Alternative Power Source to Draw Underground Water

By:
Grant Masters, Emerson Jones, Beau Drumright, Nathan Heckathorne, and Patrick Schimmelbauer
Team 01

Engineering Analysis

Report 3

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Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

Contents

1. Introduction

Babbitt Ranches is the 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 engineering analysis performed on various systems to meet the needs that the clients have.

2. Problem Statement

Figure 1 is an aerial view of the Cemex mining site located on Babbitt Ranches' land. On this site is located a pump which is powered by a diesel generator. This pump draws water from underground to supply a high demand in various operations on the mining site. Both Cemex and Babbitt Ranches are currently looking for a new means of power for drawing water from this particular well, operated by Cemex. The current diesel generator operating the pump draws 0.3 m^3 per second from a depth of 520 m. Any alternative design would be required to supply enough power to operate within these constraints. The major problem with the current system using a diesel generator is the high cost of operation. Babbitt Ranches and Cemex are required to pay penalties for carbon emissions that the diesel generator produces. It has also become costly to maintain the supply of fuel with current fuel costs. The first priority for both Babbitt Ranches and Cemex is to lower the operating costs of their water pumping system. In addition, they have also expressed interest in mitigating their carbon emissions.

Figure 1: Courtesy NASA

3. 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, Figure 2 and Figure 3, show that the wind resources for Arizona are suboptimal for reliable power generation. Figure 2 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. The industry standard for considering turbine implementation, at a site with high power requirements, is a demand of 7 m/s. It can be seen in Figure 3 that, except for a select few locations, the wind resource at 80 meters is less than adequate for wind turbine application in large scale power generation.

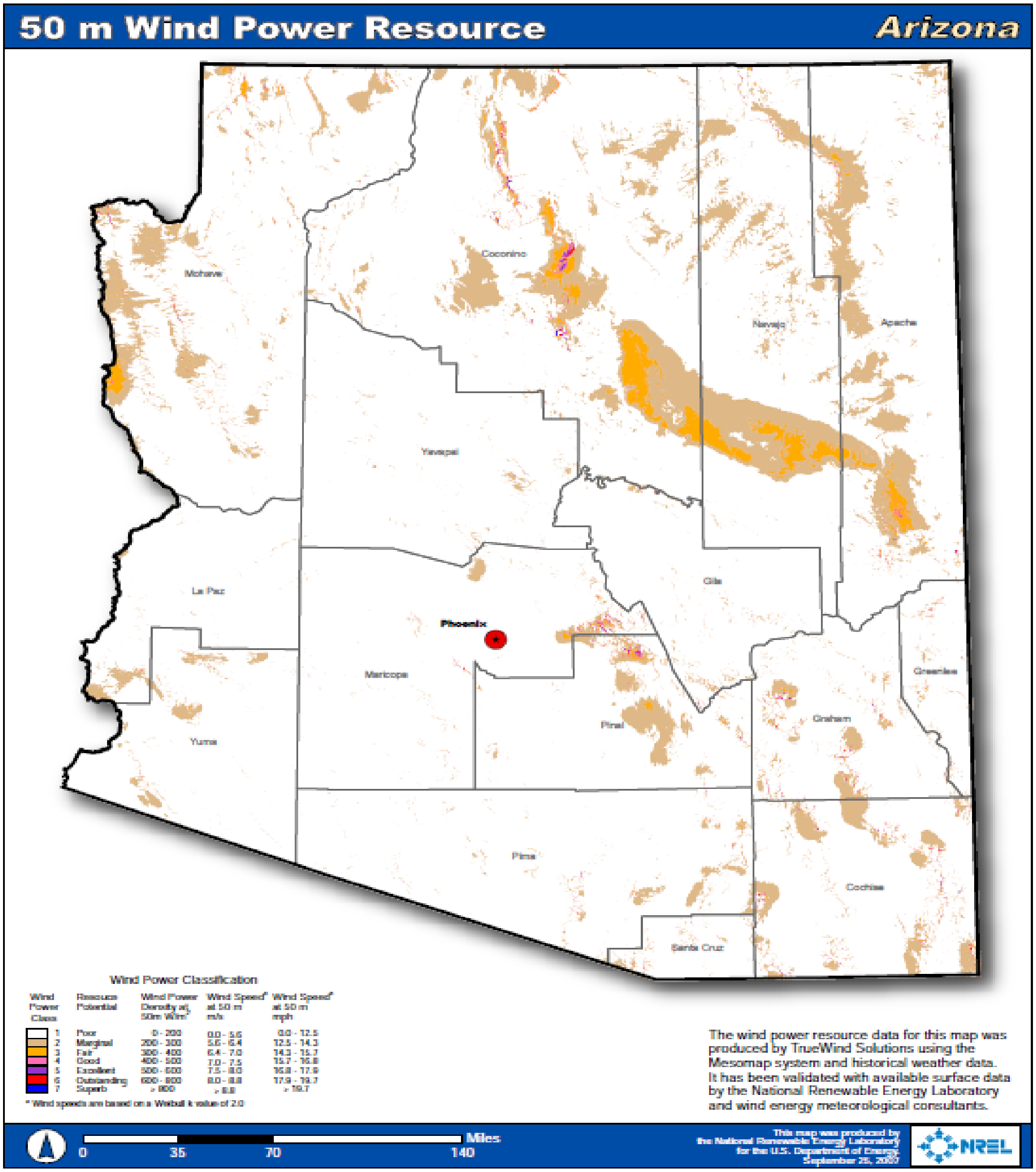
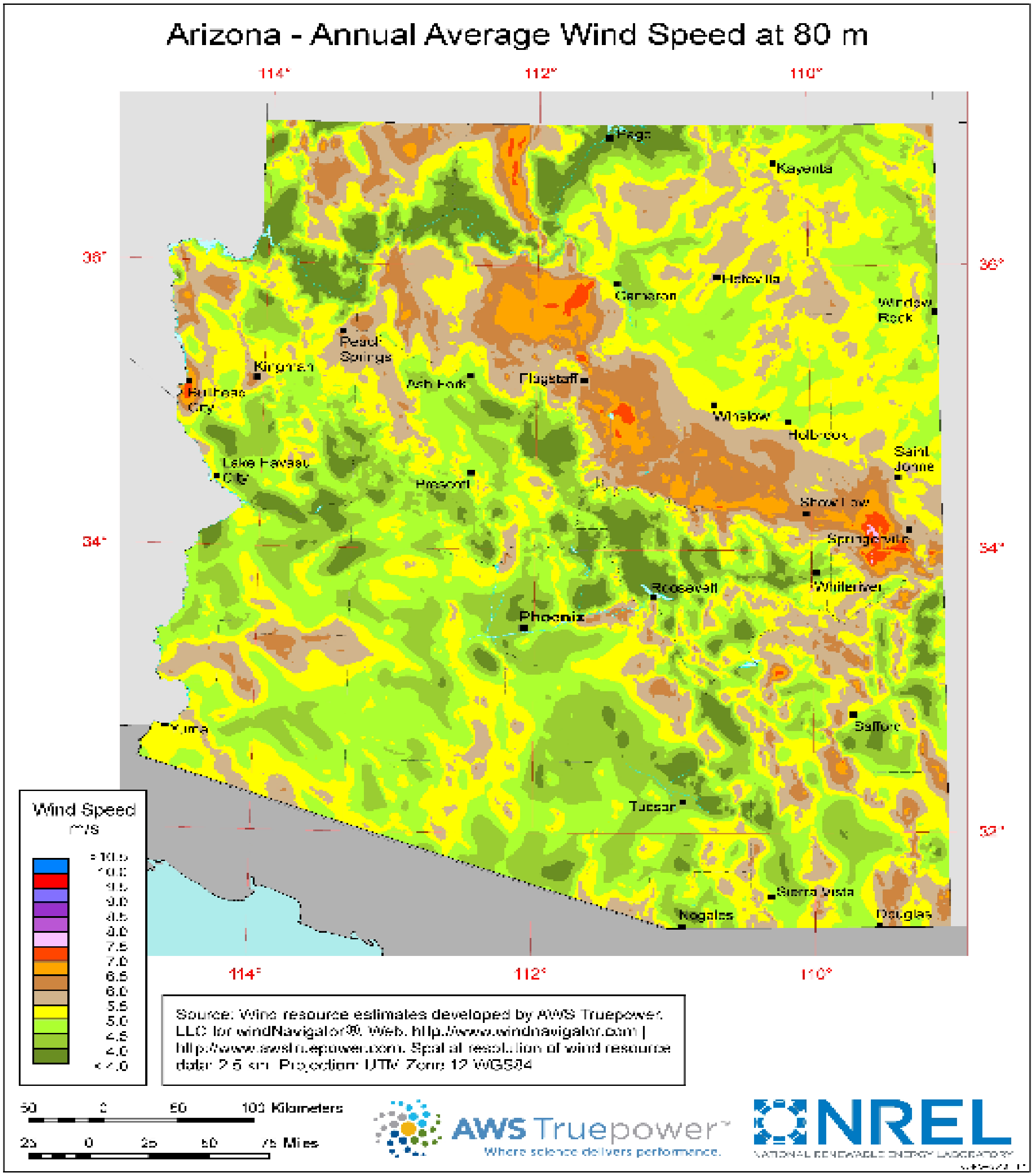


Figure 2: Wind Resource at 50m



Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 12 WGS84

Figure 3: 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 these 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 4 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.

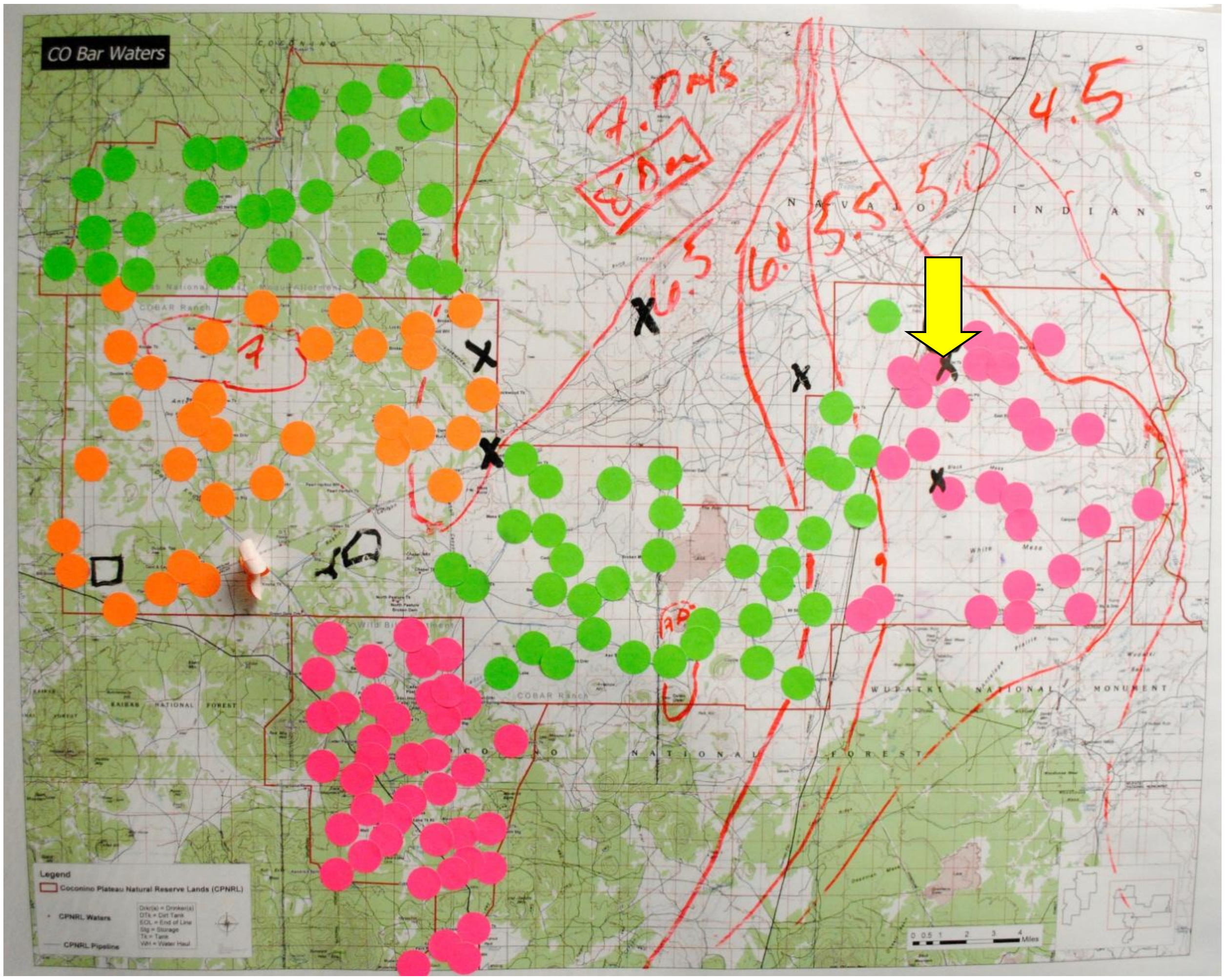


Figure 4: Topographical map of CO Bar Ranchlands - Courtesy: David Willy

4. 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 (C_p). 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 3 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 1).

Table 1

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

This 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 power. 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 5 is one result of that code.

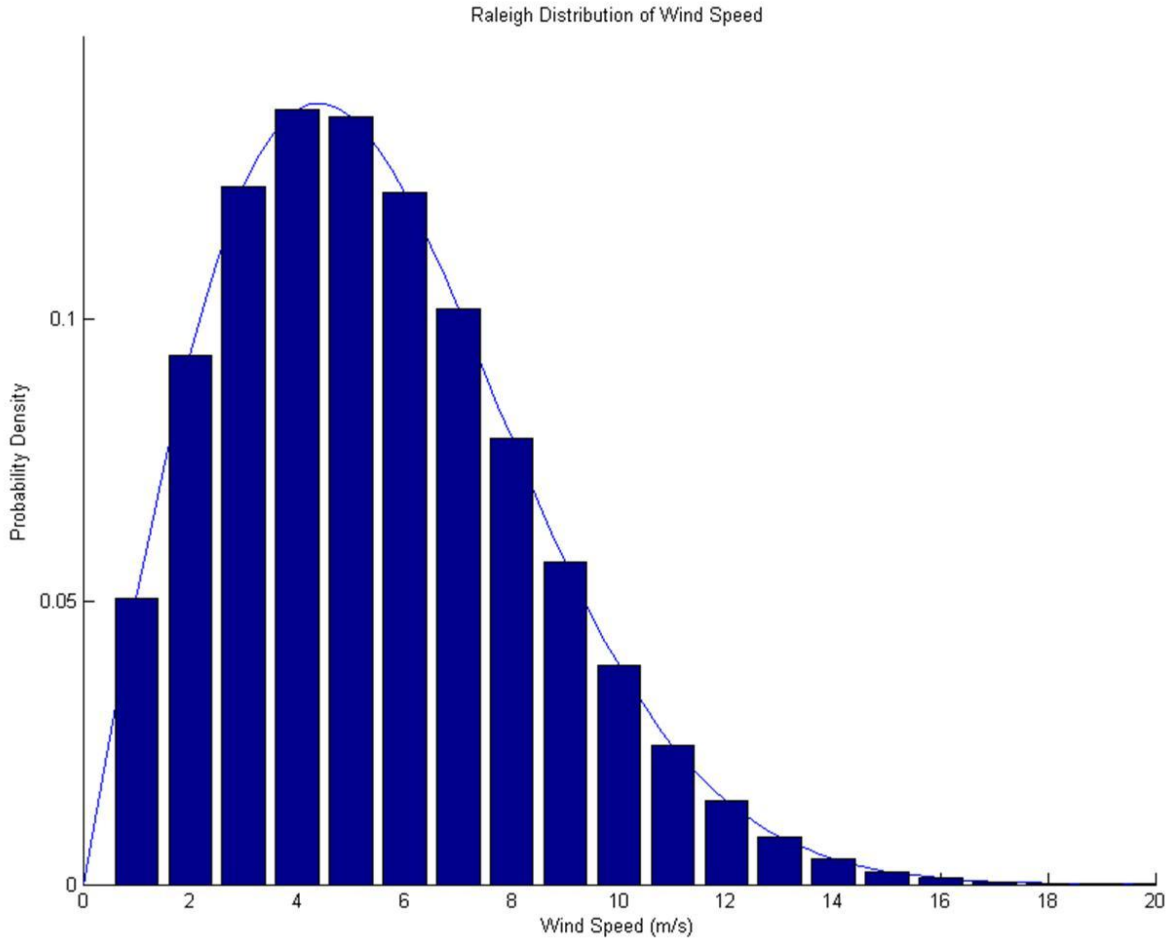


Figure 5: Raleigh Distribution Based on Average Wind Speed

Figure 5 displays how the frequency of wind speeds may vary throughout a typical day with an average of 5.5 m/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 14 m/s. Figure 5 illustrates that there would be a large percentage of wind velocities that are less than 4.5 m/s, which would be unusable for this operation. 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.

5. Wind Power Cost

Assuming a turbine of these specifications and a given average wind speed of 5.5 m/s 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 2 which includes a subsidy (30% of installation cost) by the Federal Government for renewable energy projects.

Table 2

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	$

Table 3 shows the cumulative cash flow schedule for these specifications. Factoring in yearly expenses of turbine maintenance as well as depreciation and fuel savings from replacing the power source, the payback period of this project is approximately 5 years. Figure 6 demonstrates this data graphically.

Table 3

Year Of Operation	At Installation	1	2	3	4	5
Gross Installation Cost	-1,250,000.00					
Federal Tax Credit (30% of installation cost)	375,000.00					
Annual Turbine Maintenance		-18750	-18750	-18750	-18750	-18750
MACRS Depreciation		75000	75000	75000	75000	75000
Diesel Fuel Savings		122500	122500	122500	122500	122500
Annual Cash Flow	-875,000.00	178750	178750	178750	178750	178750
Cumulative Cash Flow	-875,000.00	-696,250.00	-517,500.00	-338,750.00	-160,000.00	18,750.00

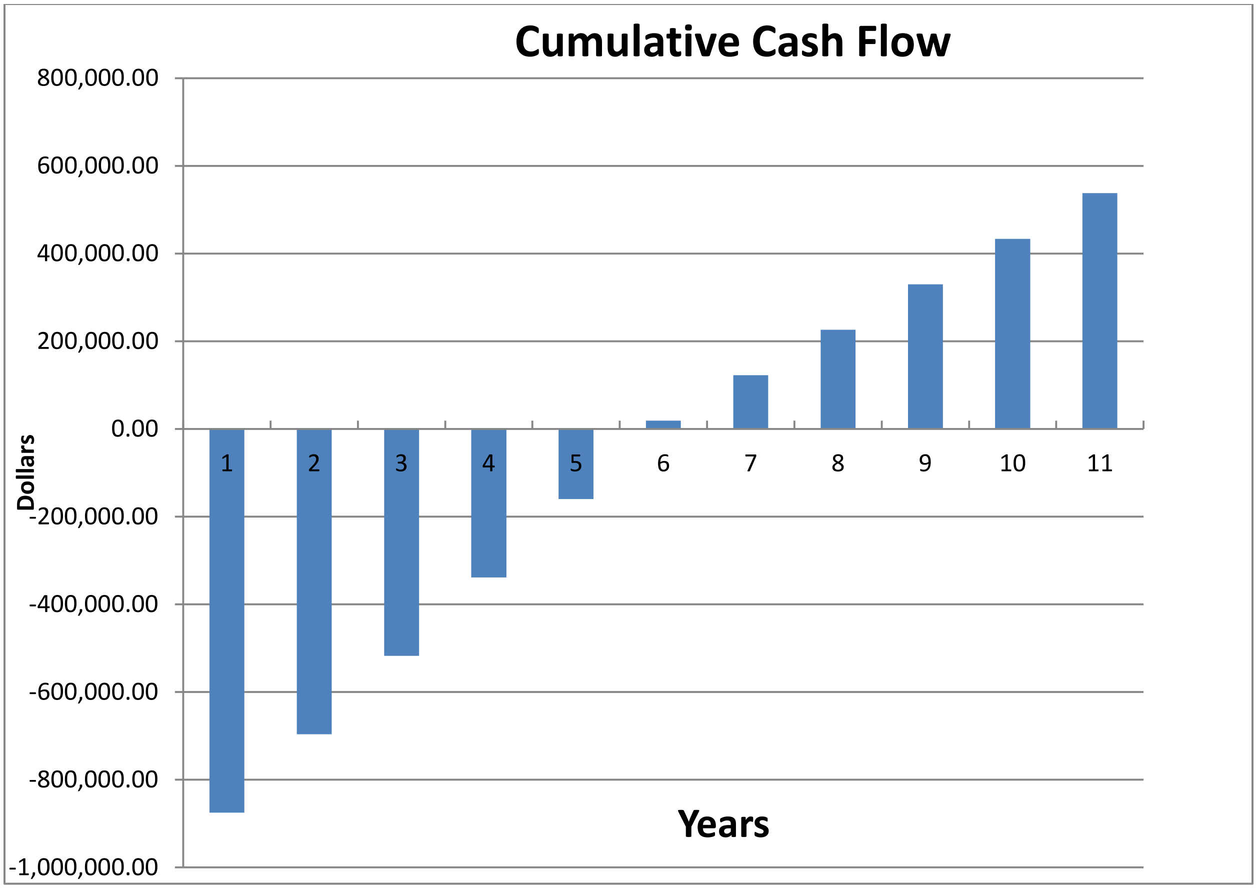


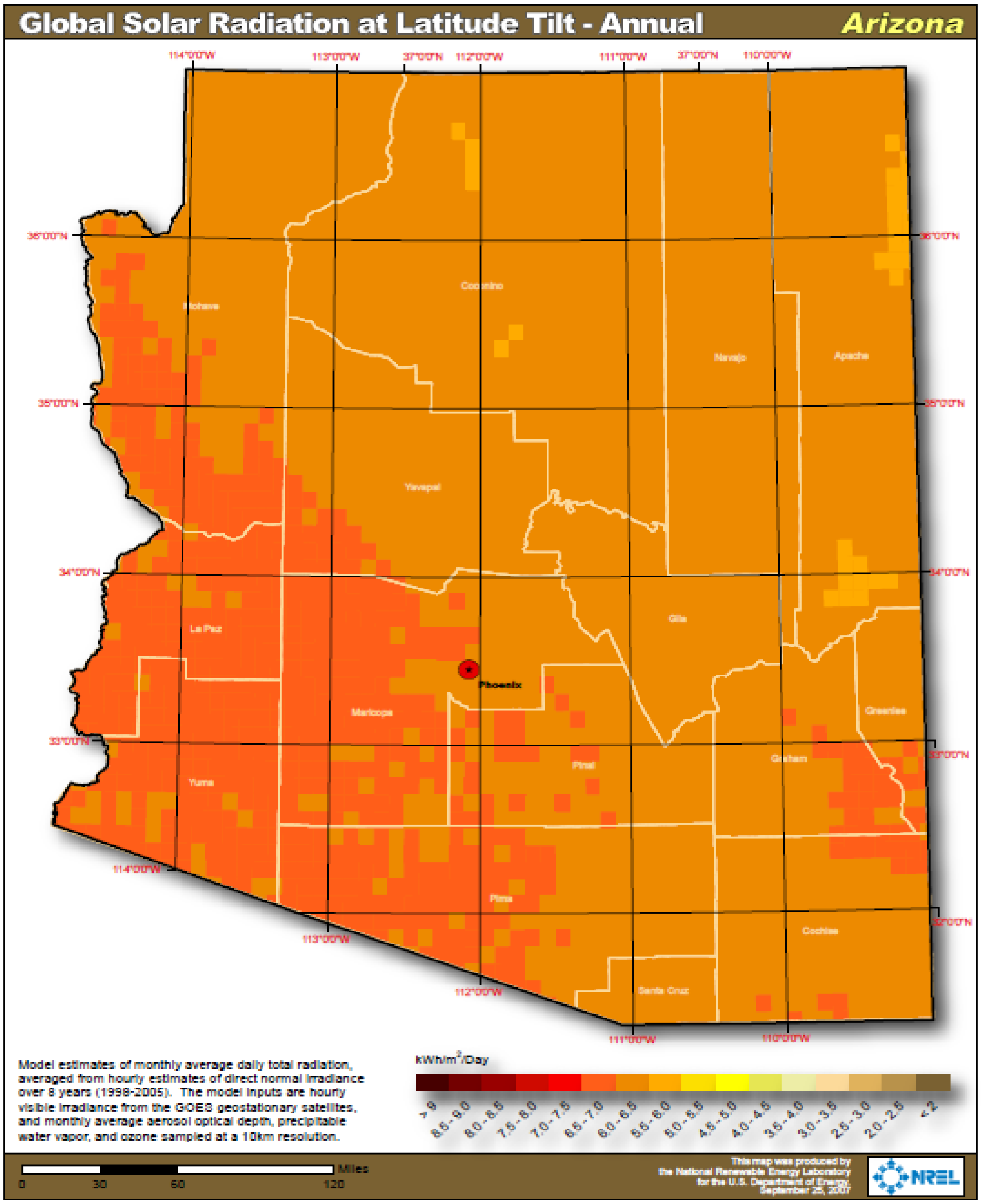
Figure 6: Cumulative Cash Flow for Wind Power

6. Wind Power Discussion

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, one assumption from the previous calculation is that a wind turbine would completely replace a diesel generator. However, 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 obviate the installation of a wind driven power generation system and the associated large capital investment.

7. Solar Resource

Arizona is well known for having an extremely high percentage of days with full sun. Figure 7 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.



Model estimates of monthly average daily total radiation, averaged from hourly estimates of direct normal irradiance over 8 years (1998-2005). The model inputs are hourly visible irradiance from the GOES geostationary satellites, and monthly average aerosol optical depth, precipitable water vapor, and ozone sampled at a 10km resolution.

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. September 25, 2007

Figure 7: Solar Resource for Arizona

8. Photovoltaic System Analysis

A Photovoltaic system collects energy from the sun through several stages. The PV array is angled to receive the optimal amount of radiation from the sun. A battery bank is used as a storage medium for the energy received by the PV array. Charge controllers are necessary to prevent overcharging of the battery and control the rate at which the batteries are charged. An inverter is required to convert the electricity from DC to a more compatible AC.

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 1,200 kWhr 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.

It is recognized that large shifts in the weather can greatly impact the operation of a solar array. For instance, storms may occur where the sun could be completely obstructed by clouds for several days. In calculating the size of the battery bank and PV array, the team assumed the system would need to autonomously function for three days. This would provide three full days of standard water pumping operations, fully dependant on the energy stored in the battery banks, before sunlight would be required to continue operations. From this analysis specifications were found for a photovoltaic system that would be able to meet the pumping requirements.

Table 4

System Specifications		
Power requirements of pump	50	kW
Hours per day	24	hr
Energy usage per day	1200	kW*hr
Inverter Efficiency	96	%
Days of Autonomous Function	3	Days
AC Daily Load	1250	kW*hr
Batteries	192	batteries
Solar Panels	1431	modules

9. Photovoltaic System Cost

A photovoltaic system of these specifications will meet the energy demands of the client. The associated cost of such a system is illustrated in Table5.

Table 5

Estimated Cost				
Cost per Unit Battery	6,800	$		
Total Battery Cost			1,305,600	$
Cost per Unit PV Module	250	$		
Total Panel Cost			357,750	$
Estimated Inverter Cost			75,000	$
Estimated Construction Cost			75,000	$
Sales Tax			191,219	$
Total Before Credits			2,004,569	$
State Credits				
No Sales Tax on Solar Panels A.R.S. § 42-5061 (N)			(39,353)	$
10% off Installed Cost, Up to $50,000			(50,000)	$
Federal Tax on State Credits			29,486	$
Federal Credits				
30% for Solar			(582,511)	$
Total			1,422,058	$

Table 6 shows the cumulative cash flow schedule for these specifications. Factoring in yearly expenses of panel maintenance as well as depreciation and fuel savings from replacing the power source, the payback period of this project is approximately 8 years. Figure 8 is a graphical representation of this data.

Table 6

Year Of Operation	At Installation	1	2	3	4	5	6	7	8
Gross Installation Cost	-2,073,350.00								
Federal Tax Credit (30% of cost)	622,005.00								
Annual Array Maintenance (1.5%of installation cost)		-31100.25	-31100.25	-31100.25	-31100.25	-31100.25	-31100.25	-31100.25	-31100.25
Tax Savings from MACRS Depreciation (5yr)		124401	124401	124401	124401	124401	124401		
Diesel Fuel Savings (annual cost of fuel)		122500	122500	122500	122500	122500	122500	122500	122500
Annual Cash Flow	-1,451,345.00	215800.75	215800.75	215800.75	215800.75	215800.75	215800.75	91399.75	91399.75
Cumulative Cash Flow	-1,451,345.00	-1,235,544.25	-1,019,743.50	-803,942.75	-588,142.00	-372,341.25	-156,540.50	-65,140.75	26,259.00

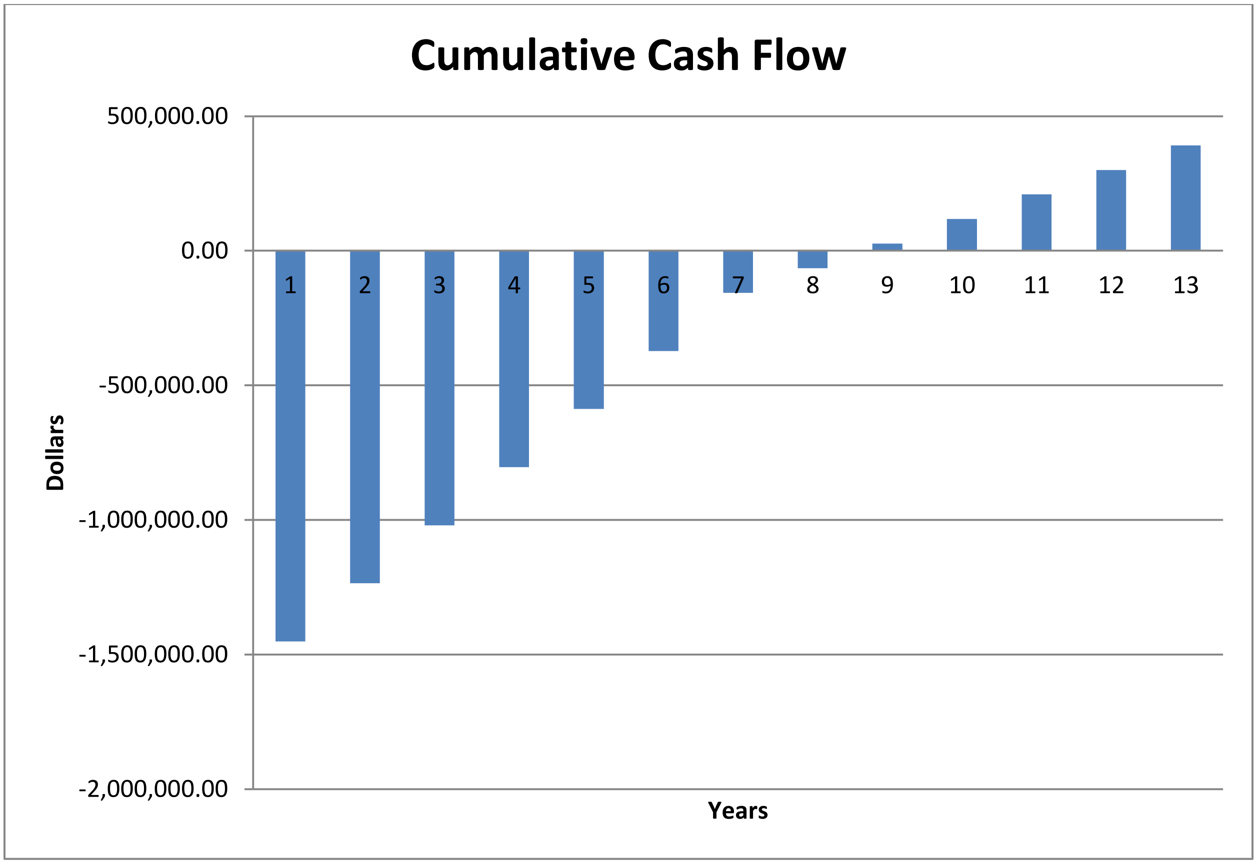


Figure 8: Cumulative Cash Flow for Photovoltaic System

10. Photovoltaic System Discussion

The previous analysis described was done with costs for residential component. Costs are anticipated to be further reduced by bying on a commercial basis. The largest cost associated with the current design has shown to be electrical storage. The batteries found that would meet power storage requirements are estimated to cost $1.3 million. This makes up more than half of the total cost before credits are taken into account.

The current design appears to be cost prohibitive. There are three main approaches to lowering the cost: finding less expensive components of the system, eliminating unessesary components, and finding further incentives. Eliminating the batteries from the system would greatly reduce the cost due to their large impact on the cost of the PV system. Eliminating the battery bank would require a deisel generator to be on site for backup when the solar resource is not providing sufficient power.

With batteries possibly eliminated from the design, the PV panels would be equipped with microinverters which are run into a controller. The controller would power the pump using the PV array when power from the solar resource is sufficient. It would switch to the diesel generator for supplementary power when the PV array is insufficient.

The majority of alternative energy systems would not be cost effective without incentives such as government tax credits. Further exploration of incentives could provide a more feasible way to implement the PV system. The team will also explore the APS utility incentive which is offered for off-grid, commercial sites at $1.35 per W DC (APS, WEB). For a 50 kW DC system the estimated utility incentive would be $67,500. Arizona also has a property tax incentive which would allow for improvements from installing renewable energy systems to be exempt from the determination of property tax liability (SES, WEB2).

Even with the large costs associated with photovoltaic systems, they are proving to be a very good solution to the problem, due to the great solar resource available at the site.

11. Backup System Analysis

Currently, the backup system that has been considered would be a combination of wind, energy, solar energy, and the diesel generator coupled with a bank of storage batteries. The team is currently conducting more research in order to find more alternative systems that are capable of producing enough power to operate the pump.

The team is currently investigating a backup system that is capable of combining wind, solar, and diesel energy into one system. The combination of the two alternative energies is connected to a controller that uses the power from either source to run the pump or to store the energy in backup storage batteries. 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. The price for a storage battery will be $161 per kW; this would make a total of $322,000 for our client. Although size is not a major consideration for the client, a 2MW storage battery would be approximately the size of four commercial shipping containers.

Figure 9 shows a schematic of the potential layout of the backup system. In this application, the end user would be the pump.

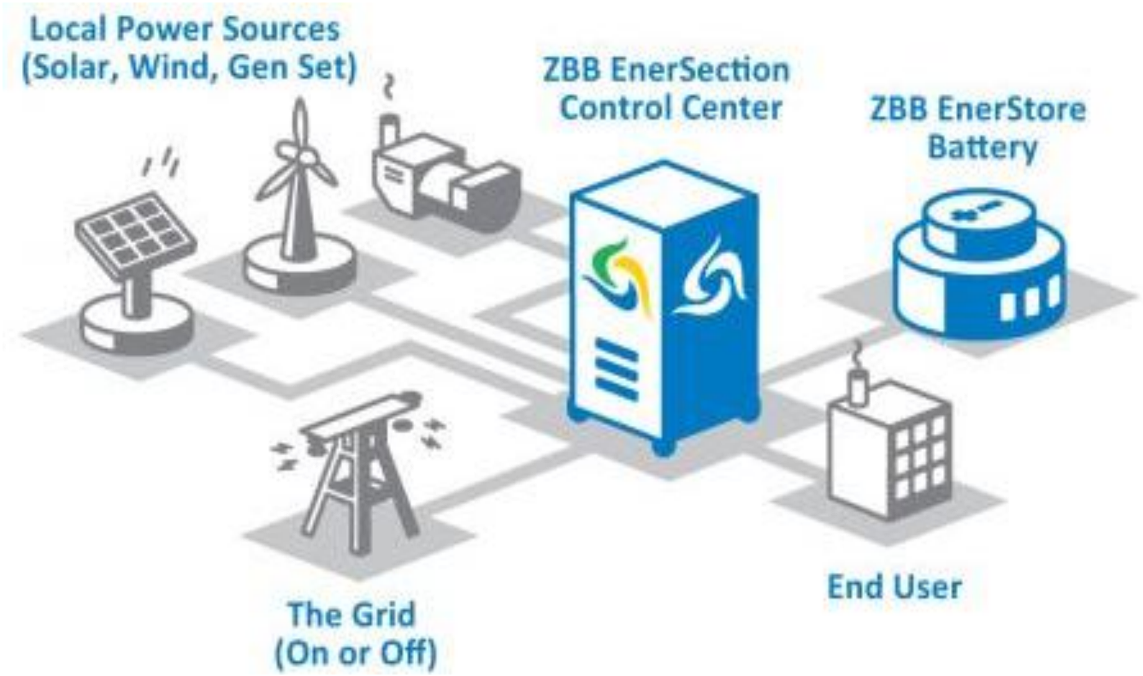
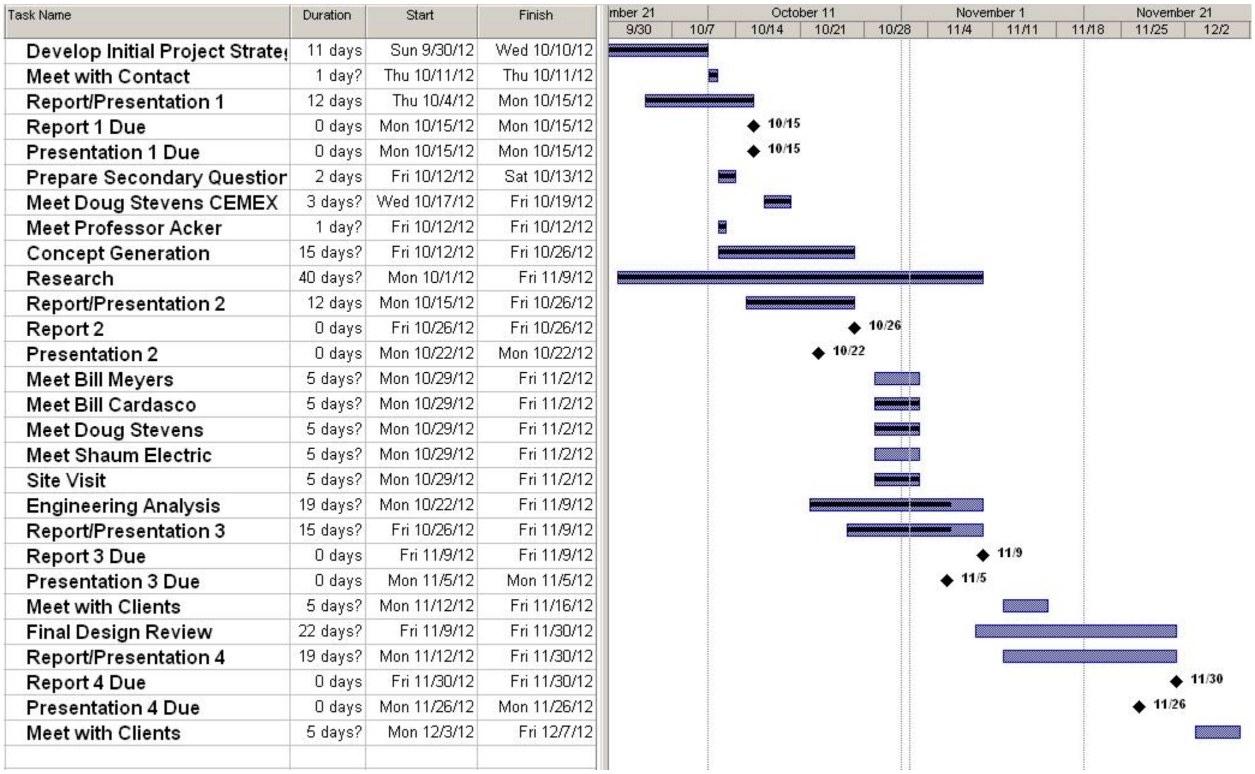


Figure 9: ZBB Backup System

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 their needs.

12. Gantt Chart

The updated Gantt chart detailing the project schedule can be seen in Figure 10 below:



Task Name	Duration	Start	Finish
Develop Initial Project Strate	11 days	Sun 9/30/12	Wed 10/10/12
Meet with Contact	1 day?	Thu 10/11/12	Thu 10/11/12
Report/Presentation 1	12 days	Thu 10/4/12	Mon 10/15/12
Report 1 Due	0 days	Mon 10/15/12	Mon 10/15/12
Presentation 1 Due	0 days	Mon 10/15/12	Mon 10/15/12
Prepare Secondary Questior	2 days	Fri 10/12/12	Sat 10/13/12
Meet Doug Stevens CEMEX	3 days?	Wed 10/17/12	Fri 10/19/12
Meet Professor Acker	1 day?	Fri 10/12/12	Fri 10/12/12
Concept Generation	15 days?	Fri 10/12/12	Fri 10/26/12
Research	40 days?	Mon 10/1/12	Fri 11/9/12
Report/Presentation 2	12 days	Mon 10/15/12	Fri 10/26/12
Report 2	0 days	Fri 10/26/12	Fri 10/26/12
Presentation 2	0 days	Mon 10/22/12	Mon 10/22/12
Meet Bill Meyers	5 days?	Mon 10/29/12	Fri 11/2/12
Meet Bill Cardasco	5 days?	Mon 10/29/12	Fri 11/2/12
Meet Doug Stevens	5 days?	Mon 10/29/12	Fri 11/2/12
Meet Shaum Electric	5 days?	Mon 10/29/12	Fri 11/2/12
Site Visit	5 days?	Mon 10/29/12	Fri 11/2/12
Engineering Analysis	19 days?	Mon 10/22/12	Fri 11/9/12
Report/Presentation 3	15 days?	Fri 10/26/12	Fri 11/9/12
Report 3 Due	0 days	Fri 11/9/12	Fri 11/9/12
Presentation 3 Due	0 days	Mon 11/5/12	Mon 11/5/12
Meet with Clients	5 days?	Mon 11/12/12	Fri 11/16/12
Final Design Review	22 days?	Fri 11/9/12	Fri 11/30/12
Report/Presentation 4	19 days?	Mon 11/12/12	Fri 11/30/12
Report 4 Due	0 days	Fri 11/30/12	Fri 11/30/12
Presentation 4 Due	0 days	Mon 11/26/12	Mon 11/26/12
Meet with Clients	5 days?	Mon 12/3/12	Fri 12/7/12

Figure 10: Gantt Chart

11. References

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