PRELIMINARY ENGINEERING AND ECONOMIC ASSESSMENT OF ENERGY CONSUMPTION AND RENEWABLE ENERGY PRODUCTION POTENTIAL FOR VASHON-MAURY ISLAND

These pages represent the work of Princeton Energy Resources International, LLC under Contract to the Institute for Environmental Research and Education (IERE). The work was paid through a generous grant from Paul G. Allen.

BOUNDARIES AND DESCRIPTION OF VASHON-MAURY ISLAND, WA

Vashon-Maury Island (see Figure 1) is located in the Puget Sound, about 8 km by water southwest of Seattle in Washington State. An unincorporated area within King County, the island has a year-round population of 10,500 (1997), and is designated “rural” under the county’s comprehensive growth management plan. About 80% of the land area is in trees and open spaces. With no bridges to the mainland—and little resident interest in building any—transportation on and off the island is by auto/passenger ferry or private boat.

The island is about 8km (5mi) by water southwest of Seattle. The island is approximately 21km (13mi) long and 10km (7mi) wide, with a total area of 96 km^2 (37 square miles). There are actually two islands, Vashon and Maury Islands that are joined by a narrow isthmus.

On the west side, the island is separated from the mainland by Colvos Passage, a 1.5km wide channel running the full length of the island. The channel is very deep, 50 fathoms (300ft) on most parts. The Passage probably follows a fault line, as they trend in that direction in this area. Earthquakes are quite frequent and should be considered in any plant design. The shoreline on the south end of the island and at Quartermaster Harbor are environmental protected areas and habitat for salmon spawning.

Fig. 2 is a topographic map of the island, showing key geographic, environmental, and cultural features. The red “pins” represent high terrain where wind resources might be optimal.

Figure 1Fisheries Map of Vashon-Maury Island

Fig. 2 Topo Map of Vashon-Maury Island

ENERGY PROFILE OF VASHON-MAURY ISLAND

Vashon-Maury Island currently uses a variety of fuels to meet its residential, commercial and transportation needs. In general, the energy consumed on the island for these sectors is representative of the energy use of the surrounding areas, in part because the island's infrastructure is well connected to the mainland.

Table 1 provides an overview of the various components of the island's energy consumption.

Table 1. Annual Energy Consumption of Vashon-Maury Island

Resource			
General	Specific	Quantity	Units
Electricity	Grid Connection (PSE)	105,379,500	kWh/yr
Fossil Fuels	Natural Gas	153,000,000	cu ft/yr
	Fuel Oil	500,000	gal/year
	Propane	370,000	gal/year
	Gasoline	1,700,000	gal/year
	Diesel	2,180,000	gal/year
Biomass	Fire Wood	2,150	cords/yr
	Landfill Gas (CH_4)	15,242,400	cu ft/yr

The remainder of this profile provides details about each of these energy consumption elements. After a discussion of the data presented in Table 1, this overview translates these quantities into equivalent electrical terms to provide insight into the amounts of electric generating renewable technology capacity that would be required to meet the island's transportation requirements with hydrogen fuel.

Current Energy Consumption

Electricity

Nearly one third of the energy used on the island is in the form of electricity. A substantial portion of the island (about 50%) utilizes electric heat. The remainder of electricity use is for cooking, cooling, lighting, and other small uses.

Consumption

The island consumes an estimated 105 million kWh per year (source Puget Sound Energy). This represents a per capita consumption of 10,000-11,000 kWh/year. Puget

Sound Electric (PSE) supplies the island with electricity through multiple connections. PSE generates electricity primarily with regional hydropower resources.

Electrical Load

The average Vashon-Maury Island Daily Load Profile for January and July 2001 is shown in Figure 1 (source PSE). The profile indicates a 6 MW baseload and 11-12 MW hourly peak, on average, in the summer months, and a 10 MW baseload and 18-19 MW hourly peak, on average, in the winter. The reported instantaneous highest demand recorded for the island was 22 MW. The peak hours of the day occur in the mornings from 6am to 10am, and again in the afternoon and evening from 4pm to 9pm.

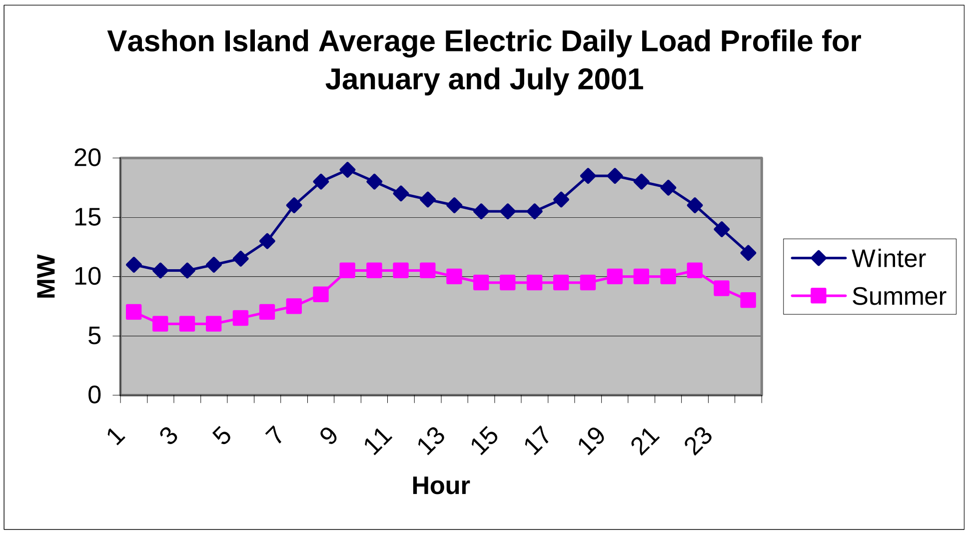


Figure 1. Vashon Island Average Electric Daily Load Profile

There are a total of 6161 electricity accounts on the island. Because nearly half of the island's homes, 2900 of 6100, use electric heat, accounting for the peak loads being higher in the winter months than in the summer months

Electrical Energy Costs

The time of day pricing for PSE power on the island is shown in Table 2.

Natural Gas

Uses

Natural gas is used by 940 households on the island for heating and other household purposes. There are only two commercial users of natural gas.

Consumption

The total consumption for the island is estimated at 153 million ft^3 per year (source: PSE). This is equivalent to 154,071 million Btu (MMBtu) per year. Natural gas is supplied to the island via a pipeline connecting at Sandford Point on the west side of the island.

Table 2. PSE Time of Day Pricing for Vashon-Maury Island, by Customer Type

Customer Type	Time of Day	Price ($/kWh)
Residential	6-10AM	0.086
	10AM-5PM	0.076
	5-9PM	0.086
	9PM-6AM	0.068
	Sun + Holidays	0.068
	Energy Credit	~ (.014) if less than last years consumption
	Energy Conservation Program	0.000328
	Energy Exchange Credit*	(.0135)
Commercial	Energy Charge	0.0656
	Energy Conservation Program	0.000294

* Credit resulting from Federal Columbia River benefits from BPA

The total consumption for the island is estimated at 153 million ft^3 per year (source: PSE). This is equivalent to 154,071 million Btu (MMBtu) per year. Natural gas is supplied to the island via a pipeline connecting at Sandford Point on the west side of the island.

Load Shapes

The hourly and seasonal consumption (shown in figure 2) follows patterns similar to electricity consumption, with higher consumption experienced in the morning and afternoon/evening winter peaks. Also, due to its use as a heating fuel, consumption during the winter months is more than double that in the summer. As can be seen in figure 2, the average winter on-peak usage is about 40,000 ft^3/hour. The highest hourly winter usage was about 50,000 ft^3/hour.

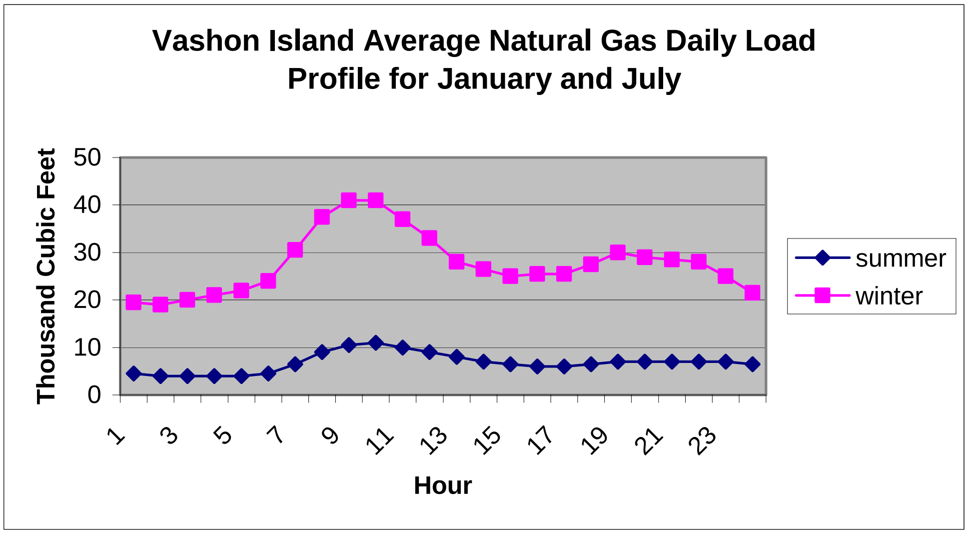


Figure 2. Vashon Island Average Natural Daily Load Profile

Fuel Oil

Uses

Fuel oil is used almost entirely for residential heating.

Consumption

Heating oil usage is estimated to be 500,000 gallons per year. The energy content of this annual heating oil total is 70,000 MMBtu per year.

Load Shapes

The use of heating oil is assumed to follow the same winter shape as natural gas, with a morning peak being the dominant feature of that load shape.

Costs

The cost of heating oil fluctuates with world oil and regional market trends, but, nationally, averaged about $1.41/gallon, without taxes, during the 2001-2002 winter heating season.

Propane (LPG)

Uses

Propane is used on the island for heating and other general household purposes.

Consumption

Data on propane use was not available from vendors. For this study, it is assumed that propane is used at a rate equal to one-half that of heating oil on an energy basis, or about 380,000 gallons/year (source: IERE). The energy content of this propane is 35,000 MMBtu/year.

Load Shapes

The use of propane is assumed to follow the same winter shape as natural gas, with a morning peak being the dominant feature of that load shape.

Costs

The cost of propane fluctuates with world oil and regional market trends, but averaged, nationally, about $1.27/gallon, without taxes, during the 2001-2002 winter heating season.

Fuel Wood

Uses

Fuel wood is used primarily for residential space heating.

Consumption

Fire wood consumption for the island is estimated at 2,150 cords per year (source: local wood vendors). Using standard assumptions of 3,000 lb/cord, 20% moisture content for the wood and 8,000 Btu/dry lb, the annual energy content of this resource can be calculated to be 41,280 MMBtu.

Load Shapes

As a heating source, wood consumption occurs primarily during winter months

Gasoline

Uses

The island's motor transportation energy needs are assumed to be met entirely by gasoline. Other transportation fuels, such as diesel, electricity, hydrogen, LNG, LPG, or CNG, are assumed to be negligible for the analysis of current energy usage.

Consumption

Annual gasoline consumption is estimated from discussions with vendors to be 1,700,000 gallons per year (source: IERE). The energy content of this gasoline is 212,500 MMBtu/year.

Load Shapes

Gasoline use is assumed to be relatively constant throughout the year.

Costs

Gasoline costs vary during the course of the year, but the cost of gasoline purchased on the island is typically several cents higher than on the mainland.

Diesel

Uses

Diesel is used primarily for fueling the island's ferries.

Consumption

Annual diesel consumption is estimated at 2,180,000 gallons per year, based on information from vendors and Washington State Ferries. All of this fuel is loaded onto the ferries at sites off of the island.

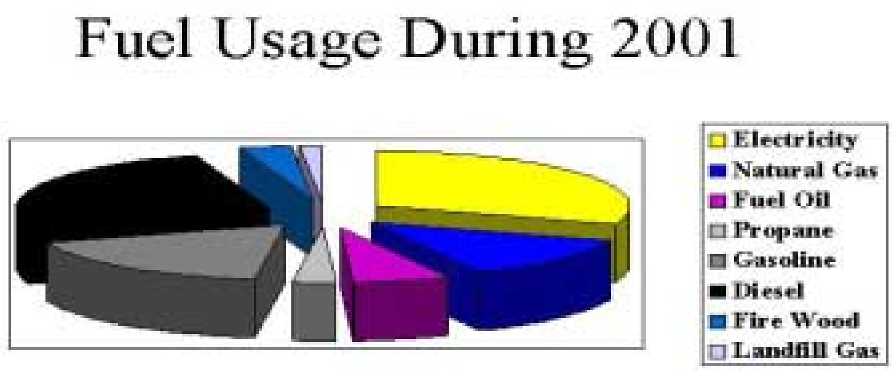
Energy Consumption Totals

Table 2 characterizes the current energy usage for Vashon-Maury Island.

Table 2. Summary of Current Annual Vashon-Maury Island Energy Use

Resource				Btu	Conversion	
General	Specific	Quantity	Units	Conversion	Units	MMBtu
Electricity	Grid Connection (PSE)	105,379,500	kWh	3,412	BTU/kWh	358,260
Fuels	Natural Gas	153,000,000	Cu Ft/yr	1,007	Btu/cu ft	154,071
	Fuel Oil	500,000	Gal/year	140,000	Btu/gallon	70,000
	Propane	377,000	Gal/year	92,700	Btu/gallon	35,000
	Gasoline	1,700,000	Gal/year	125,071	Btu/gallon	212,500
	Diesel	2,180,000	Gal/year	138,690	Btu/gallon	302,000
	Fire Wood	1,720	Cords/yr	24000000	Btu/cord	41,280
	Landfill Gas (CH_4)	15,242,400	cu ft/yr	1,007	Btu/cu ft	15,349
TOTAL						1,187,260

Energy consumption on the islands is dominated by electricity and transportation fuel consumption. Over half the non-transportation energy is used for space heating and cooking. The following chart shows the energy consumption by fuel type.



Transport Fuel Displacement by Hydrogen

One option for displacing the various transport fuels used on the island would be to convert gasoline and diesel transport fuel consumption to hydrogen. Hydrogen engine efficiencies are approximately 3 times those of gasoline engines, and double those of diesel engines. On that basis, and given 85% conversion efficiencies of commercial electrolyzers, we use an equivalence of 18 kWh of electricity to 1 gallon of gasoline, and 30 kWh of electricity to generate hydrogen equivalent to 1 gallon of diesel.

Table 3 provides equivalences in terms of how much electricity would be needed to produce hydrogen if the island's transportation energy consumption were to be converted to hydrogen.

Table 3. Electricity Required to Produce Hydrogen to Displace Transport Fuel Use

Transportation Fuel	Annual Fuel Usage	Electrolyzer Electricity Requirements	Electrical Capacity Required (at 80% capacity factor)
Gasoline	1,700,000 gallons	30 million kWh/year	4.4 MW
Diesel	2,180,000 gallons	50 million kWh/year	7.3 MW
TOTAL	n/a	80 million kWh/year	11.7 MW

SOLAR

Resource

The solar energy resource is characterized as either direct beam radiation or diffuse radiation. Direct Beam radiation is received from the sun without a change in direction, whereas diffuse radiation is received after it has been changed by reflection and scattering by gasses, moisture, and particulates in the atmosphere. A tracking system is required to capture the majority of direct beam radiation, whereas, it is not necessary for capturing the majority of diffuse radiation. Different collection system configurations are used for each, as will be described in more detail later. More generally, solar energy can be harnessed through one of three ways, direct conversion of the sunlight to electricity using Photovoltaics (PV), conversion of the heat contained in sunlight into electricity through Concentrating Solar Power (CSP) systems, and direct use of the heat in the sunlight through Solar Water Heating (SWH) systems.

Data Collection Approach and Sources

Local resource data for solar insolation was taken from NREL's *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, known as the "Redbook" database. The station closest to Vashon Island was Seattle. The database identifies the station as WBAN No: 24233, Latitude (N): 47.45, Longitude (W): 122.30, Elevation (m): 122, Pressure (mb): 1001
(Source: http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/)

In addition, a number of other reference sources was used for this analysis. They include:

- NREL, Resource Assessment Program
- NREL, PV Watts web site
- NREL, National Solar Radiation Data Base
- U.S. DOE, *A Consumer's Guide to Buying a Solar Electric System*
- U.S. DOE, *Solar Cell Electricity: Photovoltaics in Washington*
- U.S. DOE, EREN, Washington State Solar Resources
- U.S. DOE, EREN, CSP Technologies
- Sandia National Laboratory, *Concentrating Solar Power and Sunlab, Markets for Concentrating Solar Power*
- Washington State University, Current PV Topics
- Schatz Hydrogen Energy Center, *The Solar Hydrogen Cycle*
- Solar Washington Organization, Five Thousand Solar Rooftops by 2005 for Washington (20,000 by 2010).
- Solar Buzz, Solar Energy Industry Statistics - Costs
- Renewable Energy Policy Project, *Renewable Energy for California: Benefits, Status and Potential*

- SMUD, *Photovoltaic Economics and Markets: The Sacramento Municipal Utility District as a Case Study*
- Watt, M. et al, *Assessing the Potential for PV in Buildings*

Solar Resource Potential

Table 1 provides an estimate of the total resource available on the island, assuming the entire surface area could be covered with solar conversion equipment. This information is provided only as a point of reference, or upper limit, realizing that the actual useable quantities are much smaller.

Table 1 Estimated Maximum Energy Potential from the Solar Resource on Vashon Island

	Average Daily Insolation ($kWh/m^2/day$)	Available Area	Maximum Available Annual Energy (kWh/yr)
Maximum Potential			
Total Horizontal	3.8	90 sq. km. (entire island)	125 billion kWh/yr
Direct Normal	2.9	90 sq. km. (entire island)	95 billion kWh/yr

The average solar energy (based on data from Seattle) received at this site for a flat-plate collector at a fixed pitch equal to the site latitude – 15 degrees, which use the total horizontal insolation, was 3.8 kWh/m^2 per day, or 1,387 kWh/m^2 per year. Using that figure, the total amount of convertible energy from the entire 90 sq. km. (37 square miles) of the island (i.e. covering the entire island in PV modules) is 125 billion kWh per year. While this represents the maximum "technical" upper bound of the resource for the island, it does not include conversion efficiency and is obviously not practical from political, social, and land use perspectives.

The average direct normal insolation measured in Seattle is 2.9 $kWh/m^2/day$, which is assumed to be the same for Vashon Island, translates into 95 billion kWh per year for the island. Note that the total horizontal insolation amount includes the direct normal component. Because the total horizontal resource is significantly greater than the direct normal, it is unlikely that concentrating systems, with their added complexity and cost, would be attractive for Vashon Island. Only total horizontal resources will be discussed further in this report.

The actual useable solar resource on Vashon Island is clearly much smaller than the 125 billion kWh/year figure in Table 1. Developing an estimate of the practical potential becomes an exercise in estimating the numbers of systems that can be installed, given the available terrain, competing land uses, building rooftop availability, and the like. It must be emphasized that the three types of system mentioned earlier, all compete for access to the same solar resource – if the incident solar resource at a particular location is used for one application with one type of conversion hardware, it cannot be used for another. In the remainder of this section, we describe the potential area available for siting solar systems mounted on the ground and on residences.

Table 2 summarizes the resource available for systems that are ground-mounted. To reduce the “technical” upper bound of 125 billion kWh/year, PERI assumed that, due to land restrictions for developed areas, agricultural or forested lands, open space, parks, water areas, environmentally sensitive lands, etc., only 1%-5% of the land area could be suitable for siting PV. This yields a range of useable resource potential of 1-6 billion kWh/year.

Table 2 Estimated Energy Availability from Ground-Mounted PV on Vashon Island

	Available Area	Annual Energy	Assumptions
Total Potential	--	125 billion kWh/year	Total island potential -- See table 1
Exclusions	1-5%	--	Estimate based on island maps
Available Insolation	--	1-6 billion kWh/year	

We next estimated the amount of roof area available for roof-mounted systems. Based on U.S. Census data, we estimated that the 6100 homes on the island, with an average 1,613 ft^2 home, account for 915,000 m^2 of floor space. If half of all homes are single story and the other half two-story, we calculated the total residential footprint on the island to be 686,000 m^2. Assuming the pitch of the average roof is 25º, the south facing rooftop area of all residences is estimated to be 379,000 m^2. Two additional knock down factors were then applied. The first is a 20% factor to account for architectural and physical integration issues (multiple roof levels or angles which reduce total accessible area, setbacks for gutters, firm attach points, etc., incompatibilities with roofing materials, and obstructions on the roof such as chimneys, antennas, etc.) Second, a 50% knock down factor was applied to the total number of homes on the island to eliminate those where shading from the sun precludes the use of photovoltaics. The latter factor is quite uncertain, and potentially even larger. The actual factor would have to be determined through a site survey. However, making the 50% assumption, this left the usable south facing rooftop area at 151,000 m^2 for the island’s residences. Given these assumptions, the total Vashon Island residential solar potential is 0.21 billion kWh/year. It should be emphasized that this figure is resource potential, or incident solar radiation, and not resource converted to actual electrical output.

Table3 summarizes the residential (rooftop) siting results.

Table 3 Estimated Solar Potential from Residential Siting of PV on Vashon Island

	Available Area	Annual Energy	Available Annual Insolation (kWh/yr)
Total residential floorspace (sq m)	915,000 sq m	--	6100 homes; 1613 sq ft. average floorspace per home
Total Residential Footprint Area	686,000 sq m	--	50% one-story, 50% two-story
Total Residential Roof Area (south facing, tilted)	379,000 sq m	--	25 degree, 50% south-facing
Exclusion for Physical Integration Issues	302,000 sq m	--	20% excluded
Exclusion for Shading	151,000 sq m	--	50% excluded
Available Insolation	--	0.21 billion kWh/yr	3.8 kWh/m^2/day

Uncertainty

Uncertainty in the solar resource assessment calculations comes from a number of sources, including the solar insolation data, the use of the Seattle station to approximate Vashon Island conditions, the choice of the area covered by PV, and the efficiencies and capacity factors assumed for the technology. The uncertainty associated with the solar insolation data from the NREL Redbook is listed in that document as 8-11%. The use of the Seattle station to approximate insolation on Vashon Island introduces only a very small additional amount above that range due to the proximity of Vashon Island to Seattle. The choice of area covered by PV panels has the potential to introduce the largest amount of uncertainty. An assessment of access to insolation considering obstructions and shading on, and orientation of, rooftops would reduce this uncertainty greatly. In addition, typical roof top PV arrays are much less than 50% of the roof area. For instance, a 2.5 kW system requires approximately 20 square meters. The assumption of 13% overall system electrical efficiency, taken from the Renewable Energy Technology Characterizations report, represents current leading-edge technology. The efficiency obtained in actual installations will vary, depending on the type of PV cells used, and the time of installation, since efficiencies are projected to continue increasing in the future.

Applicable Solar Technologies

Photovoltaics (PV)

Photovoltaics convert sunlight directly into electricity and are commercially available using off-the-shelf hardware. However, photovoltaic conversion efficiencies are relatively low (about 13%), making this an expensive alternative even in areas where solar insolation is high. High initial costs (about $7-9 per watt, unsubsidized) are offset by a long life and low operating and maintenance costs. In addition, a number of incentives and value-added attributes can increase the economic attractiveness of PV systems. These include:

- Compensation for power at retail rates, since the systems can be sited on the customer-side of the meter
- Production-based tax credits or other tax relief
- Capital cost buy-down programs
- Bulk Purchasing programs
- Net-metering options and/or rate-based incentives
- Building credits for architectural applications
- Premiums for sale as "green power"

The vast majority of systems installed today are in flat plate configurations where multiple cells are mounted together to form a module. These systems are generally fixed in a single position, but can be mounted on structures that tilt toward the sun on a seasonal basis, or on structures that track the sun east to west over the course of the day. Most flat plate modules are either constructed from crystalline silicon cells, or from thin films using amorphous silicon. Other materials such as copper indium diselinide (CIS) and cadmium telluride also hold promise as potentially lower cost thin film PV materials.

Some 120 kW of PV systems are listed by the U.S. DOE as being installed and operating in Washington State. - Source: http://www.eren.doe.gov/state_energy/states_currentefforts.cfm?stat=WA. PV installations are modular and can range in size from a few kilowatts to megawatt-scale.

Photovoltaic concentrator systems, not to be confused with Concentrating Solar Power systems described below, use optical concentrators to focus direct beam solar radiation onto solar cells for conversion to electricity. This approach still converts the sunlight directly to electricity, but due to concentrating the light on a focused area this results in a higher amount of energy produced per unit of PV cell area, compared to flat plate systems. This additional efficiency is offset by higher costs for the concentrator lenses and associated structural equipment, and the need for a tracking system to keep the module aimed towards the sun and thereby capture the direct beam radiation. These systems are not considered appropriate for Vashon Island, given the low direct normal resource.

Concentrating Solar Power (CSP)

Concentrating solar power technologies, also know as Solar Thermal technologies, convert direct beam solar radiation into medium to high temperature heat, which is then converted to electrical energy using a heat engine or steam turbine. These technologies use a variety of methods to concentrate solar energy through use of mirrors or lenses. Three types of systems can be used for CSP electricity production:

1) A parabolic trough system uses trough-shaped mirrors to focus solar energy on a linear oil-filled receiver that collects heat to generate steam in order to power a steam turbine. Through hybridization, electricity can be generated using fossil fuel to power the same steam turbine when the sun is not shining. Typical plant sizes can range from 10 to 100 MWe, but can be larger.
2) A power tower system uses many large heliostats, or individually-tracking mirrors, to focus the solar energy onto a tower-mounted central receiver filled with a molten-salt working fluid that produces steam. The hot salt can store heat efficiently to allow power production even when the sun is not shining. Typical plant sizes can range from 30 to 200 MWe.
3) A dish/engine system uses a parabolic dish-shaped reflector to power a small Stirling or Brayton engine/generator mounted at the focus of the dish. Dishes are 2 to 25 kW in size, can be used individually or in small groups, and are easily hybridized with fossil fuel.

Although CSP trough technology has been applied commercially for a centralized, bulk power application, the power tower and dish designs are still in the demonstration phase. CSP is not generally economic in the U.S. without incentives, and then only in areas of high direct beam solar radiation levels (e.g. the Southwest U.S.). They are not considered appropriate for Vashon Island.

Solar Water Heating

Solar water heating technology uses the heat of the sun's rays to heat water for domestic and commercial uses. It is one of the simplest and least expensive renewable energy alternatives. The system uses a collector to convert the sun's energy to heat and an insulated tank to store hot water for use.

About 1.2 million solar water-heating systems have been installed in the U.S., the majority of which came in the 1970's and 1980's. Due to relatively low energy prices and other factors, there are only currently about 8,000 installations per year. More than 1,000 $MW_{thermal}$ of solar water heating systems are operating successfully in the U.S., generating over 3 million $MWh_{thermal}$ per year.

In 2000, 1.2 million new single-family homes were built in the United States. Even if only a small percentage of these new homes could be sited to enable proper orientation of solar water heating systems, this presents tens to hundreds of thousands of possible system installations annually.

Typical residential solar hot water systems use glazed flat-plate collectors combined with storage tanks to provide 40% to 70% of residential water heating requirements. Systems typically generate 2500 kWh of energy per year and cost between $1.00 and $2.00/Watt$_{thermal}$. Near-term RD&D goals are to reduce the costs of solar water heating systems to 4¢/kWh$_{thermal}$ from their current cost of 8¢/kWh$_{thermal}$ using polymer materials and manufacturing enhancements, which corresponds to a 50% reduction in capital cost. (Source for general information: U.S. Department of Energy, *Office of Power Technologies' Databook*, NREL, in production, February 2002.

Energy Production Estimates

Ground-Mounted PV - An estimate of the total energy production potential for ground-mounted PV systems on the island can be made by using the estimate of available land area described earlier and technology performance data described in Section 2. Data assumptions and approaches are described in Table 3.

Table 4 Estimated Energy Production from Ground-Mounting of PV on Vashon Island

	Annual Energy	Assumptions
Available Insolation	1-6 billion kWh/yr	See table 2
Energy Production	0.16-0.8 billion kWh/yr	@ 13% average efficiency
Equivalent Capacity	150-730 MW	@ 12.5% Capacity Factor

Rooftop-Mounting of PV – In addition to ground-mounted systems, this study estimates the potential for residential roof-mounted systems.
Table 4 provides a summary of the results of that analysis.

Table 5 Estimated Energy Production from Residential Siting of PV on Vashon Island

	Annual Energy	Available Annual Insolation (kWh/yr)
Available Insolation	0.21 billion kWh/yr	See table 3
Energy Production	0.03 billion kWh/yr	@ 13% average efficiency
Equivalent Capacity	25 MW	@ 12.5% Capacity Factor

Domestic Water Heating – PERI also conducted an assessment for the potential of solar hot water heaters (SWH) on Vashon Island. However, it should be noted that PV and SWH compete for the same resource, and so the use of one of these technologies, would reduce the potential of the other. Therefore, a choice of the mix of these systems would have to be based on economic, social and other factors.

PERI assumed the energy conversion efficiency of SWH systems is 19.5% and the capacity factor is 30%. We then calculated energy and capacity potential by combining these figures with the same housing/roof space scenarios as reported in the PV assessment section above. The estimated available

Table 6 Estimated Energy Production from Residential Siting of Water Heating Systems on Vashon Island

	Annual Energy	Assumptions
Available Insolation	0.21 billion $kWh_{thermal}$/yr	See table 3
Energy Production	0.04 billion $kWh_{thermal}$/yr	@ 19.5% average efficiency
Equivalent Capacity	15.6 $MW_{thermal}$	@ 30% Capacity Factor

Table 6 provides a summary of the estimated potential for solar energy production on Vashon Island. Again, it is important to note that the residential PV and residential DHW numbers should be considered mutually exclusive since they vie for the same rooftop area.

Table 7 Estimated Energy Production from Solar on Vashon Island

	Annual Energy	Equivalent Capacity
Ground-Mount PV	0.16-0.8 billion kWh/yr	150-7300 MW
Rooftop PV	0.03 billion kWh/yr	25 MW
	Or	Or
Solar DHW	0.04 billion $kWh_{thermal}$/yr	15.6 $MW_{thermal}$

WIND

Resource

Wind energy potential on Vashon Island is limited due to a relatively poor wind resource and the need to place turbines on exposed terrain while avoiding densely populated areas on the Island. Wind energy resource potential was estimated based on large state-wide and regional scale studies and numerous wind measurement stations although none of the measurements were conducted on the Island.

Wind flow in the central part of Puget Sound around Seattle and Vashon Island appears to be shielded by the Olympic Mountains from the predominate Northwest winds. The estimated wind power class for region including Vashon Island is Wind Power Class 2, with an average of 5.6 to 6.4 m/s measured at 50 m height above the ground, on a scale of 1 to 7, with 1 being poor and 7 excellent [Reference 1].

Wind Data Collection Approach and Sources

Initial estimates of wind resource were obtained from the U.S. Department of Energy.

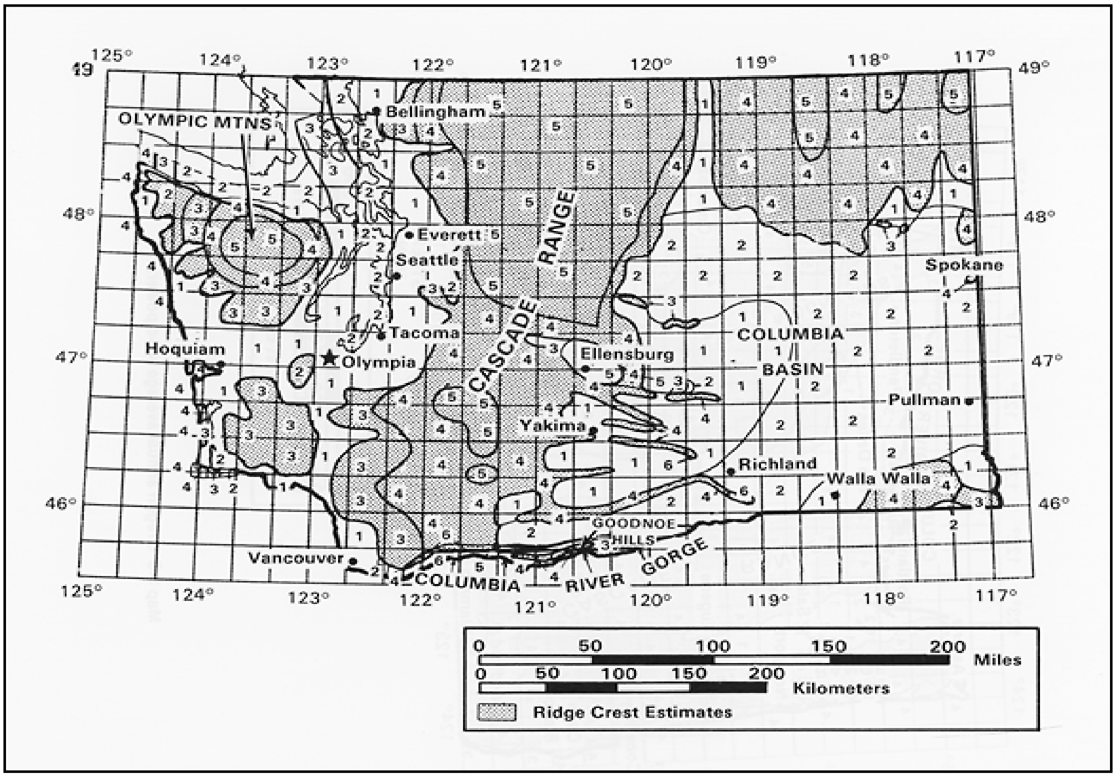


Figure 1. Washington State Average Annual Wind Power

Wind Energy Resource Atlas (See Figure 1).

This data has been supplemented by more detailed wind mapping studies conducted using new high-resolution wind flow models and Geographic Information System (GIS). This wind mapping project is coordinated by NW Sustainable Energy for Economic Development (NWSEED) and the NW Cooperative Development Center (NWCDC) and sponsored by the National Renewable Energy Laboratory (NREL), the Bonneville Power Administration (BPA), and numerous other organizations in the Northwest. The results of these studies are shown in Figure 2., [http://www.windpowermaps.org] and generally agree with the earlier results.

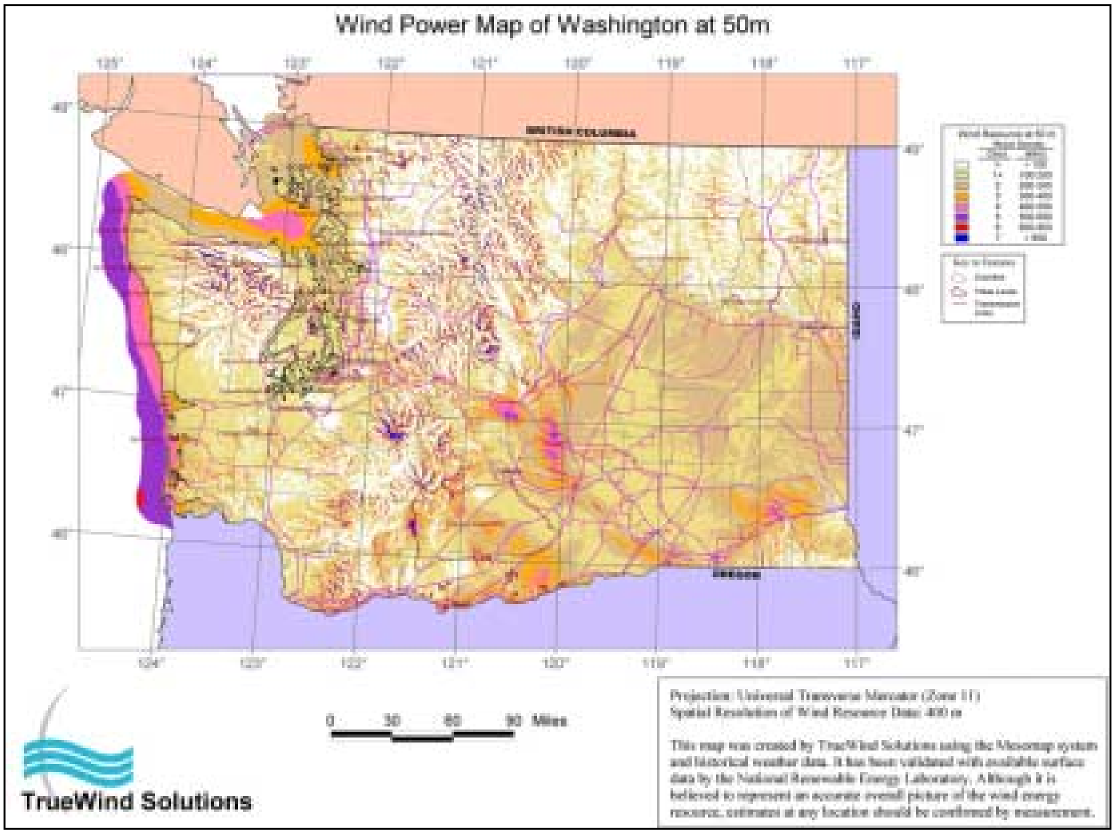


Figure 2. Detailed Mapping of Resources for Washington State

Additional detailed wind resource data collection was conducted by PERI and IERE, including wind data records from local ferry boats. Of the data sources examined, the summarized data from SEATAC airport [2] is considered to be the most reliable and appropriate for estimating the wind resource on Vashon. The measurements at the airport recorded at 137m elevation, with the anemometer 33.5m height above the ground, over a 10 year period, showed promising results. The following seasonal averages showed little variation, but with somewhat better wind in colder seasons when electricity usage for space heating is highest.

Winter	5.3 m/s
Spring	5.2
Summer	4.4
Fall	4.6

The annual average at SEATAC was reported as 4.9 m/s at 33.5m height and 5.2 m/s adjusted to 50m height.

Data for the Vashon Island National Climatic Data Center (NCDC) station was examined. The station operated from 6/1948 through 2/1955. Detailed records for the last three years of operation revealed that climatological records included temperature and precipitation but unfortunately no wind measurements.

Another consideration on wind resource assessment is the dense forests on much of the island. In most areas it would be necessary employ turbines with tall, 80m, towers to reach the free air steam above the tree canopy. Wind speed at hub height on these turbines is assumed to be similar to wind speed at the standard height of 50m. Considering the tall dense vegetation and hilly terrain effects, the wind speeds in the class-2 wind resource area are estimated to be 5 to 6m/s at the turbine hub height.

Wind Resource Potential

Wind resource potential on Vashon/Maury Islands should not be completely discounted. Although there are no wind measurements on the island and the regional the wind data sources indicate there are only moderate resources, there may be local terrain effects that could potentially improve the resource estimates. Terrain on the Island is generally more than 100 m above water level. There is high ground on many areas along the central backbone of Vashon and the high escarpment rising to 145 m along the Southeast shore of Maury Island provide potentially useful sites. Using turbines with tall towers, up to 80m, it may be possible to harvest winds that are enhanced by upper airflows that are difficult to detect and estimate from ground level.

Although it initially appears that, at best, Vashon Island has a class-2 wind power resource at most sites, collecting wind data on the Islands is very important. It is possible that sites with a higher wind power class sites are available, due to the local topography and terrain-channeling effects. Wind measurements at several locations and at three levels above the ground are necessary to verify initial estimates and to accurately project turbine energy production.

From Geological Service and DeLorme (commercial mapping software) topographic data, preliminary turbine sites were determined. Besides selecting good sites based on the terrain, it is necessary to avoid locating machines near existing homes and businesses. The normal clearance is 500 m, but in some cases 200 m may be used with permission. The primary reason for the setback is due to noise produced by the turbines. With new machines this is not much of a problem, especially when the landowner is receiving revenues from the energy production.

From preliminary map studies and terrain analysis, nine potential sites have been identified that could possibly accommodate about twenty-eight 1.5 MW turbines for a total of 42.0 MW. More possible sites were identified, but it is anticipated that various land use issues and restrictions will eliminate some sites from consideration. Upon closer inspection, it is also possible that additional sites may be available, and possibly be preferable to those listed below. Detailed siting studies are needed to determine exact locations for turbine. However, the identified sites were judged to show high relative potential, based on the following criteria:

1. High ground
2. Open or exposed terrain
3. Lack of planning/environmental restrictions

4. Construction access and roads
5. Proximity to the grid
6. Favorable soil conditions

The nine tentative site locations were refined using United States Geological Service (USGS) topographic maps. The nine potential sites are listed in Table 1 and the locations of potential turbine clusters and surrounding terrain are shown in Figure 3. The land area and number of turbines that could fit in the potential sites are shown in the Table along with expected reductions in usable sites, due to siting issues, set back requirements from buildings, and from competing land uses. These issues are expected to limit the number of turbines to about 28 that could be installed. Each turbine occupies about 1/3 acre of land and the surrounding land can be used for agriculture or other compatible land uses. As mentioned previously, in forested areas the turbines can be mounted on tall towers that extend above the tree canopy. At sites like the top of the escarpment along the south shore of Maury Island, shorter towers can be used, reducing cost and using the potential terrain induced wind acceleration.

Power lines will need to be built connecting the turbine clusters to one of the substations on the island. The turbines on Vashon Island are to be connected to substation that is centrally located on the island. See Figure 3. Estimated line lengths are shown in Table 1, and are included in wind plant cost estimates. Substations and transmission lines are assumed to have sufficient capacity to carry the wind plant energy output. A detailed project feasibility study electrical power system stability and power quality analysis.

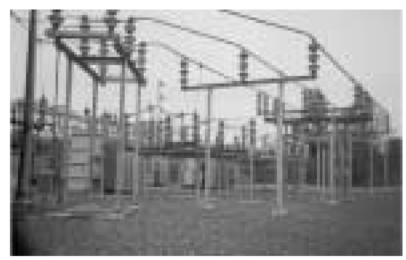


Figure 3. Substation located near the town of Vashon

Figure 4. Terrain Near Potential Wind Turbine Sites

Table 1. Potential Turbine Cluster Locations.

	North Latitude (Degrees-Minutes-Seconds)	West Longitude (Degrees-Minutes-Seconds)	Site Length (km)	Site Width (km)	Site Area (km^2)	Power Line Length (km)	Number of Turbines	
Area A	47-29-30	122-28-25	3.0	0.5	1.50	2.0	7	
Area B	47-27-30	122-29-10	1.5	0.5	0.75	0.7	3	
Area C	47-26-20	122-29-00	1.5	2.0	3.00	0	14	
Area D	47-24-15	122-29-20	1.5	1.5	2.25	2.0	6	
Area E	47-24-00	122-29-40	1.8	1.2	2.16	0.2	6	
Area F	47-21-30	122-30-40	2.0	1.0	2.00	3.0	7	
Area G	47-22-15	122-24-30	2.7	0.5	1.35	1.0	6	
Area H	47-22-05	122-26-25	1.8	0.5	0.90	0.5	4	
Area I	47-21-00	122-27-25	1.1	0.5	0.55	1.0	3	
						10.4	56	Total
							-28	Sites likely to be unavailable due to land use and setback restrictions (50% reduction)
							28	Number of Turbines

The 28 potential turbine sites will be identified from an initial set of up to 56 potential turbine sites show on Figure 4. Spacing of the turbines is, three rotor diameters (approximately 230m) within rows facing the primary wind direction, which is South-Southwest, and five diameters (approximately 400m) between rows of machines or where the terrain dictates placing turbines in the wake of upwind machines. This turbine spacing is used in Area C in Figure 4. In other areas, terrain shape and orientation dictate spacing and placement. The later is the case along the escarpment on the Southeast shore of Maury Island. Of the 56 potential turbine sites there are likely to be some sites that are not made available by the land-owner or are otherwise unsuitable for terrain, road access, up wind clearance, or other reasons. A 50% site attrition rate, to allow for these limitations, is considered reasonable for an area as built-up and constrained as Vashon//Maury Islands.

Figure 4. Potential Turbine Locations

Applicable Technologies

The GE Wind, EW 1.5/77 turbine, pictured in Figure 5, was chosen for the base case for estimating energy production potential, although other machines will be considered for cost estimations later in the study. This turbine, with the 77m rotor, is currently the largest rotor that is commercially available in the United States, is well-suited to the low wind regime found onVashon Island.
The GE Wind Energy 1.5 MW Series wind turbines are active yaw and pitch regulated machines with power/torque control capability. The rotor utilizes blade pitch regulation and variable speed operation to achieve optimum power output. The 1.5 MW Series wind turbines also feature a bedplate drivetrain design where all nacelle components are joined on a common structure. The nacelle is lined with sound insulating foam and the generator and gearbox are supported by elastomeric elements. The GE Wind Energy 1.5 MW Series technology is designed in accordance with the International Electrotechnical Committee 1400-1 Standard and Germanisher Lloyd's Rules and Regulations for wind turbine design.

Figure 5. GE Wind Energy 1.5 MW Wind Turbines

Energy Production Estimates

Detailed power and performance curves for the GE 1.5/77 were obtained from the manufacturer (Figure 6). At a 5 m/s annual average wind speed site (measured at turbine hub height) this machine will produce 2.1 million kWh annually. Some of the potential sites may see higher winds, other lower winds, so this is considered a reasonable average for this turbine on Vashon Island. Assuming this energy output for all turbines, total annual energy production from all 28 turbines would be almost 60 million kWh. See Table 2 for this data.

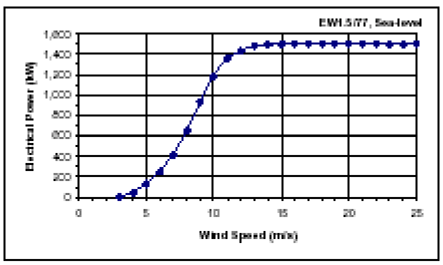


Figure 6. GE Wind Turbine Power Curve

Table 2. Estimated Energy Production from Wind Turbines on Vashon Island

	Values	Assumption
Average Wind Speed	5.0 to 6.0 m/s at 50 m height	Estimate from currently available wind maps
Single Turbine	2.1 to 3.25 million kWh/year	Estimate from GE Wind Energy Power Curve – assuming 7% losses (3% for availability, 2% for transformers and lines, and 2% for blade soiling
Annual Energy Production	58.8 to 91million kWh/year	28 turbines
Total Rated Capacity	42 MW	16 to 25% capacity factor
Operation & Maintenance	$0.01 to $0.015/kWh	Including labor, parts, periodic overhaul, insurance and taxes

Environmental Considerations

Wind energy is generally considered to be environmentally benign when compared to fossil-fuel or nuclear power plants. However, there are some important issues that need to be considered in planning wind energy projects. The most important issues are: bird impacts, visual and view considerations, roads and other construction, air craft flight patterns, noise and possibly television interference. These issues or well understood and are predictable.

Bird strikes have occurred in some of the wind plants in California. It is not recommended to locate wind plants areas with large populations of protected species or in bird fly ways. Observations during recent visits, indicate that the narrow isthmus connecting Maury and Vashon Islands is a popular bird fly way. Consequently no turbine sites are proposed in that area. The local Audubon groups can assist in determining additional areas that should be considered for exclusion.

Noise was a problem with some early turbine designs. Improved turbine sound insulation and better aerodynamic blade designs have all but eliminated the noise problem. New machines produce sound pressure levels at or below 45 dB(A) at the project property boundary line. This sound pressure level is comparable to nighttime limits for neighborhoods and educational institutions.

Television interference can occur near the turbines if old style outdoor antennas are used. In fringe areas with weak signal levels, a reflected signal from the blades can, in some cases, produce a flicker in the picture. These interference zones are near the turbines and can be eliminated by rebroadcasting the video signal on a different channel. Cable TV and satellite dish receives are not affected.

Significant uncertainties exist with regard to the wind energy production estimates. The largest area of uncertainty is the wind resource estimates. Measurements on the Island are needed to improve the accuracy of the estimates. It is possible that the energy production may be better than current estimates, due to terrain effects and because of the generation elevation of the potential sites. Issues relating to aesthetics, avian protection, land availability, environmental restrictions, and grid access, will need to be studied to establish the viability of the potential wind power plant installations.

References:

1. Wind Energy Resource Atlas: Volume 1- The Northwest Region, U.S. Department of Energy, Pacific Northwest Laboratory, PNL-3195 WERA-1, April 1980.
2. Wind Energy Resource Atlas of the United States, U.S. Department of Energy, Pacific Northwest Laboratory, DOE/CH10094-4, March 1987.
3. Northwest Sustainable Energy for Economic Development (SEED), http://www.windpowermaps.org/, May 2002.
4. http://www.gepower.com/wind/en_us/ge_wind_energy/products/15/15data.html

BIOMASS

Resource

Table 1 provides an overview of biomass resources available on Vashon Island. The estimated quantities for each resource were provided by The Institute for Environmental Research and Education (IERE). Moisture ranges, except for septage which also was provided by IERE, were obtained from various sources as noted below. The moisture content of biomass varies widely depending on the source, and determines the availability of solid materials that can be potentially converted to energy. The last column in table 1 shows the range of solid residues, in pounds per year, for each biomass source that could potentially be converted to energy.

Table 1 – Vashon Island Biomass Resources

Biomass Sources	Quantity	Moisture Range (wt %)	Solid Residue Range (lb/yr)
Sewage Sludge (biosolids)	90,000 gal/yr	90 – 97[1]	22,680 -75,600
Septage (biosolids)	5,000,000 gal/yr	98	840,000
Fruit Pulp	18 ton/yr	20 – 55[2]	16,200 - 28,800
Okara	1,200 ton/yr	75 - 85[6]	360,000 – 600,400
Wood Waste (Soft Wood):			

Maximum Minimum	117,00 ton/yr 1,170 ton/yr	30 – 60[1] 30 – 60[1]	9,360,000 - 16,380,000 936,000 - 1,638,000
Fire Wood	2,150 cord/yr	30 – 60[3]	2,580,000 – 4,515,000
Construction Waste	2,000 ton/yr	12 – 17[4]	3,320,000 - 3,520,000
MSW	8,449 ton/yr	12 – 32[5]	11,490,640 - 14,870,240
Landfill Gas, CH_4	1,740 cu ft/hr[7]	n/a	15.24 million cu ft/yr

[1] Donald L. Klass, *Biomass for Renewable Energy, Fuels, and Chemicals,* Academic Press, 1998.
[2] Assumed same moisture content as bagasse. Bagasse moisture content was obtained from Reference 1.
[3] Assumed to be the same as soft wood.
[4] *Wood Handbook,* USDA Forest Products Laboratory, 1999.
[5] *Encyclopedia of Chemical Technology* – Fuels from Waste, Vol. 11.
[6] www.ag.uiuc.edu/~intsoy/soymilk.htm (University of Illinois at Urbana-Champaign)
[7] Methane portion of total landfill gas flow (estimated by IERE at 10%).

Note: 1.0 cord of wood = 3000 lb (approximately). Density of sludge is assumed to be 8.4 lb per gal.

Data Collection Approach and Sources

Estimates of the available quantities of each biomass resource were provided by IERE. Other data was required to adequately characterize the resources to allow an analysis of their energy potential. Additional data includes moisture content, and heating value of the biomass sources. In addition, the data collection effort helped identify the most current data on available biomass conversion technology and their applicability to the Vashon Island-specific resource base.

An Internet search and a more conventional literature search were conducted to update the data already held in-house. These sources included:

- *Wood Handbook*, USDA Forest Products Laboratory, Madison, WI, 1999.
- *Encyclopedia of Chemical Technology – Fuels from Waste, Vol. 11.*

- Donald L. Klass, *Biomass for Renewable Energy, Fuels, and Chemicals,* Academic Press, 1998.
- Donald L. Klass and G.H. Emert, *Fuels from Biomass and Waste,* Ann Arbor Science, 1981.
- *Research in Thermochemical Biomass Conversion,* Elsevier Applied Science, 1988.
- *Handbook of Water and Wastewater Treatment Technologies,* N. P. Cheremisinoff, Butterworth Heinemann, 2002.
- *Data Summary of Municipal Solid Waste Management Alternatives,* SRI International, 1992.
- *Savannah River Resource Recovery Project,* confidential data.
- *A Technology Development Consortium for The Three Rivers Waste Management Center, METC, August 29, 1994.*
- *www-unix.oit.umass.edu/~ansci332/images/okaracompare.jpg*
- *www.ag.uiuc.edu/~intsoy/extrusn.htm*
- www.ag.uiuc,edu/~*intsoy/soymilk.htm*
- *www.eren.doe.gov/consmumerinfo/refbrief/ab5.html*
- *The Soybean Processing Decision,* Gerald Plato, www.ers.usda.gov
- *www.urec.net/users/pammark/process.htm*
- *www.iita.org/info/ph/mar974.htm*
- *www.cooknaturally.com/glossary/analysi.htm*
- *Update of Hydrogen from Biomass – Determination of the Delivered Cost of Hydrogen,* NREL, April 2000(Revised July 2001)
- *Gasification: The Enabling Technology,* Renewable Energy World, September-October 2000.
- *Small-Scale Biomass Gasifiers for Heat and Power – Global Review,* H.Stassen, World Bank, 1995.
- *Waste-to-Energy Installations,* (Steam, Chapter 27), Babcock & Wilcox.
- *Statistical Analysis – Single Family Residential Waste Stream,* personal communications, August 1994.
- *Characterization of Municipal Solid Waste in the United States: 1994 update, EPA, November 1994.*
- *PulseEnhanced™Steam Reforming for Biomass Power Generation,* Manufacturing and Technology Conversion International, Inc.
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- *BG-System™,* BG Technologies USA Inc.
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- *The Next Generation of Waste-to-Energy,* Solid Waste Technologies, Sept/Oct 1997.
- *Sewage Sludge As A Feedstock For Gasification,* Mathew A. McMahon, R. Khan, and M. Amrhein, Texaco.
- www.epa.gov/outreach/agstar/librar/biocycle3.htm
- www.epa.gov/outreach/agstar/operation/index.htm

- www.epa.gov/outreach/tech/developers.html
- *Use of Public Lands to Fuel Biomass Electric Power Production*, William H. Carlson, National Conference on Opportunities to Expand Renewable Energy on Public Lands, November 2001.

Biomass Resource Potential

Estimates of the energy content for each biomass resource stream are provided in Table 2. As the table shows, the available energy is the product of the weight of the solid residues and the heating value of each different biomass resources. The heating value of biomass is affected by the ash content and the chemical composition of the biomass. Different components in the biomass have different heats of combustion because of their different chemical structures and carbon content. As carbon content increases and the degree of oxygenation is reduced, the molecule structures become more hydrocarbon-like and the heating value increases. Typical organic components of woody type biomass and municipal solid waste (MSW) are celluloses, hemicelluloses, lignins and crude protein.

Table 2 Estimated Energy Content of Biomass Sources in Vashon Island

Biomass Sources	Solid Residue Range (lb/yr)	Heating Value (Btu/lb)	Available Energy Feedstocks (MMBtu/yr)
Swage Sludge (biosolids)	22,680 - 75,600	8,217[1]	186 - 621
Septage (biosolids)	840,000	8,217[1]	6,902
Fruit Pulp,	16,200 - 28,800	3,600[2]	58 - 104
Okara	360,000 - 600,000	3,600[2]	1,296 - 2,160
Wood Waste (Soft Wood)	936,000 - 16,380,000	8,733[1]	8,174 - 143,048
Fire Wood	2,580,000 - 4,515,000	8,733[3]	22,531 - 39,429
Construction Waste	3,320,000 - 3,520,000	8,733[3]	28,994 - 30,740
MSW	11,490,640 - 14,870,240	4,830[4]	55,500 - 71,823
Landfill Gas, CH_4	15.24 million cu ft/yr	1000 Btu/ft^3	15,242

[1] Donald L. Klass, *Biomass for Renewable Energy, Fuels, and Chemicals,* Academic Press, 1998.

[2] Assumed a heating value equal to that of bagasse. Bagasse heating value was obtained from *Fuels from Biomass and Waste* by Donald L. Klass and G.H. Emert, , Ann Arbor Science, 1981.

[3] Assumed to be soft wood.
[4] *Encyclopedia of Chemical Technology – Fuels from Waste, Vol. 11.*

Resource Characteristics

As noted earlier, the physical and chemical characteristics of biomass resources vary widely. This variation can be among different samples of what would nominally seem to be same resource. Variations could occur from one region to another, especially for waste products. This wide variation sometimes makes it difficult to identify a "typical" value to use in the analysis. When selecting a single value is problematic, this report uses ranges of likely values. The section provides details about the assumptions embedded in the values in Tables 1 and 2.

Sewage and Septage: For example the suspended solid particles in raw sewage is reported to range from 100 to 350 mg/l (http://ohioline.osu.edu/aex-fact/0768.html) while that of septic tank sludge is 310 to 93,378 mg/l (EPA 832-f-99-068, September 1999).

Okara: Okara, or the residue from the commercial processing of soybean, contains 8% protein on wet basis, or about 40% on a dry basis (www.ag.uiuc.edu/~intsoy/soymilk.htm). Thus, the wet Okara contains about 80% moisture.

Wood and Wood Wastes: Most of the wood and wood waste sources in the northwest of the U.S. come from softwood. Because the moisture content of green biomass can be quite high and can negatively impact the conversion of biomass to energy processes, pre-drying may be needed. Moisture content of 10 to 20% is usually preferred. The construction lumber is generally kiln dried to ensure uniform moisture among different pieces. Dry lumber as defined in the American Softwood Lumber Standard, has maximum moisture of 19% (*Wood Handbook*, Forest Products Laboratory, 1999). However, wood exposed to outdoor atmosphere reaches a moisture equilibrium content depending on the humidity and temperature. The equilibrium moisture content of exposed wood (construction lumber) in the Seattle-Tacoma area of Washington ranges from a low of about 12% in July to a high of about 17% in December.

Municipal Solid Waste (MSW): The characteristics of MSW can vary widely, depending on local economy, industry, recycling and sorting waste collection habits and many other factors. Table 3 illustrates the wide range of MSW feedstock composition, which, in turn, implies a wide range in moisture content and heating values.

Table 3. MSW Composition[1]

MSW Component	**Wt% Range**
Food waste	9.1 –36.0
Yard Waste	0.3 – 41.5

MSW Component	Wt% Range
Glass	6.0 – 23.2
Metal	5.9 – 14.5
Paper	21.1 – 53.3
Plastic and textiles	0.0 – 5.2
Wood, leather, and rubber	0.0 – 2.1
Other	0.0 –9.0

[1] *Encyclopedia of Chemical Technology – Fuels from Waste, Vol. 11*

Although Table 2 includes an estimate of the heating value of Vashon Island's MSW resources, further data on the MSW feedstock stream could help refine that and improve the estimate of the island's MSW potential.

Landfill Gas: Data provide by IERE indicates that the landfill gas methane content is 10% of the total gas flow.

Resource Uncertainties

Uncertainties associated with the availability and suitability of biomass resources for energy production are primarily due to their varying moisture content, and to a lesser degree to their chemical composition and heating value. As the moisture content of biomass increases the efficiency of thermal conversion process decreases and at some point more energy may have to be spent to dry the biomass than it contains. Microbial conversion processes do not require drying of biomass, however they are not as efficient as thermal processes. These uncertainties can be reduced by conducting a detailed chemical and physical analysis of the biomass sources.

Applicable Technologies

Biomass conversion processes can be divided into two broad categories: microbial conversion and thermal conversion. Anaerobic digestion is the most advanced and widely used microbial biomass conversion technology.

The thermal biomass process can be divided into four primary groups: combustion, pyrolysis, gasification, and steam reformation processes. Each technology, depending on the reactor design, can be further categorized as a fixed, bubbling-bed, circulating-bed, or entrained bed system. Gasifiers can be further classified as high- or low-pressure and air-blown or oxygen-blown. Steam reformation processes use indirect heating methods and either bubbling or circulating fluidized bed reactors. Each of these configurations is best suited to feedstock streams with certain characteristics.

Combustion processes are used to generate steam for power generation, heating or drying. Pyrolysis of biomass feedstock produces bio-oil that can be used as a fuel additive or that can be steam-reformed to generate synthesis gas for power generation or to produce hydrogen.

Air blown gasifiers produce a low Btu gas while oxygen-blown gasifiers produce a high Btu gas. However, due to the high cost of oxygen-generation units, oxygen-blown gasifiers are generally high pressure and not economical at small sizes. Steam reformation of biomass generates a medium Btu gas. The product gas from a gasifier can be used in a steam turbine to generate steam or, after further processing, can generate hydrogen. The only exception is the product gas from air-blown gasifiers. The synthesis gas from air-blown gasifiers contains a large amount of nitrogen, which makes it less desirable for hydrogen production.

As noted earlier, it is not necessary to reduce the water content of a high-moisture or wet biomass feedstock for microbial conversion processes (i.e., digesters). However, efficiency of the thermal conversion processes such as combustion, gasification, or stream reformation are affected by the moisture content of biomass – the lower the moisture content, the larger the amount of energy needed to remove the water. The fluid-bed combustors are generally designed to operate with biomass fuels having a moisture content of up to 50%. Optimum moisture content for the efficient gasification of biomass is 15%, although gasification processes have satisfactorily converted feedstock containing up to 35% moisture (Donald L. Klass, *Biomass for Renewable Energy, Fuels, and Chemicals*, Academic Press, 1998). In steam reformation processes where steam is a reactant, water content in the feedstock can be beneficial.

Technology Specifically Suited to Vashon Island's Resources

The available biomass resources at Vashon Island contain a wide range of moisture, as indicated in Table 1.

Sewage and Septage: Highly wet biomass sources (i.e, sewage and septic sludge) are most likely candidates for microbial conversion processes. A well-operated digester produces about 0.8 to 1.1 m^3 of biogas per kg of volatile solids (organic material constitutes about 73% to 77% of dry solids) destroyed. However, it should be noted that about 60% of the produced gas is used to heat the digester (Donald L. Klass, *Biomass for Renewable Energy, Fuels, and Chemicals*, Academic Press, 1998) leaving only about 40% of the biogas for power generation or hydrogen production. Assuming that in average 50% of the organic material is converted to biogas, then one can calculate the biogas production. For example, the biogas production potential from septage can be calculated as follows:

Total solids = 840,000 lbs per year (from Table 1)
Total organic solids = 840,000 * ((73 + 77)/2/100)
Total organic solids = 630,000 lbs per year
At 50% conversion, organic solids converted to biogas = 315,000 lbs per year
= 142,881 kg/yr
Thus, biogas produced = 142,881 * ((0.8 +1.10)/2) = 135,737 m^3 per year.

Assuming 60% of the biogas is used for heating the digester then annually 54,344 m^3 or 1,918,870 ft^3 is available for power generation or hydrogen production. Methane constitutes about 68% (volume) of the biogas. The remainder is mostly CO_2. The heating value of the biogas is about 680 Btu per ft^3. Assuming a heat rate of 9450 Btu/kWh (HHV basis, *Characterization of DG Technologies*, PERI) for a gas turbine system, the expected annual power generation is 138,078 kWh (1,918,870*680/9,450).

Landfill Gas: At 10%, the methane content of the landfill gas appears to be too low for power generation or hydrogen production. Methane gas content in excess of 50% is reported on a consistent basis (Donald L. Klass and G.H. Emert, *Fuels from Biomass and Waste*, Ann Arbor Science, 1981).

MSW, Biomass Residues, Wood and Wood Waste: Two options may be considered for potential conversion of the remaining biomass resources. They are pyrrolysis and steam reformation processes.
Pyrrolysis is the decomposition of biomass by indirect heating. The pyrrolysis products are char, gases, light and heavy liquids, and water in varying amounts depending on the feed composition, fuel particle size, heating rate, temperature, reaction time, and reactor type. Higher temperatures and longer residence times (or reaction times) promote gas production, while higher char yield results from lower temperatures and slow heating rates. High temperature pyrrolysis is still in the early development stages. Low temperature pyrrolysis is practiced at some places in the U.S., at small scale, for production of bio-fuel as an additive to diesel fuel. The selling price of the bio-fuel is about one dollar higher than the cost of diesel fuel and produced on a pre-ordered, pre-paid basis (NPR, May 2002). The pyrrolysis liquid accounts for 45-50% (weight), char for about 33–37 %, and the gases for 16-17% of the pyrrolysis products on dry basis. As indicated earlier, the product yields are highly dependent on the feed composition, however assuming a liquid yield of 60% (on dry basis) for a low temperature pyrrolysis one can estimate the liquid production for Vashon Island to range from a low of 4,327,320 lbs per year to a high of 15,026,280 lbs per year. This value is estimated by summing the solid residues from fruit pulp, Okara, wood waste, firewood, construction waste, and MSW and multiplying that sum by 60%. The gas and char products could be used to generate the heat required for pyrrolysis reactions (about 1000 ^{B}F).

Another option is to steam reform the available biomass (solid residues from fruit pulp, Okara, wood waste, firewood, construction waste, and MSW). Steam reforming converts almost all of the carbonaceous material in the feed to a medium Btu (350-500 Btu/ft^3) gas product. The product gas contains mostly hydrogen, carbon monoxide and carbon dioxide. It should be noted that not all of the energy content of biomass is used to produce steam as well as heating the feed material to the steam reformation temperature (about 1500 ^{B}F). The carbon conversion can be as high as 99% and resulting in a gas yield of over 100% of the dry solid feed. Two processes, PulseEnhanced™ Steam reforming and SilvaGas™ Biomass Gasification are currently at demonstration stages for biomass feedstocks. The PulseEnhanced™ Steam reforming is being offered, however, on commercial basis for applications for black liquor recover in the pulp and paper industry.

Assuming a product gas yield of 85% and the sum of solid residue for fruit pulp, Okara, wood waste, firewood, construction waste, and MSW one can estimate the gas production to range from 6,130,370 to 21,287,230 lb per year (or 383,148 to 1,330,452 moles per year assuming a gas molecular weight of about 16 lbs per mole). That is 137,550,132 to 477,632,268 ft^3 per year. At an average heating value of 425 Btu/ft^3 ((350 +500)/2) for the product gas, the annual available Btu for power generation ranges from 58,458 $x10^6$ to 202,993 $x10^6$ Btu. Assuming an average heat rate of 9,450 Btu/kWh for a gas turbine system, the estimated power generation potential rages from 6,186,032 to 21,480,740 kWh annually.

Energy Production Estimates

Table 4 summarizes the findings of the biomass analysis for Vashon Island.

Table 4. Energy Production Estimates

Biomass Resource	Energy
Sewage	4,000-12,000 kWh/yr
Septage	0.1 million kWh/yr
Landfill Gas	No apparent value
MSW, Biomass Residues, Wood, and Wood Waste	4-15 million lb liquid/yr or 6-21 million kWh/yr

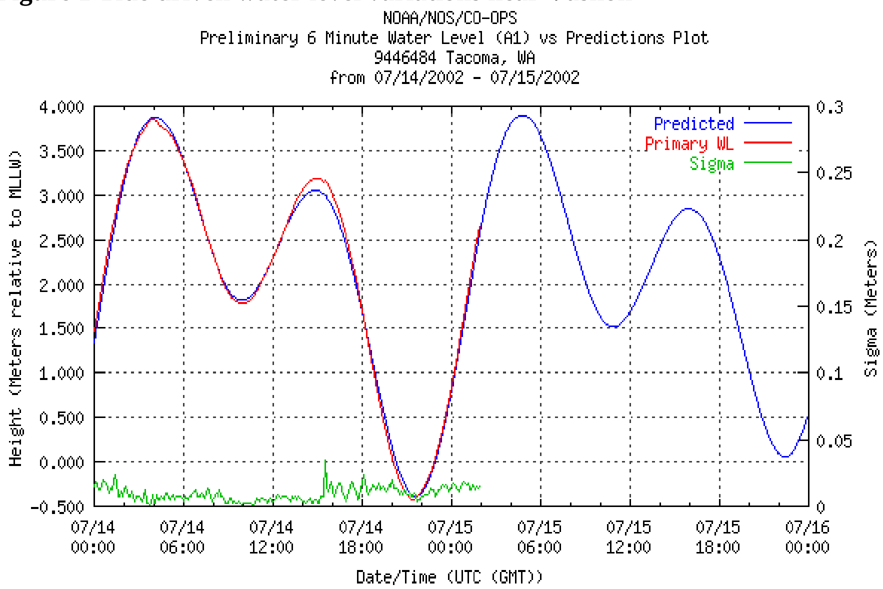
TIDAL ENERGY

Resource

There is substantial tidal flow around Vashon Island due to the average diurnal water level variation. National Ocean and Atmospheric Administration (NOAA) data show a typical water level variation at Tacoma of over 4.0 m. See Figure 1. Tidal flow through the Colvos Passage on the west side of Vashon Island has a unique unidirectional pattern flowing only in a northern direction. This unusual tidal flow pattern in the Passage is probably caused by the ebbing current from the Narrows, west of Tacoma, that is naturally directed into the Passage by the land formation at Point Defiance. Flood tidal flow in East Passage around Vashon Island, follows a more typical reversing pattern. Flow in Colvos Passage may also be affected by the time difference between the ebb tidal induced currents flowing first from Bremerton area past Blake Island, north of Vashon

Island and then later from Tacoma. Flow patterns in the region have been studied and documented in and report titled "Current Structure in Elliot Bay Washington: 1977-1996" Reference [1].

Figure 1 Tide driven water level variations near Vashon



Data Collection, Approach and Sources

Tidal flow direction and velocity data were provided by IERE from several sources. The hourly current flow rates were obtained from local tidal flow charts [2]. Flow rates were the highest in the North end of the Colvos Channel, and off Cove Point in the vicinity of the under-sea power cable crossing. Figure 2 shows the maximum predicted flow rate of 1.5 knots that occurs in coincidence with maximum ebb current at Tacoma Narrows. The current is over 1 knot for a six-hour period around the peak and some of that energy could be captured from the flow. For the next six hours the current ranges from "weak and variable," to 0.6 knots, which is too low to provide usable power.

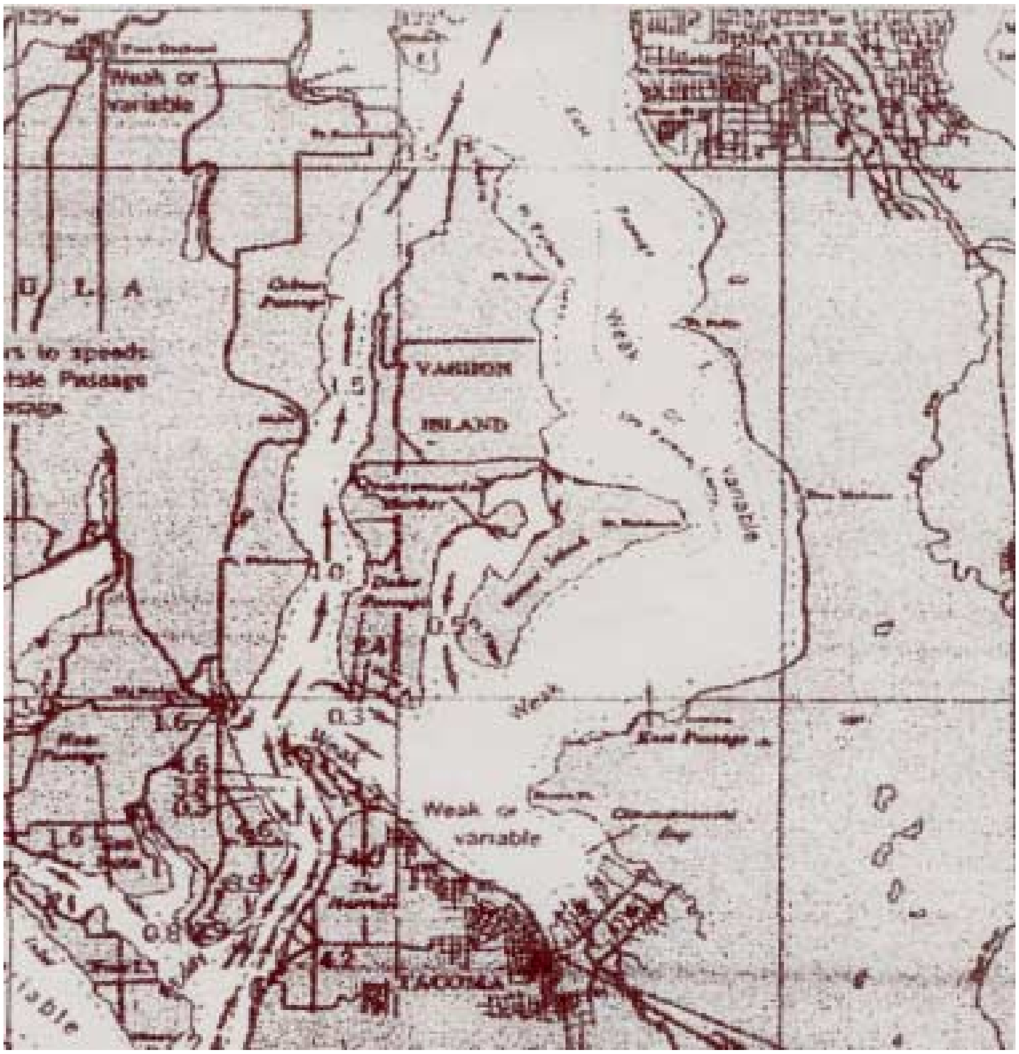


Figure 2 Tidal Current Chart - Maximum Ebb at Tacoma Narrows

Tidal Resource Potential

These tidal flows were used to estimate the resource potential input to the tidal energy turbines. See table 1 for a summary of the estimated available tidal energy. However, flow rates were only available as averages and are likely to vary considerably between diurnal tidal cycles. This is a potential source of error since there is a large difference in height in daily tides in the vicinity. For example, at the Tacoma Tidal Station, the mean range between high and low tide is 2.5 m, but the diurnal range is 3.6m, 44% higher Normally one tide each day is much higher than the other, which means the currents are much higher on alternating tidal cycles. . Figure 1 shows the typical difference in water level between two tidal cycles for Seattle. This is tidal variation is very important to energy systems because the energy production is function of the cube of the flow velocity. This means that if the flow is 3.0m/s instead of 1.5m/s, a factor of two difference in water flow velocity, there is eight times the energy in the former stream. The result is that energy production may be underestimated.

Applicable Technologies

A variety of tidal energy conversion devices have been designed and prototypes built and tested. Tidal energy traditionally involves erecting a dam across the opening to a tidal basin and harnessing the captured water using traditional hydropower technologies. A more appropriate approach for Vashon Island is to extract energy directly from tidal flow streams.

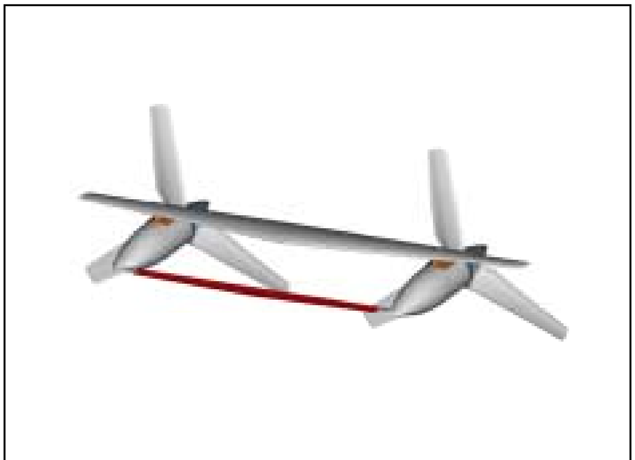


Figure 3 Aquantis Ocean Energy System

Several ocean energy systems are currently being developed that could potentially be deployed in Colovas Passage with out the need for a dam or impoundment. Typically systems are designed for use in run-of-the-river, ocean current, or tidal energy conversion applications. Different approaches under development in the U.S. and U.K., involving both horizontal and vertical axis turbines. An example of one promising system is the Aquantis ocean energy system being designed for use in the Gulf Stream off the coast of Florida is shown in Figure 3. Characteristics of various ocean energy systems are shown in Table 1.

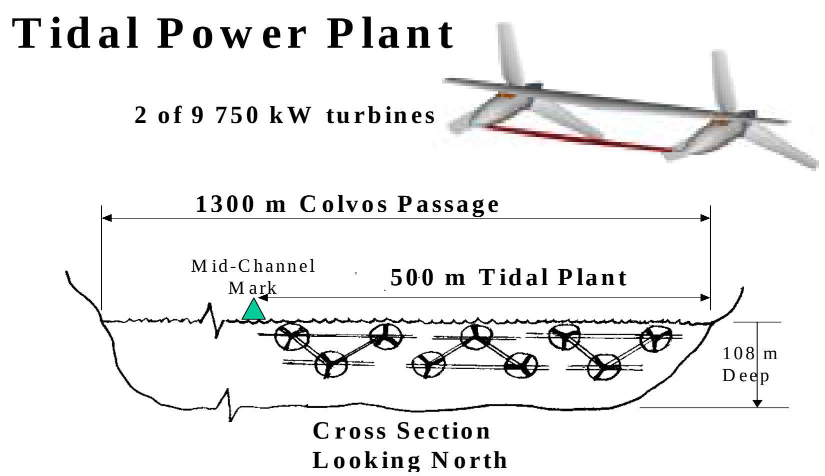
Table 1. Ocean Energy System Characteristics

	Developer	Configuration	Rotor Diameter (m)	Units - Rating (kW)	Plant Capacity (MW)
Aquantis	Dehlsen Associates, LLC, Santa Barbara, CA	Multi-blade, horizontal axis turbine	30	750kW x 9	6.75
Underwater Electric Kite	Abacus Controls, Inc., Somerville, NJ	Dual unit shroude horizontal axis hydroturbine	Approx. 3	90 kW x 60 dual units	5.4
Electric Power from Ocean Currents	GCK Technologies, San Antonio, TX	Unknown			
Blue Energy	Blue Energy Ltd.	Ducted vertical ax turbine	Approx. 7	250kW x 31 dual units	7.75

Energy Production Estimates

There are important issues to be addressed in the configuration of the tidal energy conversion system. First, the Colvos Passage must remain navigable so it is assumed that tidal energy converter may not extend beyond mid-channel, meaning turbines from 50 to 400m from shore. Also there are limits to the amount of energy that can be extracted from an open flow channel. If too many turbines are placed in the passage, the device will appear as a dam to the flowing water, which will simply stop moving or it will bypass the turbines and their will be no energy capture. To avoid this problem, the turbines in the conceptual design were placed in two rows, 5 turbines in top (near surface) row with 2 rotor diameter (2d) spacing and 4 in row at 3d depth. See Figure 4. These

Figure 4. 6.75 MW Tidal Power Plant



assumptions were used in developing the potential tidal power estimate of 6.75 MW and annual energy production of nearly 13 GWh/year. Table 2 lists energy estimated production for various time periods, based on the typical tidal cycle (Add data from Excel Spreadsheet). Because the turbines were not optimized for the available and relatively low flow rates in the Colvos channel, the plant capacity factor is only 22%. Capacity factor of over 40% should be achievable with an optimized system, which could double the energy production. Table 3 summarizes the resource level, and technology characteristics and operating costs.

Table 2. Tidal Energy in Colvos Passage

Case Data:

Total Average Flow = 28,000 m^3/sec discharge in northern direction
Tidal Cycles - 2 /day
C-Plane - 9 turbines, 30m diameter rotor, 12 degree pitch 750kW rated power at 1.6m/s = 6.75MW
Properly optimized turbines could double the energy production and plant Capacity Factor
Turbine configuration - Two rows, 5 turbines in top (near surface) row with 2d spacing and 4 in row at 3d depth

One typical Tidal cycle Mid Channel in Colvos Passage

	Time	Current	C-Plane Output	Diurnal Energy	Potential Annual Energy
Units	Hours before/after Maximum Flood at Tacoma Narrows	m/sec	MW	MWh/day	MWh/year
	-1	0.3	Below Cut-in	0	
	Max Flood	Weak	Below Cut-in	0	
	1	Weak	Below Cut-in	0	
	2	0.3	Below Cut-in	0	
	3	0.6	Start generating	0	
	4	1.1	2.25	4.5	
	5	1.3	3.15	6.3	
	Max Ebb	1.5	5.45	10.9	
	7	1.3	3.15	3.3	
	8	1.2	2.95	5.9	
	9	1.1	2.25	4.5	
	10	0.6	Below Cut-in	0	
Total Energy				35.4	12,921

Assumptions:
1. Half of Colvos Passage must remain unobstructed for navigation purposes
2. Tidal cycle flows are similar - need to study diurnal variation
3. Flow rate is uniform to depth of 90m and beyond 50m off shore
4. Low Speed Turbine Technology could increase energy capture by 20 to 30%
5. Aquantis C-Plane turbine (Picture) is one candidate design

Table 3. Resource and Technology Characteristics of Tidal Power Plant in Colvos Passage

	Values	**Assumption**
Tidal Induced Current	0 to 1.5 m/s	Estimate from tidal current charts – Diurnal hourly measurements are needed
Average Daily Flow	14,000 m^3	Discharge in Northern direction from half of Passage – assuming half is reserved for navigation
Turbine	750 kW 30 m diameter	Estimate for Aquantis, LLC turbine – would need to be optimized for the low flow in Colvos Passage
Annual Energy Production	13 million kWh/year	9 turbines
Total Rated Capacity	6.75 MW	20% capacity factor – could be increased by a factor of 1.5 or more by properly optimizing the turbine design
Operation & Maintenance	\$0.02 to \$0.03/kWh	Including labor, parts, periodic overhaul, insurance and taxes

Environmental Considerations

Tidal energy systems are generally considered to be relatively benign when compared to other hydropower systems or to fossil-fueled plants. The rotating turbine blades in a tidal plant have the potential of impacting fish. However, since these turbines are operating in a free stream with low flow rates, the blades will turn very slowly reducing the likelihood of impacts. Further, the pressure drop in the rotor plane will be orders of magnitude less than the pressure drop experienced in conventional hydroturbines. It is this pressure drop that is one of main causes of fish kills in conventional turbines in high dams. Because of the lack of experience with tidal power and because of the salmon feeding and spawning grounds around Vashon Island, this is an area that needs further study.

References

1. Curtis C. Ebbesmeyer, Carol A. Coomes, Jeffrey M. Cox, Timothy J. Crone, Keith A. Kurrus and Eric C. Noah, Evans-Hamilton, Inc. and Randy Shuman, King County Dept. of Natural Resources, "Current Structure in Elliott Bay, Washington: 1977–1996," Puget Sound Research, 1998.
2. Tidal current charts for Tacoma Narrows.
3. Hydropower Energy - Environmental Issues and Mitigation, U.S. Department of Energy, http://www.eren.doe.gov/RE/hydro_enviro.html, July 2002.

HYDROPOWER

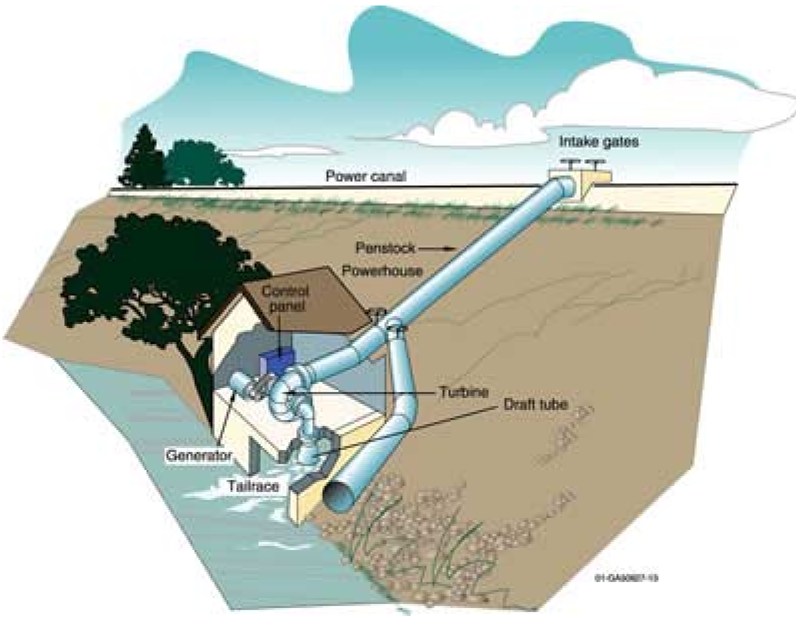
Resource

Due to the high rainfall levels of this region, it might be expected that hydropower resources would be quite abundant. However, no major rivers are present on the island, and only three primary creeks have been identified: 1) Shingle Mill Creek in the Northwest portion of Vashon island; 2) Judd Creek draining the south-central portion of the island; and 3) Fischer Creek located to the southwest of Judd Creek.

Unfortunately, Shingle Mill Creek is not considered a viable resource for even low flow hydro because it serves as a salmon spawning area, an environmentally sensitive issue in the Pacific Northwest. Judd Creek does serve 25% of the land area of Vashon, but due to the highly absorbent nature of the soil, the flow and the head of the river is very low. A visual inspection of the creeks on the island by technical staff from PERI and IERE (on 5/1/02) confirmed that possibility for developing hydroelectric power on the island is almost non-existent.

Applicable technologies

Small hydropower systems convert potential energy in running water to electrical energy. These systems require both a water source and an elevation change (anywhere from a few meters to a few tens of meters). The systems employ the head in a column of water to turn a conventional water turbine. Small systems can generate from 50 kW up to several thousand kW.
Run-of-River Projects utilize the flow of water within the natural range of the river, requiring little or no impoundment. Run-of-river plants can be designed using large flow rates with low head or small flow rates with high head. Microhydropower Projects produce 100 kilowatts (kW) or less, and can utilize both low and high heads.



(Source: http://hydropower.inel.gov/facts/types.htm)

3. Energy production estimates

N/A due to lack of resource.

GEOTHERMAL ENERGY

Resource

Vashon lies between two fault zones to the north and south of the island. No geothermal wells are on the island, and only one geothermal well has been developed on the mainland portion of King County. That location, at Hyak, is in far eastern portion of county, about 80 km from Vashon-Maury in the Cascade Mountains. The water in the reservoir at Hyak is of moderate-temperature, at 50C (122F), which is probably only suitable for direct use. The reservoir has one well providing the resource at 350 L/min, at a density of 391 mg/L. The Vashon-Maury Island area is of a very different geologic type than in the Cascade Mountain area, and geothermal resource development is not expected to be conducive for electricity production.

A report (http://www.eren.doe.gov/state_energy/tech_geothermal.cfm?state=WA) analyzing the low temperature geothermal resources in Washington state suggests that while areas of the state may be conducive for electricity production, the resource in the Vashon-Maury Island area is limited to use in a direct use setting (e.g., geothermal heat pumps).

Applicable Technologies

Several geothermal energy conversion technologies are theoretically applicable, if there was a reasonable geothermal reservoir. At a site with accessible and reasonable geothermal resources, the typical generating capacity is about 20 MW per square mile. It is unlikely that this resource could be economically developed with current technology on Vashon-Maury islands.

Energy Production Estimate

Not applicable, due to lack of accessible geothermal resource.

Geothermal power systems typically operate with better than 90% capacity factor and can produce energy at sites with good resources at 5 to 8cent/kWh today with goals of 3 to 5cents/kWh.

Ground-source geothermal heat pumps could be useful on the islands for building heating and cooling.

TECHNOLOGY ASSUMPTIONS FOR CASHFLOW MODELING INPUT

After examining the four renewable energy sources/technologies that appear most feasible for Vashon Island, it is logical to consider economic and financial feasibility. Using in-house financial tools and engineering expertise to develop technology cost and performance descriptors, PERI performed a preliminary financial analysis using a DCF-ROI (discounted cashflow return on investment) approach for each technology to determine its levelized cost of energy (COE). Data sources for costs and other parameters are listed below, and energy output data is detailed in Chapters 2 and 3. Using these data, we defined the following analysis inputs for a typical plant:

- Description of configuration
- Plant size
- Total installed project capital cost
- Annual energy output
- Annual operating expenses
- Project financial/ownership structure
- Financial assumptions

Here we summarizes basic engineering cost and performance figures for the four technologies. Next, financing scenarios and assumptions are described, and cost of energy figures for the four technologies are presented

Technology Cost and Performance Assumptions

For the four technologies, basic plant data is presented below.

Wind Energy:

Capital and operating cost estimates for wind energy projects at Vashon Island assumed a single purchase of 28 turbines and an average of 4 turbines installed at each site. Cost estimates are based on the authors' knowledge of current market activities at several planned and recently installed wind energy facilities, but do not represent quotes from the manufacturer. Given the large amount of recent market activity, these estimates are believed to be accurate within a small band of uncertainty.

Table 1 - Wind Energy

Cost/Performance Item	Value	Comments
Plant Size	Twenty eight 1.5 MW turbines, for 42 MW total capacity	Assume 5 turbines are in clusters of 3 to 5 turbines depending on available sites and terrain
Installed Capital Cost	$950 per kW	“Overnight” Cost – not including construction financing. Includes shipping, 2 year warranty, installation, commissioning
Transmission line and interconnection	$75,000 per turbine cluster	Includes step up transformer, up to 1 mile transmission line, all other interconnection equipment
Annual Maintenance	$10,000 per 1.5 MW turbine	Includes labor and parts
Levelized Periodic Replacement/Overhaul	$5,000 per 1.5 MW turbine	
Capacity Factor	24.7% for faster winds to 16.0% for slower	Power production is 16.228 mil kWh/year for faster winds and 10.512 mil kWh for slower

Cost/Performance Item	Value	Comments
Other Expenses	2% of revenues as a royalty to landowners	

Operating expense and overhaul costs are based on PERI discussions with wind turbine industry members. Royalties and other project expenses are based on extensive review of commercial projects.

Photovoltaics:

Capital and operating costs are taken from Sacramento Municipal Utility District (SMUD) experience (http://www.smud.org/pv/pvfaqs_how_much.html), and the NREL Topical Issues Brief, "Factors Associated with Photovoltaic System Costs," NREL/TP.620.29649, June 2001. A range of capital costs was modeled for this study to bracket potential purchasing approaches. That range is based on data presented in Table 2.

On the high cost end, it was assumed that systems are purchased by individual home and commercial building owners. To lower costs, a bulk purchasing program is organized and a "buy-down" incentive is in place, similar to the Sustained Orderly Development and Commercialization (SODC) program, also known as the "PV Pioneer" program, established in 1993 by the Sacramento Municipal Utility District (see http://www.smud.org/pv/pv_pioneer1.html). Under the PV Pioneer program, SMUD lowers the cost of PV systems through relatively large volume purchases, and passes the savings directly to individual system owners. Additional cost reductions are realized with a buy down grant.

Table 2 - Photovoltaics

Cost/Performance Item	Value	Comments
Plant Size	Neighborhood of 385 houses at 2.6 kW (ac rating) per house, for 1.0 MW	Additional 1 MW or larger projects may be undertaken – choice of project size was a modeling assumption
System Cost – Low	$1,750 - $3,500/kW (peak ac)	Assumes volume purchasing and buydown approach like SMUD PV Pioneer Program. (ref. SMUD)
System Cost – High	$9,100/kW (peak ac)	Based on a 4.4 kW system, each purchased individually (ref. NREL)
Annual Maintenance	$15/kW (peak ac)	(ref. EPRI/US DOE)
Capacity Factor	12.5%	(ref. Dr. P. Malte, University of Washington)

Examples of current buy down grant or low interest loan programs include: (1) the Whatcom 1000 Solar Rooftop Project in Washington, available in Whatcom and Skagit Counties; (2) the Los Angeles Department of Water Power, which provides a buy-down of $4.50/Watt for the first year of the program, phasing down to $2.50/Watt in the fifth year, plus an additional $1.50/Watt if the PV equipment is manufactured in Los Angeles; and (3) the California Energy Commission buydown program, which provides $4.50/Watt or 50 percent off the system purchase price (whichever is less).

Annual maintenance cost estimates are from "Renewable Energy Technology Characterizations," Electric Power Research Institute and US Department of Energy, EPRI TR-109496, December 1997. The capacity factor is from field experience at the University of Washington, approximately 10 miles from Vashon-Maury Island, as reported by Dr. P. Malte.

Biomass Gasification

The gasification/gas turbine generation system assumes inputs as presented below. Capital cost includes fuel handling, gasification, gas cleanup, quench, gas turbine, heat recovery steam generator (HRSG), steam cycle, compressor, and balance of plant. Capital cost also includes NOx emissions contingency, interconnect, general facilities, engineering fees, contingencies, any royalties, spare parts, and modest working capital.

Table 3 - Biomass Gasification

Cost/Performance Item	**Value**	**Comments**
Plant Size	1 MW	Small system
Captal Cost	$1,108 - $1,800/kW	
Fixed Operating Cost	$40 - $60/kW	2% to 4% of capital cost for on-site operator
Variable Operating Cost	$0.0050 - $0.0075/kWh	2% to 4.5% of capital cost, for service cost and consumables
Plant Availability	80%	Power production is 7.008 mil kWh/ year
Heat Rate	9,450 Btu/kWh	
Feedstock Cost	$0 - $60/Ton at varying moisture contents	For example, if fuel is 5 mil lb wood waste at 40% mc, 3 mil lb fire wood at 40% mc, and 3 mil lb construction waste at 15% mc, Heat Content is 6,300 Btu/lb. Feedstock Cost is $0 - $4.76/mil Btu.

The wide range for capital cost reflects both the range of technology options, and the uncertainties associated with the preliminary definition of the specific technology configuration.

The range of costs for feedstock reflects the possibility that at least some fuel could be delivered to the site at no cost as an alternative to open air burning or other means of disposal. Some wood waste, for example, might be delivered at the cost of transportation only to reduce the risk of fire hazard.

In fact, some of the feedstock may have a value to the project (a “negative cost”) if a disposal cost is associated with it. For instance, those disposing of MSW pay hauling and tipping fees to remove it. Waste wood that is currently burned may later require different disposal, raising the current cost to builders/developers and others who must dispose of waste wood. On the high end of the feedstock cost range are dedicated fuel crops, that incur costs to be planted, grown, harvested, and transported. In the middle of the cost range are biomass residues and fire wood that could be collected from natural stocks or existing commercial activities, but would still require some cost for collection and transportation. One problem biomass plants sometimes face is that fuel supply shortages sometimes develop, at which time price increases sharply, before dropping back.

Plant availability is taken from rhe EPRI-DOE Renewable Energy Technology Characterizations. Fixed and variable O&M are also based upon that source, but factored upward for a smaller plant size.

Tidal Power
For the tidal power system, assumptions are as listed below.

Table 4 - Tidal Power

Cost/Performance Item	Value	Comments
Plant Size	5.4 MW	
Captal Cost	$3,000 - $3,600/kW	
Fixed Annual Operating Cost	$70/kW	Equivalent to about $0.025/kWh for low production
Plant Capacity Factor	27.48% - 31.71%	Power production is 13.0 mil kWh/ year to 15.0 mil kWh/ year.

Capital cost includes all equipment and labor for installation. The estimate is based on discussions with leading U.S. equipment developers/manufacturer. The primary driver for the cost range is the lack of commercial experience with the technology.

ECONOMIC AND FINANCIAL APPROACHES AND ASSUMPTIONS

Previous "Part 1" chapter set forth basic engineering cost and performance figures for the four renewable energy sources/technologies that appear most feasible for Vashon Island. In this chapter, "Project Economic and Financial Review - Part 2," we describe financing assumptions, present Cost of Energy figures for the four technologies, and describe results.

Ownership/Financing Options and Key Finance Assumptions

IPP Project Finance:

For renewable energy projects, the typical, most widely-used ownership/financing scenario is that of an Independent Power Producer (IPP) using Project Finance. A private company, such as the unregulated subsidiary of a utility holding company or an independent energy company, builds, finances, and owns the project and sells power. Traditionally, the IPP contracts with and sells power to a utility and/or to a large retail buyer or organized group of buyers, and the power purchase agreement ensures a sufficiently stable revenue stream, that investors, particularly lenders, are confident their capital will be repaid and they will earn an attractive return. IPP's generally employ Project Finance, structuring the plant financing so that debt and equity investment is collateralized or secured by only the one project. Debt and equity investors have no recourse or claim to the IPP's pool of projects or its corporate assets (which contrasts with Corporate Balance Sheet Financing). Should the IPP sell power on a merchant basis, at rates that fluctuate with the market and without a fully committed long-term power purchase contract, then the plant becomes riskier for investors and they demand higher debt coverage ratios and increased equity returns.

Tax-Free Public Power using tax-free, long-term, well-secured debt

Another option is that a tax-free, publicly-owned utility or rural co-op owns and finances the project. For Vashon Island, today, it is not likely that a public utility would finance a new plant, applying cost-based revenue requirements and using 100% debt for thirty years. It is slightly more likely that a rural electric cooperative would undertake the project, although the reader may consider this option, also, to be far-fetched. Our purpose in preparing a tax-free ownership/financing scenario is to bracket COE figures on the low side, to show how low the Cost of Energy for certain proposed renewable energy plants may be using long-term, favorable debt financing.

As is well-known, rural electric co-ops are not-for-profit organizations that sell power to their members, avoiding the Investor Owned Utility conflict where owner/shareholders want high returns but customers want low rates. Traditionally financed by government debt, coops have not built equity to the levels required by public markets. Government debt is provided by the U.S. Department of Agriculture's Rural Utilities Service (RUS), as section 305 insured loans and through section 306 and 306a loan guarantees (where section number refers to the Rural Electrification Act of 1936).

For insured loans, if project debt to equity is 80% to 20%, then RUS may provide 70% of the debt as an Insured Loan for 20+ years at a low municipal rate and require that 30% be taken as a Supplemental Loan, also at 20+ years, from another source (e.g., well-established co-op lenders like CFC (Herndon Va) or CoBank (Denver), at a higher rate), where the Supplemental Loan is not subordinate, but concurrent. For a RUS Loan

Guarantee, the rural co-op obtains debt from a bank or other lender and, since RUS guarantees payment, the interest rate is reduced and life of the loan is stretched longer. For both types of finance, it is important to note the loans made or guaranteed by RUS are NOT project finance, secured only by the one project, but are well-secured, with a mortgage on existing co-op property and a claim to cash and future revenues. Further, RUS regulations require that Co-op borrowers meet certain minimum Debt Coverage standards, so it is not cost-effective to finance with 100% debt.

Basic Finance Assumptions and Methodology

To analyze the four renewable energy technologies, certain basic assumptions were made that hold for all plants. Inflation is estimated at 3.0%. Project life is 30 years, with sufficient O&M to pay for periodic overhauls. The plant's start date is January 1, 2004.

Plant and equipment costs for the four technologies were set forth in the previous chapter. Plant and equipment costs represent, by far, the largest portion of total plant cost. However, other capital costs are added, including interest during construction, a 6-month debt service reserve on total debt, and financing fees. Wind and solar energy, sized at over 200 kW, are exempt from State sales tax. By contrast, for biomass gasification and base case tidal power, the 8.80% state sales tax rate that applies near Seattle was added.

O&M and insurance are assumed to escalate at the rate of inflation. Property taxes are calculated based on a market assessment that initially declines with wear and tear on equipment till it stabilizes at 35% to 50% of historical cost. Revenues for all plants except biomass escalate at inflation less 1% (or 2.0%), presuming the plant owner negotiated this feature with power purchasers, as an escalation rate they'd be happy to accept. Biomass revenues must cover the cost of fuel which escalates with inflation, so biomass revenues escalate at inflation less 0.5% (or 2.5%), which is not quite so attractive but not bad. Furthermore, all plants except basecase Biomass assume a two-tier revenue pattern, where revenues drop some after debt is repaid, in years 16 or 21 as described below, and resume escalation at the rate that is slower than inflation.

Federal income tax is estimated at 35%. Washington's Business and Occupation tax is 3.873% for power, and this rate is applied to revenues (not income). The rural co-op cases do not pay property tax, federal income tax, or state B&O tax. For IPP cases, accelerated 5-year depreciation is taken for Wind and Solar, and is assumed to apply also for Biomass. Fifteen-year depreciation is taken for Tidal Power, but this assumption might be researched further. Depreciation does not matter for rural coops, except as a measure of wear and tear shown for financial reporting.

As regards financing, IPP debt to equity is assumed to be 70% to 30%, except when tax benefits are available and financing is adjusted to 60% debt to 40% equity. Given a 30-year project, debt life is 15 years. Debt's interest rate is estimated conservatively as 7.00%, assuming 10-year Treasury Notes at 5.0% and a 2.0% spread. Debt coverage requirements are assumed to be 1.70 times average and 1.40 times worst year. Equity investors are assumed to demand an after-tax return of at least 17%.

Special tax benefits are available for several renewable technologies. For wind there is an inflation-adjusted 1.50 cent/kWh Federal Production Tax Credit (PTC is currently 1.7 cents/kWh) that runs ten years and is available for plants that come on-line by December 31, 2003 (which is close enough to January 1, 2004, that an enterprising developer would surely work to start one day early). Furthermore, observers are confident the PTC deadline will be extended to December 31, 2006, with the Congressional Energy Bill, now in Conference Committee. Special tax benefits for solar include the Section 48 Energy Tax Credit, calculated as 10% of capital cost. There are no special tax benefits for biomass, because the proposed plant would accept waste wood and other feedstocks and is not a dedicated fuel, closed loop facility that qualifies for the Section 45 PTC. There are no special tax benefits for Tidal Ocean Power.

As regards tax-free rural co-op financing, for the RUS Insured Loan, project debt to equity is assumed to be 80% to 20%, with 70% of the debt a loan from RUS at 5.50% and 30% the Supplemental Loan at 9.1%, both conservatively requested for a term of 20 years, although longer loans would be available. For the RUS Guaranteed Loan, debt to equity is assumed to be 75% to 25%, with debt at 6.50% for 20 years. Co-op loans meet lower standards of debt coverage, at 1.25 times for the worst year. Equity is provided by the rural co-op itself, not by outside investors, and a lower return may be accepted, which is estimated to be 12%.

Since rural co-ops are tax-free, they cannot utilize tax benefits. However, to complement the tax credits for taxable parties developing renewable energy projects, in 1992, Congress established the Renewable Energy Production Incentive (REPI) for state and local government and tax-exempt organizations producing power from solar, wind, biomass, and geothermal energy. REPI is defined as an inflation-adjusted 1.5¢/kWh cash payment paid for the previous year's power production. However, REPI funding is subject to Congressional appropriation each year and, since 1997, funds have not been sufficient to fully pay so-called Tier 2 plants, composed of lower ranking open loop biomass and landfill gas plants, where technology is demonstrated, vs. the new technology Tier 1 plants. REPI is currently slated to expire for plants built after September 30, 2003 but the Congressional Energy Bill, now in conference committee, would extend the construction date to September 30, 2013. Consequently, in this analysis, we are not so confident as to use REPI to repay debt, but we use it only to increase equity return and assume that, if REPI materializes, then the co-op may rebate it to Members.

Cost of Energy Results

For IPP and tax-free Rural Co-op cases, using the financial assumptions described above, for each of the four renewable energy technologies, our financial staff entered plant cost and performance data into our discounted cash flow model. As the project owner would do, we balanced obtaining (1) the lowest Cost of Energy (COE) as required by power purchasers against (2) minimum debt coverage requirements of lenders and against (3) the minimum after-tax return on investment required by the owner/developer and outside equity investors.

The COE's shown below are the minimum COE's that satisfy debt coverage and equity return requirements, such that debt and equity investors will participate. COE's may be calculated in nominal or current-dollars or, as sometimes appeals to government and academic researchers who investigate trends over very long time frames, on a constant-dollar basis that excludes inflation. To calculate a levelized COE, the revenue stream of an energy project is discounted using a standard rate to yield a NPV (Net Present Value). This NPV is levelized, again using a standard rate, to an annual payment, and is then divided by the project's annual energy output to yield a value in cents per kWh. Nominal COE's are calculated using one nominal discount rate (e.g., 8.5%), both for the NPV and to levelize. Constant-dollar COE's, that exclude inflation, are calculated using the nominal rate to figure NPV and then the constant-dollar rate to levelize (e.g., 1.085/1.03 – 1 = 5.34%). By applying one standard nominal discount rate and the corresponding constant-dollar rate to various projects, vs. by using each project's Internal Rate of Return, one achieves standardization. One observes multiple projects from one viewpoint, which approximates a utility power purchaser's viewpoint, which is probably the fallback source of power. One does not measure some projects using favorable rates and other projects differently.

Wind Energy

Cost of Energy results for Wind Energy are shown below.

Table 1 - Wind Energy

		Year 1 COE (year 2004$/kWh)	Nominal Levelized COE (year 2004$/kWh)	Constant-Dollar Levelized COE (excluding inflation, year 2004$/kWh)	After-tax IRR (%)
1	IPP with faster winds, taking PTC	$0.0620	$0.0689	$0.0500	22.44%
2	IPP with faster winds, no PTC	$0.0700	$0.0771	$0.0560	17.69%
3	IPP with slower winds, no PTC	$0.1080	$0.1163	$0.0845	17.35%
4	IPP with slower winds, taking PTC	$0.0950	$0.1012	$0.0735	17.64%
5	Rural Co-op with slower winds, no REPI	$0.0900	$0.1017	$0.0739	16.87%
6	Rural Co-op with slower winds, taking REPI	$0.0900	$0.1017	$0.0739	24.35%
7	Rural Co-op with faster winds, no REPI	$0.0570	$0.0656	$0.0477	16.07%
8	Rural Co-op with faster winds, taking REPI	$0.0570	$0.0656	$0.0477	27.49%

The capacity factor is 24.7% and power production is 16.228 mil kWh/year for faster winds. The capacity factor is 16.0%, with power production of 10.512 mil kWh for slower winds.

Results show a lower COE is obtained when the IPP Wind plant takes the PTC, which is likely, as observers are confident the PTC will be extended from end-year 2003 to end-year 2006 with upcoming legislation. More important than tax benefits is a steady resource because faster winds allow the developer of a Wind Farm that takes the PTC to significantly lower COE, from $0.1012/kWh to $0.0689 in nominal dollars.

Tax-free rural co-op financing does not provide any advantage over the IPP taking the PTC if winds are slow ($0.1017/kWh vs. $0.1012 nominal). It provides about one third cent advantage if winds are fast ($0.0656/kWh vs. $0.0689 nominal). As discussed, because the REPI for tax-free owners is uncertain, it is not used to repay debt which would lower COE but, if it materializes, REPI is added to equity return, where it may be rebated to customers or used for other purposes. Except for the possible rebate, wind project customers are fairly indifferent to ownership/financing method. Since IPP structure is "easier" for owners and does nor involve mortgaging all company assets for one project, IPP structure applied to a strong resource may be the preferred method.

Solar Photovoltaics
For financial modeling purposes, the 1 MW Photovoltaics plant is composed as a Bulk Neighborhood project, with rooftop systems of 2.6 kW (ac rating) on 385 homes. Cost of Energy Results are presented below.

Table 2 - Photovoltaics

		Year 1 COE (year 2004$/kWh)	Nominal Levelized COE (year 2004$/kWh)	Constant-Dollar Levelized COE (excluding inflation, year 2004$/kWh)	After-tax IRR (%)
1	IPP with low Capital Cost (thru volume purchase and buy-down) at $2,500/kW	$0.32	$0.36	$0.26	17.46%
2	IPP with high Capital Cost at $8,000/kW	$1	$1.08	$0.78	17.14%
3	Rural Co-op with low Capital Cost at $2,500/kW	$0.26	$0.30	$0.22	12.89%

Photovoltaics show a wide range of capital costs due to the inclusion of a bulk purchase approach and buy down incentives. The high cost IPP plant, where systems are purchased individually, with now capital cost subsidies, shows a nominal COE of over $1.00 per kWh. The low cost IPP plant, where the developer buys in bulk and has access to a buy-down program, such that capital cost is reduced by about 70% to $2,500/kW, shows a COE that is reduced by about 67% to $0.36/kWh.

Because it is very capital-intensive (even at $2,500/kW, which is about 2.5 times the price of wind at $950/kW), PV pays high federal and state income tax. PV benefits when taxes are removed, as shown by the Rural Coop Case, where taxes are eliminated and COE declines about 6 cents to $0.30/kWh.

Biomass Gasification
Cost of Energy results for the 1 MW Biomass Gasification plant are presented below.

Table 3 - Biomass

		Year 1 COE (year 2004$/kWh)	Nominal Levelized COE (year 2004$/kWh)	Constant-Dollar Levelized COE (excluding inflation, year 2004$/kWh)	After-tax IRR (%)
1	IPP with $1,110/kW Capital Cost and $2/Ton fuel	$0.0450	$0.0545	$0.0396	23.32%
2	IPP with $1,800/kW Capital Cost and $60/Ton fuel	$0.1050	$0.1333	$0.0968	17.54%

Only two cases were studied for Biomass. When high-capital cost is combined with a high fuel price of $60/Ton (or $4.76/MM Btu), then nominal COE is $0.1333/kWh. If fuel cost can be significantly reduced to almost nothing and if capital cost is also reduced, then COE falls by more than half, to $0.0545/kWh, in nominal dollars.

Biomass Gasification represents a new technology, with research aimed at larger plants. Nonetheless, if an inexpensive but reliable source of fuel is available, COE is attractive.

Tidal Ocean Power
Cost of Energy results for Tidal Ocean Power are presented below.

Table 4 - Tidal Power

		Year 1 COE (year 2004$/kWh)	Nominal Levelized COE (year 2004$/kWh)	Constant-Dollar Levelized COE (excluding inflation, year 2004$/kWh)	After-tax IRR (%)
1	IPP with low Capital Cost at $3,000/kW, cap factor of 31.71%, NO sales tax	$0.2150	$0.2368	$0.1720	17.36%
2	IPP with high Capital Cost at $3,600/kW, cap factor of 27.50%, 8.80% sales tax	$0.3050	$0.3350	$0.2433	17.26%
3	Rural Co-op with low Capital Cost at $3,000/kW, cap factor of 31.71%, NO sales tax - BUT UNLIKELY	$0.1500	$0.1755	$0.1275	14.64%

As shown, higher cost Tidal Power with a reduced capacity factor makes for a nominal COE of $0.3350/kWh. If costs can be lowered and power production increased and if the sales tax is cut, then COE drops ten cents to $0.2368/kWh. Tax-free rural co-op ownership and financing appear to reduce COE another six cents, but because the co-op would mortgage all assets for one plant employing a risky, new technology, it is unlikely such a financing would ever be undertaken. Technology developers ought to focus on reducing cost, increasing performance and gaining operational experience.

Conclusions and Recommendations

The above analysis screens four renewable energy technologies for Vashon Island. The reader is reminded that tidal power cost and performance are broadly estimated, wind energy is analyzed with the most detail, and solar pv and biomass gasification are in the middle. Screening on the basis of nominal levelized COE for plants with COE's under $0.1200/kWh, say, would select all wind cases (reflecting fast and slow wind speeds, taking or not the PTC or REPI); would exclude solar photovoltaics, would include that biomass where capital cost and fuel cost are low; and would exclude tidal power. Screening on the basis of constant dollar COE for those plants with COE's under $0.100/kWh, say, would yield similar results, including all wind cases, no solar pv cases, both biomass cases, and no tidal power cases.

These results suggest further investigation of wind and biomass might prove fruitful. Biomass gasification is a new technology that may be worth investigating if an inexpensive, reliable long-term supply of fuel can be found.

Further, wind is a commercially available technology. Interestingly, analysis showed greatest improvement in COE from locating a strong wind resource vs. adjusting financing or tax assumptions (although the later may be useful, also). Analysis further demonstrated that wind is sufficiently capital intensive, that even if O&M and other expenses increase at the rate of inflation, that project revenues can escalate at a rate slower than inflation (e.g., at inflation less 1%), which is an attractive selling feature to power purchasers. Wind economics are sufficiently strong that the owner need not escalate revenues quickly and backload principal repayment of debt. Bankers, owners, and power purchasers may all relax with clean, comfortable cash flows, where the project makes good economic sense.