Preliminary Analysis of an Industrial Photovoltaic System and Comparison of Its Performance with a Wind Energy System and a Fuel Cell Power System

Amal Kabalan, LEED A.P.
Consulting Engineer

The purpose of this article is to test the feasibility of installing a Photovoltaic (PV) System on an industrial facility and then compare its costs to both a Wind Turbine and Natural Gas Fuel Cell system. A model that predicts the energy which a Photovoltaic (PV) System can generate in a certain location based on insolation data and shading will be used. The model also calculates the savings and the pay-back period based on current state subsidies and federal tax incentives. The article will start by describing the project and will simulate the energy expected from the solar panels. The article will then proceed to compare the power output and the cost of a Photovoltaic System to that of a Wind Energy System and a Fuel Cell Power System.

Solar System Analysis

The example industrial location is located in Pottstown, Pennsylvania, which is 40 miles west of Philadelphia. Due to its proximity to Philadelphia, it is reasonable to consider that it has the same latitude, longitude and weather conditions to that of Philadelphia for the purpose of the analysis. Latitude is 39.88 and longitude 75.25. Elevation is 6 meters. Figure 1 shows the location of the facility (B) in correspondence to Philadelphia (A). The facility has south and north exposures. The orientation is shown in Figure 2.

Figure 1: Location of the suburban residence in relation to Philadelphia.

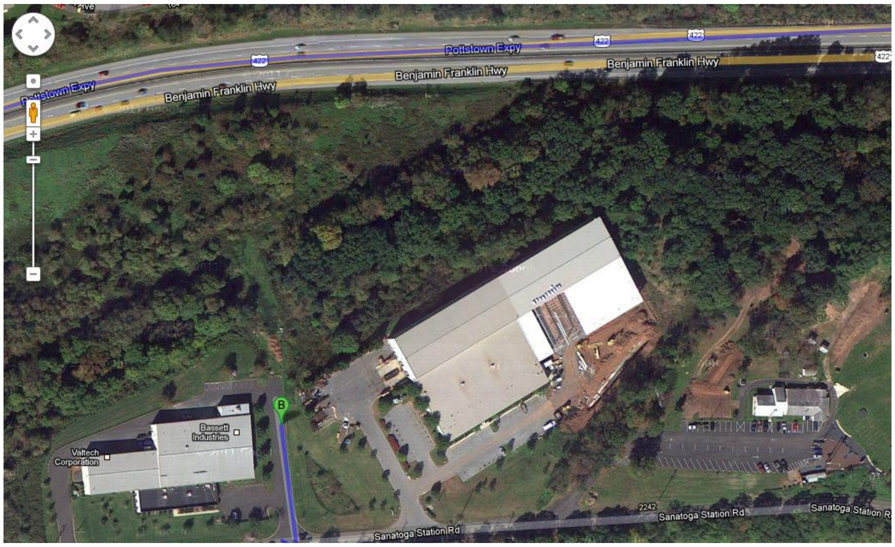

Figure 2: Orientation of the industrial facility.

Incident solar radiation

	Philadelphia, PA							Latitude 40.50 N					
Tilt	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Year**
Lat-15	2.4	3.2	4.1	4.9	5.5	5.9	5.9	5.5	4.8	3.8	2.4	1.9	4.2
Lat	2.6	3.4	4.2	4.8	5.2	5.4	5.5	5.3	4.8	4.1	2.6	2.1	4.2
Lat+15	2.7	3.5	4.1	4.4	4.6	4.7	4.8	4.8	4.6	4.1	2.7	2.2	3.9
90	2.5	3	3.1	2.9	2.6	2.5	2.6	2.9	3.2	3.3	2.3	2	2.7
1-Axis (Lat)	2.9	3.9	5	6	6.6	7.2	7.2	6.8	6	4.8	2.9	2.3	5.1
Temp. C	0.9	2.7	9.4	15.7	21.4	26.1	28.1	27.1	23.5	16.9	10.2	3.7	15.5

Figure 3: PA solar radiation data for flat plate collectors (1994)

The south facing roof gets the maximum exposure of sun during the day, so this is where the solar panels can be mounted. The incident solar radiation (KW/m^2) that the roof will get changes with the time of the day and the month of the year and the inclination of the roof. Figure 3 provides the incident solar radiation data for Philadelphia which can be used in Pottstown as well.

Shading

The roof will not have any shading from surrounding trees or obstacles. This is a great advantage since shading will not affect its performance throughout the year.

Calculation

The facility has an energy usage of 1,471 MWh/year. Installing a 1,028 KW solar panel system will generate around 1,124 MWh/year (this number is arrived at by a series of calculations that involve converting from DC to AC power and taking into account the solar radiation of Pottstown). Thus a 1,028 KW system will provide around 75% of the facility consumed energy. The total cost of the system without any off-setting incentives is $7.1 million.

Financial Analysis

The following factors determine whether the investment in a solar system yields a net profit or loss:

1. Installed cost of the system
2. The federal tax incentives and subsidies available
3. The state tax incentives and subsidies available
4. The tax bracket that the owner's property falls under
5. The percentage of rate increase and rate structure changes of the local utility

For the system under study, Figure 4 depicts the relation between the first three factors mentioned above.

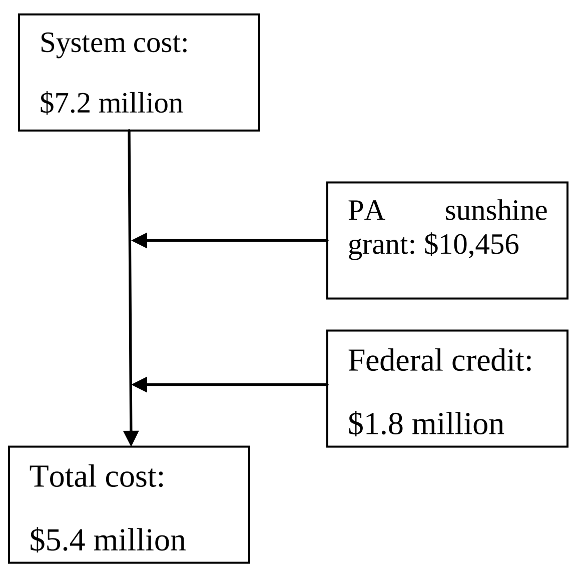

Figure 4: Federal and state incentives decrease the initial price of the system.

The initial cost of the system is $7.1 million. The owner can make use of the PA sunshine grant. The Pennsylvania Commonwealth Financing Authority board voted on April 14th, 2009 unanimously to borrow $30 million to get the Pennsylvania Sunshine Program (Sunshine) started. Enacted in July 2010 as part of Gov. Rendell's $650 million Alternative Energy Funding Act, Sunshine is expected to provide rebates of the system cost to help cover the cost of buying solar power systems. Of the $650 million fund created by the Act, $500 million will be administered by the Commonwealth Financing Authority (CFA), and $150 million will be transferred in General Fund tax revenue between FY 2008-09 through FY 2015-16 for various consumer programs.

The $650 million will be allocated as follows:

- $150 million General fund allocation
- $500 million to the Commonwealth Financing Authority

    a. $165 million for alternative energy grants/loans administered by CFA, including loans to businesses or nonprofit economic development organizations and loans or grants to political subdivisions for clean energy projects, loans and grants to businesses for alternative energy production projects, and loans and grants to businesses, nonprofit economic development organizations or political subdivisions for site preparation (the loan or grant shall not exceed $30 million per project)

    b. $100 million for consumer solar energy projects administered by the Department of Environmental Protection (loans will not exceed 35 percent of the purchase or installation price)

    c. $80 million for loans and grants for alternative energy production projects related to solar energy (the loan or grant shall not exceed $30 million per project)

    d. $40 million transferred to the Ben Franklin Technology Development Authority to support early-stage activities and research to develop and implement alternative energy and energy efficiency technologies

e. $40 million for the Low-Income Home Energy Assistance Program (LIHEAP)

f. $25 million for loans or grants for small-scale renewable energy projects, including geothermal technologies or wind energy projects, including manufacturing facilities for wind turbines

g. $25 million for loans or grants for high performance buildings to individuals or small businesses

h. $25 million for pollution control technology grants for coal-fired power plants that have an installed capacity of less than 500 megawatts to enable them to comply with new state/federal regulations.

Accordingly, the business owner should receive $10,456 from the state programs. In the latest federal energy bill passed by the government, the business owner can make use of a 25 percent incentive of the cost of the solar power system. Based on the system described above the business can receive $1.8 million as incentives from the government in the form of grants as stated in article “a” of the Alternative Energy funding act. Thus the total cost of the system to the business will be approximately $5.4 million.

The rate structure that will be considered uses a generation charge of $0.1245/KWh. This is based on the charge rate from the owner’s utilities grid in January 2010. The rate structure is not fixed and so it can increase or decrease with time. However, the current trend is for the costs to increase over time. Also the rate structure can be different from one region/utility to another, so caution is urged before extrapolating costs. For example, in 2008 PECO residential customers in the West Chester area were charged $0.148/KWh for the first 600 KWh used and $0.0729/KWh for the rest. This is an important consideration because it means that the solar power generated is competing with the lower generation charge. A common mistake is to assume that the most expensive power will be avoided. This means that when the financial analysis is done to calculate savings or profit, the analyst should use the correct values for each increment of power off-set. For industrial users the owner also pays an additional charge for Electric High Tension Service for power consumed between 100 KW and 500 KW. In this particular case the owner pays on average $ 2,035/ month for the Electric High Tension Service charge.

Results

The PV power output of the system was predicted based on the insolation data presented in the earlier section. As shown in Figure 6 the highest solar output is in the summer months of June, July and August. The output drops in the months of the winter to the lowest power output in January. The actual power usage of the industrial facility is also shown in Figure 5. For the summer months the PV power output meets the demands of the facility. However, as can be seen in the chart, in the winter months the power output of the PV system drops and thus the utility will be needed to supply the power not provided by the PV system.

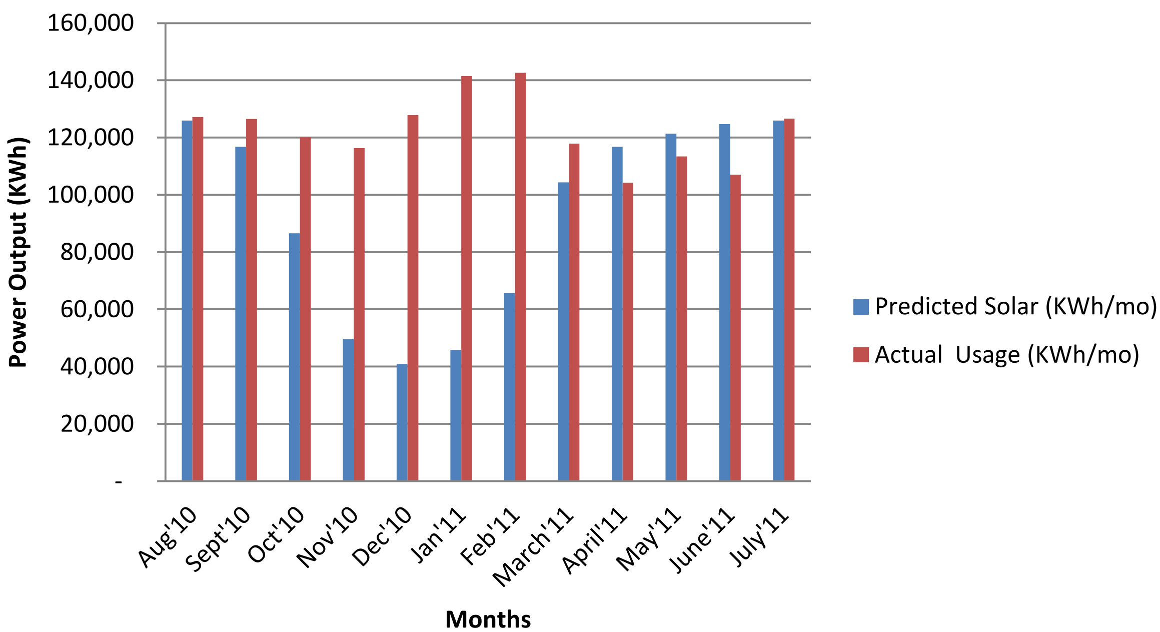

Figure 5: The predicted solar energy per month vs. the recorded solar energy measured.

Figure 6 shows the current electric bill per month and the predicted electric bill after installing a PV system. The electric bill decreases significantly as expected, in April, May and June as the PV system will generate more power than what is required by the facility. The excess power will go back to the utilities and the electric meter will run backward. This means that the facility is selling power to the electric grid. The savings will be at the highest in those months. In December, January and February the facility will use a higher percentage of power from the electric grid compared to the summer months. This is because the PV system is not generating enough power to supply all the demand. The total savings on the electric bill is predicted to be

$164,401 per year. The PV system has an initial cost of $5.2 million. After considering all costs, this translates to a payback period of 32 years.

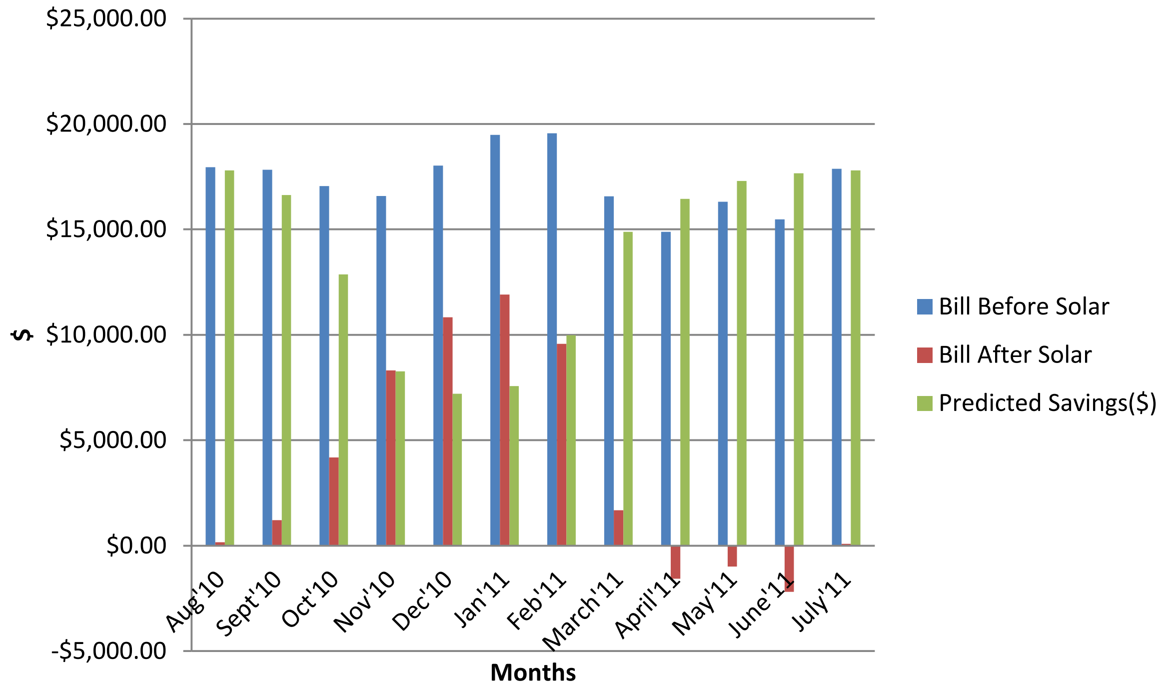

Figure 6: The predicted usage savings generated by using a PV system.

Wind Energy System

The main question under consideration when designing a wind energy system is how much of the energy in the wind can be captured and converted into electricity? The answer depends on a number of factors, namely:

1. The machine (rotor, gearbox, generator, tower control)
2. The terrain (topography, surface roughness, obstructions)
3. The wind regime (velocity, timing, predictability)

We will assume that the wind power density has been evaluated for the site under study. It is known that the highest efficiency possible for the rotor itself is 59.3%. In optimum conditions, a modern rotor will deliver about three-fourths of that potential. To keep from overpowering the generator, however, the rotor must spill some of the most energetic high-speed winds, and low-speed winds are also neglected when they are too slow to overcome friction and generator losses.

Combining all of these factors leaves us with overall expected conversion efficiency from wind power to electrical power of approximately 30%.

The monthly average wind speed for Pottstown, PA is shown in figure 7. The annual wind average is 18.64 mph which will be used in the analysis. It is important to note that the average wind speed in Pottstown is higher than the national average which makes the site favorable for wind energy systems. We will suppose that a NEG Micon 230/48 (230-kW generator, 48-m rotor) wind turbine will be used. The turbine will be mounted on a 50-m tower. Taking all the above assumptions into account the energy that will be delivered is forecast to be 1,491 MWh/year. The energy requirement of the industrial facility is 1,471 MWh/year; thus the wind turbine can supply the power needed by the whole facility, when wind is available. The total cost of the system is $1.4 million. The price does not include the maintenance cost of the system.

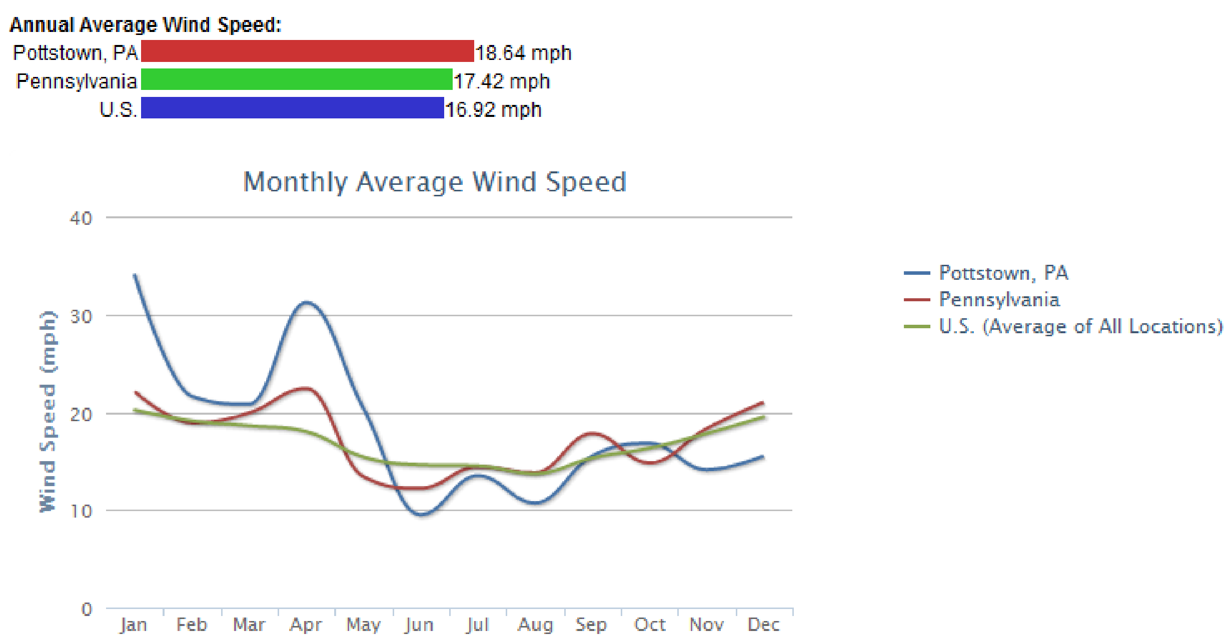

Figure 7: Monthly average wind speed in Pottstown, PA.

<u>Fuel Cells Energy Servers</u>

Another form of an energy system that can be used to provide electricity for the business is a fuel cell. The fuel cell uses air and natural gas to produce electricity, water and small amounts of carbon dioxide. The fuel cell can be thought of as a battery that always runs. It consists of three parts: an electrolyte, an anode, and a cathode.

For a solid oxide fuel cell, the electrolyte is a solid ceramic material. The anode and cathode are made from special inks that coat the electrolyte. Unlike other types of fuel cells, no precious metals, corrosive acids, or molten materials are required. In this cell, an electrochemical reaction converts fuel and air into electricity without combustion. As long as there's fuel, air, and heat, the cell continues producing clean, reliable, affordable energy.

Bloom Energy and Clear Edge Power are two of the major companies manufacturing and providing fuel cell systems. Bloom Energy has two fuel cell models: ES-5700 (200W) and ES-5400 (100W). The ES-5700 will be used in this analysis and its data sheet is shown in figure 8.

The electric usage of the current facility is 4,240 kWh/day. Assuming that the fuel cells are operated for 9hrs/day, the total energy produced per day by the fuel cells will be 1,890 kWh/day. This means that installing 2 fuels cells will provide 90 % of the electric power needed by the facility.

Cost Analysis

Current price of natural gas is $9.48/1000ft^3$ and since the fuel cell system requires 1.32 MMBtu/hr this means that to operate the system for 9 hours per day, the cost of natural gas will be $110/day ($3,310/month). The initial cost of the system is not reported by the company; however, “60 minutes” reported that a Bloom Box costs $800k p/unit. If we assume that this price is accurate it will cost the owner $1.6 million to install such a system and use fuel costing approximately $40,000 per year.

Technical Highlights	
Inputs	
Fuels	Natural Gas, Directed Biogas
Input fuel pressure	15 psig
Fuel required @ rated power	1.32 MMBtu/hr of natural gas
Outputs	
Nameplate power output (net AC)	210kW
Base load output (net AC)	200kW
Electrical efficiency (LHV net AC)	> 50%
Electrical connection	480V @ 60 Hz, 3 or 4-wire 3 phase
Physical	
Weight	17 tons
Size	26' 5" x 8' 7" x 6' 9"
Emissions	
NOx	< 0.07 lbs/MW-hr
SOx	negligible
CO	< 0.10 lbs/MW-hr
VOCs	< 0.02 lbs/MW-hr
CO_2 @ specified efficiency	773 lbs/MW-hr on natural gas; carbon neutral on Directed Biogas
Environment	
Standard temperature range	-20° to 45° C (extreme weather kit optional)
Humidity	0% - 100%
Seismic Vibration	IBC site class D
Location	Outdoor
Noise @ rated power	< 70 DB @ 6 feet
Codes and Standards	
Complies with Rule 21 interconnection standards	
Exempt from CA Air District permitting; meets stringent CARB 2007 emissions standards	
Product Listed by Underwriters Laboratories Inc. (UL) to ANSI/CSA America FC 1	
Additional Notes	
Operates in a grid parallel configuration	
Includes a secure website for you to showcase performance & environmental benefits	
Remotely managed and monitored by Bloom Energy	
Capable of emergency stop based on input from your facility	

Figure 8: Data sheet of the ES-5700 fuel cell model

Figure 9 shows a comparison chart of the initial cost of the three systems under study. The PV option has the highest cost followed by the fuel cells and then the wind energy system. Figure 10 shows the yearly electric bills that are predicted with each of the systems installed. Since the PV system designed covers 75% of the power demand by the facility the rest of the demand will be supplied through the electric grid. This translates to a yearly eclectic bill of $43,000. The wind power system designed supplies all of the demand and thus theoretically the yearly bill will be $0, however some grid power will be necessary to supplement at times. We say theoretically because we cannot guarantee that the wind will be available at minimum velocity all year long. However,

in days where there is excess wind the additional power generated can be supplied to the grid and thus balances out the bill. The fuel cell power servers require $40,000 in natural gas fuel costs per year. The system designed for this project supplies 90% of the demand. Thus the electric grid is still needed and will result in an electric bill of approximately $60,000. Based on the above numbers the payback period for solar, fuel cells and wind power systems are expected to be 30, 9 and 6 years respectively

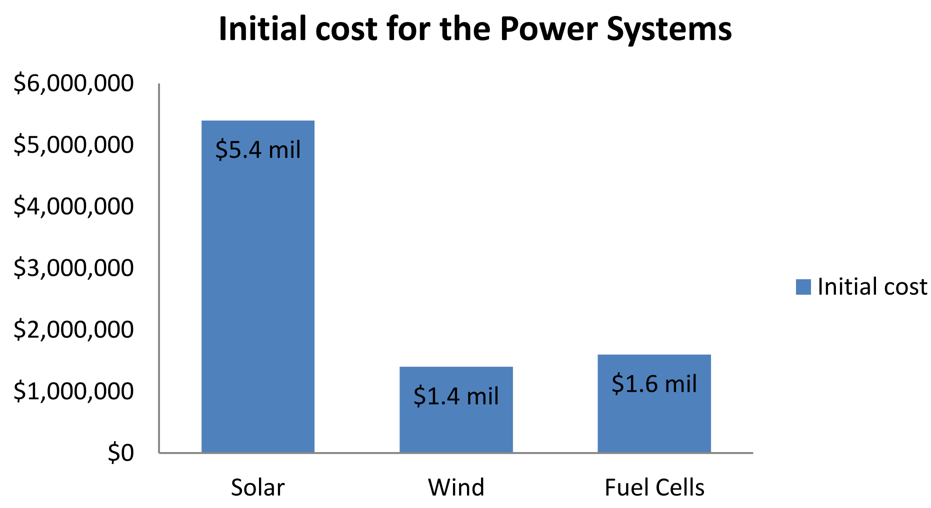

Figure 9: Initial cost for each of the PV, wind and fuel cells power systems.

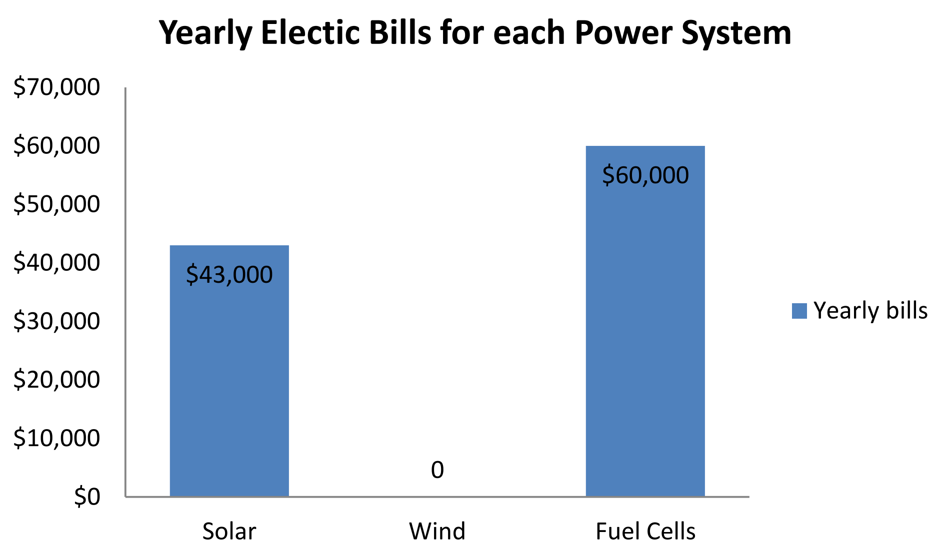

Figure 10: Yearly bills due with each power system.

Conclusion

A preliminary engineering and financial analysis of installing a photovoltaic system on an industrial facility was developed and discussed. The location and incident solar radiation of the business under study is very favorable for installing the system. The facility has minimal shading which makes it ideal for a solar power system. The facility has ample roof area for installing such a system as well. Studying the energy consumption of the business showed that consumption peaks in the summer, which adds to the advantages of installing a solar power system. Finally a financial analysis was conducted that took into account the increase in utility rates and financing option available for the owner. The payback period is expected to be around 30 years and only after significant time will the owner will be able to generate a profit. Compared with other power systems, the PV system is the most expensive however it does offer the lowest maintenance requirements needed. The most cost effective option is a wind power system followed by a natural gas fuel cell power server. The reader is cautioned that highly variable site specific data is needed to extrapolate these analyses to another location or for another business use. The author can be contacted at amal.kabalan@villanova.edu.