline may result in significant cost savings.

Freezing Spray – Water spray will freeze if it comes in contact with protruding surfaces of the Oyster machine. Such ice build-up could add significant mass to the system and hence affect its tuning behavior. Attention should be paid during the detailed design phase to addressing this issue.

Foundation Design – The first Oyster was deployed on bedrock. An alternative foundation design will have to be used at this deployment site because the seabed at the deployment location likely consists of sand and mud.

Wave Resource Measurements – The presented performance estimates are based on modeling the wave energy resource. This introduces significant uncertainty into the process. Acoustic Doppler Current Profiler (ADCP) wave measurement device should be deployed at the likely deployment location for at least one year. This will allow for model calibration and an accurate assessment of the resource at the deployment site.

5. Cost Estimate

For emerging renewable energy technologies such as wave energy, the only method of estimating project costs (and underlying economics) is modeling technology-related parameters and estimating costs based on historical quotes and projects in related technology fields and projects. This approach introduces a significant amount of uncertainties, especially with technologies that have not yet been tested at full scale. Experience gained by EPRI and others in this field show that manufacturers typically underestimate cost in the early stages of development, and as the technologies progress towards commercial maturity, such cost-projections increase. The actual build and operational cost of a pilot device or a pilot tidal-farm, then, will reveal a complete cost picture and provide a solid starting point for further cost-studies.

Once a technology reaches commercial maturity, volume production will begin driving down cost. Figure 18 shows the typical cost projection as a function of design maturity.

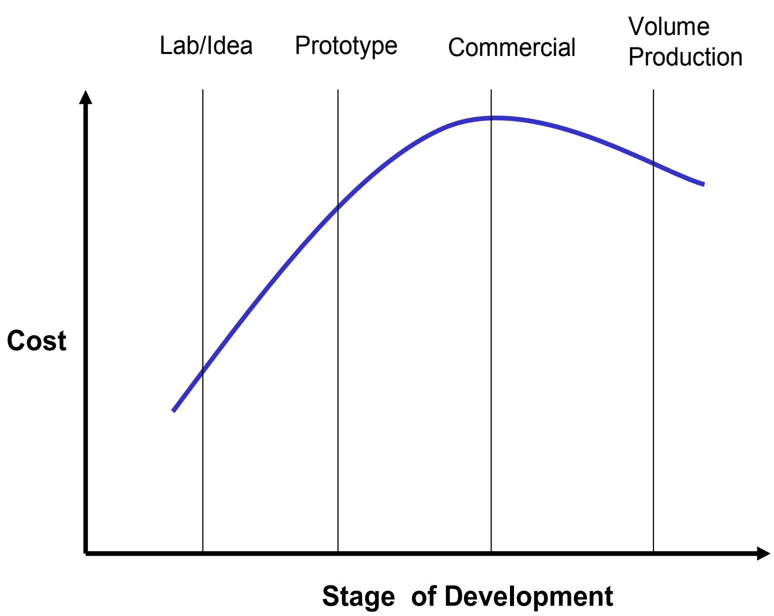

Figure 18 - Cost projection as a function of Development Status

Based on experience of estimating energy project cost, EPRI has developed a cost estimate rating table which assesses the likely range of uncertainty based on the technology's design maturity and the amount of detail going into the cost estimate. The cost estimate for a Yakutat wave power plant is placed in the simplified-preliminary level of detail and technology's stage of maturity at the pilot level, thereby yielding a likely cost uncertainty of – 30 to +30%.

Table 7 - EPRI cost estimate rating table

Cost Estimate Rating	A Mature	B Commercial	C Demonstration	D Pilot	E Conceptual (Idea or Lab)
A. Actual	0	-	-	-	-
B. Detailed	-5 to +5	-10 to +10	-15 to +20	-	-
C. Preliminary	-10 to +10	-15 to +15	-20 to +20	-25 to +30	-30 to +50
D. Simplified	-15 to +15	-20 to _20	-25 to +30	-30 to +30	-30 to +80
E. Goal	-	-30 to +70	-30 to +80	-30 to +100	-30 to +200

Likely Cost Uncertainty

In addition to technology-related cost uncertainties, the cost for raw materials such as steel and copper has increased significantly, and many relevant industries such as subsea cable manufacturers have limited additional capacity to meet global infrastructure expansions. As a direct result, end product costs are artificially inflated. A comparison of manufacturer quotes for subsea cables between 2004 and 2007 revealed a cost increase of over 200% for a similar cable. Other industries are affected by this trend as well. Wind energy reached an all-time low in the year 2000 when the cost of wind energy reached an all-time low of about $1100 per installed kW. Since then, cost has steadily increased and is now (2008) pushing $2000 per kW.

Many of these technologies were developed overseas in Europe (mainly the UK). Historical exchange rates make a direct correlation between building cost in the US and Europe difficult and requires independent cost-buildups for most projects. As a result of the above factors, significant uncertainties in the prediction of cost remain, and any cost and/or economic projections of these emerging technologies should be viewed with these factors in mind. The only way to reduce these uncertainties to an absolute minimum is to base cost projections on technology that is as mature as possible and use a consistent methodology to assess the technologies themselves.

Costs were estimated based on device data supplied by Aquamarine Power under non-disclosure agreement. An independent cost build-up was generated to independently evaluate the individual cost elements. Because most of this data is commercially sensitive, only high-level results are presented here.

Table 8 - Cost, Performance and Economic Summary ($2009)

	1 Unit		2 Units		4 Units		8 Units	
Capital Cost	USD	$/kW	USD	$/kW	USD	$/kW	USD	$/kW
Device Structure	$3,840,000	$4,923	$6,912,000	$4,431	$12,441,600	$3,988	$22,394,880	$3,589
Water Pipeline	$1,344,000	$1,723	$2,419,200	$1,551	$4,354,560	$1,396	$7,838,208	$1,256
Power House	$1,359,000	$1,742	$2,478,000	$1,588	$4,716,000	$1,512	$9,192,000	$1,473
Installation Cost	$2,347,200	$3,009	$3,288,000	$2,108	$4,724,400	$1,514	$6,945,000	$1,113
Total Cost	$8,890,200	$13,677	$15,097,200	$11,613	$26,236,560	$10,091	$46,370,088	$8,917
Annualized OPEX	$330,000	$508	$510,000	$392	$810,000	$312	$1,400,000	$269
Performance								
Rated Power	650	kW	1300	kW	2600	kW	5200	kW
Capacity Factor	48.00%		48.00%		48.00%		48.00%	
Availability	95%		95%		95%		95%	
Annual Energy Output	2596	MWh	5193	MWh	10386	MWh	20772	MWh
Cost of electricity (constant $)	45.1	cents/kWh	38.0	cents/kWh	32.3	cents/kWh	28.4	cents/kWh

The above cost breakdown demonstrates that the device itself accounts for only about 1/3rd of the total project cost. At smaller scale, costs are clearly dominated by installation and pipeline cost. These cost items are highly dependent on the results of a detailed reconnaissance study, which will inform the detailed design of the system at deployment site of interest. Further, detailed resource assessments have proven to be of critical importance when evaluating the wave energy climate in the near-shore environment. As such, these detailed studies are critical to further the understanding of the real cost of the overall system.

Some of the main assumptions for this cost-estimate were:

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; 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. Operational procedures were then outlined to replace these components and carry out routine maintenance. The access arrangement has a critical influence in determining what kind of maintenance strategy is pursued and on 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 the costs of maturing an offshore oil and gas project, which is typically at about 1.5% of installed cost.

Device Cost: Device Cost was estimated by using a weight breakdown structure supplied by Aquamarine Power and using appropriate $/ton of manufactured steel figures.

Power Conversion System: The cost of the hydroelectric power plant on shore was estimated using cost data from hydroelectric power equipment.

Installation and Operation Cost: These costs are dominated by mobilization. Seattle is roughly 1000 miles and Anchorage 600 miles by boat. These costs could be significantly reduced if a vessel of opportunity could be used to install and recover the device (i.e. a tug delivering fuel to the village).

Pre-construction cost: Cost for permitting, detailed design and technical studies needed before construction are not included in the capital cost presented in Table 1, but are estimated at between $1.5M and $2M.

6. Economic Assessment

The cost of electricity (COE) was calculated for Yakutat Power, an Alaskan State Municipal Generator (MG). EPRI strongly recommends that Yakutat Power develop its own in-house economics capability. The potential large investment that Yakutat Power is considering making in wave power is a strong reason for developing an internal capability to estimate project economics.

Non-taxable municipal utilities set electricity rates that cover all operating costs. Generation projects are financed by issuing tax-exempt bonds, enabling municipal utility generators to access some of the lowest interest rates available

The EPRI-regulated MG methodology is based on a levelized cost approach using constant dollars (Jan 1, 2010 dollars) with plant start-up in January 2013 and a 20-year book life. The purpose of this methodology is to provide a consistent, verifiable and replicable basis for computing the LCOE of a wave power generation project (i.e., a project to procure, construct, operate and maintain a wave energy power plant – note that the cost to engineer the final design and permit the plant is NOT included).

The results of this economic evaluation are intended to help utility managers to determine the degree of financial incentives required to satisfy a business case. It will also help government policy makers to 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 it. Such technology support is typically done through funding R&D and through incentives for the deployment of targeted renewable technologies.

For this Yakutat wave energy study project, key project and financial assumptions are as follows:

- Total plant costs expressed in beginning of 2010 (Jan 1, 2010)
- All costs in current January 1, 2010 dollars
- Pre construction studies start date = January 1, 2011
- Construction begins Jan 1, 2012
- Construction period is 1 year
- Plant start up is Jan 1, 2013
- 20-year plant life

- Inflation rate of 3.0%, based on the U.S. Producer Price Index for 2003 [1]
- Projects 100% financed by the Bond Market
- Cost of capital = 4.75% nominal
- Not taxable
- No financial incentives

The yearly electrical energy produced and delivered to bus bar by the –single Oyster unit, 650 kW device with a 48% capacity plant described in this report is estimated to be 2,596 MWh/year The elements of cost and economics (again, in Jan 1 2019 constant $) are:

- Total Plant Cost = $8,890,200
- Annual O&M Cost = $330,000 (which includes the annualized cost of a 5-yearly reventive maintance cycle)
- Municipal Generator (MG) Levelized Cost of Electricity = 45.1 cents/kWh with no financial incentives

As the scale of the plant is increased from 1 to 2, 4 and 8 oyster units, the COE is lessened to 28.4 cents/kWhr at the 8 oyster unit size.

The detailed worksheets, including financial assumptions used to calculate these COE, are contained in Appendix A.

[1] Source: U.S. Bureau of Labor Statistics, 2004

7. Conclusions

This study presents the results of a conceptual system definition and feasibility study for a small wave power plant deployed in Yakutat, Alaska. An initial high-level scoping study showed that given the small generation capacity needed, it is unlikely that a deep-water wave power conversion plant would make economic sense. The cost drivers at the small scale proposed are the subsea cable cost and installation and operation cost, which are dominated by offshore operational considerations. It was therefore decided to focus on near-shore wave energy conversion technology.

The study scope included: (1) a shallow water wave energy resource assessment, (2) a conceptual design based on the Aquamarine Power Oyster shallow water wave energy conversion technology, (3) a cost assessment (capital and O&M), and (4) an economic analysis. Aquamarine Power's shallow water wave energy conversion technology Oyster is representative of the wave energy technology best suited for the deployment site. Oyster is a wave-actuated hydraulic pump that pumps fresh water to shore at a pressure level of about 120 bars, where it is converted into electricity using a conventional hydroelectric system and then returned to the Oyster in a closed loop. The major project elements include: (1) the Oyster WEC device, (2) a high pressure (120) bar pressure supply sub sea pipeline and a low pressure (3 bar) return sub sea pipeline, (4) an onshore turbine generator power station, and (5) a distribution line extension to connect the power station to the city electrical grid network. The proposed deployment location and related project elements are shown in the following figure.

The EPRI study showed that Yakutat has an excellent wave climate for wave energy conversion. A shallow water wave transformation model (SWAN) was used to propagate a full year of wave data to the deployment location at 13m water depth. Shallow water power densities at the deployment site of interest were assessed at between 19kW/m and 22kW/m. Based on this wave energy resource data, the resulting capacity factor of the 650 kW rated Oyster machine was assessed at 48%. Cost elements, including (1) device, (2) sub sea pipeline, (3) on-shore power station, (4) overland distribution line extension, (5) installation, and (6) operation and maintenance were assessed for the plant at four different sizes (1, 2, 4 and 8 units at 650 kW per unit), as summarized in Table 1 below. Cost of electricity was then computed using a Municipal Utility Ownership economic model. Cost of electricity is estimated to be about 45 cents/kWh (in constant Jan 1, 2010 dollars) for a 20-year plant-life. Cost and economic uncertainties at this early stage of project development are still quite substantial; based on EPRI's experience with similar projects at a conceptual stage of development, cost is estimated on the order of +/- 30%.

Table 9 - Cost, Performance and Economic Summary

		1 Unit		2 Units		4 Units		8 Units	
Capital Cost		USD	$/kW	USD	$/kW	USD	$/kW	USD	$/kW
	Device Structure	$3,840,000	$4,923	$6,912,000	$4,431	$12,441,600	$3,988	$22,394,880	$3,589
	Water Pipeline	$1,344,000	$1,723	$2,419,200	$1,551	$4,354,560	$1,396	$7,838,208	$1,256
	Power House	$1,359,000	$1,742	$2,478,000	$1,588	$4,716,000	$1,512	$9,192,000	$1,473
	Installation Cost	$2,347,200	$3,009	$3,288,000	$2,108	$4,724,400	$1,514	$6,945,000	$1,113
	Total Cost	$8,890,200	$13,677	$15,097,200	$11,613	$26,236,560	$10,091	$46,370,088	$8,917
Annualized OPEX		$330,000	$508	$510,000	$392	$810,000	$312	$1,400,000	$269
Performance									
	Rated Power	650	kW	1300	kW	2600	kW	5200	kW
	Capacity Factor	48.00%		48.00%		48.00%		48.00%	
	Availability	95%		95%		95%		95%	
	Annual Energy Output	2596	MWh	5193	MWh	10386	MWh	20772	MWh
Cost of electricity (constant $)		45.1	cents/kWh	38.0	cents/kWh	32.3	cents/kWh	28.4	cents/kWh

The cost at this relatively small scale (in terms of sizes of utility power plants in the lower 48) is clearly dominated by infrastructure and operational considerations related to the installation of the device in this somewhat remote location. However, present bus bar cost of electricity from the existing diesel-based generation facility comes in at about 27 cents/kWh and will only increase in the future. It may be important to note that in 2008, cost of electricity was at over 40 cents/kWh. Diesel fuel cost has dramatically increased since the year 2000 and is only temporarily lower at present because the global recession has reduced the demand on fossil fuels, creating a more attractive yet transitory pricing structure. In the long-term, energy costs are expected to increase, which creates an additional economic burden to small communities like Yakutat that are heavily reliant on diesel fuel.

A key result of the EPRI feasibility study is that the level of cost-reduction potential that could come from optimization is substantial. These cost reductions can only be quantified through detailed design and engineering analysis because most cost elements are driven by site-specific considerations. A key part of the proposed next phase is to investigate some of the identified alternate design options and detail the "optimal" solution for the site of interest. Many cost reductions could come from improved installation and operational procedures, economies of scale and the potential to locate the plant closer to shore.

EPRI recommends that this project move forward with final design and permitting activities to further reduce uncertainties and perform techno-economic optimization.

Appendix A – COE Worksheets of Single Unit Oyster Case

EPRI Ocean Energy Utility Generator Cost of Electricity Calculator

Developed for: Yakutat Power

Although EPRI is proposing to use the economics assessment methodology report previously sent to Yakutat Power and this Excel worksheet, we strongly recommend that Yakutat Power develop its own in-house economics capability or hire an independent 3rd party economist consultant. The potential large investment that Yakutat Power is considering making in wave power is a strong reason for having an internal capability to estimate project economics. This is research-grade software and EPRI can provide no guarantee that it is bug-free nor can warranty this software

Developed By: Roger Bedard
EPRI
3420 Hillview Ave.
Palo Alto, CA 94304

INSTRUCTIONS

Indicates Input Cell (either input or use default values)

Indicates a Calculated Cell (do not input any values)

Strike outs indicate difference from Investor Owned Utility worksheet

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
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
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) - Jan 1, 2010$

TPC Component	Unit	Unit Cost	Total Cost (Jan 1, 2010$)	
Device Structure	1	$3,840,000	$3,840,000	
Water Pipeline	1	$1,344,000	$1,344,000	
Powerhouse	1	$1,359,000	$1,359,000	
Installation	1	$2,347,200	$2,347,200	
			$0	
			$0	
TOTAL			$8,890,200	

TOTAL PLANT INVESTMENT (TPI) -Jan 1, 2010$

End of Year	Total Cash Expended TPC (Jan 1, 2010$)	Before Tax Construction Loan Cost at Debt Financing Rate	Jan 1, 2010 $ Value of Construction Loan Payments	TOTAL PLANT INVESTMENT - Jan 1, 2010
2010 -2011		$0	$0	$0
2012	$8,890,200	$955,697	$779,171	$9,669,371
Total	$8,890,200	$955,697	$779,171	$9,669,371

ANNUAL OPERATING AND MAINTENANCE COST (AO&M) - Jan 1, 2010$

Costs	Yrly Cost	Amount	
Labor and Parts	$88,000	$88,000	
Annualize cost 5 yearly overhaul	$107,430	$107,430	
Insurance (1.5% of TPC)	$133,353	$133,353	
Total		$328,783	

FINANCIAL ASSUMPTIONS

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

1	Rated Plant Capacity ©	0.65	MW
2	Annual Electric Energy Production (AEP)	2,596	MWeh/yr
	Therefore, Capacity Factor	45.6	%
3	Year Constant Dollars	2010	Year
4	Federal Tax Rate	35	%
5	State	Alaska	
6	State Tax Rate	0	%
	Composite Tax Rate (t)	0.35	
	t/(1-t)	0.5385	
7	Book Life	20	Years
8	Construction Financing Rate	6.09	
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	6.09	%
	Nominal Discount Rate Before-Tax	6.09	%
	Nominal Discount Rate After-Tax	3.96	%
15	Inflation Rate = 3%	3	%
	Real Discount Rate Before-Tax	3.00	%
	Real Discount Rate After-Tax	0.93	%
16	Federal Investment Tax Credit	0	
17	Federal REPI (1)		$/kWh
18	State Investment Tax Credit	0	% of TPI
19	State Investment Production Tax Credit	$0	Credit - 1st year only for ≥ $10M plant
20	Renewable Energy Certificate (2)	0	$/kWh
21	State Tax Depreciation	0	Installation Cost

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)

NET PRESENT VALUE (NPV) - 2009 $

TPC $8,890,200

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
2012	**8,890,200**					**8,890,200**
2013	8,890,200	444,510	444,510	0	0	8,445,690
2014	8,890,200	444,510	889,020	0	0	8,001,180
2015	8,890,200	444,510	1,333,530	0	0	7,556,670
2016	8,890,200	444,510	1,778,040	0	0	7,112,160
2017	8,890,200	444,510	2,222,550	0	0	6,667,650
2018	8,890,200	444,510	2,667,060	0	0	6,223,140
2019	8,890,200	444,510	3,111,570	0	0	5,778,630
2020	8,890,200	444,510	3,556,080	0	0	5,334,120
2021	8,890,200	444,510	4,000,590	0	0	4,889,610
2022	8,890,200	444,510	4,445,100	0	0	4,445,100
2023	8,890,200	444,510	4,889,610	0	0	4,000,590
2024	8,890,200	444,510	5,334,120	0	0	3,556,080
2025	8,890,200	444,510	5,778,630	0	0	3,111,570
2026	8,890,200	444,510	6,223,140	0	0	2,667,060
2027	8,890,200	444,510	6,667,650	0	0	2,222,550
2028	8,890,200	444,510	7,112,160	0	0	1,778,040
2029	8,890,200	444,510	7,556,670	0	0	1,333,530
2030	8,890,200	444,510	8,001,180	0	0	889,020
2031	8,890,200	444,510	8,445,690	0	0	444,510
2032	8,890,200	444,510	8,890,200	0	0	0

CAPITAL REVENUE REQUIREMENTS - 2009$

TPI = $9,669,371

End of Year	Net Book	Returns to Equity Common	Returns to Equity Pref	Interest on Debt	Book Dep	Income Tax on Equity Return	REPI	Capital Revenue Req'ts
	A	B	C	D	E	F	H	I
2012	**8,890,200**							
2013	8,445,690	0	0	541,413	444,510	0	0	985,923
2014	8,001,180	0	0	514,343	444,510	0	0	958,853
2015	7,556,670	0	0	487,272	444,510	0	0	931,782
2016	7,112,160	0	0	460,201	444,510	0	0	904,711
2017	6,667,650	0	0	433,131	444,510	0	0	877,641
2018	6,223,140	0	0	406,060	444,510	0	0	850,570
2019	5,778,630	0	0	378,989	444,510	0	0	823,499
2020	5,334,120	0	0	351,919	444,510	0	0	796,429
2021	4,889,610	0	0	324,848	444,510	0	0	769,358
2022	4,445,100	0	0	297,777	444,510	0	0	742,287
2023	4,000,590	0	0	270,707	444,510	0	0	715,217
2024	3,556,080	0	0	243,636	444,510	0	0	688,146
2025	3,111,570	0	0	216,565	444,510	0	0	661,075
2026	2,667,060	0	0	189,495	444,510	0	0	634,005
2027	2,222,550	0	0	162,424	444,510	0	0	606,934
2028	1,778,040	0	0	135,353	444,510	0	0	579,863
2029	1,333,530	0	0	108,283	444,510	0	0	552,793
2030	889,020	0	0	81,212	444,510	0	0	525,722
2031	444,510	0	0	54,141	444,510	0	0	498,651
2032	0	0	0	27,071	444,510	0	0	471,581
Sum of Annual Capital Revenue Requirements								14,575,038

FIXED CHARGE RATE (FCR) - NOMINAL AND REAL LEVELIZED - 2009$

TPI = $9,669,371

End of Year	Capital Revenue Req'ts Nominal A	Capital Revenue Req'ts Nominal A	Capital Revenue Req'ts Real D	Capital Revenue Req'ts Real D
2012				
2013	985,923	985,923	778,297	850,466
2014	958,853	958,853	734,881	803,024
2015	931,782	931,782	693,333	757,624
2016	904,711	904,711	653,583	714,187
2017	877,641	877,641	615,559	672,638
2018	850,570	850,570	579,197	632,904
2019	823,499	823,499	544,430	594,913
2020	796,429	796,429	511,197	558,599
2021	769,358	769,358	479,438	523,895
2022	742,287	742,287	449,096	490,739
2023	715,217	715,217	420,114	459,070
2024	688,146	688,146	392,440	428,830
2025	661,075	661,075	366,021	399,961
2026	634,005	634,005	340,809	372,411
2027	606,934	606,934	316,754	346,126
2028	579,863	579,863	293,812	321,056
2029	552,793	552,793	271,937	297,153
2030	525,722	525,722	251,088	274,370
2031	498,651	498,651	231,222	252,663
2032	471,581	471,581	212,300	231,986
2033	14,575,038	14,575,038	9,135,509	6,961,120

	Nominal $	**Real $**
1. The present value is at the beginning of 2009 and results from the sum of the products of the annual present value factors times the annual requirements	10,412,379	9,251,264
2. Escalation Rate	3%	3%
3. Discount Rate = i	6.09%	3.00%
4. Capital recovery factor value = $i(1+i)^n/(1+i)^n-1$ where book life = n and discount rate = i	0.08782263	0.067215708
5. The levelized annual charges (end of year) = Present Value (Item 1) * Capital Recovery Factor (Item 4)	914,442	621,830
6. Booked Cost	9,669,371	9,669,371
7. The levelized annual fixed charge rate (levelized annual charges divided by the booked cost)	**0.0946**	**0.0643**

LEVELIZED COST OF ELECTRICITY CALCULATION - MUNICIPAL GENERATOR – 2010$

COE = ((TPI * FCR) / AEP + (NPV (of O&M costs) * CRF) / AEP
In other words…
The Cost of Electricity =
The Sum of the Levelized Plant Investment + Annual O&M Cost + Levelized Overhaul and Replace
Cost
Divided by the Annual Electric Energy Consumption

CONSTANT DOLLARS

COE - Capital Cost	33.26
COE - O&M	11.88
COE TOTAL (cents/kWh)	45.1445