RACE ROCKS SUSTAINABLE ENERGY SYSTEM DEVELOPMENT

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Abstract

Race Rocks is a small archipelago located just Southwest of Victoria, British Columbia in the Juan de Fuca Strait. An important Beacon for Coastal Navigation in this busy area is located on Race Rocks, which is also home to a stunning variety of marine mammals and birds. The Race Rocks site has become Canada's first Marine Protected environment and is now carefully managed by a group of interested parties including Pearson College and The Canadian Coastguard.

The environmental integrity of the site is often jeopardised to bring diesel fuel to the site and the noise pollution on the site due to the diesel generators is significant. IESVic has stepped forward to evaluate the potential of renewable energy sources on-site to power a sustainable energy system. A preliminary study was performed as an innovative graduate course at the University of Victoria that exposed students to sustainable energy system design.

Our conclusion is that with Tidal currents of up to 3.7 m/s, average winds of 21.6 km/h and large amounts of solar insolation, there are ample renewable resources available on the site to develop a sustainable integrated energy system capable of providing reliable power for the site. Race Rocks is therefore ideally suited to become a showcase for renewable energy generation.

This paper outlines the results of the feasibility study, discusses the opportunities available at Race Rocks and examines the progress to date. Requirements for the implementation of a sustainable energy system on the site are discussed.

1 Introduction

As very eloquently discussed by L. R. Wallis in his speech to the American Nuclear Society, the world needs energy in increasing amounts if we are to bring those in the developing world up to any reasonable standard of living [1]. As well, we would like to decrease the impact that energy services have on the environment both locally and globally.

Renewable energy is often promoted as the most environmentally safe, clean, sustainable energy source by various authors and organizations (ex. [2-4]). Other authors claim that there is no way for renewable energy to provide the energy needs of our society and that we therefore need to continue to burn oil and coal (ex. [5]). Others accept the fact that renewable energy will play a role in meeting societies energy needs but are sceptical of claims that they will be able to provide significant base load requirements (ex. [6, 7]).

To evaluate these claims and determine the actual ability of renewable energy to meet the energy demands both of today and tomorrow requires an in-depth knowledge about renewable technologies as well as an accurate assessment of the resources available. The Race Rocks site, as discussed below, provides a unique opportunity to develop such a knowledge base and make it widely available through the racerocks.com website. This paper introduces the Race Rocks site, discusses the initial feasibility study and presents the further work being performed by IESVic on this exciting project.

2 Race Rocks

Race Rocks is a small archipelago located southwest of Victoria, British Columbia in the Juan de Fuca Strait. Being both an important navigational beacon and a home to a stunning variety of marine mammals and birds, this site has been designated Canada's first Marine Protected Area and is currently managed by a group of interested parties including Pearson College and the Canadian Coastguard.

Although there are a number of other renewable energy demonstration sites being developed or studied around the world (ex. [8-12]), Race Rocks has two significantly unique characteristics that make it an ideal site. First, the site is a Marine Protected Area and an ecological reserve. Secondly, the site is connected to the Internet by the racerocks.com website.

As a Marine Protected Area and ecological reserve, it makes sense that the environmental impact of the site, both locally and globally, be minimized. The local effects of the current energy system include noise pollution and the significant risk of diesel fuel spills during fuel transportation to and from the island. As well, emitting carbon dioxide and other gaseous combustion products is widely considered to be a global environmental problem. Reducing the impact of such an important site will show Canadian leadership in renewable energy and environmental conscience.

Pearson College has been developing the racerocks.com website in an attempt to create a virtual eco-reserve out of Race Rocks, thereby reducing the potential impact visitors have on the site. By allowing people to "visit" the site over the Internet the number of actual visitors to the site can be kept to a minimum. This website site creates some significant opportunities for a renewable energy demonstration system. By using the racerocks.com website, any energy system on the site can be made entirely accessible over the internet, thereby allowing people from all over the world to access the information on renewable energy, evaluate the performance of the energy system on the site, and thereby make realistic decisions on renewable energy.

3 Energy Services at Race Rocks

The Race Rocks site requires energy services to operate and maintain the navigational aids and to support the custodians for the ecological reserve and Marine Protected Area. Currently a 25kW diesel generator provides the electrical energy for these energy services and a backup generator is available (see Figure 1). Fuel for these generators is shipped to the site by the Pearson College workboat, which uses a large tank to transport the fuel. The diesel is then pumped from the dock, across the island, and into the holding tanks on the island. For each refuelling, this operation is repeated a number of times until the holding tanks on-site are full. This complex operation is repeated about every six weeks to keep the site operational.

This energy system has some significant impacts on the site. First, the noise from the diesel generators disturbs the serenity of the site and affects the wildlife. The emission of carbon dioxide and other diesel emissions, though they do not directly affect the site, do cause environmental impacts. As well, the risk of diesel spills while refuelling is a significant concern since the operation is not a simple one.

Figure 1: Race Rocks Diesel Generator and Tanks

4 Renewable Energy System Description

With the vision of a renewable energy system laboratory in mind for Race Rocks, the overall architecture of a renewable energy system needs to be considered. Since the goal of any energy system is to provide energy when required, and with the knowledge that renewable resources are intermittent, we can identify the components and their interactions of such a system, as shown in Figure 2.

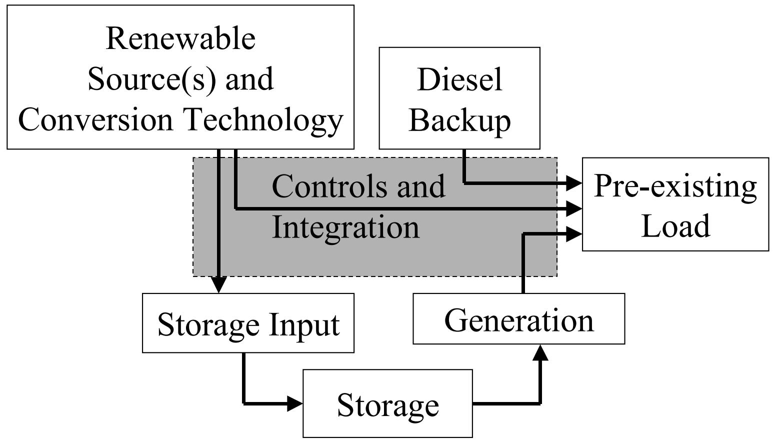

Figure 2: Proposed Energy System

From this figure, we can see that there are a number of different items that need to be considered when developing a renewable resource-based energy system:

- Renewable resource availability
- Source conversion technology
- Demand cycle (pre-existing load)
- Storage system including input, storage and generation

The focus of the remainder of this paper is the development of a model for each of these components, the integration of these models into an overall energy system model, and the results obtained.

5 Renewable Energy Feasibility Study

The initial feasibility study looked at the renewable resources on the site, the conversion technologies for each resource and the energy storage technologies. All this information was combined into a single energy system model that was then used to develop a number of possible renewable energy systems.

5.1 Renewable Resources

The Race Rocks site is ideal in that it has significant renewable resources available. The site is located beside a narrow channel with tidal currents running through it every six hours, it is located in the middle of a large straight and therefore has good wind resources, and it is considered one of the sunniest sites in Canada.

Tidal flow data was obtained from the Institute of Ocean Sciences [13] from a current meter that was installed at Race Rocks from September 1980 to October 1981. The data obtained was complete except for an approximate one-month gap when the meter was not functioning. In order to obtain an accurate year of data from these pieces, the data was spliced together and reorganized to produce a typical year. The data obtained for tidal fluxes was given in m/s and this was converted into an hourly energy flux, $\dot{E}$, using:

$$\dot{E} = \frac{1}{2}\rho V^3 \qquad (1)$$

where V is the velocity of the flow and ρ is the fluid density.

The wind data for Race Rocks was obtained from Environment Canada in a condensed, monthly-binned format that was produced from the wind sensor on Race Rocks. Using this binned format, a typical year of wind data was modelled using a modified Weibull distribution to obtain hourly wind estimates. Short-term averaging was used to produce a more realistic wind profile for the year. Again, equation 1 was used to convert the modelled wind velocity into an hourly energy flux.

Since there has never been a measurement of solar insolation at Race Rocks, insolation data for Victoria International Airport was obtained from Environment Canada as monthly means and variances. Using a normal distribution and this data, a typical year of solar data was generated. Again short-term averaging was used to produce more realistic solar profiles. Since solar data is already given in units of energy flux, no conversion was necessary with this data to obtain an hourly energy flux.

Figure 3 shows the hourly variation of the tidal and wind profiles as calculated by the above models. This figure shows both the variation of the wind and tidal fluxes throughout the day as well as the deterministic nature of the tidal flux.

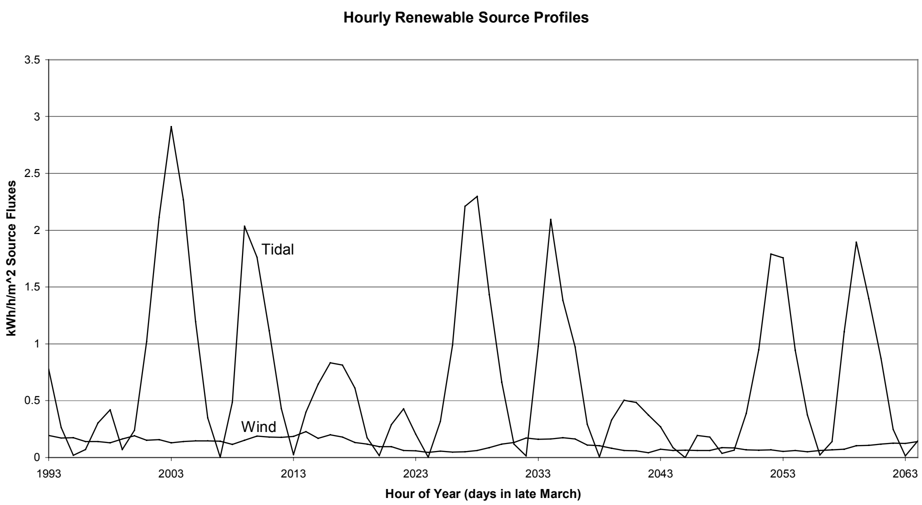

Figure 3: hourly Variation of Tidal and Wind Resource

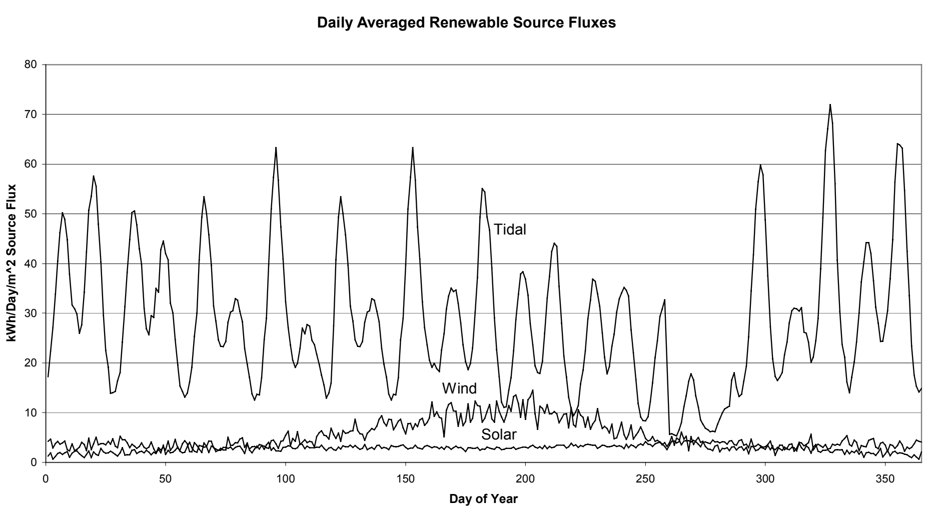

Figure 4: Daily Average Energy Fluxes at Race Rocks

The calculated energy fluxes were averaged to produce a daily averaged energy flux, in kilowatt-hours per day per square meter as shown in Figure 4. This figure shows the differences in the energy flux of each of the resources as well as the yearly variability of each resource. The relative consistency of the wind data over multiple days is due to the short term averaging mentioned above.

The information obtained from these source models was coupled with a simple model for the conversion technology that considers the efficiency, maximum output, and other such factors to provide an output in kW.

- Tidal: a 1.6m by 1.6m Darrieus Turbine as described by Shiono et al [14] [15]
- Wind: a Bergey Excel Wind Turbine was modeled [16]
- Solar: a 15% efficient photovoltaic panel was considered [3].

The output from these models was coupled with the demand analysis (see below) into the full energy system model, which is discussed later in this paper.

5.2 Demand Analysis

To analyse the required demand at Race Rocks, a number of assumptions had to be made regarding the hourly, daily and seasonal variations of the demand. Unfortunately, the data available from Race Rocks consisted only of engine logs taken by the custodians of the site. These logs recorded the voltage and amperage of the generators twice per day. Using this, a general idea of the amount of energy used by the site was established. This information, however, did not allow for the hourly determination of load since the logs were recorded only twice per day. To establish a reasonable daily variation, BC Hydro typical demand profiles [17] were used to model the demand. Specifically, the demand was modelled as twice the typical BC Hydro household loads for coastal BC, to include both houses on the island, plus a base load of 3.5 kW to cover the energy required for the desalination unit, winches, pumps and other such items that are unique to a remote location such as Race Rocks. Figure 5 shows the daily average demand profile for a full year and Figure 6 shows the hourly profile as used for this study. Since this study, a power meter has been installed out at Race Rocks and data is being gathered to further this analysis.

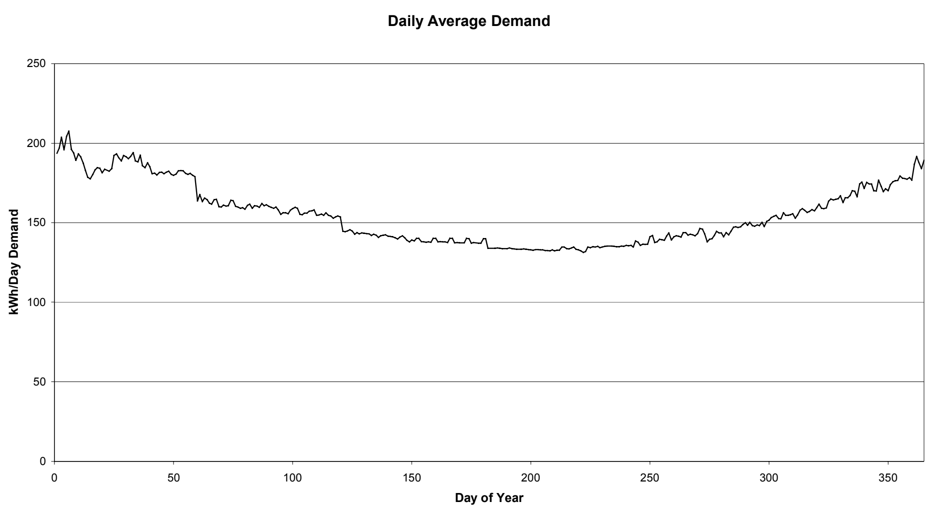

Figure 5: Daily Average Demand

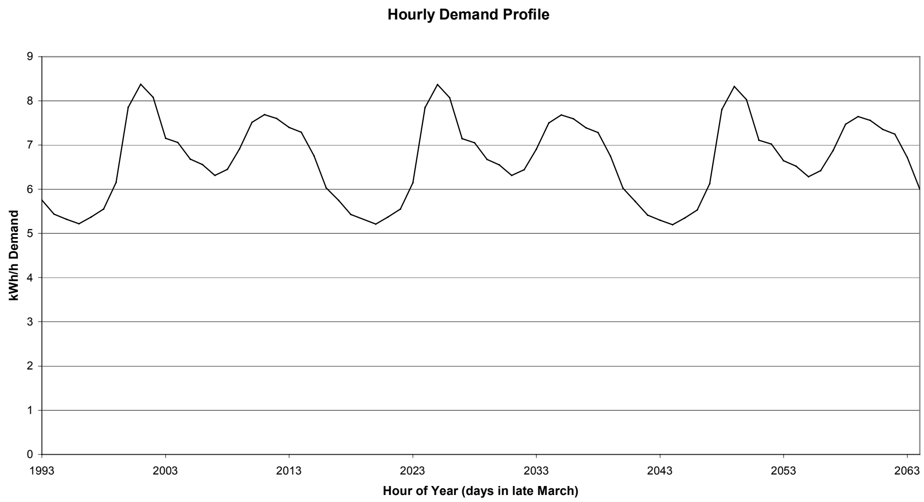

Figure 6: Hourly Demand Profile

5.3 Storage: The Role of Hydrogen

Any renewable energy system requires an energy storage system due to the inherent cyclic nature of renewable resources. There are various types of storage systems available both commercially and in the pre-commercial stage. For large-scale energy storage, three technologies are generally considered: pumped storage such as pumped hydro, compressed air energy storage (CAES), and batteries [18]. However, for small and medium scale storage systems, pumped hydro and CAES do not scale down effectively.

The use of batteries, although they often have high throughput efficiency, do not allow for longer-term storage and/or deep cycling, as this significantly impacts the performance of the system [19]. Recently, there has been some interest in using hydrogen in combination with either a regenerative fuel cell system or an electrolyser/fuel cell system to store energy [20-22]. The most promising system may be a hybrid energy storage system as described by Vosen [19], which utilizes both batteries and a hydrogen system to store energy for use with a renewable energy system. Such a system can take advantage of the features of both hydrogen and batteries. It seems clear that hydrogen should have a role in energy storage for a renewable energy system at Race Rocks.

For integration into the Race Rocks Energy Balance, A simple storage model was developed. This simple model considered only the overall size of the storage system, the input (conversion to hydrogen) and output (conversion back to electricity) efficiencies, as well as a starting storage size. In this paper, the storage efficiencies are given as a single throughput-efficiency instead of input/output efficiencies for brevity.

6 Energy System Model

The models for the renewable resources, demand and storage are integrated into an overall energy system model using Microsoft Excel. Microsoft Excel's simple macro language, the ability to integrate different models on different worksheets into a single workbook and the ability to make the program accessible to a wide audience made it an ideal choice of modelling program. A conceptual schematic of the model developed in Excel is shown in Figure 7.

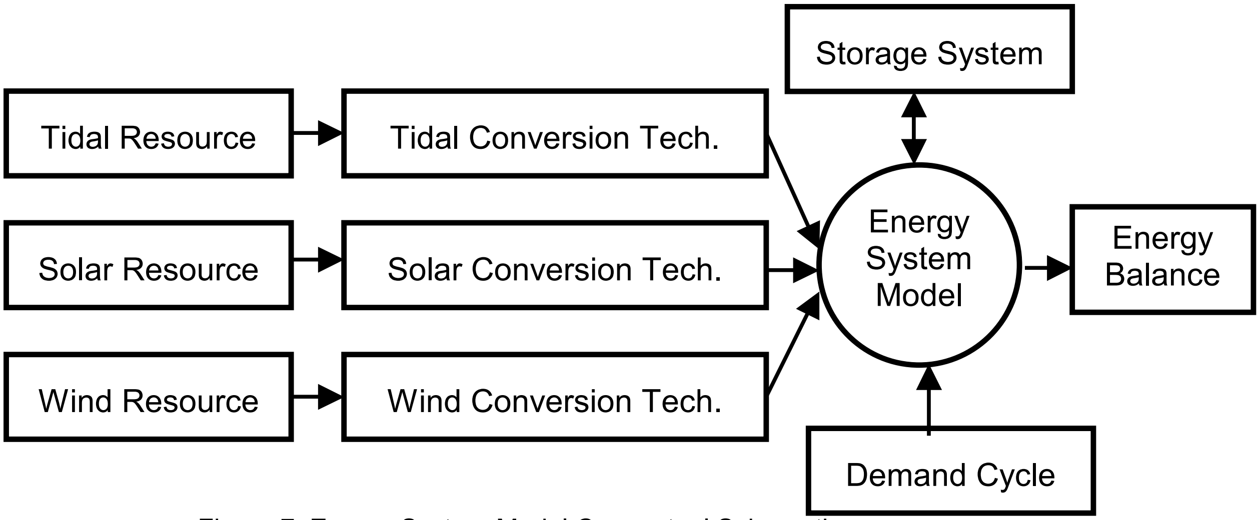

Figure 7: Energy System Model Conceptual Schematic

The model sums the energy available from the source conversion technologies for each hour of the year and compares this to the pre-existing load (demand). If there is an excess resource, the excess is added to the available storage (upon accounting for the input efficiency of the storage system). If there is a negative balance, i.e. the resources cannot meet the demand, the available storage is reduced by the amount required (accounting for the output efficiency of the storage system). This is done for each hour of the year to produce a storage system balance. The energy balance is used to indicate when the storage system is full (the balance is positive, indicating dumped energy) and when the storage system is empty (the balance is negative, indicating a brownout or blackout). The front panel of the model is shown in Figure 8.

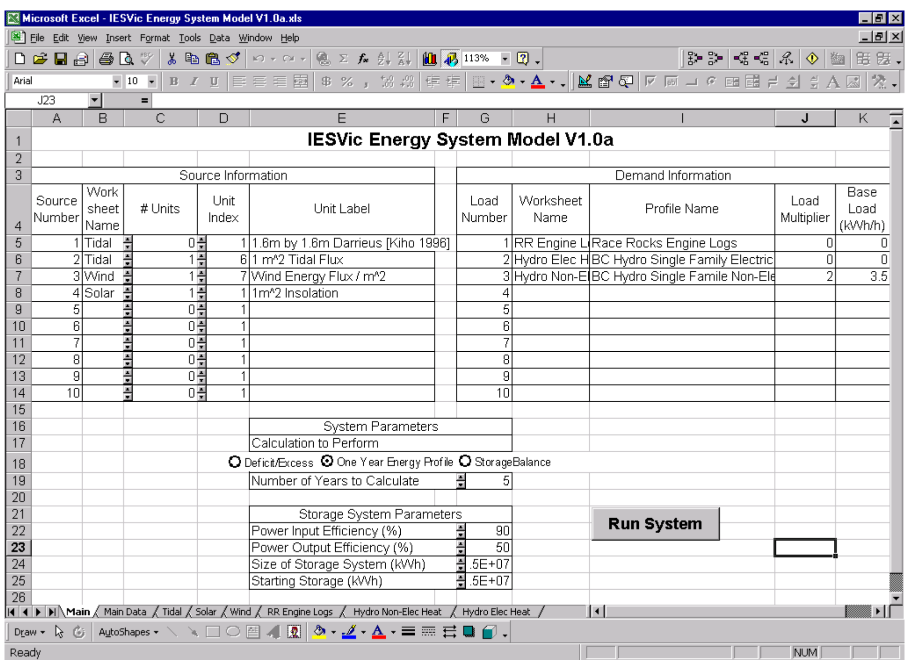

Figure 8: IESVic Energy System Model V1.0a Front Panel

This model allows us to determine the energy balance for the site with any combination of sources, any performance for conversion technologies, any arbitrary storage system, and any arbitrary demand cycle.

It allows us to optimize the effect of storage efficiency, storage size and the size of the resource conversion technology. We can effectively evaluate the ability of renewable resources to supply energy to the Race Rocks site.

7 Results

A number of different simulations were carried out to develop an idea of appropriate energy systems for the site. Table 1 shows the results for six different energy systems that could power the site with minimal disruption. Note that the amount of storage has been included in this table in both kWh, as calculated by the model, and in equivalent standard hydrogen T-cylinders to allow for easy visualization. A hydrogen T-cylinder is approximately six feet high and one foot in diameter and contains hydrogen at a pressure of 2500 psi (a total of about 7.6 standard cubic meters of hydrogen per cylinder).

Source	Technology and Number of Units	Total Active Area (m^2)	Portion of Gr. Race Rock[1]	Storage	Hydrogen T Cylinders[2]
Tidal	20 - 1.6m by 1.6m Darrieus	51.2	0.5%	500kWh (45%)	26
Tidal	15 - 1.6m by 1.6m Darrieus	38.4	0.4%	1500kWh (45%)	78
Tidal	12 - 1.6m by 1.6m Darrieus	30.7	0.3%	3000kWh (45%)	156
Wind	8 - 10kW Bergey	308.6	3.1%	200kWh (85%)	11
Wind	9 - 10kW Bergey	347.2	3.5%	300kWh (45%)	16
Solar	1500 - 1m^2 Panels @ 15%	1500.0	15%	500kWh (45%)	26

Table 1: Potential Renewable Energy System Designs for Race Rocks

The active area of each system is a convenient way of comparing the actual physical systems even though they would be significantly different in how they are implemented. For example, even though the solar panels may be oriented towards the sun, the area of land they require is still approximately the area of the panels, as they would be shading at least this much area. A wind or tidal turbine would probably take up less actual land area, but the area in front of the turbine (as well as behind) would need to be kept clear for the turbine to operate. This allows us to draw the conclusion that the tidal systems, as shown in Table 1, would take up the least amount of land (or sea) area, correlating well with our expectations from the relative magnitudes of the source fluxes as discussed in section 5.1 Renewable Resources.

The storage results from the energy system model are the most interesting. We know that the tide runs through the passages around Race Rocks every six hours and that the wind and solar resource can often go for days without any significant available energy. Because of this, one would expect the tidal systems to require only six to eight hours of storage while the wind and solar systems could require over 48 hours of storage. Our results indicate that the storage required for wind and solar is significantly less than that required for the tidal system. We believe this result is due to the short-term averaging of the models. Due to the deterministic nature of the tidal data used for this model, we are more confident in these results and expect that the wind and solar energy systems would actually require between three and five times the amount calculated by the model for the tidal system. It is clear from these results that the choice of model has a significant effect on the outcome of any simulation of this type.

As well as developing these results, the effect of different parameters on the overall energy system is also interesting. For example, the three tidal systems nicely illustrate the inverse correlation between the size

[1] Great Race Rock has an approximate area of 10,000 m^2.
[2] Calculated based on the LHV of Hydrogen.

of the generation units and the required amount of storage. The two wind systems show the effect of differing the storage efficiency. These two systems were modeled to represent a battery storage system at 85% and a fuel cell electrolyser system at 45%. These general rules can be used to optimize the systems designed.

An energy system using tidal turbines for Race Rocks would provide the most effective and reliable power for the site due to the large tidal fluxes running past the islands. The cost of a slightly larger tidal turbine to reduce the energy storage system will likely provide a more cost effective system. However, this requires an economic analysis of each of the systems, which was not part of the scope of this project.

8 Conclusions

With tidal currents of up to 3.7 m/s, average winds of 21.6 km/h and large amounts of solar insolation, there are ample renewable resources available on the site to develop a renewable integrated energy system capable of providing reliable power for the site. As well, the ability to make such a system transparent and accessible through the racerocks.com website, and to reduce the environmental impact of energy related services on the site by using renewable resources is appealing. Race Rocks is therefore ideally suited to become a showcase for renewable energy generation.

We can conclude that a tidal energy system for the site would likely have the least environmental impact due to the smaller systems required. The deterministic nature of the tidal flow would provide the most reliable power for the site and would also require the least amount of storage. The development of a tidal turbine energy system for the site is appealing and IESVic is continuing work on this project by re-developing the models using gathered data from the site and more accurate algorithms.

Finally, the effect of the model chosen on the results produced is significant. Although figures like Figure 3 and Figure 4 are relatively easy to develop and look realistic, the underlying model that they are based on must be accurate to provide a good estimate of the storage system. This is especially important since the storage system, which is one of the least developed of the technologies being considered for the site, is probably one of the most expensive components.

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