A Cost Efficiency Analysis of Energy Options for the Dow Wetlands Classroom

Anna Frankel

Abstract Dow Chemicals has proposed to build an educational facility located on its wetland preserve site in Antioch, California. A diversified energy supply mix has been considered for the classroom building and Dow has a unique opportunity to incorporate renewable energy into the new classroom design. California's energy crisis demonstrates the need for renewable energies, decreasing the dependency on non-renewable resources such as carbon producing fossil fuels that are limited and unsustainable. This study uses *HOMER*, an energy analysis software, in a comparative analysis to calculate which combinations of renewable and traditional energy sources would be the most cost effective for the wetlands, identifying the pros and cons of the different mixes. *HOMER* integrates various costs and technology data with important site specific data like climate and local economic costs. Unquantifiable environmental factors such as habitat destruction and wildlife disturbance are incorporated into the analysis, encompassing the full range of environmental and economic variables operating in the decision making process. Careful evaluation of energy services and environmental effects integrated with cost efficient analysis from *HOMER* revealed that a combination of photovoltaic modules, batteries, and converters would best serve the Dow Wetlands site. Even though renewables are more expensive than other technologies, their non-economic benefits outweigh the economically cheaper grid option. These findings will be presented to Dow in hopes of influencing site planning and design. Investing in renewable energy projects like the Dow classroom can help to offset future problems that may arise from traditional sources of energy.

Introduction

An educational facility will be constructed on the Dow Wetlands preserve site in Antioch, California. Dow Chemicals has a unique opportunity to incorporate renewable energy into the new classroom design, where the future building may benefit from the use of solar and wind energies. Green buildings like the Dow facility would assist in the greater goal of sustainability by using these renewable energies (Cole 1999). Here, sustainability is defined as the interconnections between society, environment, and economy and the balance that is formed to meet present needs and those of the future as well (SD Gateway 2004, elect. comm.). In 2000, California alone spent 929 million dollars on energy for electrical utility needs alone (EIA 2004, elect. comm.). Of 8,518 trillion Btu of energy used by Californians, only 319 trillion Btu came from geothermal, wind, photovoltaic, and solar renewable energies. Barbiroli (1999) warns of the relative scarcity of non-renewable energies and the destruction that come from their combustion, resulting in well documented problems such as acid rain and the greenhouse effect. Yet California energy consumption, as elsewhere, is dominated by petroleum based resources that result in carbon emissions. Investing in projects such as the Dow classroom, as an alternative to the petroleum dominated energy sector, can help to offset future problems that may arise from traditional sources of energy.

The history of the wetlands begins with its acquisition in 1989 by Dow Chemicals from US Steel for $11 million as a buffer zone around the Dow chemical plant in Antioch (Andrews 2003, pers. comm.). An area of the site was flooded when the levy that was protecting the old, unutilized agricultural lands was breached. Dow management officials decided to let the area stay flooded, and in 1997 applied to the Wildlife Management Council to begin restoration of the site into a natural habitat. Efforts to involve the community in the wetland restoration have included educational classes taught on site, some guided tours, and an open house day for the whole community. High school and middle school students go to the wetlands and learn about environmental science, using the site as an educational tool.

In the case of the Dow Wetlands, Dow Chemical Company has designated the 470-acre site located south of the San Joaquin River a preserve area. Surrounding the wetlands is a manufacturing plant, sewage treatment plant, main roads, and train tracks. Inside Dow Wetlands there are four different water bodies: the Beaver Pond, Cattail Marsh, Tidal Marsh, and Kirker Creek. Various habitats are found on site such as grassland, riparian corridors, marshland, and forage fields. Dow has suitable habitat for many animals including beavers, otters, egrets, hawks, falcons, coyotes, turtles, and frogs. Currently three endangered species are found onsite and rehabilitated birds are also released into the area. Since the start of the riparian restoration, native plants and animals have found their way back into the once desolate wetlands.

Restoring the ecosystem and implementing renewable energy for the classroom are two important contributions to a more sustainable future. To protect the preserve, it is imperative that the classroom building be built with the least amount of possible impacts to habitat and disturbance to wildlife (Papamichael 2000). Renewable energies can be used to create a stand-alone building where traditional power grid construction would not alter the fragile wetland ecosystem. The proposed building would be approximately 3,500 square feet and include classroom facilities, lab areas, restrooms, computer labs, a kitchenette, multi purpose room, and other resting areas (Andrews 2003, pers. comm.). It would also serve as a lab for University of California, Berkeley undergraduate students who conduct water hyacinth, anoxia, and macro invertebrate research at the site. The facility would also be a gathering place for all parties involved in Dow Wetland research, education, and restoration. The planned educational building will become a permanent structure for the enrichment of students and the surrounding community, who all care about and engage in environmentally sustainable activities.

A diversified energy supply mix, including renewable energy technologies, has been considered for the construction of the classroom. Studies previously performed suggest the use of renewable energy technologies would be beneficial to the Dow Wetlands. Some of the benefits are environmental, social, and security in energy supplies (Weisser 2004). Prior study sites include small island developing states and small island tourist resorts; they are characterized as remote and not easily accessible with traditional energy sources similar to the Dow Wetlands site (Weisser 2004, Bakos and Soursos 2002). However, in order to make a case for the use of renewables, it is necessary to identify the pros and cons of each energy technology available and find out which factors support the use of each one or a combination of different technologies. In this project I perform a comparative analysis of energy technologies for the future classroom building. *HOMER*, an optimization software for energy analysis, calculates which combination of renewable and traditional energy sources would be the most cost effective and constructive for the wetlands site.

Using *HOMER* allows economic analysis of available technologies to be incorporated with important site specific data such as climate and local costs. The unique preserve location presents environmental factors such as habitat destruction, wildlife disturbance, and aesthetic value that are discussed in conjunction with *HOMER* results to encompass the full range of variables operating in the decision making process. Because the combination of technologies utilized plays an essential part on the environmental impacts, sensitivity analyses are incorporated to see how they affect *HOMER* cost efficiency results. Careful evaluation of energy services and environmental impact integrated with cost efficient analysis from *HOMER* allows for a comprehensive assessment of which energy sources would be the best choice for the Dow Wetlands educational facility. Dow Chemicals can weigh the pros and cons of each situation to select the optimal energy system to be used for the educational facility.

Methods

This study uses the energy optimization software program *HOMER*, version 2.07 created by Peter Lilienthal and Tom Lambert for the National Renewable Energy Laboratory (NREL).[1] *HOMER* can be used to calculate which energy supply mix is the most cost effective for the wetlands classroom. Data variables specific to the site were inputted into the program along side technology options and costs, which were run through *HOMER* to obtain optimal sizes and costs for different combinations of energies (renewable and traditional) available for the site. For the analysis, the different energy technologies considered were photovoltaic modules, wind turbines, propane generators, and grid electricity. Sensitivity analyses conducted involved maximum annual capacity shortage, creating a range of energy mixes that were optimal at different conditions for the one site.

HOMER requires the user to identify the technologies, their characteristics, and costs for consideration in the cost efficiency analysis. This data was collected for photovoltaic modules, wind turbines, generators, batteries, converters, and grid electricity which are all components of the possible combinations of energy sources for the Dow classroom. A range of sizes for each technology was also specified to find the best sizing for the system. Also entered into *HOMER* are capital, replacement, and operational/management (O&M) costs, specific to the technology. It was assumed that O&M costs were zero for all technologies because of the difficulty in finding accurate costs for this input. The program also requires corresponding environmental data for

[1] The software can be freely downloaded from the NREL website: www.nrel.gov/homer.

each technology as well. Environmental data for the Antioch site was collected for the photovoltaic system[2] and wind turbines[3]. Any other specifications of the technologies such as efficiency, lifetime, type, and other data needed was noted and inputted into *HOMER*. All these inputs are used to find the optimal mix and sizes of each technology in the total energy system. Figure 1 shows the *HOMER* interface for the different technologies and simulation inputs.

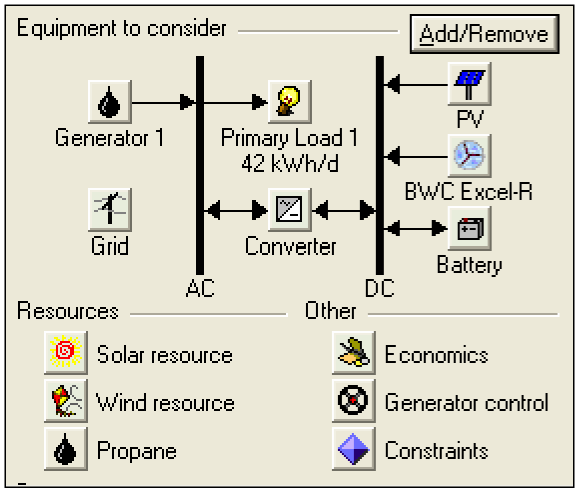

Figure 1: Screen shot of *HOMER* inputs

Load Curve To begin the analysis, an important specification that has to be taken into account was the usage loads of energy consumption. Finding out an average seasonal load amount as well as possible extreme numbers helped to determine which technologies best handled the needs of the classroom. The energy consumption is represented in a load curve. A load curve has each hour of the day on the x-axis and the total kilowatt-hour (kWh) used by the building during that hour on the y-axis. The Dow classroom load curve shows maximum consumption loads, times of peak usage, minimum energy needs, and how many kWh are used at a certain hour of day. The load curve then represents the primary energy levels the system needs to function properly.

The energy needs (lights, heating, cooling, etc.) of the building were determined through discussion with Dow Wetlands managers. The average kWh of those appliances fulfilling the energy needs of the classroom was collected.[4] Each appliance was estimated to operate for a

---

[2] http://eosweb.larc.nasa.gov/sse/
[3] http://www.city-data.com/city/Antioch-California.html
[4] See Appendix 1 for quantity, average kWh, and hours/day for each appliance

certain amount of hours each day, depending on a normal day's use. The load curve was created by assigning each hour of a twenty four hour day the allotted kWh's used by all the appliances operating during that one hour. For example at 4 pm the refrigerator, lights, vacuum cleaner, digital clock, answering machine, and alarm system are operating. During this hour 2.27 kWh are consumed. At 5 pm when everyone has left the building only the refrigerator, digital clock, answering machine, and alarm system are operating. This hour uses 0.29 kWh. This was repeated for each appliance over a 24 hour period, obtaining the total load curve (Fig. 2).

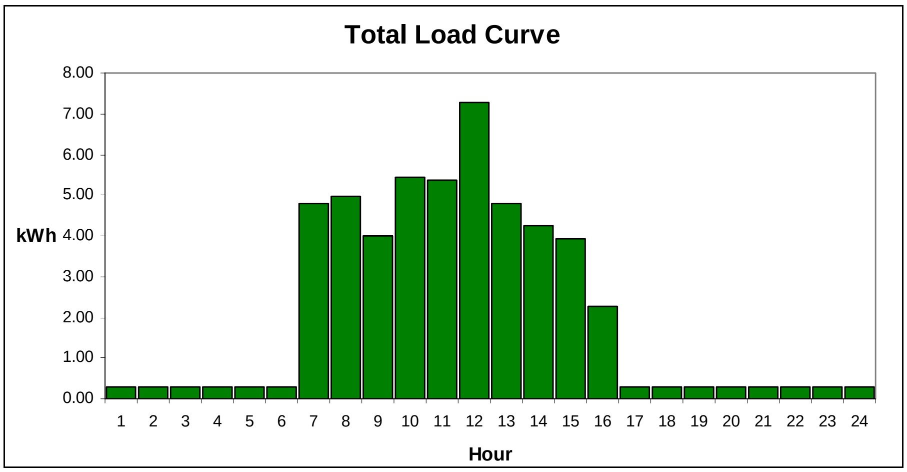

Figure 2: Total load curve of all appliances for 24 hours

To account for seasonal differences a summer and winter load curve (Fig. 3 and 4, respectively) was also created to account for certain appliances that did not run during specific months. During the summer there was no need for using the heating unit and during the winter there was no need for the air conditioner. These appliances use a lot of energy in comparison to other appliances in the classroom. Utilizing *HOMER*'s ability to synthesis data for every hour throughout the year and having two different load curves can then represent a more realistic year in the life of the building.

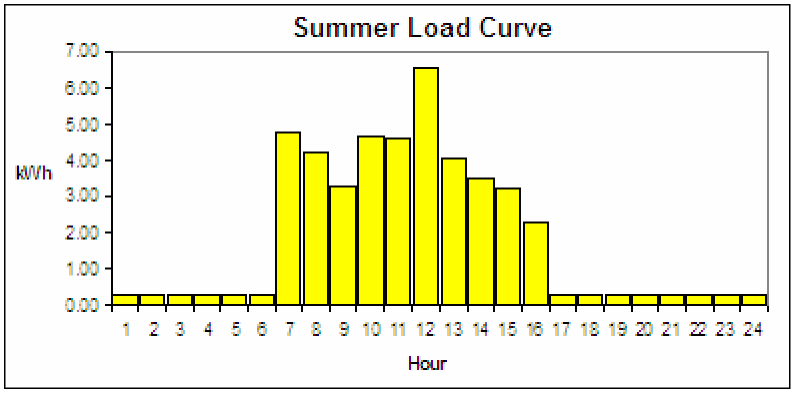

Figure 3: Summer 24 hour load curve for months of June to November

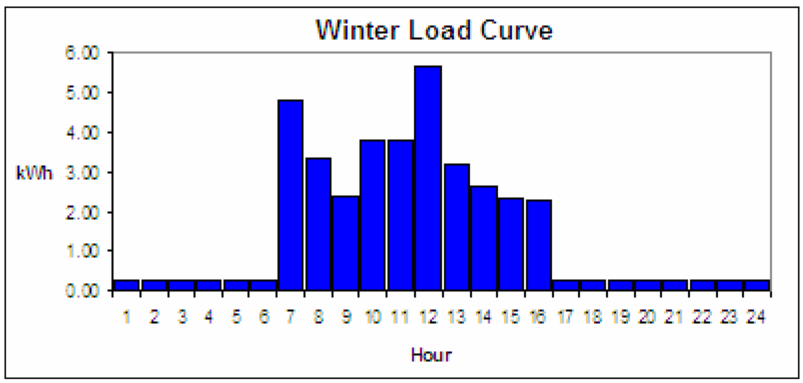

Figure 4: Winter 24 hour load curve for the months of December to May

The load curve has some assumptions associated with it. First, the two seasonal load curves are not based on actual climate data from the site. They are divided into winter (December to May) and summer (June to November) categories for simplification purposes. Secondly, the average kWh used by each appliance is not based on a specific brand and model but are common averages for similar types of appliances.[5] The building has not purchased any appliances, thus the specific wattage needed for the load curve calculations are not known. The actual wattages of the equipment in the building maybe easily incorporated into the model. Thirdly, the hours of use for each appliance may vary from day to day. It is assumed that each appliance is used at the same time each day for the same length of time, which may not always be the case. Variability with users and different activities in the building prevents detailed energy consumption data by hour. *HOMER* allows for a more realistic load curve though, using daily and hourly noise as randomness in the simulation. Daily noise controls the size of the curve while hourly noise

---

[5] See Appendix 1 for quantity, average kWh, and hours/day for each appliance

changes the shape of the load curve. Default daily noise at 15% and hourly noise at 20% was used to run the load curve simulation. Therefore in one day there can be a standard deviation of 15% and 20% each hour. This randomness is important to the simulation as it generates load curves for months and hours that have not been specifically conceived. Lastly, there is no differentiation between a weekday and a weekend because of the similarity of activities. The building will on average be used for 22 days throughout the month for the same uses no matter what day it is (Andrews 2003, pers. comm.).

Photovoltaic (PV) Inputs[6] To perform the cost efficiency analysis, capital, replacement, and O&M costs corresponding to different sizes for the PV array was entered into *HOMER*'s "Costs" data, creating the estimated cost curve. Sizes are measured in kilowatts (kW) for non-tracking systems only. Here the replacement cost of the PV array is assumed to reflect only the replacement of all the modules, not including wiring, controllers, etc. For example, a 0.9 kW PV system has a capital cost of $5,705, replacement cost of $400 for each module, and $0 for O&M. *HOMER* calculates predicted capital, replacement, and O&M costs for different PV sizes that will be considered in the model from the entered costs. The box labeled "Sizes to consider" was inputted with perspective kW systems that could be used at the Dow classroom. These sizes were smaller and larger than 11.3 kW, the average peak energy load, to find what optimal combination of PV modules would be needed in conjunction with other technologies. Providing the program with a range of sizes helps to narrow down the best array size for the energy needs.

Other inputs necessary to run the model were derating factor, slope, azimuth, and ground reflectance. Derating factor is the efficiency loss of a PV module over time, which was set at default 90%. The 10% inefficiency maybe caused by dirty panels, varying temperature, or loss in energy transformation. Slope and azimuth was site specific and are important, affecting the PV module output and setup. Figure 5 shows the module facing south. The azimuth is the angle within the cardinal plane from north that the module is turned. The perfect slope and azimuth positions the PV modules to obtain the maximum amount of solar radiation, increasing the modules' efficiency. Ground reflectance was set at default 20%, representing the grassland ground cover. The lifetime of the PV panels was said to be 30 years.

[6] See Appendix 2 for all photovoltaic references, costs, and inputs

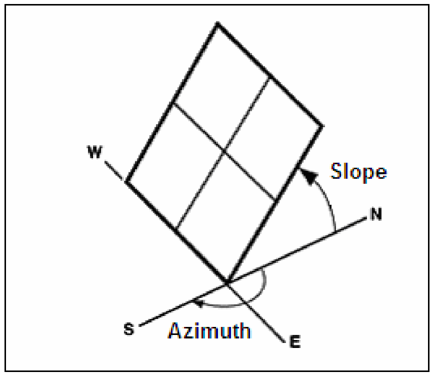

Figure 5: PV module facing south at fixed tilt

Solar Resource The PV array's output is directly affected by the latitude, daily amount of solar radiation that reaches the site, and clearness index. Solar radiation is the measurement of energy on an area over time; the unit used is kWh/m^2/day. The clearness index is the ratio between the amount of solar radiation that hits the earth's surface from the top of the atmosphere, expressed as a fraction from zero to one. A high clearness index means that the air is very clear without obstructions to solar radiation. Latitude determines the solar radiation, clearness index, and affects how the PV modules are placed and sized. Antioch, California is located on latitude 38˚ north and longitude 121.8˚ west.[7] Using data collected from NASA, the specific solar radiation data for Antioch was 5.996 kWh/m^2/day and the average clearness index is 0.746 (Fig. 6).[8]

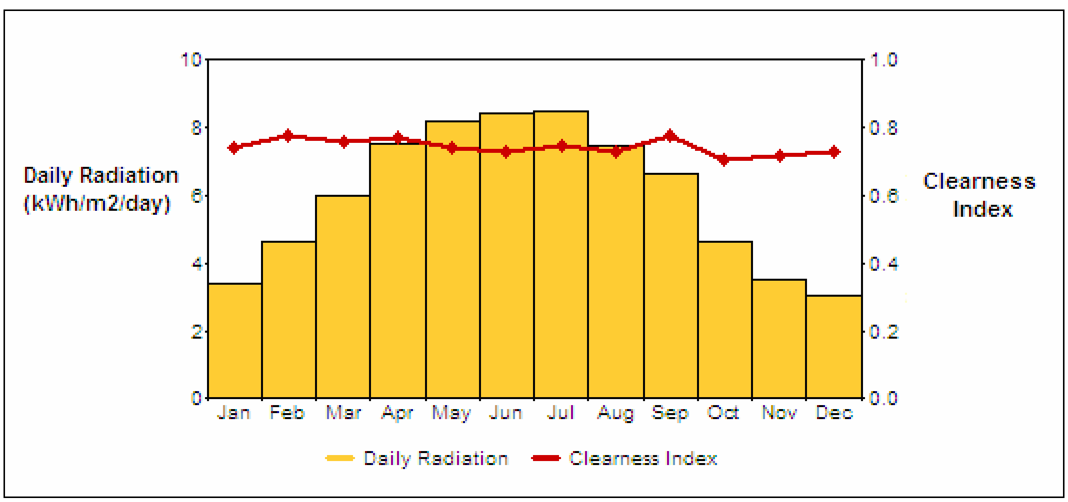

Figure 6: Average daily solar radiation and clearness index for each month

7 http://www.stateguide.com/ca/Antioch/
8 http://eosweb.larc.nasa.gov/sse/

Wind Turbine Inputs[9] For this technology option, *HOMER* already has different brands and models of wind turbines embedded into the software to pick from. The process to choose which wind turbine to run in the model depended on the average wind speed in Antioch as well as the minimal wind speed needed to produce power for each turbine model. Average wind speed for the area was 3.5 m/s.[10] Most of the models provided in the program had relatively high optimal wind speeds. The Bergey BWC Excel-R was chosen because its power curve best suited the wind resources available at the Dow Wetlands site. Even though the optimal wind speed for the BWC Excel-R is around 13 m/s the slope at 3.5 m/s wind speed still produces more kW than the other models. The wind turbine "Costs" data asks for capital, replacement, and O&M costs and quantity of wind turbines. The "Sizes to consider" input was again entered with the number of wind turbines that the system could possibly use for the Dow classroom. This ranged from 0 to 1 because a greater number of wind turbines on site would not be aesthetically pleasing as well as the possibility of potential bird hazards that may occur.

Properties affecting wind turbine output was lifetime, power curve scaling factor, and wind speed scaling factor. The power curve scaling factor is used to find the actual output from the wind turbine at certain air density conditions. Air density is dependent on elevation where higher elevations have decreased air density. In the model, it is assumed that the wind turbine will run according to its power curve without any interference from air density because the site is very close to sea level. The power curve scaling factor is then left at the default value of one. The wind speed scaling factor is used to calculate the wind speed at the turbine hub height from the height that the wind speed was measured. This factor was also left at one because the height from which the readings were taken was unknown.

Wind Resource Information for the monthly average wind speed (m/s) at Antioch, California was inputted into *HOMER* (Fig. 7).[11] The advanced parameters for the site are the Weibull k value, autocorrelation factor, diurnal pattern strength, and hour of peak wind speed. These four parameters were kept at their set defaults of 2, 0.85, 0.25, and 15 respectively. There was no data collected to accurately use specific values for these advanced wind turbine parameters. The assumption made for the wind resource input is that *HOMER* defaults can

[9] See Appendix 2 for wind turbine references, costs, and inputs
[10] http://www.city-data.com/city/Antioch-California.html
[11] http://www.city-data.com/city/Antioch-California.html

adequately represent the site's wind patterns.

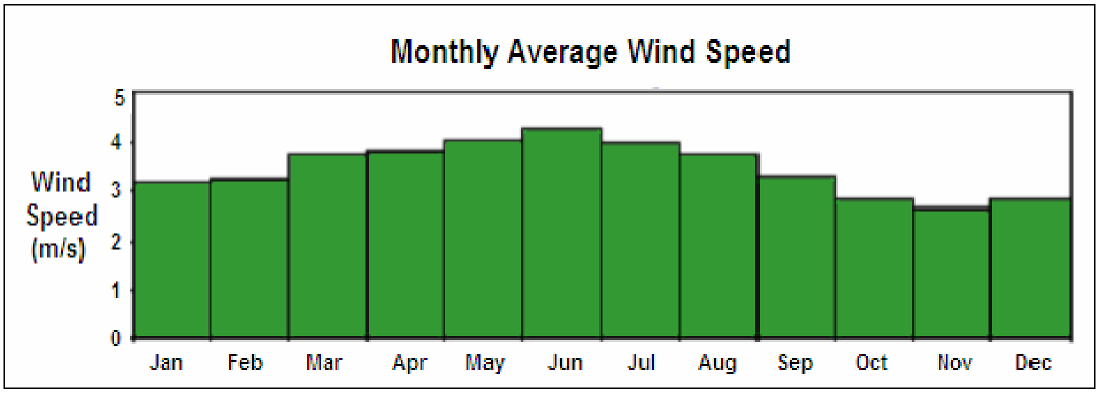

Figure 7: Average monthly wind speed for Antioch, California in m/s

Battery[12] *HOMER* provides different battery types and models for battery inputs. Any of the batteries may be used but the Trojan L16P was the battery chosen because it is a 6 volt battery and had a nominal capacity (the amount of energy that can be drawn out from the battery) of 360 Ah. It represents a very typical type of battery that can be used in a system that needs to store energy. The "Costs" data for the battery inputs asks for quantity of batteries, capital, replacement, and O&M costs. A wide range of quantities for batteries was entered into the "Sizes to consider" input because with larger sized PV arrays less batteries would be needed. Finding the right size for the battery component of the system is important because during winter or consecutive days of cloudy weather, the battery component maybe the only source of energy available. This stipulation is valid as it discounts the addition of a generator into the energy combination mix, which would otherwise contribute to the energy load needed. The minimum battery life was set to five years similar to most manufacturers' warranties of the same length.

Converter[13] A converter is used in the system because there is both AC and DC components in the energy mix. The inputs for the converter under the "Costs" data are size in kW, capital, replacement, and O&M costs. The most important factor for converters is their ability to manage the electricity load that the building is using. A good converter should also be able to handle surges of power as well. The lifetime and efficiency of the converter was an average estimate from the manufacturers' specification. The "Inverter can operate simultaneously with an AC

[12] See Appendix 2 for battery references, costs, and inputs
[13] See Appendix 2 for converter references, costs, and inputs

generator" input was checked because a switched inverter would not be in use for the building. The rectifier inputs were set at default values because at this time it is unknown which specific type of converter would be use and what rectifier would therefore be in place.

Generator, Fuel, Generator Control[14] The "Costs" data for the Generator button are size in kW, capital, replacement, and O&M costs. General inputs are lifetime, minimum load ratio, and heat recovery ratio. Lifetime for the generator comes from the manufacturer's specifications. The minimum load ratio is the allowable amount of energy that the generator has to use if it is running. This is set at the default value of 30%. The heat recovery ratio is set at zero because it is unknown how much heat energy produced by the generator can be reused. This variable is dependent on the type of generator as well as the manufacturer's design. Fuel curve inputs are important to the efficiency of the generator. *HOMER* allows for different types of fuels to be chosen for the model simulation. Propane was selected as the generator fuel because of its relatively high efficiency in comparison with other fuels available as well as being easily obtainable. Intercept and slope are found using the size of the generator and fuel consumption rates.

Fuel inputs in this model represent propane prices in $/L. To direct the generator functions certain conditions are implemented in the Generator Control button. All the inputs found under this button are defaults and assumed to adequately represent the functions and operations of the generator in the model simulation.

Grid[15] Dow Chemical Company estimated the cost for grid construction. The traditional grid construction cost was calculated as dollar per foot of power line from the PG & E estimate. *HOMER* allows choice in how the grid is integrated into the energy supply mix. The two options available are to model a grid-connected system and a stand-alone system. A grid-connected system uses the grid as a vital energy source in the supply mix. Choosing the stand-alone system option models the grid as an alternative to the renewable technologies. The stand-alone system was selected because this option provides a breakeven point analysis of how far away the building has to be before grid construction is more cost effective. This information would be helpful in the Dow Wetlands situation as the site is not yet planned in a designated area or distance from main power lines. Knowing this information from this model may change the

---

[14] See Appendix 2 for generator references, fuel inputs, generator controls, costs, and inputs
[15] See Appendix 2 for grid references and inputs

energy planning and design of the classroom. When the stand-alone system option is selected the variables left to fill in are the "Grid extension costs". The inputs for this section include the capital cost of the grid extension in $/km, O&M costs in $/yr/km, and price of power obtained from the grid in $/kWh.

Economics and Constraints[16] The economic inputs are used as baseline data for all the technologies to find the most cost efficient energy combinations over the whole building's lifetime. The inputs for the economics data include annual real interest rate, project lifetime, cost of unmet load, system fixed capital cost, system fixed O&M cost, and carbon tax. Each of these inputs affects the total energy supply mix because of changing costs over time due to an economy which is always rising or falling. *HOMER* assumes inflation rates are constant for all the inputted costs of *HOMER*. The "Cost of unmet load" is set at zero because it is an assumption of this model that there will be no penalty if there is energy needs that are not met. "System fixed capital cost" and "System fixed O&M cost" are set at zero because they are two costs that are not available for the simulation. Being set at zero does not affect the results as to which energy combination mix is the most cost efficient because these costs affect all the systems by the same amount. Carbon tax inputs are in $/ton. This tax is leveled against any carbon emissions that each fuel burning technology may emit. These values are then incorporated into other O&M costs for each system.

Numerous different energy combinations are narrowed down to a certain few with the Constraints option. All possible systems must meet these specified criteria to be considered optimal and cost effective. The first input is "Maximum annual capacity shortage" which is the maximum value that the system can have unmet energy loads. This variable was set at 5%, allowing for a small amount of acceptable shortage. The reasoning behind this decision is that if the variable was set at zero there will be additional strain on the system, requiring equipment during times of high demand. The probability of having numerous major power outages is rather low, yet a lot of money and resources would be used to account for a small percentage of energy disasters. Having a limited capacity shortage allows the system to meet most energy demands without increasing expenditures greatly. The "Minimum renewable fraction" represents the minimum portion of the total energy system that must be renewable. This variable is set at zero for the possibility that the best system does not contain any renewable technologies. The

[16] See Appendix 2 for economics and constraints references and inputs

"Operating reserve" inputs found in the Constraints option were left at default values. The assumption made for these inputs is that *HOMER* defaults can adequately represent an average operating reserve.

Sensitivity Analysis The sensitivity analyses for this model simulation was run for the maximum annual capacity shortage (MACS) percentage. This variable out of all the variables in *HOMER* can affect all the combinations of energy systems. Higher or lower values for the amount of unmet load changes the *HOMER* outputs for sizing of each technology, the function of each technology, and how frequently it would be used. The sensitivity analysis then ran optimization simulations under 5% and 10% MACS.

Results

The results of the simulation found that a system consisting of PV arrays, batteries, and converters is the most optimal cost effective energy mix for the Dow classroom from the six different possible technologies. The two different MACS percentages both show this same mix as optimal but with varying sizes, costs, and prices for each specific technology (Table 1).

Maximum Annual Capacity Shortage at 10%

PV (kW)	XLR	Gen1 (kW)	Batt.	Conv. (kW)	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Propane (L)	Gen1 (hrs)	Batt. Lf. (yr)
7.0			35	7.0	$ 58,440	$ 74,080	0.205	1.00	0.10			9.4
8.0		0.5	40	9.0	$ 67,650	$ 92,121	0.242	1.00	0.01	513	205	10.0
6.0	1		30	6.0	$ 78,272	$ 92,576	0.256	1.00	0.10			9.0
7.5	1	0.5	35	9.0	$ 91,674	$ 113,567	0.298	1.00	0.01	426	170	10.0
9.0	1	2.0		7.0	$ 95,361	$ 847,627	2.342	0.86	0.09	51,298	5,392	
9.0		2.5		7.0	$ 67,754	$ 1,139,058	3.120	0.79	0.08	73,182	6,163	

Maximum Annual Capacity Shortage at 5%

PV (kW)	XLR	Gen1 (kW)	Batt.	Conv. (kW)	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Propane (L)	Gen1 (hrs)	Batt. Lf. (yr)
7.5			40	7.5	$ 62,740	$ 78,999	0.212	1.00	0.05			10.0
8.0		0.5	40	9.0	$ 67,650	$ 92,121	0.242	1.00	0.01	513	205	10.0
6.5	1		35	8.0	$ 83,908	$ 99,140	0.266	1.00	0.05			10.0
7.5	1	0.5	35	9.0	$ 91,674	$ 113,567	0.298	1.00	0.01	426	170	10.0

Table 1: *HOMER* optimal results for different maximum annual capacity shortage percentages

The first line of each MACS in Table 1 shows the best optimal energy system for the Dow classroom building. Each subsequent line is ordered by cost efficiency from the net present cost (NPC).

The makeup of each system is the same but the sizes of each component within the system are different. At 10% MACS, the optimal energy system is sized smaller and has a NPC that is lower than the 5% system. With a smaller system the costs go down for buying energy and the construction of the classroom building. Greater capacity shortages results in lower cost of energy (COE) as shown in Table 1. The tradeoff is having hours or days without adequate amounts of energy to meet the minimum energy needs for the classroom.

Total capital cost is the cost of the whole project at the beginning of its lifetime. This includes components and installation. NPC represents the total present costs of the system. Within the total costs of the system an additional breakdown of costs is shown in Figures 8 and 9 for each specific technology. The majority of costs come from the PV array at 62% with around 38% of costs from batteries and converters. The capital and replacement costs are spread throughout the lifetime of the building that was set at 30 years. The total annualized cost is the same as the capital and replacement costs because no O&M costs were incorporated into the optimization model. Other technologies like generators or the grid may have some O&M costs that are associated with taxes placed on their emissions, which would alter the total annualized costs per year. These “other” costs were not shown because the PV array produces no carbon emissions were produced.

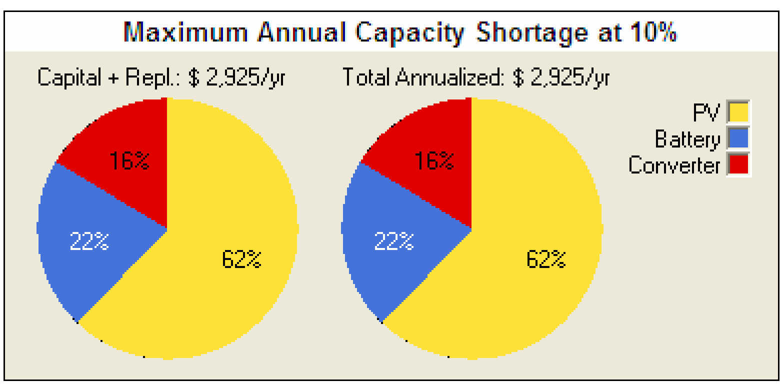

Figure 8: Capital and replacement costs, and total annualized costs at 10% maximum annual capacity shortage

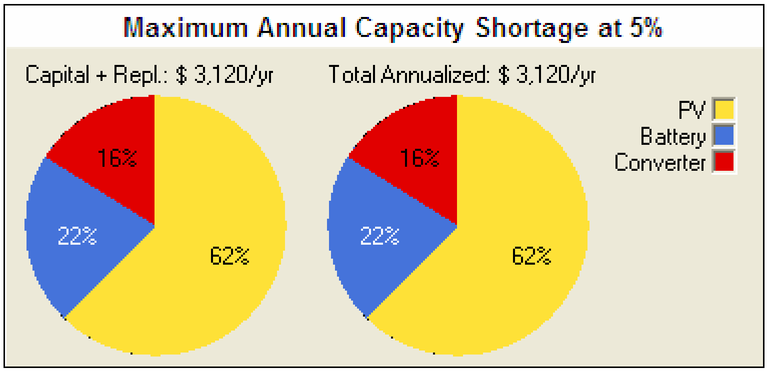

Figure 9: Capital and replacement costs, and total annualized costs at 5% maximum annual capacity shortage

HOMER provides, under the stand alone system option, the breakeven distance which is where the NPC of the stand alone system would equal the NPC of the grid extension. The breakeven distance for 10% MACS was 0.01023 km and 0.0523 km for the 5% MACS.

Discussion

To find the most cost efficient energy mix for the Dow Wetlands classroom *HOMER* was used. The results of the simulations with sensitivity analysis on MACS showed an energy system made of PV modules, batteries, and converters to be the most cost efficient throughout the lifetime of the Dow building.

The optimization results favor larger kWh sized systems with respect to the smaller MACS percentage wed. This makes sense as there must be a greater ability to supply energy and a larger sized system would fulfill this need. With a larger system, the costs increase accordingly as shown by the higher NPC for the 5% MACS simulation at $78,999. Lower NPC of $74,080 for the 10% MACS simulation are a result of less equipment and modules needed to support the system, yet there will be times during the year that a surge in load means needs cannot be covered. This tradeoff must be considered in the construction of the building. Perhaps since the facility will be serving students the managers of the site may wish to have 5% MACS instead of 10% despite the increased cost. The annualized cost per year for the building ranges from $2,925 to $3,120 for the two MACS, which can be paid within the 30 year lifetime of the building. These numbers are again based on estimates of the technologies and other assumptions about the site. It is worth noting that Dow should take these numbers into consideration but be aware that there are most likely additional costs associated with the project that was not taken into consideration. It is important to keep in mind that *HOMER* only models the best available combination based on the inputted variables. But as a rough estimate, this study provides comparative costs that can affect the energy decisions for the Dow classroom building. Dow may choose an option other than the PV array, batteries, and converters system due to factors out of the scope of *HOMER*, such as any liability issues with students onsite, funding, or desirable design and aesthetics. Even though the *HOMER* results show a generator as less cost effective, Dow may also choose to round out their energy needs with the generator as a forward looking precaution against exceeding their set capacity shortage percentage.

Each optimization result's cost effectiveness is based on the NPC. Each energy combination is then listed as the most cost effective in this manner. *HOMER* provides other valuable information that can be used in conjunction with NPC to consider which energy mix is the most optimal. One such variable is the cost of energy (COE). This number reflects the average cost of each kWh of power that Dow would have to pay for each system. The COE is pertinent to fixed future operation costs. Keeping in mind that the simulation represents a stand alone building, Dow can either save or pay more for their electricity in comparison to standard grid prices to the COE. If the electricity bought from the grid experiences price escalation, Dow would be saving on each kWh they produce themselves. In the light of the recent California Energy Crisis, the price of electricity varies and is not stable. Dow may find producing their own energy from the renewable technologies more economical and secure than what can be provided from the grid. On the other hand, to pay for the building there are fixed, unchanging, construction costs. If for some reason the price of electricity produced by the grid decreases, Dow could not capitalize on the lower prices. Seeing that California's energy situation is unstable it would be wise to invest in the renewable energy system because of the more consistent supply of solar energy.

The results for the breakeven grid distance are different between the two MACS. Breakeven distance is the distance where the price of the grid extension from the nearest power line will equal to the price of constructing the stand alone building with the renewable energy mix. For both MACS this means the building has to be at least the breakeven distance away from the nearest grid electricity source before a stand alone system would be more economical. At 10% MACS, it will be more economical to construct the Dow classroom building 0.01023 km or farther away. Any closer than this distance and Dow would be better off constructing a grid extension. At 5% the breakeven distance is 0.0523 km. The 10% MACS breakeven distance is much shorter than the 5%. Building the Dow classroom facility at 10% MACS will then be more cost effective in terms of breakeven distance. Yet both these distances are very short distances meaning that Dow has more available sites for the building that are more economical with a stand alone and renewable energy mix than a grid extension. Besides being economical, the stand alone option would be more environmentally friendly because of the lack of carbon emissions from electricity utility production. *HOMER* only took into account mitigation carbon taxing but other environmental externalities such as social costs and other air pollutants still stem from electricity emissions that should be added to the existing carbon taxes for future sensitivity analyses (Matthews and Lave 2000).

Factors such as habitat destruction, wildlife disturbance, aesthetic value, and sustainability of energy combination are difficult to quantify. These are factors fall into environmental and health costs that are generally overlooked in economic analysis but they are an important part of the building construction and should be considered in the decision making process (Bakos *et. al* 2003). One option for the building was to just build a grid extension which would have caused much disturbance to the site. The construction of the building itself already has set impacts to the site by being a permanent structure on the wetland preserve. There would be additional disturbance as grid construction takes up more land. Using the renewables that are just situated on or by the classroom would reduce possible impacts to the habitat and wildlife. Dow, in its effort to create a classroom building that embodies some of the sustainability beliefs taught there, would benefit from the renewable energy mix. The building can also be aesthetically tied to environment and blend naturally into the landscape. Grid construction or even a wind turbine may not conform to these standards. Aesthetics then is just another factor that must be taken into consideration as Dow continues it's planning and design.

Taking the breakeven grid extension distance and site factors into account, the most optimal choice for Dow is to use the energy combination of a 7 kW PV array, 35 batteries, and 7 kW converter at 10% maximum annual capacity shortage. The building can be built 0.01023 km away from a grid source and be more cost effective then actually constructing an extension. The NPC is less than the system at 5% MACS too. There will be less money paid throughout the lifetime of the building as COE is $0.205/kWh. Overall, if the decision is made to use renewable technologies in the Dow Wetlands classroom, 10% MACS would be the best option.

Acknowledgements

I would like to especially thank Sergio Pacca for all of his support and generous help. To Bonnie Wang, Kathy Tung, Jack Cheng, Emily Lee, Pamela Han, Kevin Golden, and Stephen Andrews, thank you for giving me encouragement and support. And thanks to Krist Jensen and Sheryl Sturges of Dow Chemical for their cooperation and kindness.

References

Alvarenga, C.A., Costa, D. and Lobo, A.R. 1996. Renewable sources for decentralized energy supply. Renewable Energy 9: 1152-1155.

Andrews, S.P. ESTP Program coordinator, UC Berkeley, California. 2003, personal communication.

Bakos, G. C. and Soursos, M. 2002. Technical feasibility and economic viability of a grid-connected PV installation for low cost electricity production. Energy and Buildings 34: 753-758.

Bakos, G. C., Soursos, M., and Tsagas, N. F. 2003. Technoeconomic assessment of a building-integrated PV system for electrical energy saving in residential sector. Energy and Buildings 35: 757-762.

Barbiroli, G. and Focacci, A. 1999. An appropriate mechanism of fuels pricing for sustainable development. Energy Policy 27: 625-636.

Cole, R. 1999. Building environmental assessment methods: clarifying intentions. Building Research and Information 27: 230-246.

Cotrell, J. and Pratt, W. 2003. Modeling the Feasibility of Using Fuel Cells and Hydrogen Internal Combustion Engines in Remote Renewable Energy Systems. WINDPOWER 2003, Austin, Texas.

Energy Information Administration (EIA). 2003. http://www.eia.doe.gov/emeu/states/main_ca.html, accessed February, 2004.

Lilienthal, P. and Lambert, T. *HOMER*, version 2.07. National Renewable Energy Laboratory: http://www.nrel.gov/homer.

Matthews, H. S. and Lave, L. B. 2000. Applications of environmental valuation for determining externality costs. Environmental Science Technology 34: 1390-1395.

Metz, B., O. Davidson, J. P., and Swart, R. 2001. Climate Change 2001: Mitigation. Cambridge University Press, Cambridge. 762 pp.

Papamichael, K. 2000. Green building performance prediction/assessment. Building Research & Information 28: 394-402.

SD Gateway. Sustainable Development Communications Network. 2004. http://www.sdgateway.net/introsd/definitions.htm, accessed February, 2004.

Suganthi, L. and Williams, A. 2000. Renewable energy in India - a modeling study for 2020-2021. Energy Policy 28: 1095-1109.

Weisser, D. 2004. On the economics of electricity consumption in small island developing states: a role for renewable energy technologies? Energy Policy 32: 127-140.

APPENDIX 1

Appliance	Quantity	Average kWh*	Hours Used/Day
Central Air Conditioning	1	3.2	8
Resistance Heating	1	1.5	4
Electric Water Heating	1	4.5	1
Dishwasher-Energy Saver	1	1.2	0.5
Large Fridge	1	0.075	24
Microwave	1	1.2	0.5
Toaster oven	1	1.2	0.5
Coffee maker	1	1.02	1
Computers	12	0.048	3
Color monitors	12	0.067	3
Laser printer (idle)	1	0.05	1
Laser printer (printing)	1	0.18	0.5
Photocopier (standby)	1	0.06	3
Photocopier (copying)	1	1.5	0.5
Fax machine (standby)	1	0.02	8
Fax machine (active)	1	0.1	0.5
VCR	1	0.012	2
53-inch projection TV	1	0.2	2
32-watt fluorescent light bulbs	40	0.032	10
Vacuum cleaner	1	0.7	1
Digital clock	1	0.002	24
Answering machine	1	0.012	24
Alarm or sprinkler timer	1	0.2	24

*The kWh for each appliance was averaged between three different resources
http://tony.mapledds.com/wattage.html
http://www.pge.com/res/energy_tools_resources/energy_calculator/index.shtml
http://www.srpnet.com/prices/pdf/appliance1700.pdf

APPENDIX 2

PV Inputs

Cost						
Size (kW)		Capital ($)		Replacement ($)		O&M ($/yr)
0.60^		4226^		3990^		0
0.90*		5705*		4800*		0
1.92*		12440*		11040*		0

Sizes to Consider (kW)			**Properties**			
0	5.5	6	Lifetime (yrs)	30	Slope (degrees)	38
6.5	7	7.5	Derating Factor (%)	90	Azimuth (degrees)	0
8	8.5	9	Tracking System	No	Ground Reflectance (%)	20

^ http://www.independent-power.com/medium_system.htm
* http://www.rockygrove.com/design/samples.html

Wind Turbine Inputs

Turbine Type		BWC Excel-R	
Cost			
Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	27880^	19400^	0

Sizes to Consider (Quantity)		**Other**					
0	1	Lifetime (yr)	30	Power curve scaling actor	1	Wind speed scaling factor	1

^ http://www.bergey.com/

Battery Inputs

Battery Type		Trojan L16P	
Cost			
Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
8^	2080^	215^	0.00
16*	3150*	185*	0.00
24*	4630*	185*	0.00

Sizes to Consider (Quantity)								**Advanced**	
0	20	25	30	35	40	45	50	Minimum battery life (yr)	5

^ http://www.independent-power.com/medium_system.htm
* http://www.rockygrove.com/design/samples.html

Converter Inputs

Cost			
Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
2.00^	3358^	1795^	0
3.60*	1755*	1450*	0
8.00*	8090*	6200*	0

Sizes to Consider (kW)			**Inverter Inputs**			
0	5	5.5	Lifetime (yrs)	15	Efficiency (%)	94
6	6.5	7	Inverter can operate simultaneously with AC generator			Yes
7.5	8	8.5	**Rectifier Inputs**			
9	9.5	10	Capacity relative to inverter (%)	100	Efficiency (%)	85

^ http://www.independent-power.com/medium_system.htm
* http://www.rockygrove.com/design/samples.html

Generator Inputs

Cost			
Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
10^	5461^	3148^	0.000

Sizes to Consider (kW)			**General**			
0	0.5	1	Lifetime (hr)	15000	Type	AC

1.5	2	2.5	Minimum load ratio (%)	30	Heat recovery ratio (%)	0
Fuel Curve						
Fuel	Propane		Intercept (L/hr/kW rated)	4.5	Slope (L/hr/kW output)	0.68

^ http://www.generatorjoe.net

Generator Controls

Dispatch strategy							
Load following	No	Cycle charging	Yes	Apply setpoint SOC	Yes	Setpoint SOC (%)	80
Advanced							
Allow systems with multiple generators						Yes	
Allow multiple generators to operate simultaneously						Yes	
Allow systems with generator capacity less than peak load						Yes	

Fuel

Propane Inputs			
Price ($/L)	0.40^	Limit usage to L/yr	No

^ http://www.eia.doe.gov/oil_gas/petroleum/info_glance/prices.html

Grid

System		Stand alone
Grid extension costs		
Capital ($/km) 117,000^	O&M ($/yr/km) 0	Grid power price ($/kWh) 0.19^

^ Jensen, Krist. Manager, Dow Wetlands, Antioch, California. 2003, personal communication

Economics

Economic Inputs			
Annual interest rate (%)	1.13^	System fixed capital cost ($)	0
Project lifetime (yr)	30	System fixed O&M cost ($/yr)	0
Cost of unmet load ($/kWh)	0	Carbon tax ($/ton)	410*

^ http://www.federalreserve.gov/releases/h15/update/
* http://www.grida.no/climate/ipcc_tar/wg3/037.htm

Constraints

Constraints				
Maximum annual capacity shortage (%)	10	5	Minimum renewable energy fraction (%)	0
Operating reserve: As a percent of load				
Hourly load (%)	10		Annual peak load (%)	0
Operating reserve: As percent of renewable output				
Solar power output (%)	25		Wind power output (%)	50