Alternative Power Source to Draw Underground Water

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Team 01

Project Proposal

Report 4

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design – Fall 2012

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Contents

1. Problem Statement

1.1 Introduction

Babbitt Ranches is a large producer of AQHA quarter horses and is home 730000 acres of land, with an additional 300000 acres deeded, located between Flagstaff Arizona and the Grand Canyon. In addition to raising livestock, Babbitt Ranches hosts a mining operation run by CEMEX. CEMEX, a global building materials company that distributes and sells cement, currently mines aggregate on Babbitt Ranches' property. This report will detail the approach taken, engineering analysis performed, and a final proposal for a solution to meet the needs that the clients have.

1.2 Background Research

Figure 1, on the following page, is an aerial view of the CEMEX mining site located on Babbitt Ranches' land. With the large amount of machines and operations using water, there is a very high demand for water on the site. There is one generator, rated at 60 kilowatts (80 horsepower) that supplies power to the pump. The generator rating is more than adequate to meet the pump's power rating of 45 kilowatts (60 horsepower). This pump supplies water from a depth of 520 meters (1700 feet) below the surface at a flow rate of 0.2838 m^3/min (75 gallons per minute). On average, CEMEX is pumping 30,000 gallons of water per day. Because of the high amount of water being pumped, there is a resulting high usage of diesel fuel. The large amount of diesel fuel being purchased by CEMEX, allows for a lower than average price of $3.50 per gallon of fuel.

FIGURE 1: COURTESY NASA

1.3 Needs Identification

On October 11, 2012 the team met with the client Billy Cardasco, President of Babbitt Ranches. Mr. Cardasco identified the combined need of CEMEX and Babbitt Ranches for a new means of providing energy to draw water from wells with depths beyond 800 feet at various well sites throughout Babbitt Ranches' land. The first priority for both Babbitt Ranches and CEMEX is to lower the operating costs of their water pumping systems. In addition, they have also expressed interest in mitigating their carbon emissions. Considering all wells on Babbitt Ranches' property, the well that is utilized by CEMEX is the most demanding design challenge and has the highest diesel fuel usage. Therefore, Mr. Cardasco would like a solution to be found for the CEMEX dedicated well, which then can be applied to other wells that are found throughout the ranch property.

Need Statement: The client is unsatisfied with the cost of fuel as well as the emission penalties required to draw 75 gallons of water per minute from 1700 feet below the surface.

1.4 Project Goal and Scope of Project

One initial goal for the team was to research the obstacles associated with drawing water from the prescribed depth. This would improve the team's understanding of the problem as well as put the team in a better position to think of innovative ideas to solve the problem. The long term goal was be to design an alternative energy source for the pump used by CEMEX. This new design would improve on the existing pump system and its power supply, as well as draw the energy from an alternative source. If the design was shown to improve the costs of the current system, the solution would able to be incorporated into similar designs for all of Babbitt Ranches' pumps.

Goal Statement: The team will design an alternative energy source that can be utilized to draw water from wells at 1700 feet that can reduce the client's current operating expenses.

Scope of the Goal Statement: The team plans to analyze the problems that Babbitt Ranches and CEMEX are experiencing, and through the analysis, create a design that meets the objectives set forth for this project. A working prototype was not in the scope for the time of this class.

1.5 Objectives

The defined objectives for this design project are seen in Table 1 below.

TABLE 1: OBJECTIVES

Objective	Basis of Measurement	Units
Meet Depth Requirements	Well depth	feet
Reduce Costs	Operating/Maintenance costs of diesel engines	$
Maintain Flow Rates	Flow rates of current system	gallons/min
Maximize Alternative Energy	Amount of energy from alternative sources	hp-hr
Decrease CO_2	Carbon emissions of diesel engines	lb CO_2/year

1.6 Constraints

The following is a list of constraints for the project:

1. The pump is required to pump water from 1700 feet.
2. The pump must operate at a flow rate of 75 gallons per minute.
3. The energy system must supply 50 kW of power to the pump.

1.7 Criteria Tree

The criteria tree for this design project can be seen in Figure 2 below. It is useful to break down the various design aspects of ideas for a solution to the problem

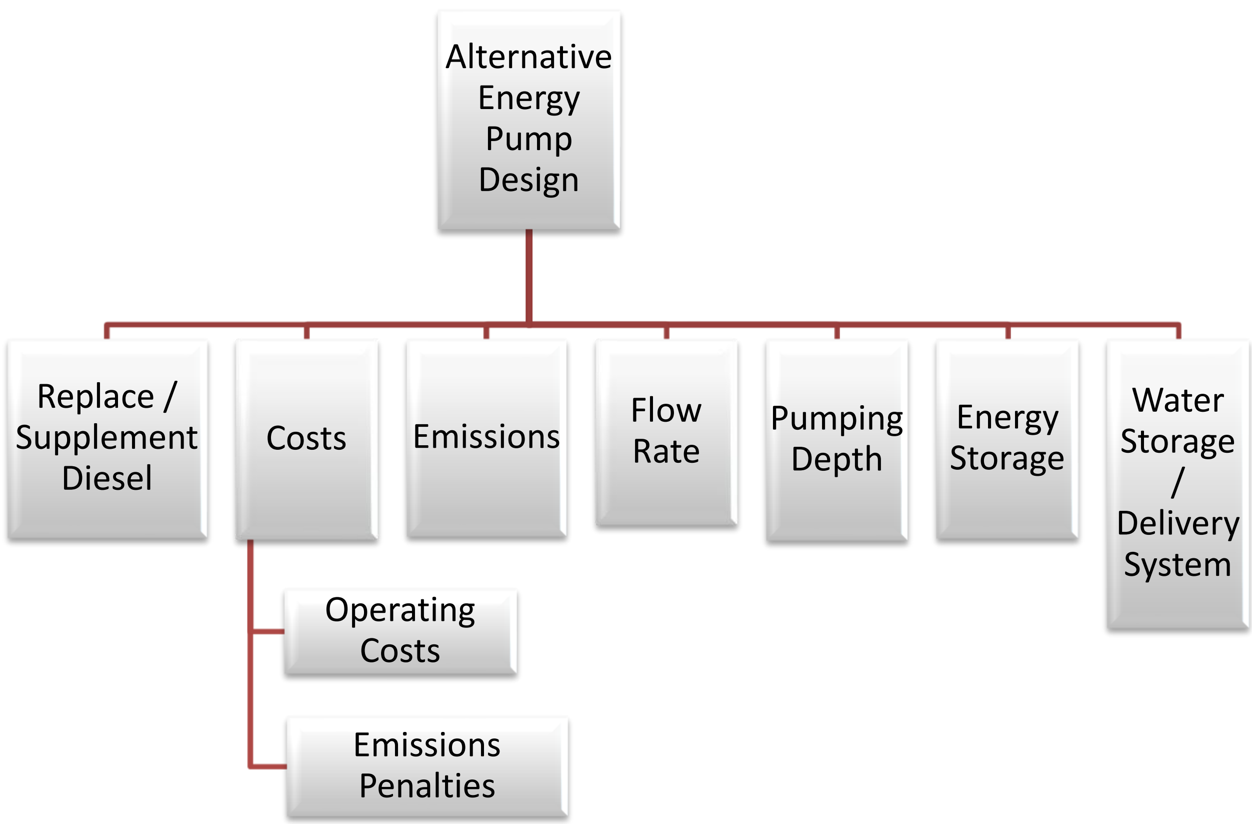

FIGURE 2: CRITERIA TREE

1.8 Quality Function Deployment & House of Quality

The following is a quality function deployment chart, which is useful to relate requirements from the sponsor with engineering requirements that must be met.

		Engineering Requirements							Bench Mark
		Conversion Technology Efficiency	Generator Power Output	Generator Efficiency	Pump Power Requirements	Pump Efficiency	Pump output capacity	Cost	Diesel Generator
Customer Requirements	Reliable							X	O
	Sufficient gal/min				X	X	X		O
	Pump water from1700 ft.		X	X	X				O
	Utilizes alternative energy source	X							
	Emission Reduction							X	
	Low running cost	X						X	
	Units	%	hp	%	hp	%	gal/min	$	

FIGURE 3: QUALITY FUNCTION DEPLOYMENT

The House of Quality for this design project can be seen in Figure 4 below. This is useful to relate the interdependence between the engineering requirements. Note that a "+" indicates a proportional relationship between the engineering requirements.

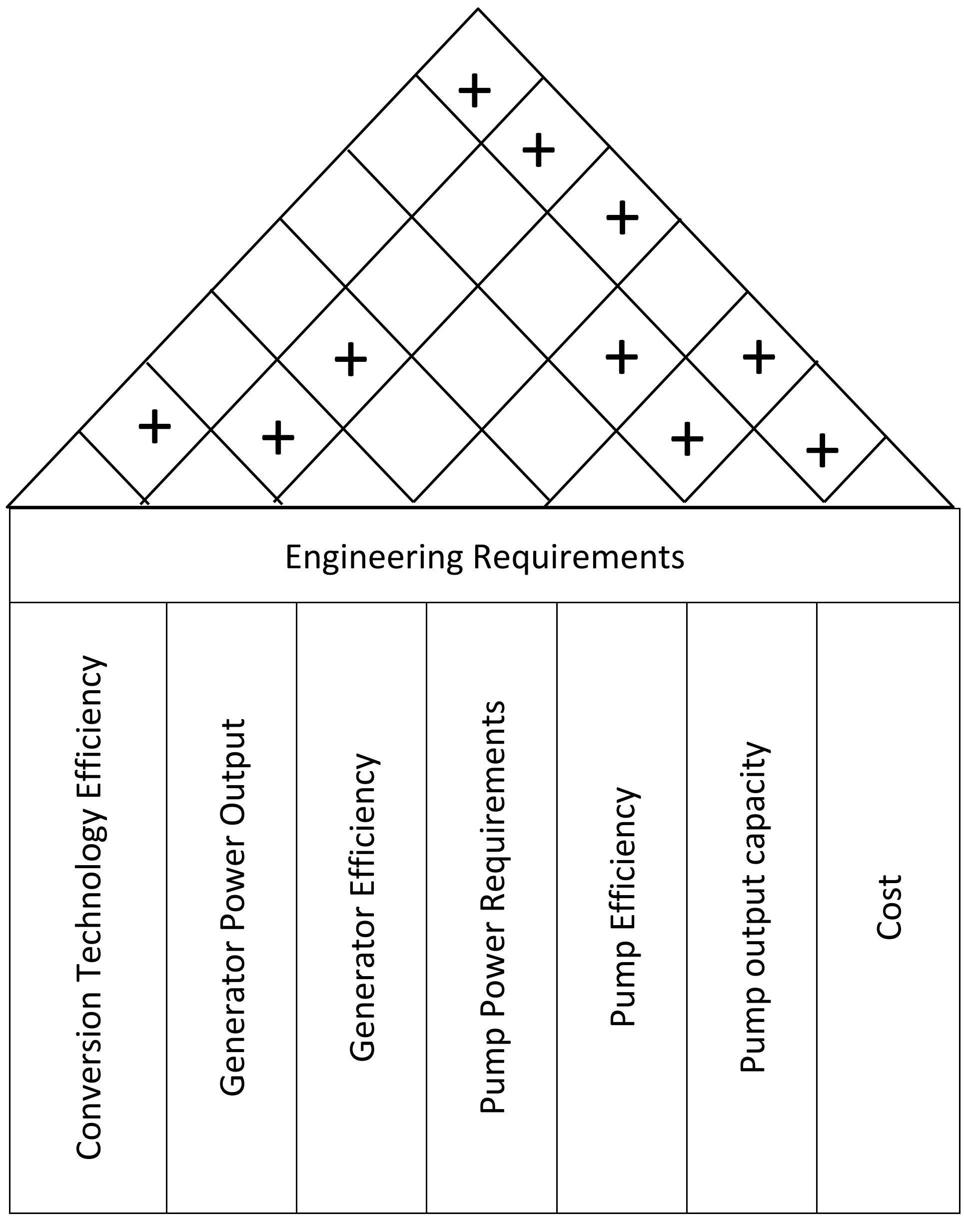

FIGURE 4: HOUSE OF QUALITY

2. Concept Generation

To approach the solution the team researched various alternative methods for powering the CEMEX pump at the specified flow rate and depth. Table 2 shows a list of all initial ideas to provide a new means of power to the water pump. These ideas for capturing energy were compiled into four categories based on the natural resource in use. The table also shows ideas for backup systems to meet the pump demands when the alternative energy source would not be available.

TABLE 2: DESIGN CONCEPTS

Capture		Option 1	Option 2	Option 3
	Solar	PV array	Concentrator--Steam	Concentrator--Sterling Engine
	Wind	Wind Turbine	Array of Turbines	Vertical Axis
	Geothermal	Vertical Loop	Buried Loops	
	Bio-Mass	Wood	Old Construction Materials	Cellulose
Backup				
	Fossil Fuel	Diesel	Gas Turbines	
	Electric	Battery Bank		
	Water Storage	Water Storage Pond	Increase Tank Storage Capacity	

2.1 Solar

The concept of using the energy from the sun led to three initial ideas: PV array, solar concentrator with steam cycle, and solar concentrator with a sterling engine. An array of photovoltaic panels, when sized appropriately, would be able to produce the energy needed to power the pump. The footprint of such an array is not an issue because the client has indicated space is not a constraint for the design.

The second idea is based on the notion that solar irradiance can be focused by a solar concentrator and used to heat steam. The heated steam would be used in a Rankine power cycle where the solar concentrator acts as the heat generator.

An additional concept was a solar concentrator which would be used to heat the working fluid in a stirling engine. Stirling engines are simple, efficient, and rely on temperature differences to generate energy. The solar concentrator would be focused on the hot part of the stirling engine. The cold part of the engine would be encased with a cooling fluid. Inside the stirling engine, the working fluid goes through cycles of expansion and contraction because of the temperature changes. The pistons move linearly and are attached to a system that translates the linear motion into rotational motion. The rotational motion would spin the magnets of an electric generator.

2.2 Wind

The team initially came up with three possible ideas to harness wind energy. A large single wind turbine that would generate enough power to supply the needs of the pump was considered. An alternative option would be an array of several turbines. Compared to one turbine, an array of turbines would mean smaller turbines but more space needed to set them up. A third idea was a vertical axis wind turbine. Vertical axis turbines are in their infancy relative to research, availability, and industry acceptance.

2.3 Geothermal

The geothermal resource inspired two initial ideas in terms of the system set-up. A vertical loop system would have one loop go deep into the earth and back, would require depths of about 50 meters to 70 meters. Holes are bored deep into the ground then pipes are run down into the holes as shown in Figure 6 on the following page. Horizontal loop systems would have a loop buried less deep in the earth that coiled several times. Horizontal loops (buried loops) require a pit dug below the frost line of the soil as shown in Figure 5. Plastic pipes are laid in the bottom of the big pit. The pipes are laid out in a fashion that resembles a spring that has been smashed radially. With either a vertical or horizontal loop layout, the system is a closed loop where the earth heats the internal fluid. The fluid is usually a type of glycol mixed with water. A pump returns the fluid to a compressor where the heat is then concentrated and used to run a heat-based power source.

FIGURE 5: HORIZONTAL LOOP

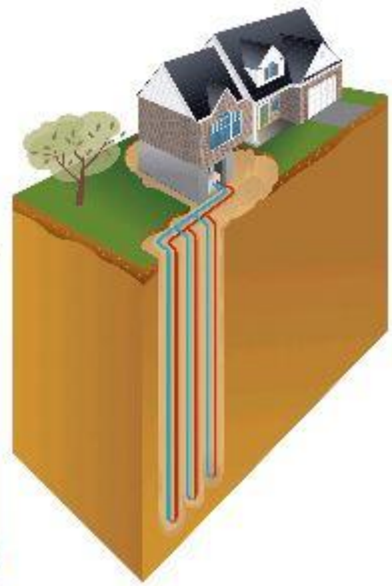

FIGURE 6: VERTICLE LOOP

2.4 Biomass

The biomass resource inspired three initial ideas based on the expected available resources. The client CEMEX indicated that they are planning on having a landfill near the mining pit, where waste construction materials can be brought. Wood is a common construction material and potentially available most of the time in CEMEX's landfill. The main sources of biomass would be wood and scrap construction materials. Also, Northern Arizona has many ecological restoration projects where small diameter trees are cleared and burned in piles. These trees could be used for biomass fuel. The biomass could be processed into biodiesel, which means that the client could maintain their current system. Alternatively, the biofuels could be burned and used in a combustion chamber for part of the Rankine cycle.

2.5 Backup System

The unreliable nature of wind energy and the cyclical nature of solar energy dictate the likely need for backup power sources. Fossil fuels are a reliable resource if alternative resources are not available or insufficient supply the necessary power. For the chosen system, there is the probability that alternative energy production will not always meet the client's needs. The client could maintain their current system but only use the diesel engine generator if the alternative energy source is unable to provide adequate power.

Another back up option for fossil fuels would be natural gas turbines. Natural gas turbines are efficient and have lower emissions relative to diesel engines. The price of natural gas is expected to decline throughout the USA because of recent technological developments in fracking, the process where air, water, and other chemicals are pumped into the ground to break apart shale and release natural gas.

Excess energy could also be stored in deep cycle batteries. If the system produces more energy than needed, the energy could be stored. If this stored energy is needed, the generator can run on energy from the batteries.

An idea for water storage was also brought up in the initial concept generation process, where there could be and increase the capacity of water storage of the current system, such as installing an extra water tank. An extra water tank would allow the client to pump more water than usually necessary, so that if the alternative energy resource is not available for some time, excess water is still available.

3. Concept Selection

Refinement of ideas generated through brainstorming sessions was crucial to determine the feasibility of each idea previously discussed. The team analyzed each idea, looking at different aspects such as expense of implementation, complexity of the system, and availability of the system for purchase.

According to the U.S. Department of Energy's report entitled, Geothermal Technologies Program, Arizona, the San Francisco Volcanic Field is one of several largely untapped geothermal resources in Arizona. It has not actually manifested any attributes of a good geothermal power source on the surface, but it has very similar geology to areas in other states with high temperature geothermal resources. The shortcoming of this option as a power source is the immense initial cost of heavy research into the geothermal resource and implementation of a power harnessing system. Large corporations such as Arizona Power Service Company are currently looking into geothermal resources elsewhere in the state, but the value of the geothermal attributes that the San Francisco Volcanic Field may hold is largely unknown. This lack of data combined with huge potential costs for such a system to harness geothermal energy has led to this idea no longer being pursued.

The National Renewable Energy Laboratory created a report entitled, *A Geographic Perspective on the Current Biomass Resource Availability in the United States*, which looked into various forms of biomass for locations across the United States. When compared with the nation, Northern Arizona has very small amounts of crop residues available for biomass consumption. Methane and manure were also viable options as Babbitt Ranches has a large amount of livestock. Unfortunately, as stated in this report, manure that is deposited on fields and pastures produces an insignificant amount of methane. Ponds and holding tanks proved to be much more effective to capture the energy in manure. Logging residues, such as unused portions of trees that are cut, are also not adequate for Northern Arizona, contrary to initial beliefs. Urban wood residues such as waste from construction are an option for the site, but gaining enough quantity to supply the power needs of the pump would be very difficult. Figure 7 below from the report displays the overall lack of biomass availability in Northern Arizona.

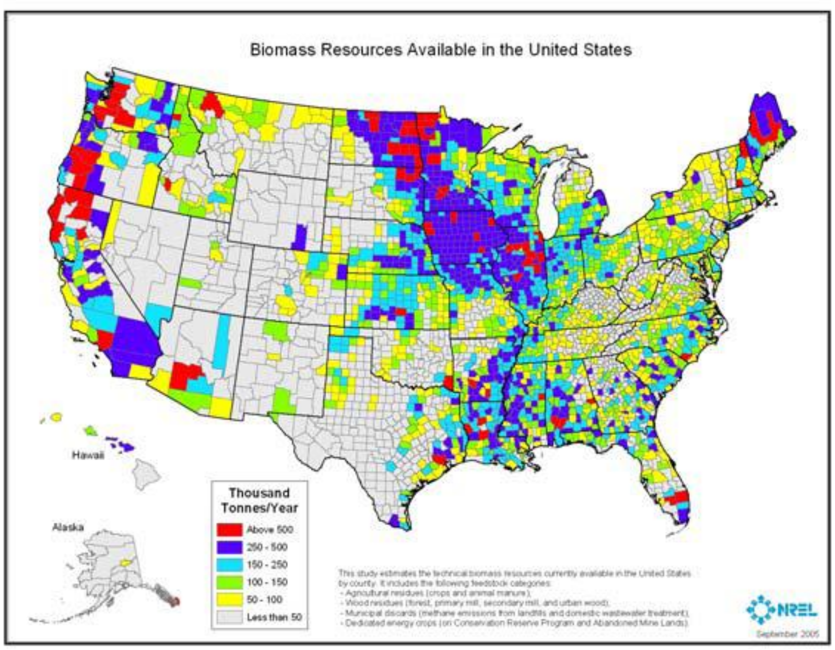

FIGURE 7: BIOMASS RESOURCES AVAILABLE IN THE UNITED STATES

Natural gas pipelines through Arizona unfortunately run miles away from the construction site. The nearest pipeline that could be routed from would provide too large of a cost to implement. Unfortunately transporting canisters of natural gas on trucks turns out to be an unviable means of supplementing the mains source of power. The infrastructure is just not established in Northern Arizona for such a large amount of natural gas needed.

The National Renewable Energy Laboratory also has reported a map, shown below in Figure 8 that displays the solar resources for photovoltaic panels in the United States. The region just above Flagstaff sees 6 to 6.5 kWh/m^2/Day on average, making solar PV, as well as a solar concentrator with a stirling engine, a promising option for the design.

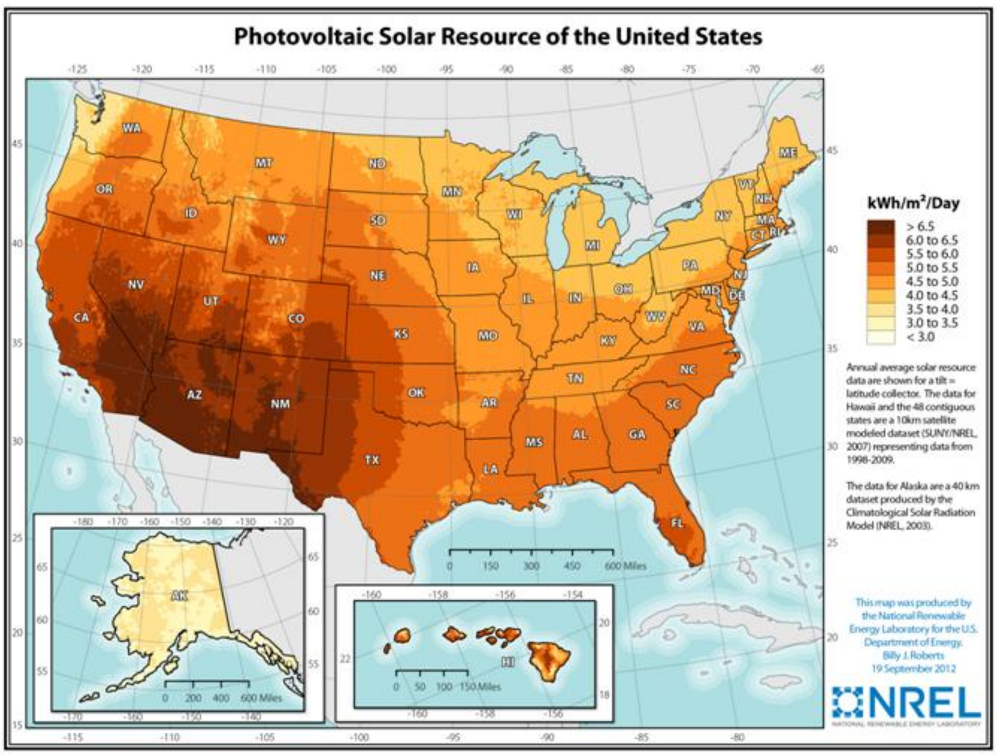

FIGURE 8: PHOTOVOLTAIC SOLAR RESOURCE OF THE UNITED STATES

A very large benefit of wind turbines that is similar to the benefits of PV is that the two technologies are heavily increasing in production and demand. This means there is availability of these technologies to adequately provide power for the design requirements. There are also benefits of implementing multiple systems to meet the power requirements, which could be very effective in the design. The availability of wind power will cause it to be analyzed further.

To further analyze the three options that proved to be most viable, solar PV, wind turbines, and a stirling engine, the team established evaluation criteria, shown in Table 3 below, that would be assigned to the systems attributes. A perfect performance level for the new design would cost less than $100,000 initially and would output at least 100 kW of power, which would provide enough power to the pump and leave extra to be used for other CEMEX operations.

TABLE 3: EVALUATION CRITERIA

Performance Level	Criteria Metrics		
	Value	**Cost $**	**Power (kW)**
Perfect	**10**	**<100,000**	**>100**
Excellent	**9**	**<200,000**	**>90**
Very Good	**8**	**<300,000**	**>80**
Good	**7**	**<400,000**	**>70**
Satisfactory	**6**	**<500,000**	**>60**
Adequate	**5**	**<600,000**	**>50**
Tolerable	**4**	**<700,000**	**>40**
Poor	**3**	**<800,000**	**>30**
Very Poor	**2**	**<1,000,000**	**>20**
Inadequate	**1**	**<1,500,000**	**>10**
Useless	**0**	**>2,000,000**	**<10**

Based on these criteria, ratings were assigned to each idea in the decision matrix, shown in Table 4 on the next page. Initial estimates of power output by each idea singularly reached 50 kW. Initial estimates of cost of the designs gave: $305,000 for a PV array, $380,000 for a wind turbine, and $1,100,000 for a sterling engine and concentrator.

TABLE 4: DECISION MATRIX

Criteria	Units	Design Option					
		Solar (PV array)		Wind (Turbine)		Stirling engine	
		Raw Score	Value on Scale	Raw Score	Value on Scale	Raw Score	Value on Scale
Cost	$	305000	7.9	380000	7.2	1100000	1.8
Power	kW	50	5	50	5	50	5
Total			12.9		12.2		6.8
Normalized total			0.40		0.38		0.21

The decision matrix shows that the stirling engine was the least effective solution relative to the others. The solar PV array and wind turbine were equally viable options from the design matrix.

The concept selection analysis suggested that implementing either a wind turbine(s) or solar array would be the most feasible option. The group then moved forward with the selections derived from the concept generation but will not rule out other potential design options, until all of the necessary engineering analysis has been performed.

4. Engineering Analysis

4.1 Wind Resource

When considering wind turbines as an application for power generation, the average wind speed at a certain site is extremely important for determining the energy potential. This importance lies in the cubic relationship between wind speed and potential power. The following two wind data maps, Figures 9 and 10, show that the wind resources for Arizona are suboptimal for reliable power generation. Figure 9 illustrates that the resource for most of the state is insignificant at 50 meters, measured vertically from ground level. The cost of creating a turbine to harness wind energy at this height would not be feasible for the resulting power that is achieved. It can be seen in Figure 10 that, except for a select few locations, the wind resource at 80 meters is less than optimal for wind turbine application in large scale power generation.

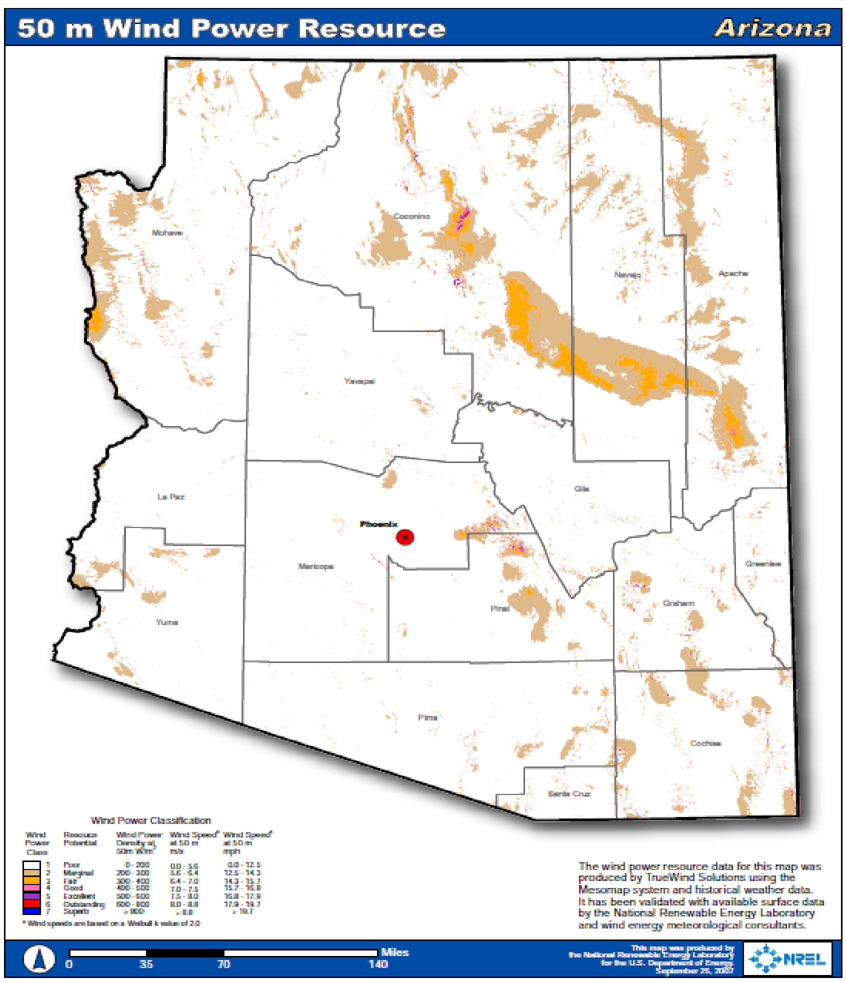

FIGURE 9: ARIZONA WIND RESOURCE AT 50 M

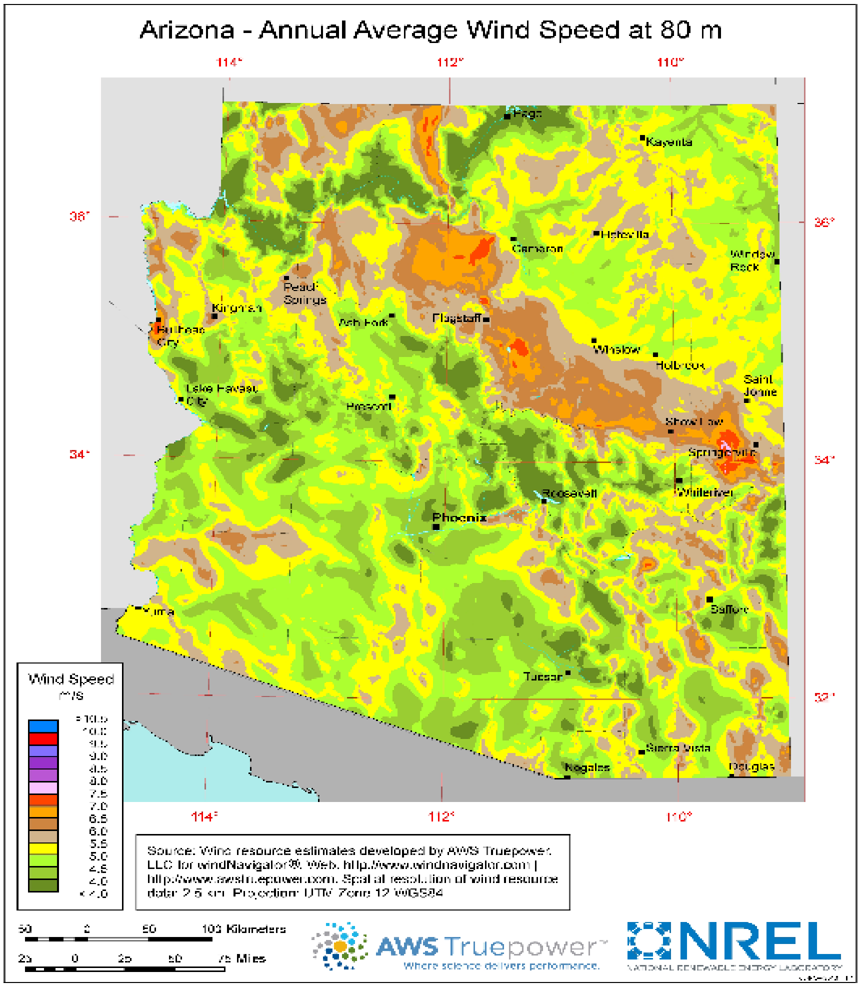

FIGURE 10: WIND RESOURCE AT 80M

These relatively low numbers do not imply that wind power is not obtainable at locations with lower wind velocities and higher boundary layers. Smaller wind turbines can begin generating power at slower velocities, but this option requires higher quantities of turbines to meet the power demands. Large turbines can also function in areas with lower wind speeds, but larger turbines require a significant initial wind speed to overcome the torque required to turn the rotor, implying fewer hours of power production. The core problem for using wind turbines in commercial application at sites with low wind velocities is that the turbine height, quantity, and the size of turbines, coupled with significant downtime, drastically increase the initial investment while prolonging a reasonable payback period.

Figure 11 is a topographic map of the CO Bar Ranchlands where the CEMEX site is located. The boundaries of the CO Bar lie within the regions that contain the colored dots, which indicate watering holes. The map shows the average wind velocity (m/s) profiles that are present in the area. The CEMEX site is specified by the large yellow arrow. It can be seen from the map that the average wind velocity for the CEMEX location is 5.5 m/s, which is low in terms of the standard for ideal power potential for wind turbine placement.

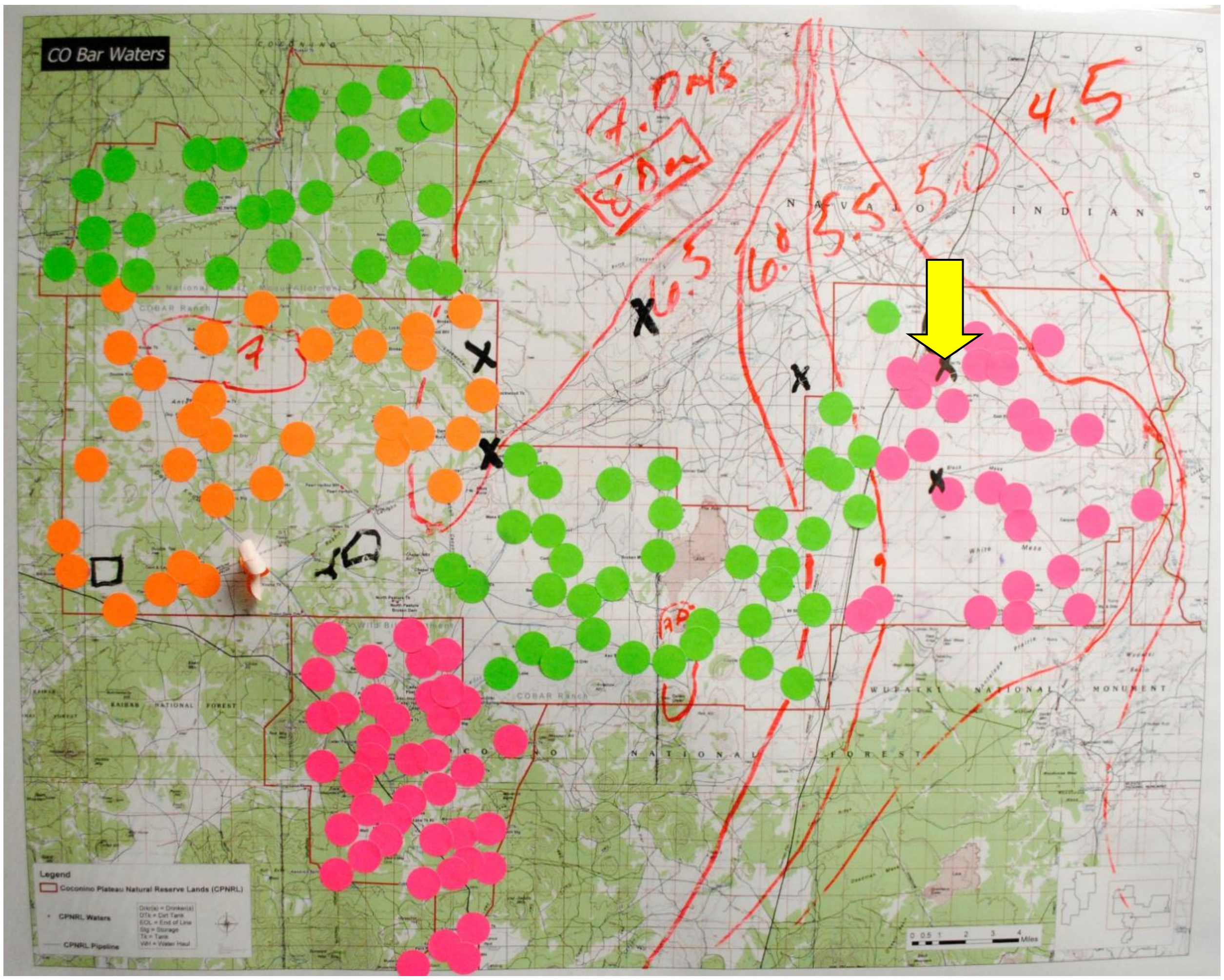

FIGURE 11: TOPOGRAPHICAL MAP OF CO BAR RANCHLANDS - COURTESY: DAVID WILLY

4.2 Wind Power Analysis

The power that is available to a wind turbine is dependent upon the swept area of the rotor blade (A), the density of the air (ρ), and the velocity of the air (v). Considering the limitations imposed by Betz limit and other losses associated with the system, it is appropriate to assign a turbine efficiency (Cp). The formula that governs the amount of power that a wind turbine can extract from the wind is given as:

$$P_{turbine} = \frac{1}{2} A C_P \rho v^3$$

Air density was calculated for the appropriate elevation of 2100 m and a turbine efficiency of 35% was assumed. In addition, NREL (National Renewable Energy Laboratory) data shown in Figure 9 was used to find average wind velocities at 80 meters above ground level. This data was input into a worksheet to calculate the total energy production of the turbine over the period of one year (Table 5).

TABLE 5: WIND TURBINE ANALYSIS

System Specifications		
Power requirements of pump	50	kW
Hours per year	8760	hr
Energy usage per year	438000	kW*hr
Average wind speed	5.5	m/s
Rotor diameter	50	m
Height	80	m
Air density(at 2100 m elevation)	0.924	kg/m^3
Power (wind)	150.92	kW
Turbine efficiency (assumed)	0.35	%
Power (Turbine)	52.82	kW
Yearly energy production per turbine	462,734.72	kW*hr
Number of turbines	1	
Total energy production per year	462,734.72	kW*hr

The average wind speed of 5.5 m/s is helpful for determining a wind turbine(s) that would be required to be able to fully operate the water pump. However, wind turbines are not able to run on minimal amounts of wind speeds. For example, the wind turbine being considered in subsequent analysis to meet the energy requirements is only able to operate on wind speeds greater than 4.5 m/s. Thus, a MATLAB code was written to plot a Raleigh distribution based on an average wind speed of 5.5 m/s. Figure 12 is one result of that code. It displays how the frequency of wind speeds may vary throughout a typical day with an average of 5.5 m/s. Figure 12 illustrates that there would be a large percentage of wind velocities that are less than 4.5m/s, which would be unusable for this operation.

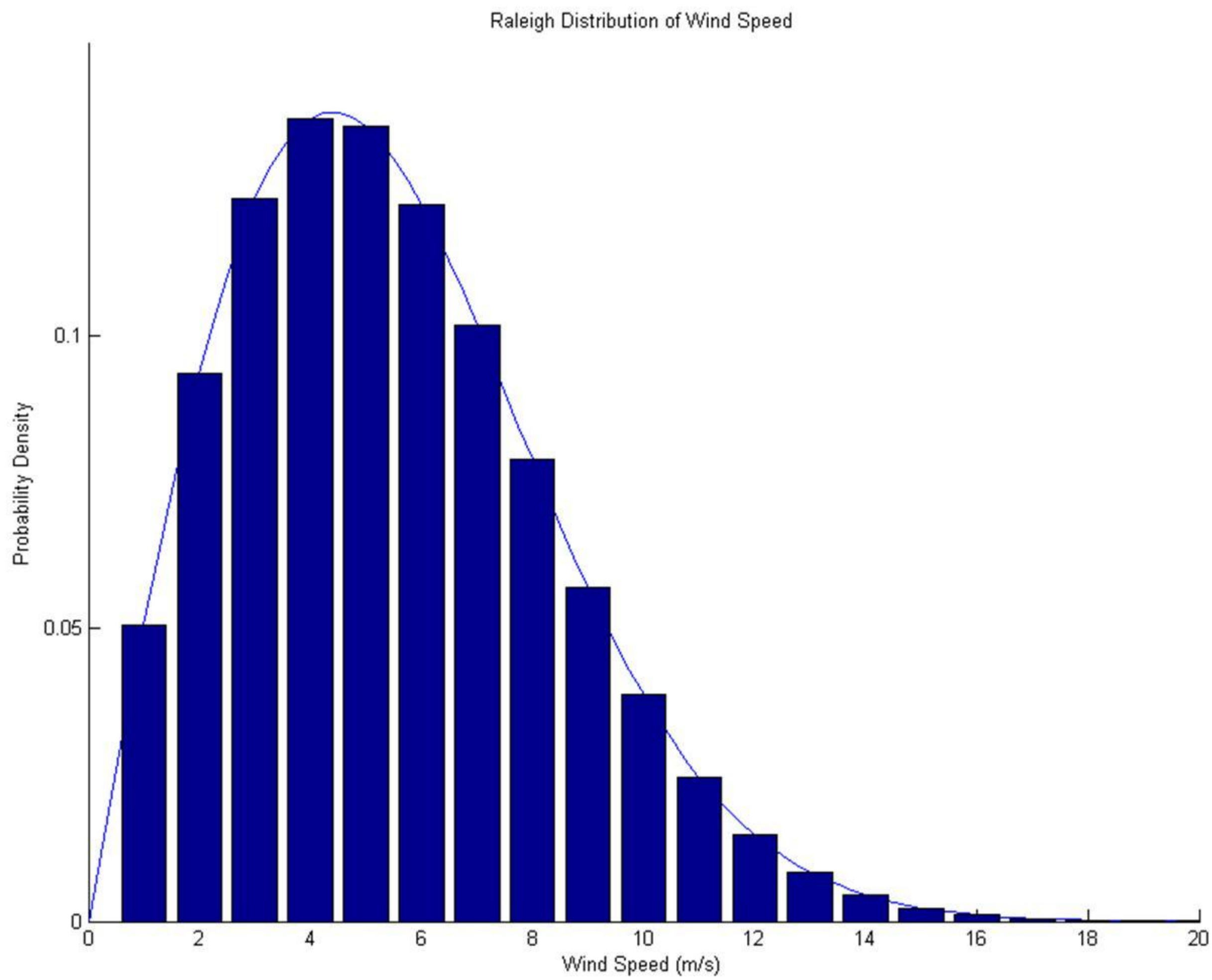

FIGURE 12: RALEIGH DISTRIBUTION BASED ON AVERAGE WIND SPEED

Calculations were then performed to determine the properties of the usable wind that the CEMEX site would experience. These showed that the site would receive usable wind speed (above 4.5 m/s) 64.29% of the time.

A wind turbine's cut in speed is defined as the wind speed that is necessary to provide enough torque to turn the turbine and generate power. For most turbines cut in speed is approximately 4.5 m/s. Additionally, wind turbines do not produce power at their designated power rating until wind speeds reach approximately 14m/s. Figure 13 below shows an idealized power curve for a wind turbine with a 30 m rotor diameter. It shows the amount of power that this particular turbine would output based on the wind speed available. It shows again that the poor average wind speed would provide very low amounts of power comparable to how much power the turbine can actually produce. This would mean that purchasing a turbine would be far overpaying for the turbine's power potential, when only much lower amounts of power are needed.

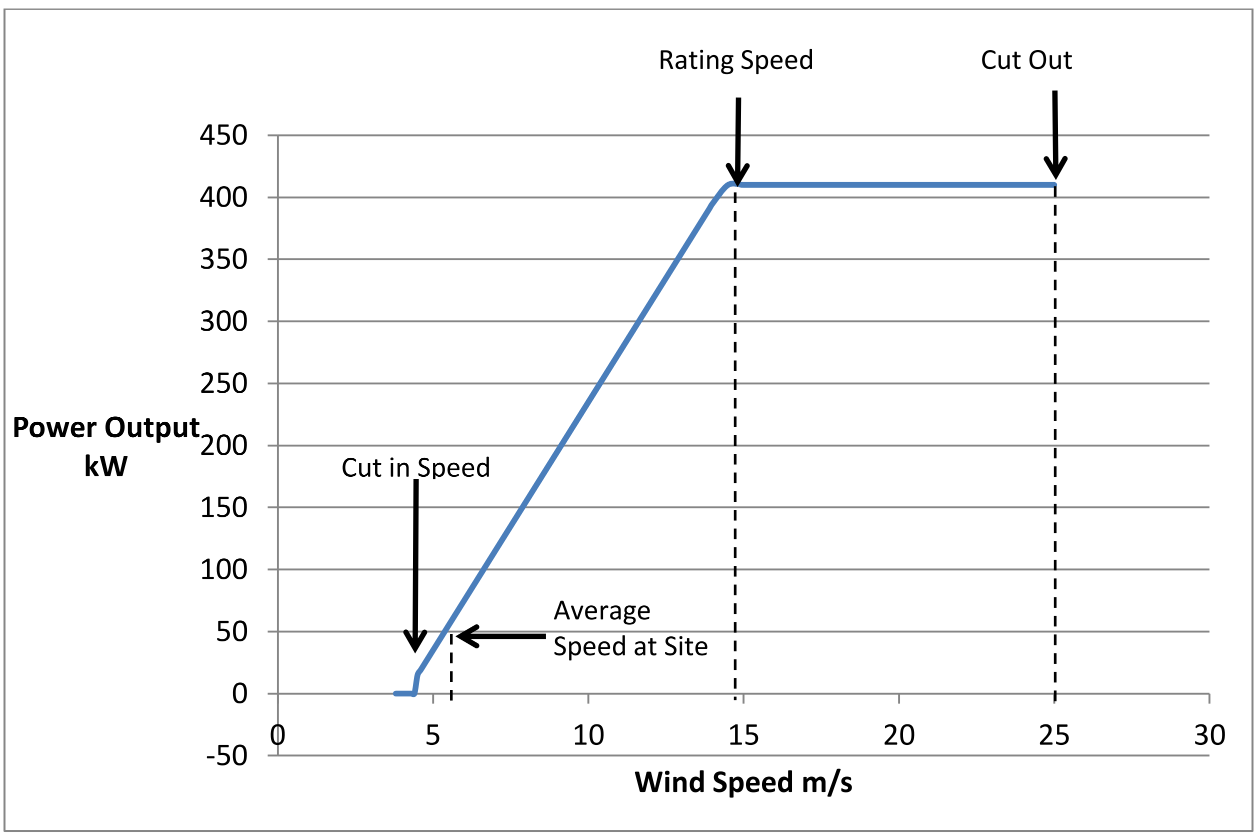

FIGURE 13: IDEALIZED POWER CURVE - 30M ROTOR DIAMETER

4.3 Wind Power Cost

Assuming a turbine of specifications previously discussed and a given average wind speed of 5.5m/s that will meet the energy demands of the client, a cost analysis was performed. The associated cost of a wind turbine of this scale is illustrated in Table 6 which includes a subsidy (30% of installation cost) by the Federal Government for renewable energy projects.

TABLE 5: WIND POWER COST

Estimated Cost		
Average cost of single Turbine	1,250,000.00	$
Installation Cost of Turbine Array	1,250,000.00	$
Federal Tax Credit	375,000.00	$
Net Cost	875,000.00	$

The average wind speed at the location is approximately 5.5 m⁄s. The relatively poor wind speed requires that the wind turbine be oversized to compensate, increasing the cost of installation. Additionally another large problem with a wind turbine would be that a standard diesel generator would have to be fully available, at full cost of fuel and ownership, to meet the power needs of the client if the turbine production was suboptimal. This requirement coupled with the poor average wind speed may prevent the installation of a wind driven power generation system and the associated large capital investment. The team recommends that a wind power resource no longer be considered to meet the needs of the client.

4.4 Backup System Analysis

Research has shown that there are storage batteries available, which are capable of storing up to 2MW. These storage batteries are able to run the pump without using the diesel generator, if that were wished by the client, where the client would be able to save money on diesel. A 2MW storage battery would be approximately the size of four commercial shipping containers. Figure 14 shows a schematic of the potential layout of the backup system. In this application, the end user would be the pump. However, after more research prices appear to be too high to be a feasible use for the system.

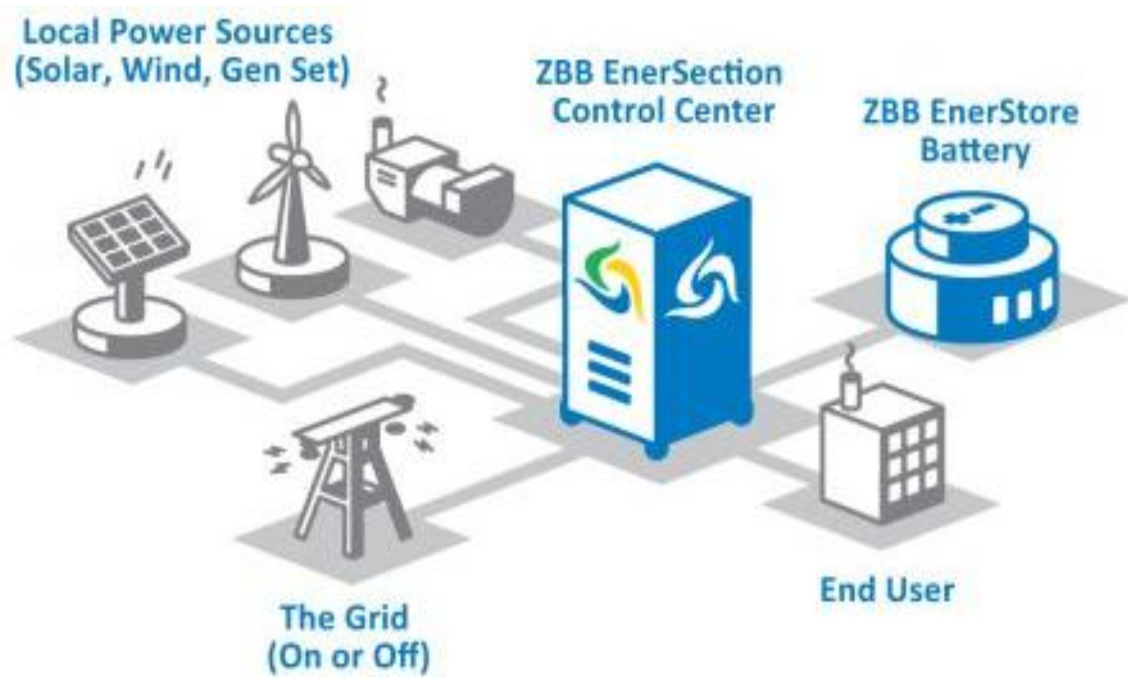

FIGURE 14: ZBB BACKUP SYSTEM

Another backup solution would be to increase the size of the current storage tanks. There are two possible ways to increase the storage capacity. The client could either increase the size of the current storage tank, which would cost approximately $0.50 per gallon, or the client could install an additional storage tank. A new storage tank could have the capacity of 30,000 gallons. In order to increase the storage capacity properly, the client may have to operate the pump on its maximum output. If the natural resources were only available for a few hours, the client would pump as much water as possible during the peak availability such that enough water would be stored to satisfy needs.

4.5 Solar Resource

Arizona is well known for having an extremely high percentage of days with full sun. Figure 15 shows the average sun resource for Arizona in kWh/m^2/day. The CEMEX site experiences 6.0-6.5 kWh/m^2/day, which is more than adequate for the consideration of solar installation. These values alone indicate that solar may be a highly optimal resource for this application.

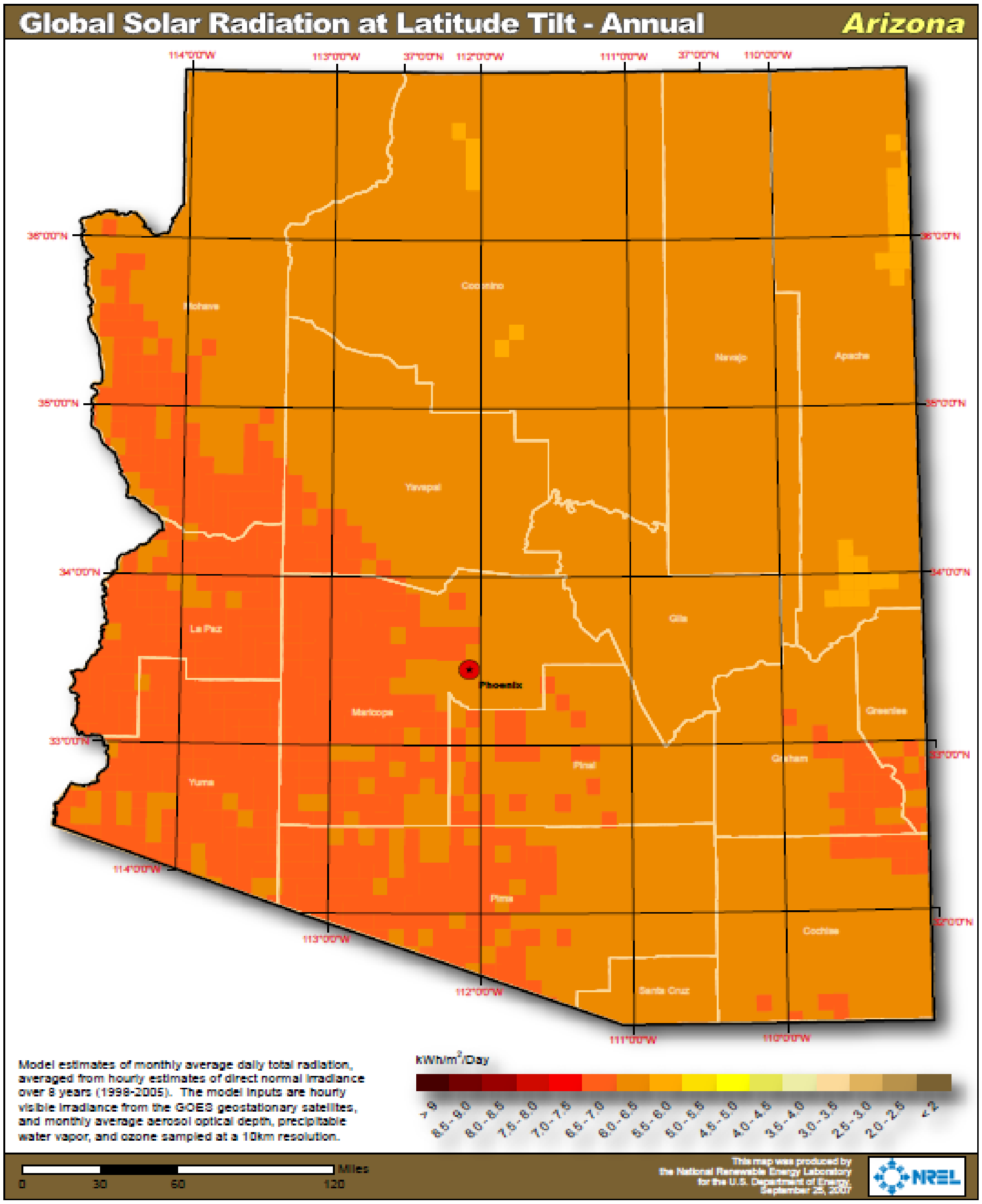

FIGURE 15: SOLAR RESOURCE FOR ARIZONA

4.6 Photovoltaic System with Battery Array Cost Analysis

One main idea of how to utilize the resource of the sun was to use a photovoltaic panel (PV) array with a corresponding battery array. The PV panels would capture energy from the sun and either send it to the pump or store it into the batteries for future use. Efforts were focused on manipulating the size of the PV array as well as the battery bank to obtain a viable solar solution to the problem. The pump requires 334 kW-hr per day to maintain current water pumping operations. For the purposes of preliminary analysis, the team analyzed Crown's "12-125-23" battery and Sunmodule's "SW 250 mono" line of batteries. The team assumed an inverter efficiency of 96% for purposes of analysis.

Research has shown that six days of autonomous function are required for systems that are not grid tied. This means that the battery array would need to provide six full days of power when there is no solar resource available for the PV array, such as during long stormy weather. For this to be possible, 384 batteries would be required to match the demand. A wholesale cost estimate of this is $1,300,000, which is comparable to the cost of the entire PV array itself. Additionally, these batteries have a maximum 11 year maximum life. Cost analysis found that there would be an 18 year time period for the batteries to pay back their cost in diesel fuel savings. This shows that it would payback period is greater than the useful life of the batteries. As a result, the team recommends that a solar array with battery backup no longer be considered to meet the needs of the client.

4.7 Photovoltaic System with Diesel Backup Cost Analysis

Various metrics were calculated to understand the performance of a solar array as compared with the current diesel generator system. The following shows the results of calculating cumulative cash flow at the optimum system size. The system was optimized to provide 100% of the pump's energy requirements given perfect weather conditions. To ensure that the pump could deliver 30000 gallons of water per day, the system was oversized to account for the changing angle of the sun. However, cloud cover may dictate that the system is unable to produce the power the pump requires and thus the pump would have to rely on the diesel generator. Various assumptions were made in calculating the performance of the system (Table 7). One assumption that must be noted is the annual increase in fuel price is 2.5%. The team's research indicates that this is a conservative annual fuel price increase.

TABLE 6: ASSUMPTIONS

Assumptions	
Factor	Assumption
Solar Resources	Assumed solar irradiance value of 900 watts per square meter
Panel Contamination	Cleaned frequently: 98% sunlight transmission
Temperature	System operates at average temperature of 25C
Orientation	South facing array: Tilted at optimal angle for given latitude
Shading	Array can provide power for 80% of available hours per year
Energy Delivered	Various system losses: Delivery is 81%
Fuel Price	Diesel fuel will rise 2.5% annually
Diesel Generator	Generator must be available to ensure power demands are met

The cumulative cash flow for the project can be seen in Figure 16. The project will have a payback period of greater than 20 years. With an annual fuel price increase of 2.5% the fuel savings are not sufficient to offset the project cost.

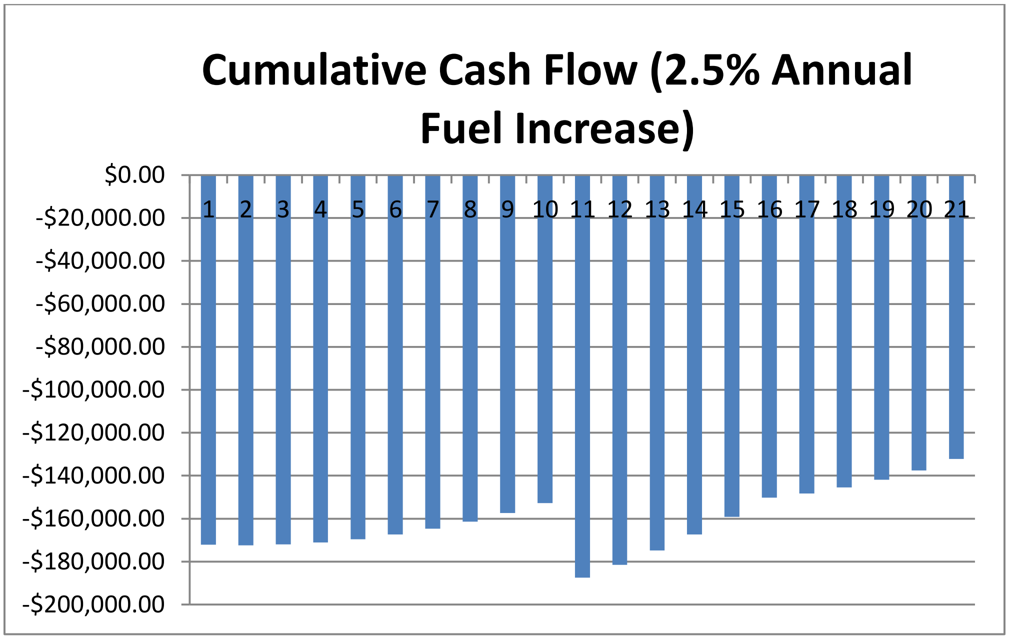

FIGURE 16: CULUMLATIVE CASH FLOW

The payback period for the previous iteration of the project was found to be suboptimal. The team discovered that an annual fuel price increase of 4.5% brought the project payback period into a reasonable timeframe. The team's reevaluation of assumptions is illustrated in Table 8.

TABLE 7: ASSUMPTION REEVALUATION

Assumptions	
Factor	Assumption
Solar Resources	Assumed solar irradiance value of 900 watts per square meter
Panel Contamination	Cleaned frequently: 98% sunlight transmission
Temperature	System operates at average temperature of 25C
Orientation	South facing array: Tilted at optimal angle for given latitude
Shading	Array can provide power for 80% of available hours per year
Energy Delivered	Various system losses: Delivery is 81%
Fuel Price	Diesel fuel will rise 4.5% annually
Diesel Generator	Generator must be available to ensure power demands are met

The associated system configuration necessary to meet the power demands of the pump can be seen in table 9.

TABLE 8: ESTIMATED SYSTEM SIZE

Estimated System Size	
Solar Rating Northern Arizona (Watts-per-square meter)	900
Panel Efficiency	15%
System Efficiency	81%
Number of Panels	420
Equivalent Area Required (square meters)	504
System Power Delivered (kilowatts AC)	55.34

The team created a MATLAB program which would take these inputs, as well as local weather and sun conditions, to create a plot of the total energy the PV panels are able to output as a function of the hour of the day. This plot is shown below in Figure 17.

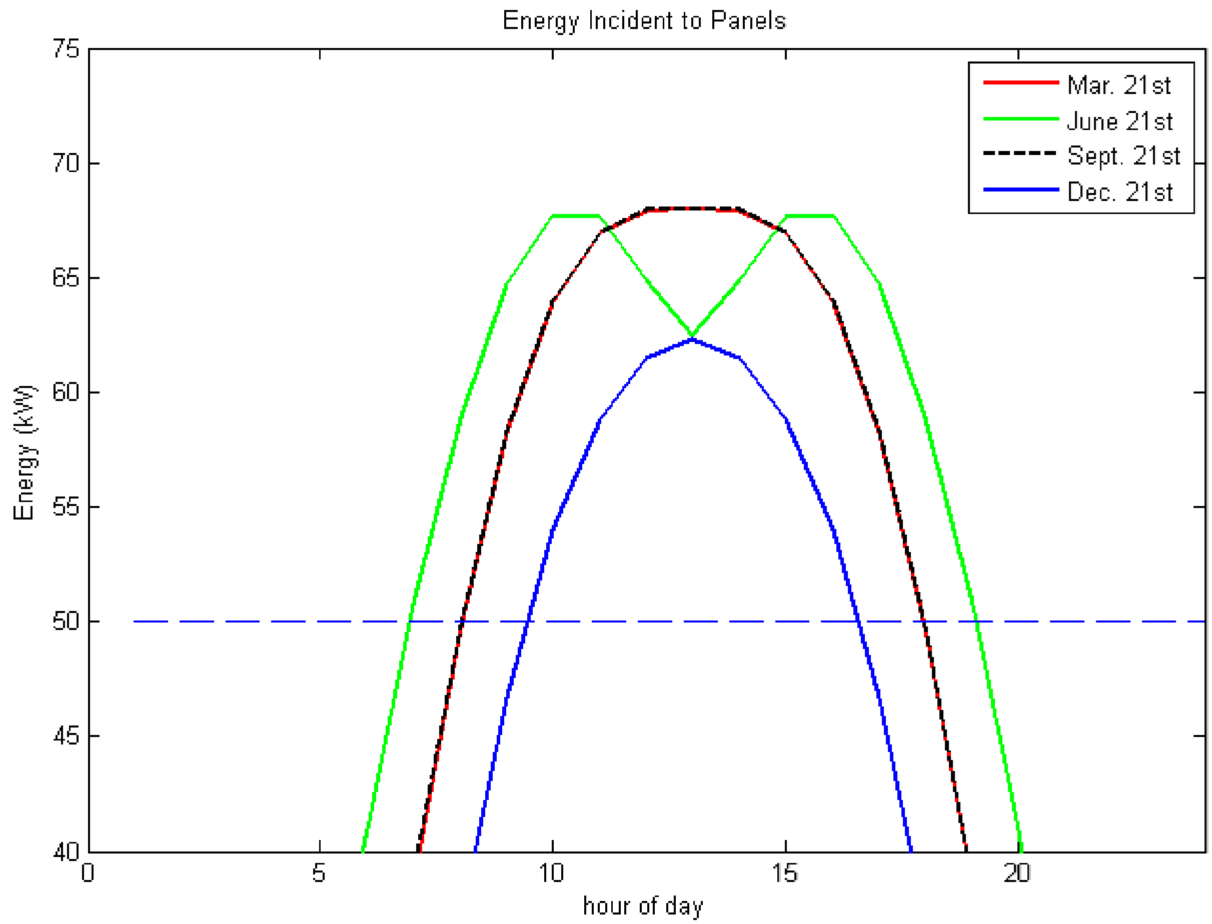

FIGURE 17: ENERGY AVAILABLE TO PV ARRAY VERSUS HOUR OF DAY

The estimated system cost is based upon average system a cost of similar size is shown in Table 10.

TABLE 9: ESTIMATED SYSTEM COST

Estimated System Cost	
Average Cost per Watt (AC):	$7.00
System Installation Gross Cost	$387,368.81

Financial Incentives at the time of installation are shown in Table 11. Refer to Cumulative Cash Flow in Table 13 to see incentives span the life cycle of the array of 20 years. A number of incentives for renewable energy installations exist. The few listed are applicable for an off-grid installation in Arizona of the rated size.

TABLE 10: FINANCIAL INCENTIVES

Financial Incentives	
Federal Tax Credit (30% of cost)	$116,210.64
State Credits corporate (10% of gross cost)	$38,736.88
Utility Credits APS Utility rebate ($1.35 per Watt AC)	$74,706.84
AZ solar energy production tax credit ($0.01 per kilowatt-hr)	$25,566.34
ESTIMATED NET COST	$132,148.10

Figure 18 is the summary of the cumulative cash flow the installation can expect over time. The annual net cash flow is the total cash after all costs are summed with all incentives, fuel savings, and tax effects. Cash Flow breakeven is where the chart crosses the $0 point. The chart illustrates that the project will have a payback period of approximately 19.5 years (column 1 represents cash flows at installation i.e. year zero, therefore column 20 is representative of year 19).

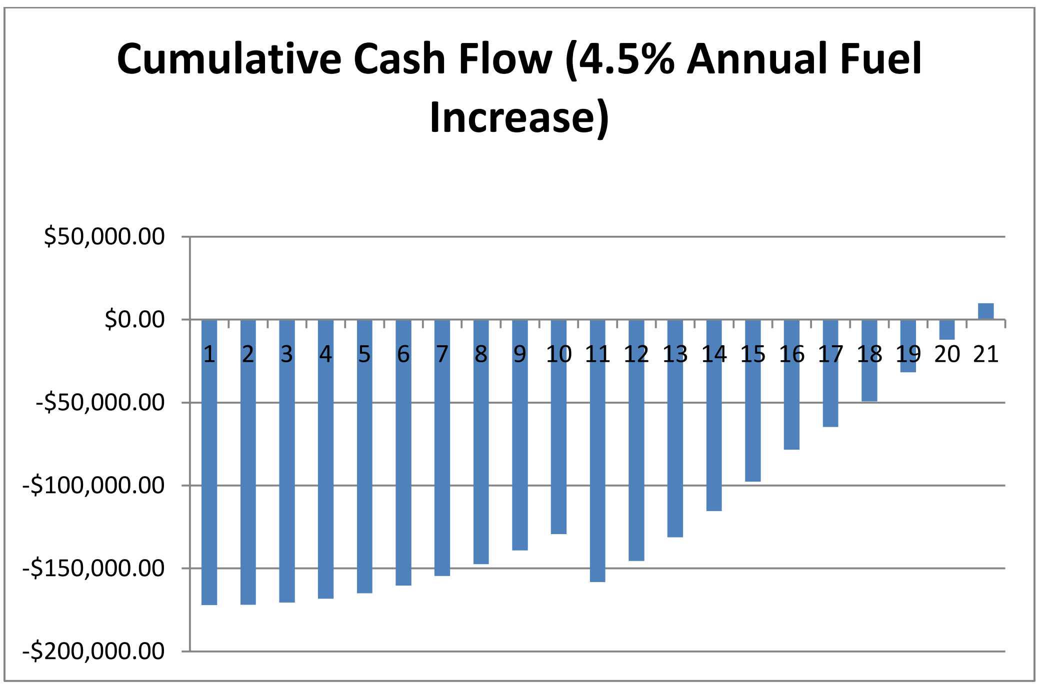

FIGURE 18: CUMULATIVE CASH FLOW

Financial and environmental benefits of the solar array are listed in Table 12.

TABLE 11: SAVINGS AND BENEFITS

Savings And Benefits	
Average Monthly Fuel Savings (20 year life)	$3,797.16
Average Annual Fuel Savings (20 year life)	$45,565.94
20 Year Fuel Savings	$911,318.75
Levelized cost of Solar Energy for Installation ($/(kW-hr))	0.49
CO2 Saved over lifetime of array (Tons CO2)	1,628.19

Cash flow and cumulative cash flow by year is illustrated in Table 13. The current year's value of cumulative cash flow is the sum of the previous year's cumulative cash flow and the current year's annual cash flow.

TABLE 12: CUMULATIVE CASH FLOW BY YEAR

Year Of Operation	At Installation	1	2	3	4
Gross Installation Cost	-$387,368.81	$0.00	$0.00	$0.00	$0.00
Federal Tax Credit (30% of cost)	$116,210.64	$0.00	$0.00	$0.00	$0.00
AZ solar energy production tax credit	$25,566.34	$0.00	$0.00	$0.00	$0.00
State Credits corporate	$38,736.88	$0.00	$0.00	$0.00	$0.00
Utility Credits APS Utility rebate	$74,706.84	$0.00	$0.00	$0.00	$0.00
Tax Savings from 15 year straight line	$0.00	$7,747.38	$7,747.38	$7,747.38	$7,747.38
Diesel Fuel Savings per Year	$0.00	$29,049.33	$30,356.55	$31,722.59	$33,150.11
Annual System Maintenance	$0.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00
Cost for fuel to run generator	$0.00	-$6,550.34	-$6,845.10	-$7,153.13	-$7,475.02
Generator Purchase (10 year life)	-$35,000.00	$0.00	$0.00	$0.00	$0.00
Generator tier 4 maintenance program	-$5,000.00	$0.00	$0.00	$0.00	$0.00
Annual Cash Flow	-$172,148.10	$246.37	$1,258.82	$2,316.84	$3,422.46
Cumulative Cash Flow	-$172,148.10	-$171,901.74	-$170,642.92	-$168,326.08	-$164,903.62

Year Of Operation	5	6	7	8	9
Gross Installation Cost	$0.00	$0.00	$0.00	$0.00	$0.00
Federal Tax Credit (30% of cost)	$0.00	$0.00	$0.00	$0.00	$0.00
AZ solar energy production tax credit	$0.00	$0.00	$0.00	$0.00	$0.00
State Credits corporate	$0.00	$0.00	$0.00	$0.00	$0.00
Utility Credits APS Utility rebate	$0.00	$0.00	$0.00	$0.00	$0.00
Tax Savings from 15 year straight line	$7,747.38	$7,747.38	$7,747.38	$7,747.38	$7,747.38
Diesel Fuel Savings per Year	$34,641.86	$36,200.75	$37,829.78	$39,532.12	$41,311.07
Annual System Maintenance	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00
Cost for fuel to run generator	-$7,811.40	-$8,162.91	-$8,530.24	-$8,914.11	-$9,315.24
Generator Purchase (10 year life)	$0.00	$0.00	$0.00	$0.00	$0.00
Generator tier 4 maintenance program	$0.00	$0.00	$0.00	$0.00	$0.00
Annual Cash Flow	$4,577.84	$5,785.21	$7,046.91	$8,365.39	$9,743.20
Cumulative Cash Flow	-$160,325.78	-$154,540.57	-$147,493.66	-$139,128.27	-$129,385.06

Year Of Operation	10	11	12	13	14
Gross Installation Cost	$0.00	$0.00	$0.00	$0.00	$0.00
Federal Tax Credit (30% of cost)	$0.00	$0.00	$0.00	$0.00	$0.00
AZ solar energy production tax credit	$0.00	$0.00	$0.00	$0.00	$0.00
State Credits corporate	$0.00	$0.00	$0.00	$0.00	$0.00
Utility Credits APS Utility rebate	$0.00	$0.00	$0.00	$0.00	$0.00
Tax Savings from 15 year straight line	$7,747.38	$7,747.38	$7,747.38	$7,747.38	$7,747.38
Diesel Fuel Savings per Year	$43,170.07	$45,112.72	$47,142.79	$49,264.22	$51,481.11
Annual System Maintenance	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00
Cost for fuel to run generator	-$9,734.43	-$10,172.48	-$10,630.24	-$11,108.60	-$11,608.48
Generator Purchase (10 year life)	-$35,000.00	$0.00	$0.00	$0.00	$0.00
Generator tier 4 maintenance program	-$5,000.00	$0.00	$0.00	$0.00	$0.00
Annual Cash Flow	-$28,816.99	$12,687.62	$14,259.93	$15,902.99	$17,620.00
Cumulative Cash Flow	-$158,202.05	-$145,514.43	-$131,254.50	-$115,351.51	-$97,731.51

Year Of Operation	15	16	17	18	19	20
Gross Installation Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Federal Tax Credit (30% of cost)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
AZ solar energy production tax credit	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
State Credits corporate	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Utility Credits APS Utility rebate	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Tax Savings from 15 year straight line	$7,747.38	$0.00	$0.00	$0.00	$0.00	$0.00
Diesel Fuel Savings per Year	$53,797.76	$56,218.65	$58,748.49	$61,392.18	$64,154.82	$67,041.79
Annual System Maintenance	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00	-$30,000.00
Cost for fuel to run generator	-$12,130.87	-$12,676.76	-$13,247.21	-$13,843.33	-$14,466.28	-$15,117.27
Generator Purchase (10 year life)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Generator tier 4 maintenance program	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Annual Cash Flow	$19,414.27	$13,541.90	$15,501.28	$17,548.84	$19,688.54	$21,924.52
Cumulative Cash Flow	-$78,317.24	-$64,775.34	-$49,274.06	-$31,725.22	-$12,036.68	$9,887.85

The previous analysis shows the high sensitivity of the payback period to the percentage rise in fuel price. The volatility of fuel prices makes it difficult to make an accurate forecast of future prices. Given a modest annual fuel price increase of 2.5% the installation payback period is much greater than 20 years. At a 4.5% annual fuel price increase the payback period approaches an appropriate timeframe for a project of this scale.

4.8 Diesel Generator Analysis

One of the clients' main concerns is the purchase of a new diesel generator to conform to new EPA standards. This factor directly relates to why they are considering alternative energy as means of drawing water before the new emission standards take effect. If an alternative energy system could be designed to draw the water and fulfill the flow requirements of the client, there would be no need to purchase a new generator and potentially, a huge savings on the cost of diesel fuel.

The upcoming Tier 4 Emissions Standards were initiated by the EPA in 2006 for all non-road diesel generator sets. The program introduces a significantly more stringent set of limitations placed on diesel generators to reduce carbon emissions. The program started taking place in 2011 and finalizes in 2015. The time period for conforming to the new Tier 4 standards is indicative of generator size, with larger generator sets required to conform earlier followed by smaller generators to conform by 2015. The following chart illustrates the year in which specific generator sets must comply with the new EPA standards.

EPA Stationary Diesel **Non-Emergency** Genset Emissions Standards

bkW	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
<8gggg	10.5 8.0, 1.0	7.5 8.0, 0.80	7.5 8.0, 0.40		7.5 8.0, 0.60					
8<19	9.5 6.6, 0.80	7.5 6.6, 0.80	7.5 6.6, 0.40							
19<37	9.2	7.5 5.5, 0.60	7.5 5.5, 0.30					4.7 5.5, 0.03		
37< 56 Option 1	9.2	7.5 5.0, 0.40	4.7 5.0, 0.30					4.7 5.0, 0.03		
37< 56 Option 2	9.2	7.5 5.0, 0.40	4.7 5.0, 0.40				4.7 0.5, 0.03			
56<75	9.2	7.5 5.0, 0.40	4.7 5.0, 0.40				3.4, 0.19 5.0, 0.02			0.40, 0.19 5.0, 0.02
75<130	9.2	4.0 5.0, 0.30					3.4, 0.19 5.0, 0.02			0.40, 0.19 5.0, 0.02
130<225	9.2, 1.3 11.4, 0.54	4.0 3.5, 0.20				2.0, 0.19 3.5, 0.02			0.40, 0.19 3.5, 0.02	
225<450	9.2, 1.3 11.4, 0.54	4.0 3.5, 0.20				2.0, 0.19 3.5, 0.02			0.40, 0.19 3.5, 0.02	
450<560	9.2, 1.3 11.4, 0.54	4.0 3.5, 0.20				2.0, 0.19 3.5, 0.02			0.40, 0.19 3.5, 0.02	
560<900	9.2, 1.3 11.4, 0.54	6.4 3.5, 0.20				3.5, 0.40 3.5, 0.10				0.67, 0.19 3.5, 0.03
900<2237	9.2, 1.3 11.4, 0.54	6.4 3.5, 0.20				0.67, 0.40 3.5, 0.10				0.67, 0.19 3.5, 0.03
>2237	9.2, 1.3 11.4, 0.54					0.67, 0.40 3.5, 0.10				0.67, 0.19 3.5, 0.03

FIGURE 19: TIER 4 EMISSIONS STANDARDS-COURTESY WWWW.GENERAC.COM

As can be seen from Figure 19, the 60 kW diesel generator used at the CEMEX site does not need to be replaced until 2015. This being said, it has been difficult to price an exact generator to fulfill the needs of the client because generator manufacturers have released only larger generator sets to conform to the standards that take place in the initial stages of the Tier 4 program.

After contacting generator manufactures, it is assumed, by information given by sales agents, that although no official MSRPs have been released, they cost of a new generator that conforms to the new EPA standards should be comparable to the cost of current generators of equal power, in the range of $35,000-$40,000. Cummings Diesel stated that they offered a Tier 4 maintenance program which guaranteed that if a new generator was purchased that did not currently conform to Tier 4 standards they would overhaul or replace the generator before the standards were set to take effect. The price quoted for this guarantee was $5,000, but it was stated that was only an approximation and not an exact quote.

4.8 Cost Comparison: Solar vs. Generator

As stated earlier, the client's water demands are 30,000 gallons per day at a flow rate of 75 gallons per minute. The client currently runs a 60 kW diesel generator to meet the demand. The following comparison is based off a generator equal in size and assumes a 2.5% increase in the cost of fuel per year over the analysis period.

The future cost of fuel is difficult to determine. There is much variability in the calculations and estimations of future fuel costs. The assumed rate of increase is based off of both, reliable web sources, and historical trends.

The comparison utilizes the solar energy system introduced previously and a 60kW generator at an assumed purchase cost of $40,000. Maintenance for the generator is assumed to be 1% of the purchase price and the life cycle of the generator has been set at 10 years. In addition, the efficiency of the new generator is assumed to be equal to efficiency of the generator currently used.

The analysis is calculated using a cumulative, net present value, of both systems over a 20 year period of both systems. This time period is equal to the land lease granted to CEMEX.

Figure 16 illustrates the cumulative cash flow for the solar array at an increase in diesel fuel costs of 2.5% annually. It can be seen from Figure 16 that the solar array would not pay itself off during the 20 year period. The major cause of this is that the system would not meet the clients' water demand and would be reliant on a generator as a backup.

The following table illustrates the total initial investment and the total expenditure over the 20 year period.

TABLE 13: 20 YEAR COMPARATIVE ANALYSIS

Present Value Cost Over 20 Year Period (2.5% Fuel Increase per Year)		
	Solar	Diesel Generator
Net Installation Costs	$132,148.00	$40,000.00
Total Cumulative Cash Flow	$860,061.00	$951,676.00

5. Recommendation

Two natural resources were initially considered for a renewable energy system to pump water: wind and solar. The wind resource was found to be insufficient to meet the project requirements. This left solar as the only option. A solar system with battery storage was initially considered so the system could be completely autonomous with no back-up system required. The cost of a battery bank, sized to the project requirements, was found to be cost prohibitive. This left a final option for solar: using an over-sized solar array to power an inverter which would feed electricity directly to the pump during the hours of the day when the solar energy would be high enough to generate the required electricity.

In terms of engineering analysis, this option was found to be the most viable because solar is an abundant resource at the site and it also eliminated the extremely large battery bank. The major shortcoming of this system is that back-up diesel generation would be required.

In the calculations, it was assumed that the solar system would be able to pump 80% of the annual water requirements, thus, only 20% of the water would need to be pumped with a diesel generator.

The solar/diesel system was then financially compared to a diesel-only system. The major costs associated with a solar system are the initial investment and annual maintenance, which consists of cleaning, replacing parts, system monitoring and more. The major costs associated with a diesel only system are the initial purchase, regular maintenance, and fuel.

In comparing the two, it was found that diesel would have increase 4.5% year over year for a solar/diesel system to be cost effective (Figure 18). This means that in twenty years the price of diesel per gallon would be close to $8.44. Under these conditions it would take 20 years to recover the cost of the initial investment.

The analysis is highly subject to a variety of assumptions and beliefs about future costs. With the high energy requirement of the project, solar energy is worth considering as an alternative or supplement to diesel under any of the following conditions:

1) Technological innovation decreases solar system cost
2) Bigger alternative energy incentives are offered
3) Cost of diesel increases by 4.5% or more every year

Although a solar/diesel system currently is not a cost effective option, it is worth noting its potential for future energy generation.

6. Future Tasks

Future objectives for the team may include looking more into the current analysis. During the analysis many assumptions have been made. If the client would prefer the team to keep working on the current pump, the team is willing investigate further information for a more detailed analysis. Some contractors can be contacted to get some better information on the cost for a solar system. This gives the team and the client a better idea of the initial cost and the overall cost of the whole system.

Babbitt Ranches is operating a number of pumps on their property. The team's future objectives may include applying the previous analysis methods to wells with lower flow rates at shallower depths to find an inexpensive solution to pumping water. As mentioned before, the pump operated by CEMEX is a 45 kW pump. There is potential in finding a system that can produce enough power for a smaller pump that would still be cost effective.

In order to see if the client Babbitt Ranches is interested in us working with a different pump, the team will gather information for the smaller system. This information will be used to do some research to find some applicable options. At a different site, another alternative compared to solar might be a valid option. For instance, wind energy has varying resource availability across Babbitt Ranches, which suggests wind speeds may be adequate at different locations. Therefore the team could further pursue wind turbines as a viable power source.

In conclusion for our future tasks, the clients may decide which direction the team should take. The team can further investigate details for the CEMEX pump or start collecting data for different locations and apply similar analysis methods throughout well sites across Babbitt Ranches.

9. References

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18. The Cadmus Group, 1998. Regional Electricity Emission Factors Final Report.

Appendix A

The following is the Matlab Code used to plot the frequency of wind speed.

```
%%Grant Masters
%%Wind Speed Analysis Capstone Team 01 Fall 2012

clear;
clc;
close all

speed = 0:.25:20;

figure(1)
hold on
k=2;
c=2*5.5/sqrt(pi);
y=wblpdf(speed,c,k);
plot(speed,y,'b')
title('Raleigh Distribution of Wind Speed')
xlabel('Wind Speed (m/s)')
ylabel('Probability Density')
axis ([0,20,0,.15])

speed2 = 0:1:20;

k2=2;
c2=2*5.5/sqrt(pi);
y2=wblpdf(speed2,c2,k2);
bar(speed2,y2);

hold off

FrequencyUsableWind = 0;
z = 0;
for i = 1
    for j = 4.5*4:81
        FrequencyUsableWind = FrequencyUsableWind + y(i,j);
        z = z + speed(i,j)*y(i,j);
    end
end

FrequencyUsableWind = FrequencyUsableWind/4
z2 = z/4;
AverageUsableWindSpeed = z2/FrequencyUsableWind
```

Appendix B

The following is the Matlab Code used to plot the energy incident to the solar panels as a function of the hour of the day.

```
%Beau Drumright & Grant Masters
%NAU Capstone Team 01 Fall 2012

%clear all/close all
clc
clear all
close all

%%CHOSEN VALUES
insolation = 900; %%Average insolation (W/m^2)
panelsarea = 1.2; %m^2
numberofpanels = 482; %482
    area = 504;
conversionefficiency = .15;

%initiate matrices
dec = zeros(365,1);
t = zeros(8760,1);
w = zeros(8760,1);
Oz = zeros(8760,1);
as = zeros(8760,1);
Ys = zeros(8760,1);
theta = zeros(8760,1);
energy = zeros(8760,1);
actualinsolation = zeros(8760,1);
requiredpower = zeros(24,1);

%show line for required power in plot 4
for i = 1:24
    requiredpower(i,1) = 50;
end
%set constants
Lat = 35.2;

%create index for first set of loops
index = 0;

%first four loop to establish, hour angle, declination, zenith angle
for nd = 1:365

    %declination
    dec(nd,1) = 23.45*sind((360*(284+nd))/365);

    for t = 1:24
        %hour angle
        w(t+index,1) = 15*(t - 13);
        %zenith angle
        Oz(t+index,1) =
acosd(sind(Lat)*sind(dec(nd,1))+cosd(Lat)*cosd(w(t+index,1))*cosd(dec(nd,1)));
    end

    %advance index to continually reproduce 24 hour angles for every declination
    index = index +24;
end

%initialize index 2
index2=0;

%2nd for loop for establishing solar altitude and solar azimuth
for i = 1:365
```

```
    d = dec(i,1);
    for j = 1:24
    %solar altitude
    as(j+index2,1) = 90 - Oz(j + index2,1);
    %solar azimuth
    if w(j+index2,1) >= 0
        Ys(j+index2,1) = abs(acosd((cosd(Oz(j+index2,1))*sind(Lat)-
sind(d))/(sind(Oz(j+index2,1))*cosd(Lat))));
    elseif w(j+index2,1) < 0
        Ys(j+index2,1) = -1*(abs(acosd((cosd(Oz(j+index2,1))*sind(Lat)-
sind(d))/(sind(Oz(j+index2,1))*cosd(Lat)))));
    end
    end
    index2=index2+24;
end

%for loop for required 4 days of year
for k = 1:24
    %March 21st
    YsM(k,1) = Ys(1896+k,1);
    asM(k,1) = as(1896+k,1);
    %June 21st
    YsJ(k,1) = Ys(4104+k,1);
    asJ(k,1) = as(4104+k,1);
    %Sept. 21st
    YsS(k,1) = Ys(6312+k,1);
    asS(k,1) = as(6312+k,1);
    %Dec. 21st
    YsD(k,1) = Ys(8496+k,1);
    asD(k,1) = as(8496+k,1);
end

%plot for entire year
%plot(Ys,as);

%plots for 4 days
M=plot(YsM,asM);
hold on;
J=plot(YsJ,asJ);
hold on
S=plot(YsS,asS,'k--');
hold on;
D=plot(YsD,asD);

%axis labels, title legend, line colors
axis([-180 180 0 90]);
xlabel('\gamma (degrees)');
ylabel('\alpha (degrees)');
title('Sun Path Diagram');
legend('Mar. 21st','June 21st','Sept. 21st','Dec. 21st');
set(M,'Color','red','LineWidth',2);
set(J,'Color','green','LineWidth',2);
set(S,'Color','black','LineWidth',2);
set(D,'Color','blue','LineWidth',2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Sunrise Sunset Data
%sundata=importdata('Sunrise Sunset Data.xlsx');
%sunrise = sundata.data.Sheet1(:,3);
%sunset = sundata.data.Sheet1(:,5);

%Angle of Incidence
beta = 35; %slope of panels

%solar angle coefficients
AA = zeros(8760,1);
BB = zeros(8760,1);
CC = zeros(8760,1);
```

```
DD = zeros(8760,1);
EE = zeros(8760,1);
for i=1:8760
    AA (i,1) = sind(Lat)*cosd(beta);
end
for i=1:8760
    BB (i,1) = cosd(Lat)*sind(beta)*cosd(Ys(i,1));
end
for i=1:8760
    CC (i,1) = sind(beta)*sind(Ys(i,1));
end
for i=1:8760
    DD (i,1) = cosd(Lat)*cosd(beta);
end
for i=1:8760
    EE (i,1) = sind(Lat)*sind(beta)*cosd(Ys(i,1));
end

day = 1;
daycounter = 1;
for i=1:8760
    theta (i,1) = acosd((AA(i,1)-
BB(i,1))*sind(dec(day,1))+(CC(i,1)*sind(w(i,1))+(DD(i,1)+EE(i,1))*cosd(w(i,1)))*cosd(dec(day,1)))
;
    daycounter = daycounter+1;
    if daycounter ==25
        day = day+1;
        daycounter = 1;
    end
end

tM = zeros(24,1);
tJ = zeros(24,1);
tS = zeros(24,1);
tD = zeros(24,1);
%plot angle of insidence
for k = 1:24
    %March 21st
    tM(k,1) = theta(1896+k,1);
    %June 21st
    tJ(k,1) = theta(4104+k,1);
    %Sept. 21st
    tS(k,1) = theta(6312+k,1);
    %Dec. 21st
    tD(k,1) = theta(8496+k,1);
end

%plot angle of insidencet for four days
figure (2)
M4=plot(tM);
hold on;
J4=plot(tJ);
hold on
S4=plot(tS,'k--');
hold on;
D4=plot(tD);

%axis labels, title legend, line colors
legend('Mar. 21st','June 21st','Sept. 21st','Dec. 21st');
set(M4,'Color','red','LineWidth',2);
set(J4,'Color','green','LineWidth',2);
set(S4,'Color','black','LineWidth',2);
set(D4,'Color','blue','LineWidth',2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:8760 %%Average insolation based on the angle from the sun and total area of panels
    actualinsolation (i,1) = insolation*cosd(theta(i,1)); %Watts/m^2
end
```

```
iM = zeros(24,1);
iJ = zeros(24,1);
iS = zeros(24,1);
iD = zeros(24,1);

%energy available for 4 days of year
for k = 1:24
    %March 21st
    iM(k,1) = actualinsolation(1896+k,1);
    %June 21st
    iJ(k,1) = actualinsolation(4104+k,1);
    %Sept. 21st
    iS(k,1) = actualinsolation(6312+k,1);
    %Dec. 21st
    iD(k,1) = actualinsolation(8496+k,1);
end

%Insolation plot for four days
figure (3)
M2=plot(iM);
hold on;
J2=plot(iJ);
hold on
S2=plot(iS,'k--');
hold on;
D2=plot(iD);

%axis labels, title legend, line colors
axis([0 24 0 1000]);
xlabel('hour of day');
ylabel('Insolation (W/m^2)');
title('Insolation Incident to Panels');
legend('Mar. 21st','June 21st','Sept. 21st','Dec. 21st');
set(M2,'Color','red','LineWidth',2);
set(J2,'Color','green','LineWidth',2);
set(S2,'Color','black','LineWidth',2);
set(D2,'Color','blue','LineWidth',2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:8760 %%Energy based on the angle from the sun and total area of panels
    energy (i,1) = conversionefficiency*actualinsolation(i,1)*area/1000; %KiloWatts
end

eM = zeros(24,1);
eJ = zeros(24,1);
eS = zeros(24,1);
eD = zeros(24,1);

%energy available for 4 days of year
for k = 1:24
    %March 21st
    eM(k,1) = energy(1896+k,1);
    %June 21st
    eJ(k,1) = energy(4104+k,1);
    %Sept. 21st
    eS(k,1) = energy(6312+k,1);
    %Dec. 21st
    eD(k,1) = energy(8496+k,1);
end

%Energy plots for 4 days
figure (4)
M3=plot(eM);
hold on;
J3=plot(eJ);
hold on
S3=plot(eS,'k--');
```

```
hold on;
D3=plot(eD);
hold on;
R = plot(requiredpower,'--');

%axis labels, title legend, line colors
axis([0 24 40 75]);
xlabel('hour of day');
ylabel('Energy (kW)');
title('Energy Incident to Panels');
legend('Mar. 21st','June 21st','Sept. 21st','Dec. 21st');
set(M3,'Color','red','LineWidth',2);
set(J3,'Color','green','LineWidth',2);
set(S3,'Color','black','LineWidth',2);
set(D3,'Color','blue','LineWidth',2);

%Uncomment these 3 lines to add gridlines
%set(gca, 'Xgrid', 'on', 'YGrid', 'off','XMinorGrid','on')
%set(gca,'MinorGridLineStyle','-')
%set(gca,'GridLineStyle','-')
```