Selection of Low Power Energy Options for a Bioreactor in Remote Areas

Final Report

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1. Executive Summary

This report considers and summarizes the efficiency and viability of several alternative energy sources and associated combinations for the purposes of evaluating the option that best meets the needs of supplying power to the pumps for the ABMet bioreactors. This report considers the following energy alternatives: wind, solar, diesel, and hydro-electric. Two software packages were used in determining the best energy mix: RETScreen and HOMER Energy Plus. RETScreen is a software made available by Natural Resources Canada for statistical analysis of historical weather data. RETScreen was used to project the availability of wind and solar. HOMER was used to project the cost associated with various energy mixes and recombining each energy alternative. A decision matrix was used to assign a score to the most promising alternatives and reach a conclusion. The success criterion upon which the conclusion was based on was defined by the client and include, in order of importance: cost, reliability, a green factor, modularity, and maintenance. In considering all the factors a mix of wind and diesel was determined to be the most desirable option. Diesel as a stand-alone was the next best alternative, but was ultimately rejected based on the importance emphasized on having a green alternative available to power the pumps. Another project consideration was using a pump to drive a continuous stream up to a water tower for the purpose of backwashing the reactors to break apart the accumulated anaerobes in the bioreactors versus using a larger pump to facilitate the backwash. It was determined that a larger pump was a cheaper option as compared to the cost of constructing a water tower.

2. Introduction

GE is an organization that garners much of its success based on adaptability and diversification across industries. One of the areas that GE competes in is the food and beverage industry, which includes: critical production process and waste water systems, product safety assurance, environmental and regulatory compliance, in-plant utility performance and the ability to produce and treat the necessary quantity and quality of water and waste water. (1) Some of the specific technologies designed by GE to succeed within these industry challenges include purifying ingredient water, recovering valuable byproducts such as sugars, proteins and starches, protecting and treating cooling towers and boilers, disinfecting water and process streams, treating process water and waste water, reusing water; and measuring water quality. (1)

One of the challenges that GE faces in reaching new levels of success is in eliminating cost through efficient use of energy. “Sustainability, water reuse and waste water issues are critical to the food and beverage industry,” said Andrew Zaske, product line director, systems, water and process technologies for GE Power & Water. “Our goal is to help the industry lower energy consumption and meet regulatory and environmental requirements, all while improving water quality and water conservation.” (7)

3. Problem Statement

3.1 - The Problem

As stated GE strives to lower industry energy consumption and meet environmental requirements. This is exactly what GE is doing in a current project through the use of the ABMet bioreactor. This bioreactor is designed to handle waste water from mining flue gas and remove heavy metals and selenium byproducts before being released to the environment. GE has had great reception to this product and several of these bioreactors have been installed throughout North America. (2)

However, these reactors installed so far have been in larger housed facilities where the mine is close to the power grid and can extract its energy requirements directly from the grid. A large number of mines are located in very remote areas, such as Boulder Colorado or the Appalachians in Vermont, where an off-grid power system would be necessary for these reactors.

GE has tasked team nine with finding all possible off grid energy options to power the ABMet bioreactor in remote locations. The outline of this task will be discussed in this current section and the options for power generation in the proceeding section will be considered.

3.2 - Criteria and Constraints

When defining the scope of the project, a clear outline of what was expected for power considerations was outlined by our GE contact, Charles Bennett. The system would be a 50 gpm, single stage, two train bioreactor setup. Stages are the amount of times the water is processed and are sequential. Trains are the amount of tanks per stage. Following this decision, other key factors were discussed for the scope. This included the following criteria and constraints:

- Everything occurring inside the tank was negligible, in this energetics study only inputs and outputs were necessary for consideration. This included things such as the nutrient feed system for the bacteria within and assuming that nothing impeded flows from buildup.
- Considerations were limited to two topographical layouts for the reactor, either on level ground or with a downhill section where output water might be used for power generation.
- Retention time for waste water within the trains would be four hours.

- Two intermittent pumps on a lead lag system would sufficiently supply flow through the reactor.
- All power considerations would need to be off grid solutions with associated costs.
- A backwash system would also be considered which is used to avoid buildup of bacteria as outlined above. This system would either be setup in a water tower or need its own pump.
- The ABMet bioreactor is sold as a modular unit so that any alternative energy to include would need to be modular with the reactor as well.
- Key criteria for power options would be based on the following metrics
  - Cost
  - Green Factor
  - Modularity
  - Maintenance/Upkeep
  - Reliability

3.3 - Project Milestones

Milestones for this project can be seen in the Gantt chart in Appendix B. Upon receiving our non disclosure agreements and defining the scope with GE, our first milestone was to define scope of the project. Once our team had gathered a sufficient amount of information to define the project and scope, alternative energy options were considered based on the above metrics. The Gantt chart in this appendix was an earlier version where multiple designs were going to be proposed by different group members.

Following our interim presentation, a final proposed plan was drafted with the best combination of energy options. This would be the design which met the above five metrics the best and would be the combination presented to GE. The background of these energy options is discussed in the next section.

4. Background

4.1- Company Background

General Electric (GE) Water & Process Technologies (W&PT) brings years of experience and innovation to the water treatment industry. Before the Oakville site became a part of GE W&PT, it used to belong to Zenon Environmental Inc.

For over 20 years Zenon had specialized in wastewater treatment and, over time, it has become a world leader in the development, manufacturing, and implementation of membrane technologies for water treatment. In 2001 Zenon experienced a huge boom in business when it was commissioned to build two of the largest water processing plants using MBR (Membrane Bioreactor Technology) in the world, in Italy and Germany. Zenon's flagship product was its innovative ZeeWeed line of ultrafiltration units. In 2003 Zenon won the Stockholm Industry Water Award for the ZeeWeed membrane technology because of its contribution to safeguarding potable water supplies. GE W&PT continued to develop the ZeeWeed product line after the acquisition of Zenon in 2006.

The latest innovative products that GE W&PT have developed at the Oakville campus are the ZeeWeed 1500, a versatile and pressurized membrane suited for use in numerous applications, developed in 2008. The ZeeWeed 1500 is integrated into the PROPAK system, developed in 2009. The PROPAK system combines the ultrafiltration of the ZeeWeed 1500 with reverse osmosis for reliability, 35% reduction in carbon footprint, installation simplicity and monitoring capability. GE W&PT continues to open new water treatment plants and develop innovative products, something our group is excited to be involved in.

4.2 – ABMet Bioreactor

ABMet (Advanced Biological Metals) was a small water treatment company that was acquired by GE Water. Their removal process is a biological water treatment system that is used to remove selenium and other heavy metals before releasing water back in to the environment. The ABMet water treatment system is an innovative, pre-engineered, modular design that is very adaptable, making it appropriate for a wide range of locations and geographies. Other advantages of the system include low operating costs, the ability to remove selenates and selenites, as well as a simple yet efficient design. Currently the ABMet modular system is applied to mining, agricultural drainage, and groundwater remediation water treatment requirements.

The ABMet system begins with feed-water from a natural source, which is preferably located uphill or level with the water treatment technology. The complete system includes: a fixed bed reactor, bioreactor tanks, pumping equipment, backwash storage tanks, and a nutrient addition process. The addition of molasses as a nutrient source is used to promote microorganism growth which, in turn, uses selenium bi-products as a food source, thereby purifying the water.

Figures 1 and 2 in the Appendix include a process flow diagram and a high resolution animation of the pre-engineered system. Figure 3 shows a sketch of the system that highlights crucial design elements such as tank size, flow rate, number of trains and number of stages. Because of the multi-stage and multi train options for the design, the ABMet removal system leaves a lot of room for flexibility in terms of process design, which will be the focus of this group design project.

The main challenge the project poses is devising a low power method to pump water from the source to the tanks, while maintaining the required flow rates, in remote locations where electricity is not readily available. While many aspects of the process design are fixed, there are several parameters that can be modified and remain open to innovation. The power source may be diesel, solar, or even water powered. While the process design is already set, aspects such as process controls can be explored using both automated and manual approaches. Other parameters such as the dimensions of the bioreactor and the materials of construction for different parts of the system represent an opportunity to innovate. It may also be feasible to implement green power solutions to supplement current power requirements. This can be achieved by either a level or downhill design, such that the water source will flow down-hill and minimize pumping requirements. There is a potential opportunity to change the method for delivering nutrients into the water as it enters the system, or to even alter the nutrient feed rate to obtain a different viscosity.

Several design criteria have been established by GE W&PT. For this project, a single stage process is recommended over a duel-stage process. At this time, the project will be directed towards a two-train design schematic. A hydraulic retention time of four hours will be used for this design. Levels of nitrates and chlorides in the water must remain within an acceptable range. Temperature and pH levels of the water must also be considered. These specifications are hard constraints that are not subject to change. In addition, the maximum capacity flow rate of 50 gallons per minute must be observed, so each train will deal with a 25 gallon per minute flow rate to reach the required 50 gpm. Frequency of use of the backup pump is also an important consideration.

Design and process recommendations will be summarized in a feasibility analysis which will be delivered to the client.

4.3 – Pumping and Power Requirements

Pumping technology can be split into two main categories, dynamic (or centrifugal) pumps and positive displacement pumps. The main difference between these types of machines is the method of transferring energy to the fluid. Positive displacement pumps transfer energy to the fluid by moving the fluid into a closed volume then by moving the boundary of the closed volume the volume expands or contracts, effectively sucking in or squeezing out the fluid. In dynamic pumps, the energy transfer is accomplished with the use of rotating blades called impellers which move the fluid by creating a pressure differential. A dynamic pump is an open system and therefore there is no closed volume involved in dynamic pumps.

Positive displacement pumps are good for pumping a fluid from a large height as there is less suction head required with the closed volume. They are also better at pumping highly viscous fluids as the efficiency decreases as viscosity increases for a dynamic pump and the opposite is true for positive displacement pumps.

Dynamic Pumps are the most widely used pump types in industry; they can create large pressures and large flow rates. The market for dynamic pumps is much larger, thus the information for dynamic pumps is much easier to obtain than the information for a positive displacement pump.

Types of pumps considered for pump feeding water into the filtration system at 50 gpm. All pump descriptions are taken from the website pumpscout.com**.** (4)

- **Flexible Impeller**

Flexible impeller pumps are a type of rotary positive displacement pump that has a rotating rubber impeller with vanes that bend and then straighten as the impeller rotates to conform to the internal cam in the pump casing.

Circulator pumps

Circulator pumps are generally pumps with in-line suction and discharge flanges.

Jet pumps

Jet pumps are a type of home water well pump that is used for lower flow rates than vertical turbine types. It is a horizontal end suction pump, but makes use of an ejector to assist the flow.

Regenerative Turbine Pumps

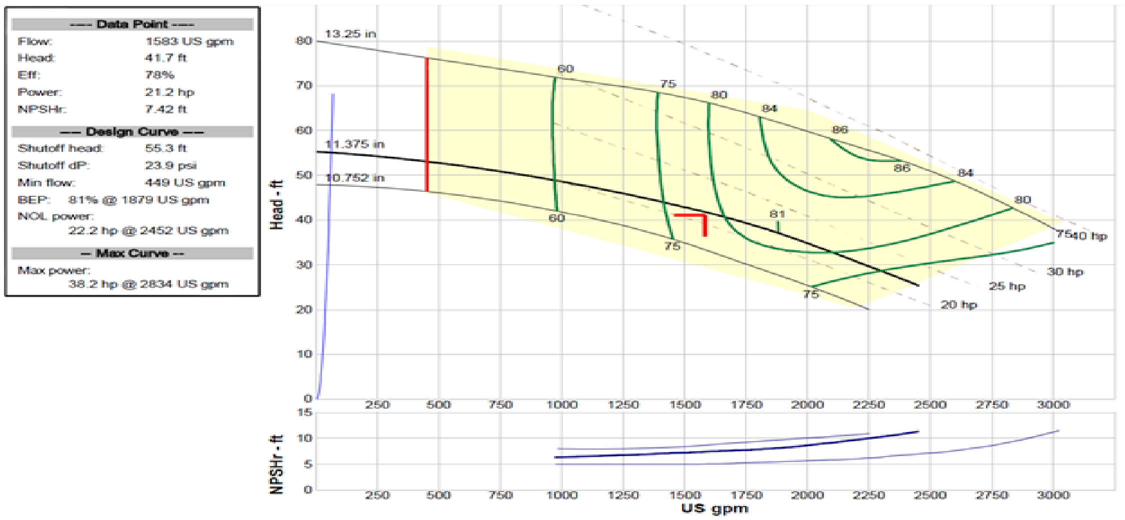
Regenerative turbine pumps are not considered a true centrifugal pump, but work on the same kinetic principal as a centrifugal pump. Instead of an impeller with vanes, the turbine impeller has blades similar to turbines, which generate the head. Normally it is end suction, single stage, though multi-stage versions are available.

Slurry Pumps

Slurry pumps are a general term for pumps that handle abrasive slurries. They may be considered an end suction pump, vertical column pump, or submersible pump.

The pumps considered could potentially offer a pump that delivers a greater efficiency than a centrifugal pump currently used, however since these pumps are less standardized than typical centrifugal pumps it is much harder to find data for the pumps. Due to limited time and information it was decided that centrifugal pumps would be adequate for this design and the Truflo Pump Selection Software was used. (2) This software takes input data such as required head and flow rate, runs through Truflo's catalogue of pumps and selects top five pumps for efficiency at these required parameters.

For the backwash pump it was found that to achieve the 41 ft. of head at the required flow rate of 1583 gpm (gallons per minute) the selected pump would have to be run with an input of 21.2 hp. The pump curve follows:



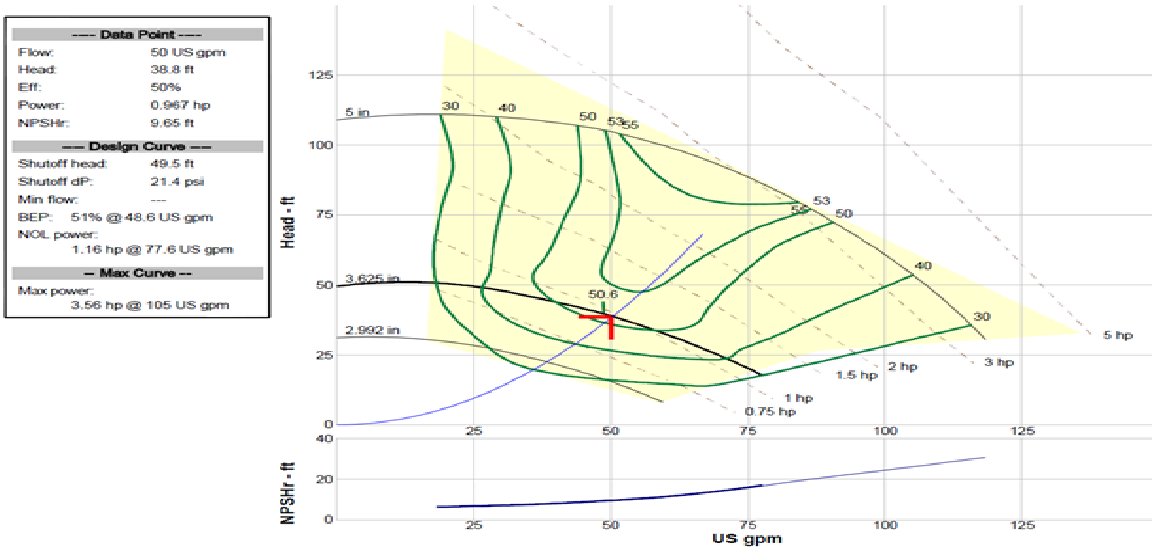
Performance Evaluation:

Flow US gpm	Speed rpm	Head ft	Efficiency %	Power hp	NPSHr ft
1900	1180	36.7	81	21.7	8.19
1583	1180	41.7	78	21.2	7.42
1266	1180	45.6	70	20.6	6.83
950	1180	49	59	19.9	6.3

Figure 1: Operating Point Pump Curve

In the above figure the red arrow points to the operating point of the pump. The most important information can be gleaned from the chart on the right which gives the flow rate, head, efficiency, power input to the pump and the NPSHr (net positive suction head required) at this operating point. Assuming that there is little elevation difference between the pump and the water source, the NPSHr can be neglected.

The main flow pump was selected in the same manner as the backwash pump, the pump curve follows:



Performance Evaluation:

Flow US gpm	Speed rpm	Head ft	Efficiency %	Power hp	NPSHr ft
60	3500	32.2	48	1	11.5
50	3500	38.8	50	0.967	9.65
40	3500	43.8	50	0.884	8.2

Figure 2: Pump Curve and Data for Main Pump

Since the flow rate is much smaller than what is typically seen in industry, the pumps that can produce this flow rate are not as efficient as pump at higher flow. Even with an efficiency of only 50% the power required to run the pump is small, 0.967 hp. Positive displacement pumps are much more efficient at this flow rate; however they are much more expensive than a dynamic pump since dynamic pumps are much more common in industry and can therefore take advantage of economies of scale. Ultimately, the added cost of going with a more efficient positive displacement pump is outweighed by the higher first cost of the machine.

4.5 – Energy Options

4.5.1 – Diesel Fuel

Currently, GE Power and Water use diesel fuel to power all generators for all applications with pumping requirements. Diesel fuel is an excellent source for these energy needs due to low maintenance and fuel costs. Fuel costs for diesel are on the order of a USD

$1/L. (3) Low fuel costs, coupled with relatively low initial costs is why this is the current power generation source in use.

Diesel engines offer the highest thermal efficiency of any internal combustion engine. (3)This is due to the high compression ratio of the fuel in the chamber. The compression is so high in fact that diesel fuel is readily combusted without any need for a spark plug or ignition source, as the pressure alone causes the fuel to ignite. Figure 3 outlines the process of diesel fuel ignition in the combustion chamber. This process offers a much higher duration and reliability of service due to fewer parts at risk of requiring replacement or disruptive maintenance over the typical service life. The durability of the materials used in a typical engine are also much higher than for engines based on a petrol fuel source due to higher pressure operating conditions. In considering all of these factors simultaneously, an advantage of the diesel engine is a long and a reliable service life.

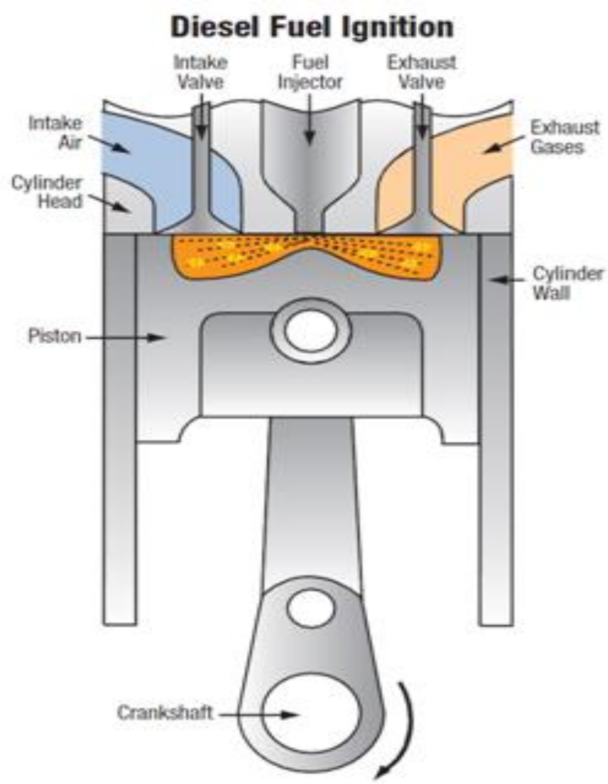


Figure 3: Diesel Fuel Ignition Chamber

When considering the types of fuel emissions caused by diesel power generation, diesel engines do not release many of the harmful exhaust products that other internal combustion engines release. Typical gasoline and petrol engines release gas components such as unburned hydrocarbons, CO, CO_2, SO_2, and several nitrous oxides NOx. The emission of these harmful gases can lead to the production of greenhouse gases and contaminants that have been shown to directly and indirectly harm the environment. (4)

Figure 4 outlines the major constituents found in both gasoline and diesel engines. It can be seen that diesel fuel is responsible for fewer CO_2 emissions. In addition, significantly smaller amounts of unburned hydrocarbons and carbon monoxide gas are emitted compared to other fuel sources or power generation methods.

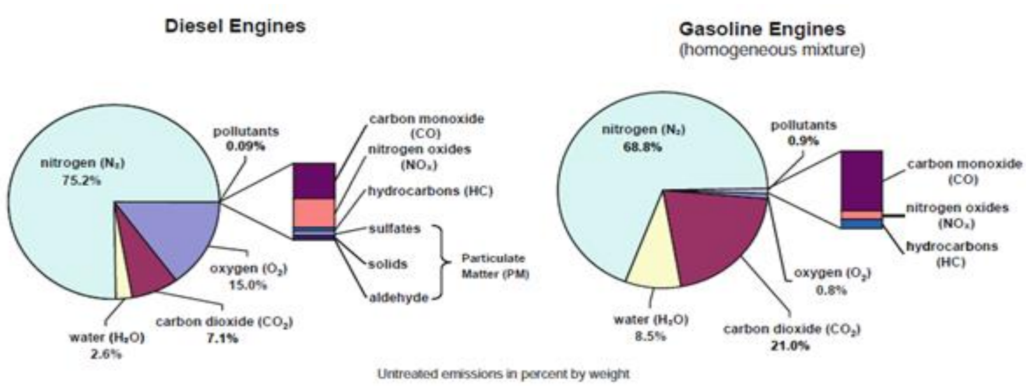


Figure 4: Diesel Engine Emission Comparison

It is also evident that a larger amount of air (N_2 and O_2) is released, though the release of sulphur content is much higher. The accelerated release of sulphur content is one of the disadvantages of using diesel fuel as an energy source, as sulphur dioxide is a major air pollutant and can be very hazardous to human health. (4)

Diesel fuels are in fact primarily distilled from petroleum. (4) Through fractional distillation, diesel is harvested from gas oil which lies in the lower part of the distillation chamber. As mentioned previously, sulfur content is an issue, and the diesel is desulphurized to allow the fuel to meet energy and environmental standards. It is comprised of various hydrocarbons (paraffins, aromatics, olefins, napthalenes, etc.) as well as additives depending on the grade. These additives may allow for less wear on the engine, or less foaming of the fuel. While the implementation of biodiesel fuels has been considered to alleviate environmental concerns, these fuels have not been shown to be as efficient as current commercial diesel fuels. (4)

The current pumps used in the ABMet Bioreactor are powered by diesel engines. These engines offer an 82% efficiency rating and operate at approximately 880 rpm. These specifications put these engines in the classification of a medium speed diesel engine. (4) They are a very common engine for pumping and are very easy to modulate because of this. Figure 5 offers a comparison of low and medium speed engines to gas and steam turbines. Medium speed diesel engines operate somewhere in the range of 2-18 MW.

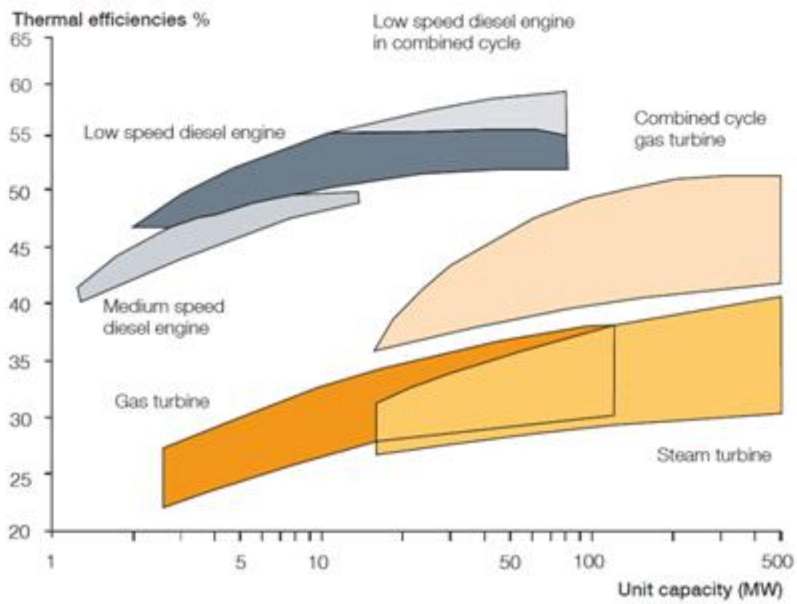


Figure 5: Thermal Efficiencies and Unit Capacity

4.5.2 – Solar

Photovoltaic energy systems or, as they are more commonly known as, solar panels, convert the energy from sunlight directly to electrical energy. This conversion process is accomplished by the "photovoltaic effect", a semiconductor effect that was first observed in 1839 (Knier). Since solar cells are a solid state device there are no moving parts and thus solar cells are maintenance free (other than occasional cleaning). Solar cells produce a direct current that can be used without modification or can be converted to AC using an inverter to be used with household appliances and machinery (CanSIA).

A typical photovoltaic energy system consists of 3 main components; the solar panels, the mounting hardware and the inverter. The solar panels themselves are usually rectangular in shape and are made by sandwiching the bare silicon cells between two layers of glass with an aluminum frame. This encapsulation serves two main purposes; to protect the silicon cells from the elements and to provide a bracket to attach the mounting hardware. The mounting hardware is also typically made of aluminum but is sometimes made of steel to cut costs. This mounting system allows for the fixed positioning of the solar panels in the most efficient angle and azimuth and also allows for efficient flow of current to the inverters. The inverters convert the direct current produced by the solar array and convert it to a useable alternating current, typically a nominal 120V.

Currently the average fully installed system price (includes inverters, mounting hardware and array) is approximately USD 5.20/W (Solar Energy Industries Association, 2011). Typically 50% of this price is for the solar panels themselves, the inverter accounts for 10% and the last 40% is mounting hardware and labour. This price has dropped over 20% in the last year alone and has decreased approximately 30% over the last three years. (Solar Energy Industries Association, 2011) The operating and maintenance costs of the installed system are one of the lowest of all energy sources and are quoted at approximately 1% of initial capital cost per year (ClearSky Advisors Inc., July, 2011). This maintenance usually includes basic cleaning of the cells and the occasional crack in the encapsulate glass. These rapidly decreasing prices combined with nearly maintenance free operation make photovoltaic energy systems more and more attractive every day.

There are several advantages associated with solar energy technology as a low power energy source. Solar energy is an abundant renewable energy resource as it can be trusted that the sun will rise each day for the foreseeable future. There is zero noise or moving mechanical parts to consider, and the technology is safe for both humans and the environment. In addition, solar technology has very low maintenance costs involved, estimated at less than 1% of the initial capital cost per year. Some disadvantages to consider include a very high initial capital cost which includes the cost of the solar panels, mounting hardware, inverters, energy storage and labor. As well, the energy is difficult and expensive to store during night time and cloudy days or periods. Another consideration is that a large surface area is needed to harness the suns energy

The main issue with photovoltaic systems in general is the large variance in available energy throughout the day as well as throughout the year. As you can see in the flowing figure, the available energy is much higher in the summer months than in the winter months. This poses a problem in our development of the ABMet system because it is difficult and expensive to store energy during the day for the night and almost impossible to store energy from the summer months for the winter months. A simple solution to this problem is to design the system to be capable of supplying most of the power in the worst case scenario; this is obviously more costly than designing for the average scenario and in some cases can be over 3 times more expensive in practice. Another strategy that can be very cost effective is the pairing of solar with other energy sources and storage systems. The diversification of the energy system allows for a smoother power curve and thus less variation. In practice solar, wind and diesel generator combos can be quite efficient and cost effective.

The other main issue with the ABMet system is that there is a high power backwash pump that is activated once a day. This load greatly increases the peak power requirements of the system and if solar were to be used alone we would have to design a system that is over 20 times larger than needed. We can accomplish buffering out the peaks using a battery system in conjunction with the most efficient combination of power sources. A battery system will allow the short interval of the backwash pump to be spread over the entire day, thus increasing efficiency of the entire system.

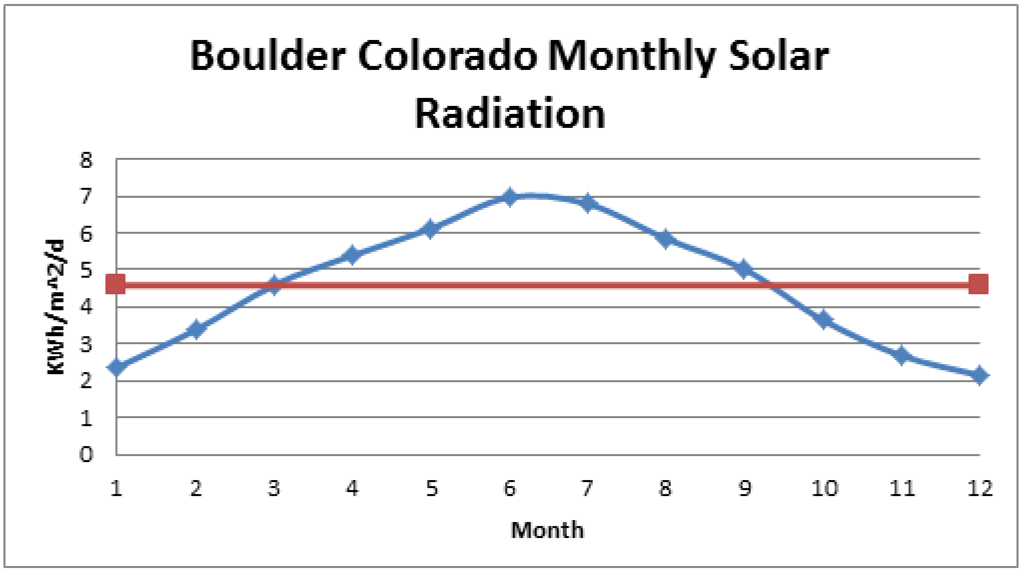


Figure 6: Monthly Solar Radiation for Boulder Colorado

A photovoltaic energy system would be well suited as an alternative energy source for the ABMet project. Since solar provides a lifetime of virtually maintenance free operation it is well suited for the off-grid remote mining location. The major drawback of a photovoltaic energy system is the large initial capital cost needed to develop and install the system. A solution to this problem is to offset peak demands with a battery backup combined with other energy sources.

4.5.3 – Wind

Another low power option to consider is the implementation of wind turbines to generate power for the remote bioreactors. In fact, GE has already efficiently implemented wind technology within another project, showing potential to adopt the technology for the ABMet application to improve existing designs. Recently GE secured an $800 million project in Rio de Janeiro, Brazil to produce 1.4 gigawatts of electricity using wind technology. (8)

GE's current product portfolio includes wind turbines with rated capacities ranging from 1.5 to 4.1 MW. In addition, GE offers support services ranging from remote monitoring and fault resolution to complete operations and maintenance support. (9) Though the power requirements considered for the ABMet Bioreactor application are significantly lower than the above rated capacities, there is a very realizable opportunity to scale up the entire system if required in the future.

The most economical application of wind turbines is usually directed towards groups of turbines referred to as "wind plants". Wind plants are groups of turbines that share common infrastructure such as electrical interconnection facilities and service roads. Wind plants can range in size from a few to hundreds of megawatts in power generation capacity. (10) In general, wind power development can cost approximately $2 million per megawatt (MW) of generating capacity installed, including the supporting infrastructure commonly referred to as Balance of Plant (BoP). (10)

In assessing the viability of a site for the use of wind power technology, there are several important considerations. Some of these considerations include, but are not limited to: wind resource characteristics (such as extreme wind conditions), setback requirements (distance to publicly accessible areas) and spacing between turbines. In addition, environmental impacts including avian, bat and other biological interference considerations are crucial. Seismic activity, noise constraints, altitude, corrosion, and extreme temperatures must be considered, as they could potentially compromise the power generating capacity and reliability of the wind power technology. (10)

Typically, a turbine will cut in and begin to produce power at a wind speed of approximately 12 miles per hour (mph). The turbine will ultimately reach its rated power capacity at approximately 28-30 mph, at which point the pitch control system begins to limit power output to prevent overloading the generator and drive train. At approximately 50 mph, the control system pitches the blades to stop rotation (which is referred to as feathering the blades) to prevent overloads and damage to the turbine’s components. (11)

When wind turbine technology is coupled with controllers, the efficiency and effectiveness are known to increase. Controllers integrate signals from sensors to control rotor speed, blade pitch angle, generator torque, as well as power conversion voltage and phase angle. The controller is also responsible for critical safety protocol, such as shutting down the turbine when extreme conditions are reached. Currently, most turbines operate in variable speed, and the control system regulates the rotor speed. This is to obtain peak efficiency in fluctuating winds by continuously updating the rotor speed and generator loading to maximize power and reduce drive train transient torque loads. Variable operating speed requires the use of power converters, which enable turbines to deliver fault ride-through protection, voltage, control, and dynamic reactive power support to the grid. (11)

There are additional operational difficulties associated with the use of wind technology. One potential issue arises when high wind speeds cause wearing of the blades, leading to a short service life. Low electricity output can result from low efficiency blade design, as outdated blade configurations are unable to capture the wind energy efficiently. Consequently, the wind power cannot be concerted to electricity efficiently enough, even if the blades are actually longer. The key factor that leads to an efficient wind turbine design is to have efficient blades matched accordingly with the correct generator load. (12)

Another potential issue associated with wind technology occurs when the furling mechanism is not responsive to the constant changes of wind speed and wind direction. The furling system responds either too early or too late to return to normal operation, which results in poor overall performance. (12)

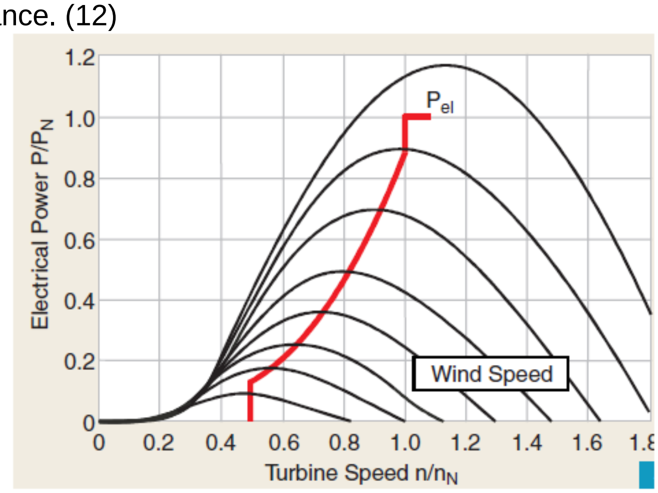


Figure 7: Power vs. Turbine Speed for Wind Speed (13)

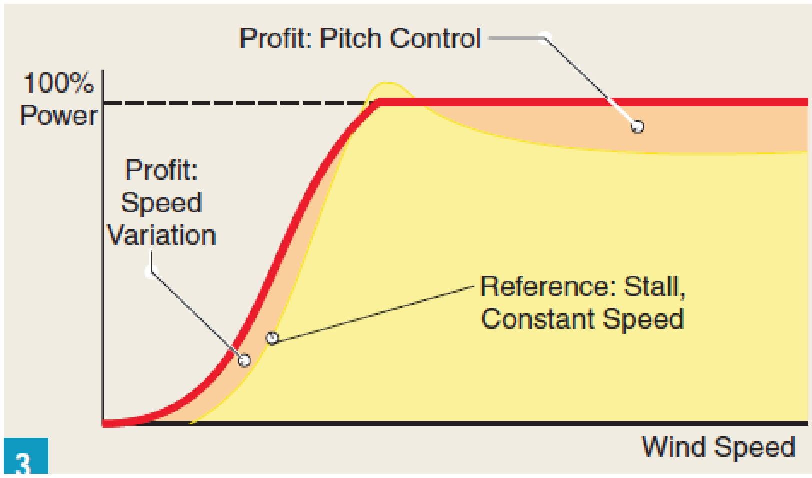


Figure 8: Wind Speed profit (13)

4.5.4 – Hydroelectric

In today's hydropower applications, changes in both potential and kinetic energy can be used to generate mechanical power and thus generate electrical power. There are three general types of hydropower systems: Impoundment, which uses a natural or man-made dam for maintaining water supply, Diversion (run of river), systems that intercept a portion of the natural flow of a river without employing an artificial dam, and Pumped *S*torage. In pumped storage, water is pumped from a source to a storage reservoir located at a higher elevation. When demand for electrical power is low, the stored water is released during peak demand, passing through a hydraulic turbine to generate power.

The main device used to capture hydro energy is the hydraulic turbine, which produces rotating shaft work that powers the electric generator. Although there are many types of hydraulic turbines, their basic approach is similar. They use a change in potential energy to increase fluid pressure and/or velocity (kinetic energy) and then deposit a portion of this hydraulic or kinetic energy on a turbine bucket to rotate a centrally located shaft. Thus, as fluid passes through the turbine, the change in its potential energy is continuously converted into mechanical power and through the use of an electric generator, electricity

The overall power that can be extracted from a system will depend on the available potential and kinetic energy as reflected by the magnitude of the total (static and dynamic) hydraulic head and conversion efficiency of the particular hydraulic turbine electric generator combination.

For hydro installations that are impoundment structures with the static head providing the energy, the dynamic head term is effectively zero. For a low-head, run-of-river system the dynamic head could be comparable to or greater than the static head.

The efficiency of the conversion process is represented by the term ε, which is always less than one. This term captures the losses that occur due to friction and other dissipative effects. The value for ε has a range of 0.9 to 0.6 depending on the type of turbine and generator being utilized. Smaller installations typically have lower efficiencies than large installations in the range of 0.8 – 0.6 or less.

Typical hydroelectric systems range from $1,200 to $6000 per installed kW according to environment Canada and have low maintenance as well as low operating costs with high reliability over the life of the system.

Impoundment hydropower integration would allow for use of a discharge pound as the impoundment structure making use of existing infrastructure. The theoretical power output of a hydroelectric system making use of a discharge pond can be easily estimated for a fixed flow rate of 50 GPM (0.05 L/s) given an elevation change by simplifying Equation 1 from before to a purely impoundment source. The potential power generation than becomes:

$$Power = (total\ hydraulic\ head)x(volumetric\ flow\ rate)x(efficiency)$$

$$= \left(\rho g Z + \frac{1}{2}\rho\Delta(v^2)\right)x(Q)x(\varepsilon),\ where\ v = \frac{Q}{A} \qquad \text{(Equation 1)}$$

Equation 1 is plotted below in Figure 9 for an efficiency of 0.8 and 0.6 to establish an operating range. As illustrated in Figure 9 at an elevation of between 41 to 54 meters (134 -177 ft) a system could provide the 1000 watt power requirement of the water treatment facility.

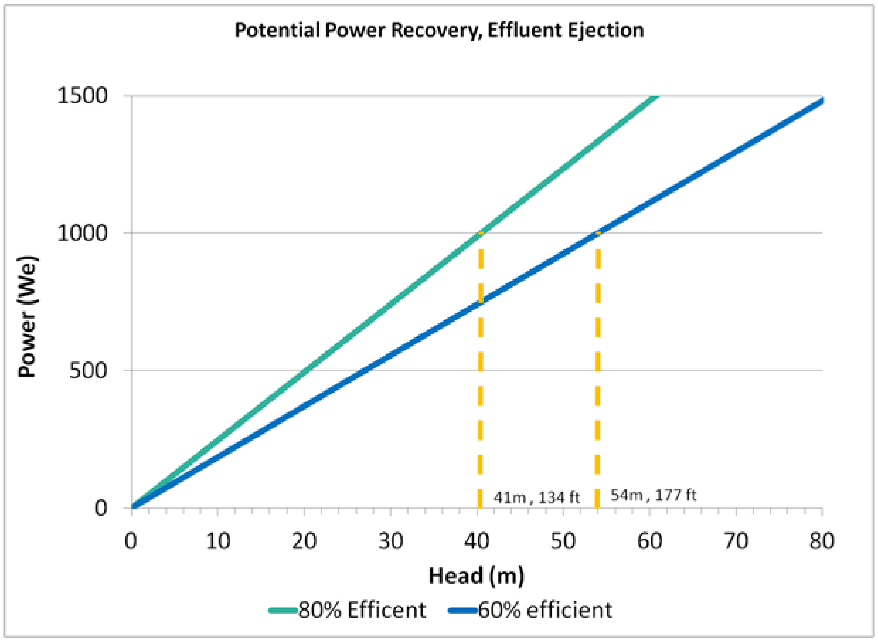


Figure 9: Potential Power Recovery

With a constant flow rate the power output of an impoundment power plant would be constant allowing the energy recovery system to provide the power requirement of the water treatment facility. The largest contributing factor to the available energy recovery would be the net height of the water head as illustrated in Figure 9. This parameter is heavily site depended. If the site was to use a river or ground effluent rejection system at the level of the treatment facility there would be no usable head. If the effluent is to be held in a settling pound that is still level with the treatment process but were the effluent is released down grade of the treatment process there could be considerable head to take advantage of for energy recovery that would otherwise be lost.

The estimated cost of an energy recovery system of 1 kW is $18,695. The estimate is detailed below in Table 1.

Table 1: Energy Recovery System Cost

Installation	$14,434
Turbine	$ 2,495
Penstock (6 in)	$ 1,766
Total Cost	$18,695

Piping is PVC schedule 40 from George Fischer Piping systems (07/11/11 catalog)
Water Storage is 3 X TP40950 rain water tanks (1)
Other costs estimated based on past projects

4.5.5 Back Pulse System

A system to de-gas and flush the Bioreactor is required for routine operation of the water treatment facility. This system requires a total dynamic head of up to 12.5 m (41.0 ft) with a flow rate of between 1131 to 1583 gpm. The frequency of operation of the back pulse system is summarized below.

Table 2: Set Points - Backwash

Description	MIN	MAX	Setpoint	Unit
Flush Flow	1131	1583		gpm
Flush Duration "De-Gas"	30	60	60	Seconds
Flush Duration "Flush"	15	20	18	Minutes
De-Gas Frequency	3	10	7	Days
Flush Frequency	15	75	60	Days

The current solution for providing the requirement for the back pulse system is the use of a large 18.6 kW pump. The use of a large pump such as this significantly increase the peak load of a power system requiring additional installed generation and storage capacity that is utilized for the short peak load durations of between 30 to 60 seconds every three to ten days and 15 to 20 minutes every fifteen to seventy five days.

A water tower can be used to build up the required volume of water for both the de-gas and flush operations over a much larger period of time effectively removing the peak power requirements thus reducing the required generation and electrical storage capacity. The water slowly builds up the power required in the form a potential energy due to an elevation change that the water tower provides. The potential energy of the water stored in the water tower offsets what would be required from a conventional batter pack for electrical storage. Often this type of storage solution can yield a higher efficiency over electrical storage in batteries.

A water tower to meet the requirements of the back pulse system parameters is summarized below in Table 3.

Table 3: Water Tower Parameters

Parameter	Metric	Imperial
Base Height	13.0 m	43 ft
Volume	120,000 l	31,7000 gal(US)
Lift Pump	7.2 l/min	1.9 gpm
Piping “demand”	-	10 in

The flow calculation for the height of the water tower includes both major and minor frictional losses for the piping system. These losses consist of pipe length, a rounded entrance, a full open ball valve and a 90 deg elbow as to facilitate the integration of the water tower into the back pulse system where the pump would have been located. Details of the flow calculations are contained in Appendix B.

The estimated cost of a water tower with the parameters outlined above in Table 2 is $23,385. This is based on the cost of common components available, summarized below in Table 4 and does not include labour costs for construction based on the assumption that GE Water and Power would be able to develop a custom solution that would be more cost effective. This value has been used for the determination in regards to cost for the best alternative and should be reevaluated before used in any construction estimates.

Table 4: Water Tower Costs Summary

	Quantity	Cost
10 INCH Piping	43 ft	$ 989
Water Storage containment	120,000 L	$ 14,097
Support Structure		$ 8000
Lift Pump and Piping		$ 299
	Total Cost	$ 23,385

Piping is PVC schedule 40 from George Fischer Piping systems (07/11/11 catalog)

Water Storage is 3 X TP40950 rain water tanks [1]

Other costs estimated based on past projects

6. Action Plan

We have decided to use the Homer Energy Software to model and optimize our renewable energy system for our ABMet off-grid solution. The Homer Energy Modeling Software allows us to calculate every possible combination of wind, solar, battery, pump, inverter and generator and will optimize parameters based on constraints (Homer Energy). Since our system is off grid it is relatively easy to model but still requires the input of wind data, solar data and all of the specific parameters for the other system components. The final optimization of the system used over 21,000 different simulations per renewable fraction set point and throughout the development of this project we have simulated well over 1 million different combinations of systems.

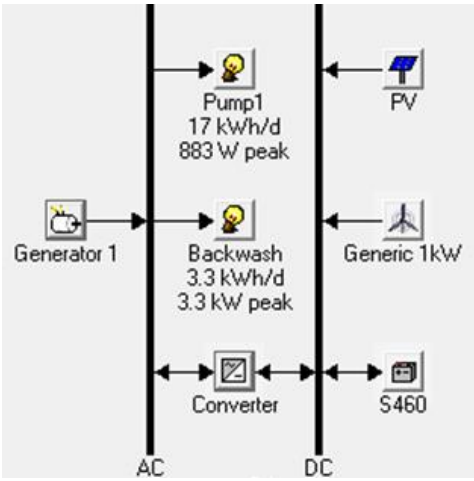


Figure 10: ABMet Electrical System Diagram

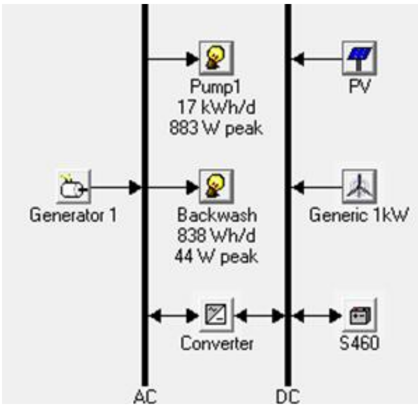


Figure 11: ABMet Electrical System Diagram With Water Tower

7. Recommendations

Evaluating all the energy options based on the success criteria defined by GE our group has determined that a wind and diesel option is the most desirable. As the reliability of a wind alternative is dictated by the site, wind as a standalone option is not desirable. Based on simulation results, wind as a standalone option is not as cost effective as a diesel option. One of the contributing factors in choosing a diesel-wind option is the importance emphasized on having a green power solution. Referring back to the decision matrix, the diesel option ranked very low as a green alternative. Otherwise diesel ranked very well in terms of reliability, low cost, modularity, and maintenance. Furthermore, the convenience of having diesel already delivered to the nearby mining sites means that there will be little in the way of additional delivery or maintenance requirements. Implementation of a diesel-wind option combines the advantages of both options, while offsetting the disadvantages of the stand alone options. A wind option will minimize the required expenditure of diesel, while a diesel generator will offset the low reliability of coping with a variable wind load. Some additional maintenance will be required in the combined option as both the wind turbine and the diesel generators must be maintained. Due to the small scale of this particular system a home scale sized wind turbine should be sufficient for the purposes of powering the ABMet pumps. The combined option sacrifices a higher capital cost as compared to the stand alone options for the benefit of lower operating costs by saving on the purchase of diesel. On a larger scale, this option would not likely be as desirable as a wind farm might be required.

8. References

[1] GE energy, *ABMet*, http://www.geenergy.com/products_and_services/products/water_and_process_equipment/knock_selenium_off_the_chart_with_ge_abmet.jsp (2011)

[2] Pump Types Guide. *Pump Scout.* [Online] 2011. [Cited: November 26, 2011.] http://www.pumpscout.com/articles-scout-guide/pump-types-guide-aid100.html.

[3] Truflo's Pump Selection Software. *truflo.com.* [Online] 2011. [Cited: November 26, 2011.] http://www.truflo.com/13.html.

[4] Mollenhauer, Tschöke, *Handbook of Diesel Engines,* Springer-Verlag Berlin Heidelberg (2010).

[5] MAN Diesel, *Two Stroke Low Speed Diesel Engines,* (2009)

[6] Dieselpage.com, *Diesel Economics and Fuel Economy*, http://www.thedieselpage.com/mileage.htm (2011)

[7] Masto H., Coffman B., Nelson K. GE's Advanced Water Technologies for the Food and Beverage Industry on Display at PACK EXPO 2011 . *Press Releases.* [Online] General Electric, 2011. http://www.genewscenter.com/Press-Releases/GE-s-Advanced-Water-Technologies-for-the-Food-and-Beverage-Industry-on-Display-at-PACK-EXPO-2011-338a.aspx.

[8] Masto H., Coffman B., Nelson K. GE Wins More than $800 Million in New Commitments for Brazilian Wind, Gas Turbine Projects. *Press Releases.* [Online] General Electric, 2011. http://www.genewscenter.com/Press-Releases/GE-Wins-More-than-800-Million-in-New-Commitments-for-Brazilian-Wind-Gas-Turbine-Projects-3371.aspx.

[9] Winning $2.7 Billion and More than 2 Gigawatts Since May Launch, GE Demonstrates Industry Leadership with Its Advanced 1.6-100 Wind Turbine. *Press Releases.* [Online] General Electric, 2001. http://www.genewscenter.com/Press-Releases/Winning-2-7-Billion-and-More-than-2-Gigawatts-Since-May-Launch-GE-Demonstrates-Industry-Leadership-with-Its-Advanced-1-6-100-Wind-Turbine-3373.aspx.

[10] Wind Energy Basics. General Electric. 2009.

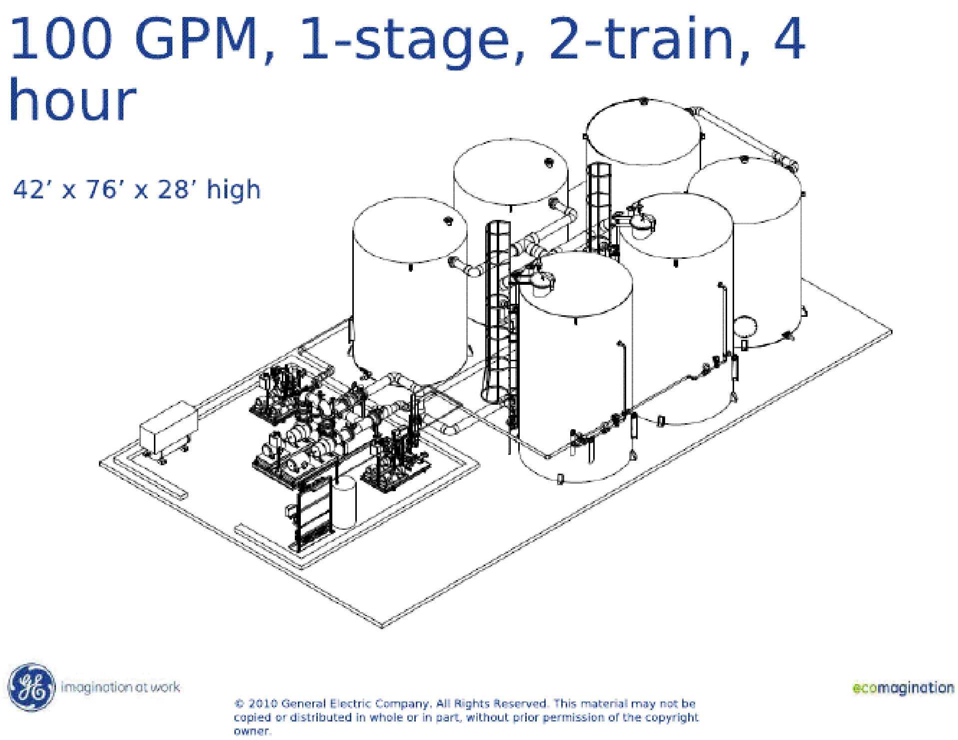
[11] Thresher R., Robinson M., Veers P. IEEE Power and Energy Magazine: To Capture the Wind. 2007.

[12] [Online] http://www.allsmallwindturbines.com/.

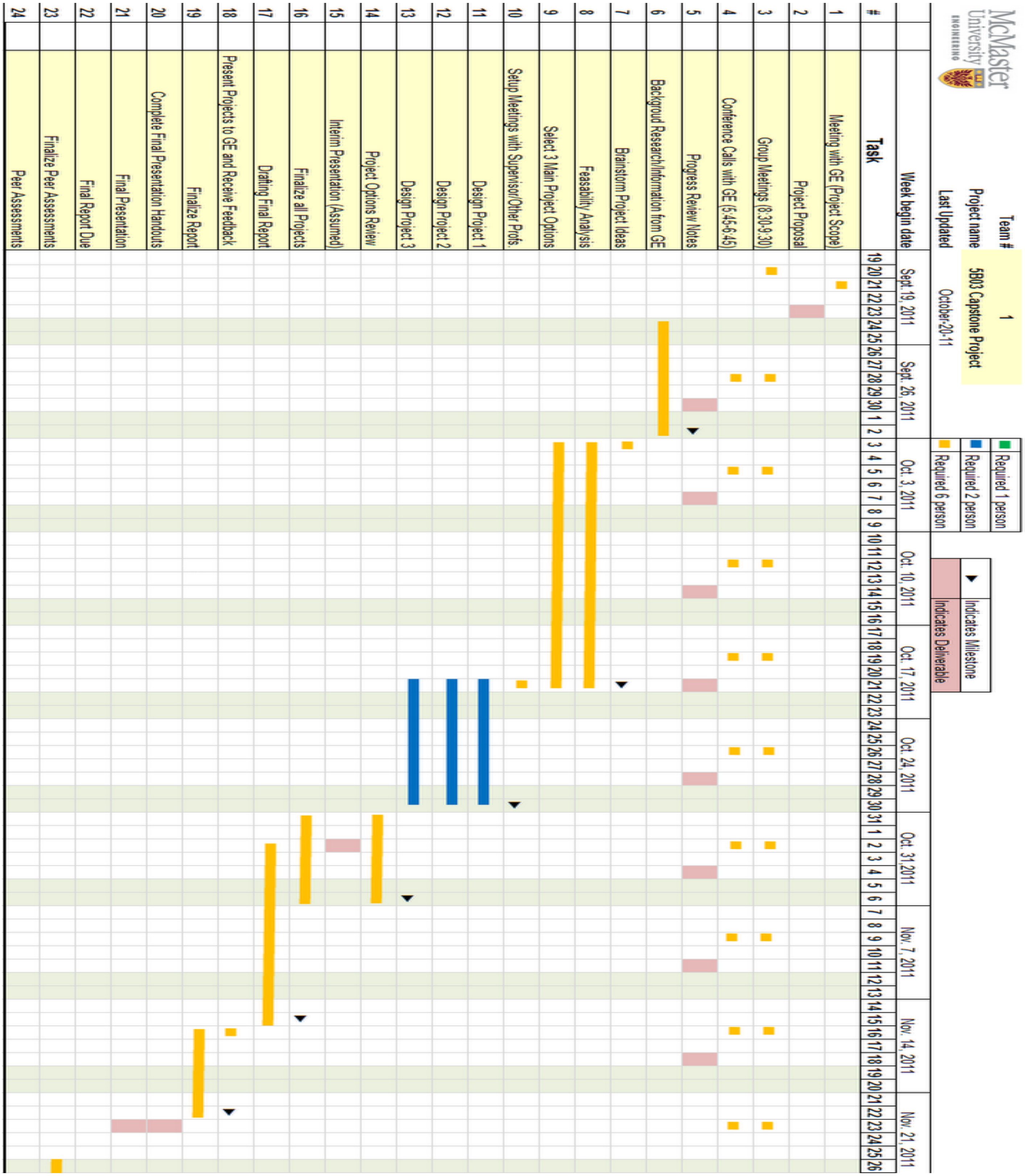
[13] Muller S., Deicke M., De Doncker R. IEEE Industrial Applications Magazine:Doubly Fed Induction Generator Systems for Wind Turbines. 2002.

9. Appendix

A. ABMet Bioreactor Visuals



B. Project Gantt Charts



C. Hydroelectric Power Calculations

Water Tower Calculations

$$\left(\frac{p_1}{\rho} + \alpha_1 \frac{V_1^2}{2} + gz_1\right) - \left(\frac{p_2}{\rho} + \alpha_2 \frac{V_2^2}{2} + gz_2\right) = h_{l_t}$$

$$g(z_1 - z_2) - \frac{p_2}{\rho} - \frac{V_2^2}{2} = h_{l_t}$$

$$g(h) - \frac{p_2}{\rho} - \frac{V_2^2}{2} = f\left(\frac{h}{D}\right)\left(\frac{V_2^2}{2}\right)_{major} + K_{Ent.round}\left(\frac{V_2^2}{2}\right) + f\left(\frac{L_e}{D}\right)_{GV\ open}\left(\frac{V_2^2}{2}\right) + f\left(\frac{L_e}{D}\right)_{90^0}\left(\frac{V_2^2}{2}\right)$$

Assumptions

$P_1 = P_{atm}$
$V_1 \approx 0$
$\alpha_2 = 1$

Solved for h with excel using goal find.

Water Tower Base Height

Constraints		
TDH	12.5	m
QDESIGN	0.0714	m3/s
QMAX	0.0999	m3/s
Pressure	122,588	Pa

Properties		
e	0.0015	mm
ρ	999.7	kg/m3
μ	1.31E-03	kg/m·s
g	9.81	m/s2

Inputs		
D	0.2032	m

INCH	m
8	0.2032
10	0.2540

Results

			Re	f	h (m)	Calculation
8 Inch Pipe						
V_{Design}	2.20	m/s	3.42E+05	0.034622	13.7	0
V_{MAX}	3.08	m/s	4.79E+05	0.034536	15.0	0
10 Inch Pipe						
V_{Design}	1.41	m/s	2.19E+05	0.034783	13.0	0
V_{MAX}	1.97	m/s	3.06E+05	0.032365	13.4	2.132E-14

Lift Pump

Constraints		
	De-Gas (s)	Flush (s)
Duration	60	1200
Frequency	259200	1296000

Results

	Volume (m^3)	Hight (m)	Flow Rate (m^3/s)
De-Gas	6	0.68	0.00002
Flush	120	13.60	0.00009
		Total	**0.00012**

Energy Systems & Design Easy Tune ® Stream Engine

The Stream Engine employs a brushless, permanent magnet alternator which is adjustable, enabling the user to match turbine output to the electrical load. It has higher efficiency than previous alternators, and is capable of outputs up to 2 kilowatt (kW).It is equipped with a rugged bronze turgo wheel, universal nozzles (adaptable to sizing from 3 mm (1/8 inch) to 25 mm (1 inch), or brass nozzle inserts, and a digital multimeter which is used to measure output current. The entire system is made of non-corrosive alloys for long life and durability.

Stream Engine Output in Watts (Continuous)

Net Head		Flow Rate Liters/sec (Gallons/min)						
		0.67 (10)	1.33 (20)	2.50 (40)	5.00 (75)	6.67 (100)	7.50 (112)	9.50 (150)
Meters	Feet							
3	10	-	20	40	75	100	130	150
6	20	15	40	80	150	200	250	350
15	49	45	100	200	375	500	650	800
30	98	80	200	400	750	1000	*	*
60	197	150	400	800	1500	*	*	*
90	295	200	550	1200	*	*	*	*
120	394	300	700	1500	*	*	*	*
150	492	400	850	1900	*	*	*	*

* In these higher output situations, it may be worthwhile to utilize more than one Stream Engine.

ES&D Price List
Easy Tune Stream Engine (SE)
1 Nozzle SE Standard……………….$2345
2 Nozzle SE Standard……………….$2495
4 Nozzle SE Standard……………….$2795
High Voltage Option………………….$275
High Current Option………………….. $275
All Bronze Option…………………….$700

Source: http://www.microhydropower.com/our-products/stream-engine/

D. Homer Analysis Software Power Optimization Results

Optimization Results (Without Water Tower)

25% Minimum Renewable Fraction

PV (kW)	G1	Gener (kW)	S460	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gener (hrs)
	5	2.5	12	4	$ 11,867	3,157	$ 52,222	0.556	0.72	1,372	3,201
1.0	4	2.5	12	4	$ 16,867	2,820	$ 52,912	0.563	0.74	1,160	2,602
1.5		2.5	12	4	$ 18,667	3,755	$ 66,671	0.710	0.29	2,214	5,929
	7	5.0		4	$ 6,733	6,562	$ 90,616	0.965	0.58	3,934	6,244
2.0	6	5.0		4	$ 16,933	5,913	$ 92,516	0.985	0.64	3,421	5,506
3.0		5.0		4	$ 20,933	6,569	$ 104,906	1.117	0.30	4,455	7,140

50% Minimum Renewable Fraction

PV (kW)	G1	Gener (kW)	S460	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gener (hrs)
	5	2.5	12	4	$ 11,867	3,157	$ 52,222	0.556	0.72	1,372	3,201
1.0	4	2.5	12	4	$ 16,867	2,820	$ 52,912	0.563	0.74	1,160	2,602
3.5		2.5	12	4	$ 29,067	3,485	$ 73,621	0.784	0.54	1,831	5,217
	7	5.0		4	$ 6,733	6,562	$ 90,616	0.965	0.58	3,934	6,244
2.0	6	5.0		4	$ 16,933	5,913	$ 92,516	0.985	0.64	3,421	5,506
6.0		5.0		4	$ 36,533	6,049	$ 113,856	1.212	0.50	3,850	6,246

75% Minimum Renewable Fraction

PV (kW)	G1	Gener (kW)	S460	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gener (hrs)
	6	2.5	12	4	$ 12,067	3,163	$ 52,495	0.559	0.77	1,267	2,887
1.0	5	2.5	12	4	$ 17,067	2,818	$ 53,084	0.565	0.80	1,046	2,298
5.0		5.0	24	4	$ 45,733	2,675	$ 79,924	0.851	0.79	738	709
2.5	10	5.0		4	$ 20,333	5,893	$ 95,660	1.018	0.76	2,936	4,748

100% Minimum Renewable Fraction

Search space was entirely infeasible due to the reliability requirements of the ABMet system.

(

PV (kW)	G1	Gener (kW)	S460	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gener (hrs)
	4	2.5	12	4	$ 11,667	2,965	$ 49,575	0.602	0.70	1,290	3,620
1.0	9	2.5	12	4	$ 17,867	2,492	$ 49,723	0.604	0.95	314	550
		2.5			$ 1,667	3,790	$ 50,113	0.609	0.00	2,707	8,760
	4	2.5		4	$ 4,467	3,670	$ 51,379	0.624	0.59	2,152	7,029
1.0	4	2.5		4	$ 9,667	3,604	$ 55,738	0.677	0.65	2,030	6,639
1.0		2.5		4	$ 8,867	3,934	$ 59,151	0.719	0.19	2,691	8,760
2.5	6		24	4	$ 30,600	2,440	$ 61,792	0.751	1.00		
1.5		2.5	12	4	$ 18,667	3,418	$ 62,361	0.758	0.33	1,913	5,753
		2.5	12	4	$ 10,867	4,441	$ 67,635	0.822	0.00	2,708	8,741
	10		48	4	$ 32,800	3,982	$ 83,702	1.018	1.00		
9.5			36	4	$ 73,000	2,875	$ 109,751	1.334	1.00		

Optimization Results (With Water Tower)

25% Minimum Renewable Fraction With Water Tower

PV (kW)	G1	Gener (kW)	S460	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gener (hrs)
	4	2.5	12	4	$ 11,667	2,965	$ 49,575	0.602	0.70	1,290	3,620
1.0	9	2.5	12	4	$ 17,867	2,492	$ 49,723	0.604	0.95	314	550
	4	2.5		4	$ 4,467	3,670	$ 51,379	0.624	0.59	2,152	7,029
1.0	4	2.5		4	$ 9,667	3,604	$ 55,738	0.677	0.65	2,030	6,639
2.0		2.5		4	$ 14,067	3,587	$ 59,917	0.728	0.35	2,374	7,722
2.5	6		24	4	$ 30,600	2,440	$ 61,792	0.751	1.00		
1.5		2.5	12	4	$ 18,667	3,418	$ 62,361	0.758	0.33	1,913	5,753
	10		48	4	$ 32,800	3,982	$ 83,702	1.018	1.00		
9.5			36	4	$ 73,000	2,875	$ 109,751	1.334	1.00		

50% Minimum Renewable Fraction With Water Tower

PV (kW)	G1	Gener (kW)	S460	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gener (hrs)
	4	2.5	12	4	$ 11,667	2,965	$ 49,575	0.602	0.70	1,290	3,620
1.0	9	2.5	12	4	$ 17,867	2,492	$ 49,723	0.604	0.95	314	550
	4	2.5		4	$ 4,467	3,670	$ 51,379	0.624	0.59	2,152	7,029
1.0	4	2.5		4	$ 9,667	3,604	$ 55,738	0.677	0.65	2,030	6,639
2.5	6		24	4	$ 30,600	2,440	$ 61,792	0.751	1.00		
3.5		2.5		4	$ 21,867	3,307	$ 64,142	0.779	0.52	2,066	6,713
3.0		2.5	12	4	$ 26,467	3,232	$ 67,779	0.824	0.53	1,660	5,047
	10		48	4	$ 32,800	3,982	$ 83,702	1.018	1.00		
9.5			36	4	$ 73,000	2,875	$ 109,751	1.334	1.00		

75% Minimum Renewable Fraction With Water Tower

PV (kW)	G1	Gener (kW)	S460	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gener (hrs)
	5	2.5	12	4	$ 11,867	2,955	$ 49,643	0.603	0.76	1,176	3,240
1.0	9	2.5	12	4	$ 17,867	2,492	$ 49,723	0.604	0.95	314	550
	8	2.5		4	$ 5,267	3,815	$ 54,041	0.657	0.78	1,826	5,964
1.0	7	2.5		4	$ 10,267	3,693	$ 57,474	0.698	0.78	1,771	5,792
2.5	6		24	4	$ 30,600	2,440	$ 61,792	0.751	1.00		
4.5		5.0	24	4	$ 43,133	2,460	$ 74,585	0.906	0.82	558	525
	10		48	4	$ 32,800	3,982	$ 83,702	1.018	1.00		
8.5		2.5		4	$ 47,867	3,407	$ 91,423	1.111	0.76	1,760	5,710
9.5			36	4	$ 73,000	2,875	$ 109,751	1.334	1.00		

100% Minimum Renewable Fraction With Water Tower

PV (kW)	G1	Gener (kW)	S460	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gener (hrs)
2.5	6		24	4	$ 30,600	2,440	$ 61,792	0.751	1.00		
2.5	7	2.5	24	4	$ 32,467	2,564	$ 65,237	0.793	1.00		0
	10		48	4	$ 32,800	3,982	$ 83,702	1.018	1.00		
	9	2.5	60	4	$ 41,467	4,399	$ 97,695	1.187	1.00		0
9.5			36	4	$ 73,000	2,875	$ 109,751	1.334	1.00		
10.0		5.0	36	4	$ 78,933	2,870	$ 115,615	1.405	1.00		0

E. Homer Analysis Optimization Assumptions

Assumption:	Capital cost of installed photovoltaic system
Value:	$5.20/W
Reasoning:	http://www.seia.org/galleries/pdf/SMI-Q2-2011-ES.pdf

Assumption:	O&M cost of installed photovoltaic system
Value:	1% of capital cost per year
Reasoning:	http://www.seia.org/galleries/pdf/SMI-Q2-2011-ES.pdf

Assumption:	Lifetime of photovoltaic system
Value:	20 years
Reasoning:	This data is given to us by the Homer software as a typical value.

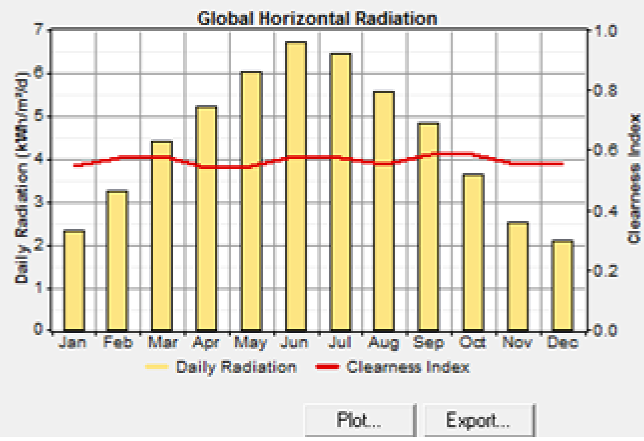
Assumption:	Derating factor for photovoltaic system
Value:	80%
Reasoning:	A factor that takes into account losses due to dirt, temperature effects etc. This data is given to us by the Homer software as a typical value.

Assumption:	Slope of photovoltaic panels
Value:	50° from horizontal
Reasoning:	Calculated on www.solarelectrictyhandbook.com/solar-angle-calculator.html

Assumption:	Azimuth of photovoltaic panels
Value:	0° (due south)
Reasoning:	Calculated on www.solarelectrictyhandbook.com/solar-angle-calculator.html

Assumption:	Ground reflectance
Value:	20%

Reasoning:	The fraction of solar radiation incident on the ground that is reflected. This data is given to us by the Homer software as a typical value.

<table>
<tr><td>Assumption:</td><td>Solar radiation data</td></tr>
<tr><td>Value:</td><td>
<table>
<tr><th>Month</th><th>Clearness Index</th><th>Daily Radiation (kWh/m2/d)</th></tr>
<tr><td>January</td><td>0.545</td><td>2.310</td></tr>
<tr><td>February</td><td>0.573</td><td>3.230</td></tr>
<tr><td>March</td><td>0.577</td><td>4.400</td></tr>
<tr><td>April</td><td>0.541</td><td>5.210</td></tr>
<tr><td>May</td><td>0.547</td><td>6.030</td></tr>
<tr><td>June</td><td>0.581</td><td>6.740</td></tr>
<tr><td>July</td><td>0.572</td><td>6.460</td></tr>
<tr><td>August</td><td>0.551</td><td>5.570</td></tr>
<tr><td>September</td><td>0.585</td><td>4.850</td></tr>
<tr><td>October</td><td>0.588</td><td>3.650</td></tr>
<tr><td>November</td><td>0.555</td><td>2.520</td></tr>
<tr><td>December</td><td>0.550</td><td>2.100</td></tr>
<tr><td>Average:</td><td>0.565</td><td>4.428</td></tr>
</table>


*</td></tr>
<tr><td>Reasoning:</td><td>Data collected from NASA for Boulder Colorado http://eosweb.larc.nasa.gov/sse/</td></tr>
</table>

Assumption:	Capital cost of installed wind system
Value:	$2000/kW installed
Reasoning:	This is the average installed system price for wind systems 1kW – 10kW

Assumption:	O&M cost of installed wind system
Value:	$100/Year/KW
Reasoning:	http://www.wind-energy-the-facts.org/en/part-3-economics-of-wind-power/chapter-1-cost-of-on-land-wind-power/operation-and-maintenance-costs-of-wind-generated-power.html

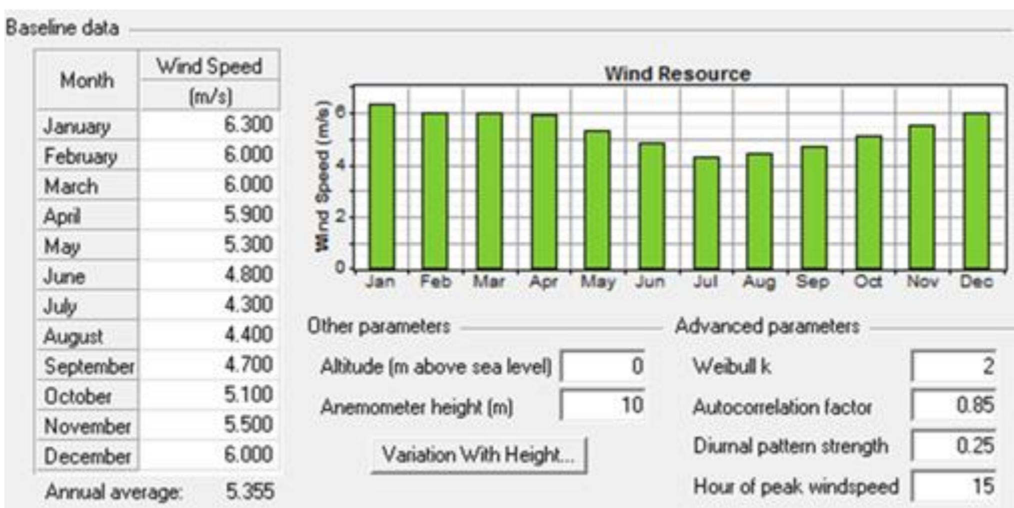
Assumption:	Efficiency of installed wind system
Value:	Efficiency curve is dependent on wind speed and is automatically generated by the Homer analysis software using typical wind turbine data in the ~3kW range

Reasoning:	N/A

Assumption:	Lifetime of installed wind system
Value:	15 years
Reasoning:	Wind turbines typically have a lifetime up to 20 years, 15 years was selected to be conservative.

Assumption:	Hub height of installed wind system
Value:	15m
Reasoning:	This value is reasonable considering the tower will be installed on top of the ABMet system.

<table>
<tr><td>Assumption:</td><td>Wind velocity data</td></tr>
<tr><td>Value:</td><td>



</td></tr>
<tr><td>Reasoning:</td><td>Data collected from NASA for Boulder Colorado
http://eosweb.larc.nasa.gov/sse/</td></tr>
</table>

Assumption:	Cost of installed diesel system (example data from Olympian GEP22-4)
Value:	$12000 for 20kW system
Reasoning:	http://www.olympianpower.com/cda/files/2127504/7/LEHF3044-08+GB+%284pp%29+GB.pdf

	http://www.pondirectpower.nl/en/ProductDetails/GEP-22-4-Closed-Set-Emergency-Power/

Assumption:	Cost of diesel fuel
Value:	$1.05/L
Reasoning:	http://www.coloradogasprices.com

Assumption:	Efficiency of diesel system (intercept coeff. and slope)
Value:	0.03433 L/hr/kW rated intercept coeff. and 0.2923 /hr/kW output slope
Reasoning:	http://www.olympianpower.com/cda/files/2127504/7/LEHF3044-08+GB+%284pp%29+GB.pdf

Assumption:	Operating and maintenance costs of diesel system
Value:	$.02/hr/kW
Reasoning:	http://www.olympianpower.com/cda/files/2127504/7/LEHF3044-08+GB+%284pp%29+GB.pdf

Assumption:	Cost of installed battery system
Value:	$600 per Surrette S460 cell
Reasoning:	We chose the Surrette S460 cells because they have a long history of reliability in off-grid applications and their technical data has been already implemented in the Homer analysis software.

Assumption:	Efficiency of battery system
Value:	Efficiency curve is dependent on multiple factors and is automatically generated by the Homer analysis software using experimental data already contained in the software.
Reasoning:	N/A

Assumption:	Number of battery cells per string
Value:	12

Reasoning:	12 cells provide a 72V DC bus, this is a typical voltage and works within the range of our inverter.

Assumption:	Capital cost of inverter
Value:	$714/kW
Reasoning:	http://solarbuzz.com/facts-and-figures/retail-price-environment/inverter-prices

Assumption:	Lifetime of inverter
Value:	15 years
Reasoning:	This data is given to us by the Homer software as a typical value.

Assumption:	Efficiency of inverter
Value:	90%
Reasoning:	This data is given to us by the Homer software as a typical value.

Assumption:	Main pump power requirements
Value:	700W continuously
Reasoning:	700W for continuous 50GPM pump from GE

Assumption:	Backwash pump power requirements (without water tower)
Value:	18.6kW for 10mins a day
Reasoning:	18.6kW is the backwash pump power from GE, 10mins a day is a worst case scenario

Assumption:	Backwash pump power requirements (with water tower)
Value:	35W 24/7
Reasoning:	A 35W pump would be able to supply enough water to fill the water tower for each backwash event.

Assumption:	Annual Interest rate%
Value:	6%
Reasoning:	Recommended starting point by GE project manager

Assumption:	Project Lifetime
Value:	25 years
Reasoning:	Recommended starting point by GE project manager

Assumption:	Dispatch strategy
Value:	Cycle Charging
Reasoning:	When the generator runs it runs at full load to charge the batteries, this increases efficiency of the generator and decreases running hours.

Assumption:	Minimum renewable fraction
Value:	0%, 25%, 50%, 75%, 100%
Reasoning:	Different test cases based on clients demand for renewable fraction

Assumption:	Hourly reserve
Value:	10%
Reasoning:	10% of hourly operating load is added to reserve