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SOLAR POWER FEASIBILITY STUDY FOR THE FORT WALLA WALLA MUSEUM

Katy Newhouse

Editors:

Eden Essick
Peter Griffin
Ben Keefer
Stacy Miller
Karl Storchmann

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Katy Newhouse

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Chapter 1: Introduction

There are many reasons to look to renewable energy for more of our electricity generation needs in the twenty-first century: the urban air pollution problems in the U.S., the vulnerabilities posed by relying on oil from the Middle East, and the need to reduce the use of fossil fuels to prevent global warming (Socolow, 1994). More and more renewable energy systems are being installed every year, but many people still question whether or not renewable energy, specifically solar energy, is really economically feasible for generating electricity. It might not be feasible based upon a weighing of private costs and benefits of the installation of a solar system. This thesis hopes to show that the results might be different when considering social costs and benefits. The author will use the Fort Walla Walla Museum (FWWM) as a case study to show the disparity between a private benefit cost analysis (BCA) and a social benefit cost analysis (BCA) of a photovoltaic (PV) system.

The FWWM was founded in 1967 with a mission to provide an understanding of the Walla Walla region's heritage which creates a foundation of community. The Museum shares this heritage through its exhibits and programs each season with more than 25,000 visitors, including 5,000 or more children from schools across the Northwest. In addition, FWWM makes a significant contribution to the region's economic development by promoting tourism with visitors from every state and more than twenty-five countries. The FWWM Board of Directors is currently in the planning stages of a massive renovation and is interested in exploring the possibility of installing a PV system which achieves the direct conversion of solar energy into electricity. The museum sees many beneficial aspects of this project. First, it would offer a way to connect the past with the future, linking the site's two windmills which once pumped water, and the proposed PV system which would generate electricity. Second, the PV system would be used to educate visitors about present day renewable energy and to become a visible example of renewable energy in Walla Walla. Finally, the PV system would provide electricity bill savings.

This thesis begins by providing a review of relevant literature in Chapter Two. Chapter Three contains the first part of the case study, which is composed of a private benefit cost analysis. Chapter Four extends the private benefit cost analysis to a social benefit cost analysis by accounting for certain externalities and exploring life cycle analysis. In the conclusion, the author will summarize the results and offer a recommendation to the museum. Last, the appendix presents an overview of photovoltaic technology and relevant figures.

Chapter 2: Literature Review

The analysis of the feasibility of a photovoltaic system for the FWWM draws from a broad array of literature mostly within energy and environmental economics. The literature considers the economics in the PV market, the electricity energy sector, and the externalities in the production and consumption of various forms of energy. More specifically, this thesis will make use of a developing literature on PV feasibility using benefit cost analysis supplemented by life-cycle analysis (LCA), which guides the social benefit cost analysis to be undertaken in this study. This chapter describes the literature and the placement of this thesis in it.

Haas (1995) addresses the conditions of the PV market and emphasizes long term thinking when dealing with PV. The high investment costs of PV, hidden environmental costs for fossil fuels, and subsidies provided to conventional energy providers alters the comparison between PV and other forms of electricity production for private decision makers. Haas recommends a policy of decentralizing PV and subsidizing more small-scale PV systems so that people's incentives would be better aligned with social benefits and costs in the cases of environmental externalities.

Muneer, Asif, and Kubie (2003) address the increasing demand for energy in the United Kingdom, escalating environmental problems, and decreasing supply of conventional energy. The authors then explore the viability of solar as an alternative energy source for the UK. They point to solar electricity as an attractive alternative because it is globally accessible, its technology is advancing very quickly, and for PV systems connected to the grid it is reliable.

Sawin (2004) explores technological advancement in the PV market and demand for solar panels. She finds that the progress of an industry relies on research and development that lead to technology improvements. The PV industry is undergoing rapid technological advances. Sawin explores the investment in PV and states that the development of the PV market is directly caused by policy actions to promote PV technology in various countries.

Much of the research on PV is related to the environmental benefits of PV in comparison with conventional fuels. Nieuwlaar and Alsema (1997) report that PV has many environmental benefits as a substitute for conventional fuels and there are no major health, safety, or environmental obstacles to overcome. In recent years, experts in PV, specifically the environmental side of PV, have convened for conferences and workshops around the world. These conferences produce valuable information about the health, safety, and environmental features of PV. They also come to agreements on the potential of PV to mitigate CO_2, and environmental life cycle assessments of PV.

A massive European research project that began in 1990 called ExternE. The participants worked to quantify all of the external costs related to energy production, transportation, and consumption. Krewitt (2002) talks candidly about the difficulty of collecting such information and the limitations that arise, especially estimating the costs related to climate change. Despite the effects of uncertainty, he argues that the data it can still be used effectively to support the benefit cost analysis needed for a social feasibility study.

In the United States, the Energy Information Association (EIA) examines electricity generation and environmental externalities using case studies from various U.S. states that have worked to incorporate externalities into their energy prices. The environmental externalities of power generation are split into four categories: air pollutants, greenhouse gases, water use, and land use values. The executive summary of the conference addresses the roles of the federal and state governments in forcing the utilities to internalize. It is concluded that requirements to internalize costs have not increased investment in alternative energy and this is because of the utilities' lack of experience in renewables, low natural gas prices, little increase in demand, and the difficulty of enforcing laws across state lines. The EIA study (1995) presents a state by state summary of the status, approach, and the reasons for incorporating externalities in that state. For the FWWM case study of this thesis, the status of Washington State's public utility commission's activities is of particular interest. The EIA study describes Washington State's status as "operational." This means that Washington has some policies that require the state's utilities to internalize externalities in some way.

Another important environmental consideration is the utilization of hazardous substances associated with different energy technologies. The National Renewable Energy Lab released a report in 1998 that outlines the technologies and substances used in the energy industry that are potentially hazardous: amorphous silicon, copper indium diselenide, and cadmium telluride. Also, the disposal and recycling of these substances is a critical part of a complete life cycle analysis of PV.

Herig et al. (2003) analyze the break-even turn-key costs of PV systems. Break-even turn-key cost (BTC) is the market value of the PV system after all the life-cycle incentives, energy savings, and externalities values are combined and then compared to the installation and operating costs. In other words BTC is the present value of the costs minus the present value of the benefits. The goal is for the BTC to be less than the installed price of the PV system, meaning it would have positive net benefits. Herig et al. provide a summary of the incentives available for commercial PV installments by state and they point to state policies as the reason the economic feasibility of solar has improved in the last decade in the U.S. Although not clarified in the article, their procedure is similar to that of a social benefit cost analysis.

The environmental economics literature provides some guidance on the theory and practice of BCA, and valuations methods provide a reference for estimating costs and benefits associated with changes in environmental goods and services. Voss (2001) provides a summary of the external costs for seven types of energy systems: coal, lignite, gas combined cycle, nuclear, PV, wind, and hydropower. His analysis incorporates a lifecycle assessment and includes six different impacts: health effects, crop losses, material damage, noise nuisance, acidification/ eutrophication, and global warming. The research also addresses the technological advancement, efficiency improvements, and the potential to reduce life cycle costs of PV.

It is important to consider life cycle costs of renewable energy because the environmental damages occur in points of the life cycle not having to do with use. In the area of renewable energy, many researchers turn to life-cycle analysis to evaluate the environmental impacts. Sorensen (2004) uses life-cycle analysis as his main tool to thoroughly show the social, economic, and scientific aspects of renewable technologies; his examples of life cycle analysis help form the LCA in this thesis. Owen (2004) clearly explains the process of including externalities in energy costs and concludes that if all costs are internalized many alternative energy technologies could compete with conventional energy technology.

In addition to the general literature on PV, this thesis uses feasibility studies conducted by other researchers for PV installations in a variety of countries. Some of these consider rural, off-grid installations in lesser developed countries. But two studies which examined grid-connected installations for non-profit or government organizations in advanced industrial countries are potentially useful for preparing this thesis.

Four PV feasibility studies consider installations in India, Qatar, and East Malaysia. Kolhe et al. (2002) employ a life-cycle cost analysis of various mixes of PV and diesel generators for a school in India. They conclude that a stand-alone PV system is the most viable option when the power needs for the school are minimal and that PV will become more competitive as PV prices decline. Marafia (2001) evaluates the feasibility of PV technology in a straightforward benefit cost analysis for stand alone PV stations in Qatar. The author concludes that PV will soon be economically feasible and emphasizes that PV is a clean source of energy though this was not explicitly addressed. Ajan et al. (2003) explore the possibility of installing an off-grid system that mixes PV technology with a diesel generator for a school in the state of Sarawak in East Malaysia. Their results provide a critical price for PV technology below which it would be beneficial for the school to invest in a PV system. In a fourth article, Matsuhashi et al. (2002) conducted a feasibility study for a CDM (Clean Development Mechanism) using PV systems. The goal of CDM, which is a program that is a feature of the Kyoto Protocol on Greenhouse Gases, is to transfer renewable energy technology from developed countries to developing countries and to reduce greenhouse gas emissions in a cost effective manner. Matsuhashi et al. evaluated a Japanese proposal to distribute Japanese-produced PV panels throughout China. The authors estimate the life-cycle costs of PV in terms of the environmental inputs and outputs and find that the majority of life cycle emissions occur during the production of PV panels rather than from the operation of the PV panel. The results showed that the net present value (NPV) for the installed PV system was negative using a 5% discount rate, but the

NPV becomes positive for lower discount rates. Government subsidies of one-third of the costs of the capital were included in the feasibility study.

Two feasibility studies are particularly useful for guiding this thesis. One was conducted for the YWCA in Boston by R.W. Sullivan Consulting and Skanska USA Building Inc. (2003). The study illustrates the steps taken to determine the most viable renewable energy installation for the YWCA, a non-profit entity. The installations of a PV system, winds turbines or fuel cells were all considered. The authors did an extensive site assessment and gathered product data from numerous solar cell manufacturers. They also looked into the costs of the balance of systems—the supplements needed for a PV system, including inverters and charge controllers. The study did not look into specific life-cycle costs but drew attention to the production and disposal of the PV system. The YWCA study has many similarities to the private feasibility study being conducted for the FWWM: they too assume that their project with be subsidized 100 percent and the PV system will only be a supplemental grid-connected power source. A study by the Shopshire Energy Team (1999) for the Shirehall in Shewbury, England is similar to the YWCA study. The feasibility study considered only the installation of grid-connected PV technology for the town hall. The Shopshire Energy Team addresses the economics of the PV system and environmental benefits such as a decrease in carbon dioxide emissions. Their benefit cost analysis shows that the county would receive a poor return on its investment and would need large grants to cover the capital costs so that the county's private costs would not exceed its benefits. These studies offer private BCAs of grid connected systems in settings that have some features that are similar to the FWWM, so they are potentially useful in constructing the private BCA in this study. The social BCA of this thesis will supplement the private BCA by considering externalities and LCA. The author will use the environmental economic literature on this topics presented in this chapter for the social BCA.

Chapter 3: Private Benefit Cost Analysis

The Fort Walla Walla Museum's decision regarding the installation of a photovoltaic (PV) system will be based on the costs and benefits that affect them as an entity. This is what is termed a private benefit cost analysis (BCA) in this thesis. In this case, it is important to emphasize that the FWWM is a non-profit entity. Unlike traditional for-profit firms, a non-profit's goal is not to maximize profits, but typically to maximize some other objective while meeting its costs. This has implications for the private benefit cost analysis because if the project achieves the objectives of the FWWM while yielding benefits that meet or exceed costs, the project is certainly feasible. The BCA forms the basis of the feasibility study that will be used to secure grant money for the PV system.

As is typical of private BCAs, the purpose is to help the FWWM to make an investment decision. The baseline from which the benefits and costs of the proposed project is measured is the current arrangement in which the FWWM purchases all its power from the grid. The benefits and costs of the private BCA are based on the changes from the baseline that would result from the project. Ideally, private benefits and costs should be quantified and monetized. Even in this simple case study, however, this is not possible. One important part of the benefits to the FWWM is the potential improvement in its ability to fulfill its mission, which is to preserve and share the Walla Walla valley heritage. This benefit is assumed to be related to visitor attendance, but the increase in visitor attendance cannot be predicted nor can the value of this hypothetical visitor increase be monetized. The other component of the benefits is the energy cost savings the FWWM would enjoy with regard to the PV system. This component can be monetized and this study does so. The costs of the proposed project are the capital costs plus the maintenance costs. The capital costs include the equipment cost, the equipment delivery cost, and the installation cost. The cleaning and replacing of parts comprises the maintenance costs. Both the costs and benefits that occur in the future will be discounted over the life of the PV system, which has a warranty of 25 years.

Table 1 shows the costs of electricity for the museum over the last three years. The second column shows the number of kWh the museum consumed over the course of the year. The third column is the amount that they paid in the year they consumed the electricity, at the current price of electricity. The final column represents the cost in 2005 dollars based upon the average Consumer Price Index (Bureau of Labor Statistics).

Table 1: Electricity Costs, FWWM 2002-2004

Year	Electricity Purchased (kWh)	Electricity Cost in Nominal Dollars	Total Electricity Cost (2005 $)	Average Cost per kWh (in 2005 $)
2002	105,223	$6,843.97	7,471.68	$0.071
2003	111,617	$7,107.76	7,586.76	$0.068

2004	116,159	$7,433.77	7,728.92	$0.067
Average	111,000	$7,128.5	7,595.79	$0.068

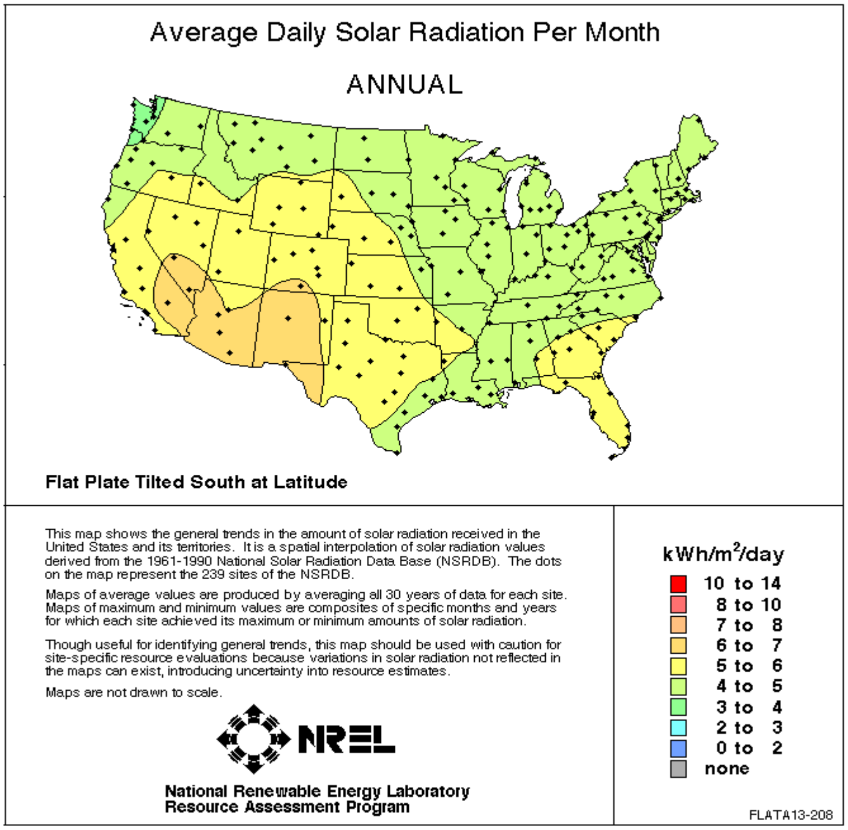
Sources: FWWM and United States Bureau of Labor Statistics
(CPI Inflation Calculator. www.bls.gov. Accessed10/3/05.)

The costs of a PV system consist of the capital costs, which includes the equipment, the delivery costs, and installation costs, and periodic maintenance costs. The equipment costs include the cost of the modules, the invertors, mounting racks, and wiring. The Table 2 shows the modules offered by three selected solar module manufacturers based on research using the Real Goods database. Real Goods is a renewable energy equipment dealer that opened in California in 1978 and has sold the equipment necessary to install thousands of kW of PV modules. Acting on their belief that knowledge is the most important product; they have conducted extensive research on solar modules and only market those with the best performance. The technology, quality, length of warranty and efficiency of the products are practically the same across PV module manufacturers. Real Goods's criterion for distinguishing which solar modules to sell is availability. Currently in the market for solar panels, production cannot meet demand and so solar modules of many manufacturers are unavailable.

Typically, the choice of solar modules depends of the installation site. The FWWM consists of four exhibit buildings that are all the same size. The building that is most suitable for solar panels is building number two because its roof is the most south facing, meaning it will receive the most sunlight. The roof area is one hundred by forty feet and the building is nineteen feet high. There is a short wall that surrounds the four sides of the roof, creating an edge on the south end of the building varies from fifteen inches to twenty-four inches. The height is important because the museum is committed to maintaining a fort-like appearance and so does not want the solar panels to be visible from the ground, so the height of the walls will be taken into consideration when determining the placement of the modules. There are hardly any obstructions on the roof. Because the roof is virtually bare, the entire roof could be covered with solar panels. The panels will be tilted at the latitude of the museum, 46.1 degrees. Tilting solar panels at the latitude of the site make the sun hit the panels as directly as possible and maximizes the potential of the modules. At this angle will be little to no obstructions (trees, foliage or other buildings) between the panels and the sun's path in the sky.

The solar modules will be the largest cost of the PV system. When deciding the exact size of the PV system, the amount of solar insolation is a key factor. Different locations around the world receive different amounts of solar insolation because of differences in the latitude, elevation and climate. Figure 1 shows the average solar insolation trends for the continental U.S. Based on Figure 1, Walla Walla receives an average of 4-5 kWh/m^2/day of solar insolation on a south-tilted surface or roughly 4.5kWh/m^2/day. Although the calculations are given in kWh/m^2/day, solar energy researchers and technicians typically express the amount of solar insolation in sun hours per day. One kWh/m^2/day is equal to one sun hour per day, so Walla Walla receives 4.5 sun hours/day (M. Morton, Personal Communication, October 18, 2005). "This chart shows solar insolation in kilowatt-hours per square meter per day in many US locations. For simplicity, we call this figure "Sun Hours / Day" (Solar 4 Power Advanced Energy Group and Real Goods, http://www.solar4power.com/solar-power-insolation-window.html, November 1, 2005)

Figure 1: Solar Radiation for the United States



This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

Source http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/serve.cgi (10/13/05)

The next step is to determine the ideal number of kWh the PV system will produce. A series of simple calculations were used to determine this number. The goal is for the museum to produce five percent of its energy needs from renewable resources. From Table 1, the museum has used an average of 111,000 kWh of power each year for the past three years. Five percent of this figure, 5,550 kWh, is the desired annual electricity production of the PV system. The PV system needs to produce 15.2 kWh/day (5,550kWh/365days). By averaging the value in Figure 1, Walla Walla receives 4.5 sun hours per day. So the size of the PV system in kW is found by dividing 15.2kWh/day by 4.5 sun hours per day which equals 3.38kW. Then this initial value needs to be adjusted for the inverter efficiency (90%), so 3.38kW divided by .9 equals 3.75kW.

This value will be used for the rest of the feasibility study and represents the desired size of the PV system.

When choosing modules for the PV system, there will be two additional variables. The first is the efficiency of the PV cells. The modules that the author is considering range from 12.5% cell efficiency to 14% cell efficiency. For example, 14% efficiency means that if the maximum amount of sunlight, 1,000W/m^2, is hitting the module, it will generate 140W of power (http://www.kyocerasolar.com/pdf/catalog/FAQ.pdf accessed 9-29-05). The second piece of valuable is the size of the solar panel. Most solar module manufacturers give the dimensions of their modules of length times width in inches. The author has converted these calculations into an area, meters-squared, so that it will be compatible with the solar radiation data.[1] Because of the varying size and cell efficiency, each kind of module will require a different number of modules in the array to generate the desired energy production.

A PV system will produce the most energy during the summer months when there is the highest number of W/m^2 or sun hours of solar radiation in a day. This peak production corresponds to when the museum is open (May through September) and when it will consume the most electrical power due to air conditioning.

Solar modules are sold in different sizes by maximum wattage. The module's maximum wattage is determined by multiplying 1,000W/m^2 (the peak, instantaneous solar radiation) by the area of the module (m^2) by the efficiency (%). The maximum wattage, efficiency, and area are different for most solar modules. Solar module manufacturers differentiate between the standard test conditions and practical test conditions. Standard test conditions (STC) are for an illumination of 1,000W/m^2. The STC wattage is for perfect test conditions and is the rating that manufacturers put on the panels. This number is misleading and PVUSA has developed practical test condition (PTC) ratings. The PTC ratings vary with each module, but generally are 17% to 20% lower than the STC (Source: http://realgoods.com/calsolar/systemproduction.html, accessed November 1, 2005). For this thesis, an average percentage of 18.5% will be used to determine the approximate PTC. The alternative value, 81.5% (100-18.5=81.5) will be referred to as the practical efficiency, not to be confused with the cell efficiency or inverter efficiency. The wattage that the manufacturer assigns to the module was multiplied by .815 to determine the practical efficiency wattage. Then this wattage is divided into 3.75kW to get the number of modules needed. The module producers provide information sheets with the specifics of each module, and an example for the Sharp 167 watt module is provided in the appendix. It shows that the optimal energy output is 167 watts when there is 1,000w/m^2 of solar energy hitting the module. Solar module manufacturers normalize the data to 25° Celsius and give the wattage output for 1,000w/m^2, 800W/m^2 and 600W/m^2.

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[1] The author first multiplied the length (in) times width (in) to get the square inches (in^2). The area in inches-squared was divided by 144 to get the area in feet-squared. Then the value in ft^2 is divided by .0929 to get meters-squared.

The author has chosen six different modules from three different companies, Sharp, Kyocera, and Shell. These three are among the most reputable solar module manufacturers. The solar modules specified in table 2 are all modules sold by Real Goods. Table 2 includes the manufacturer, the model, the type of cell in the module (single crystalline or poly crystalline), the dimensions, the wattage under standard test conditions, the wattage under practical test conditions, the cell efficiency, the inverter efficiency, the practical efficiency, the cost per module, the number of solar panels needed for the FWWM and the cost for the entire array for each of the six solar modules. Though this information is relevant as of this writing, the availability and pricing of solar modules is constantly changing because of high demand. Actually, in the past year prices of solar modules have been rising and this is expected to continue as demand continues to outrun supply (M. Morton, personal communication, October 17, 2005). For the remainder of the thesis the author considers just two solar panels as these entail the lowest total cost modules, Sharp 167 and Kyocera 80. The information sheets for these two modules are the appendix.

Table 2: Solar Modules

Manufacturer Model	Single v. Poly Crystalline	Dimensions LxW (inches)	Area in m^2	STC (W)	PTC (W)	Cell Efficiency	Inverter Efficiency	Practical Efficiency	Cost/ Module	# of modules needed	Total Cost of PV System
SHARP											
Sharp 80W	Poly	47.3x20.9	.64m^2	80	65	12.4%	90%	81.5%	$495.00	58	58 x $495 = $28,710
Sharp 123 W	Poly	59x26.1	.94m^2	123	100	12.4%	90%	81.5%	$699.00	38	38 x $699 = $26,562
Sharp 167W	Poly	51.9x39.1	1.31m^2	167	136	12.7%	90%	81.5%	849.00	28	28 x $849 = $23,772
KYOCERA											
KC80	Poly	38.4x25.7	.64m^2	80	65	14%	90%	81.5%	$439.00	58	54 x $439 = $25,462
KC120	Poly	56.1x25.7	.93m^2	120	98	14%	90%	81.5%	$685	39	39 x $685 = $26,715
SHELL											
Powermax Ultra 165-PC	Single	63.9x32.0	1.32m^2	165	134	12.5%	90%	81.5%	$940	28	28 x $940 = $26,320

Source: www.realgoods.com, www.shell.com, www. kyocerasolar.com, solar.sharpusa.com as of 10-17-05

Another major equipment component of the capital costs is called the balance of systems (BOS). As explained in Chapter 3, the BOS includes the inverter, the mounting devices, and wires. There are various companies that specialize in photovoltaic inverters, but all inverters work for all kinds of panels. Basically, the PV array produces a flow of electrons; the electrons flow though cable, the inverter reads a certain voltage and then the energy is sent either to power the museum or into the grid. Each inverter has a wattage amount which is the highest level of electricity it can convert to the grid-compatible current. Since the PV system size is 3,754 watts, a 4000 watt inverter has been chosen. This inverter is a Fronius IG 4000 and it sells for $3,925 (M. Morton, personal communication, October 18, 2005). The capital cost includes the cost of the initial inverter and the two replacements will be part of the maintenance costs. For the purposes of this study, it will be assumed that the inverter will need to be replaced every ten years. So over the life of the PV system three inverters will be required.

The next equipment component of the capital cost is the mounting equipment. The leader in mounting devices is Unirac. Both of the modules being considered are compatible with the mounting equipment from Unirac. The Unirac costs will vary with the number of panels installed. A retailer can use the number and size of the solar panels to identify exactly how many of each mounting part (rails, legs, etc.) will be needed. The same equipment, but different quantities, will be needed for the Sharp 167 and Kyocera panels. There are three different necessary Unirac products. The first is a four rail kit. The modules will be lined up in rows on either 8 or 10. For Kyocera 80, since 58 modules are needed there will be 5 rows of 10 and 1 row of 8 modules. For Sharp 167, there will be 28 modules in the system, 2 rows of 10 modules and 1 row of 8. The lengths of the rows vary with the size of modules and the number of modules in a row. The prices and number of rail kits needed are summarized in Table 3. Second, the installation will require top mounting clamps and hardware. The top mounting clamps vary slightly with the number of modules per row. To support the panels underneath adjustable legs will be purchases. Each adjustable leg is made for panels mounted at an angle of 26 to 60 degrees and has a maximum extension of 44 inches. They are each $43. Table 3 shows the costs of the mounting equipment for the Kyocera 80 and Sharp 167 PV systems. The difference in costs between the various modules can be attributed to the difference in the number of modules. To install more modules, even though each module might be slightly smaller, it is more expensive. One advantage of the Sharp 167 modules is that the museum will only have to install 28 of those in comparison with 58 Kyocera 80 modules, providing considerable savings on the cost of the mounting equipment. The difference in mounting cost will give the Sharp 167 modules a distinct cost advantage.

Table 3: Mounting Equipment Prices

	Kyocera 80			Sharp 167		
	Quantity (size)	Cost	Total	Quantity (size)	Cost	Total

Rail Kit	5 (256 in.) 1 (216 in.)	$389 $319	$2,264	2 (408 in.) 1 (324 in.)	$569 $469	$1,607
Top Mounting Clamps	5 1	$47 $40	$275	2 1	$47 $40	$134
Adjustable Legs	29	$43	$1,247	20	$43	$860
Total ($)			$3,786			$2,601

Source: www.unirac.com 10-28-05

In terms of cost, the PV modules, the inverter, and mounting devices make up the largest percentage. There are four other pieces of equipment that are needed to complete the system. The first is high voltage DC disconnect, which will cut the PV system off from the grid if for some reason there is a surge of high voltage electricity. This component will cost $165. Also, a lightning protection rod is recommended. A 650 volt lightning arrestor costs $40. The museum will also order a specific replacement fuse which will cost $5. The final piece of equipment will be a label which warns people of the danger of electric shock, and this will cost $2.20 (M. Morton, personal communication, October 26, 2005). The sum of these miscellaneous costs is $212.20.

To determine the transportation costs to ship the equipment it is assumed that the museum will buy its modules from Real Goods. The shipping costs equal 8% of the subtotal. For Table 6 the subtotal of the capital costs are multiplied by .08 to get the shipping costs. This is the approximate amount that the museum would have to pay for shipping costs if they purchased the panels, inverters, other components of the BOS, and mounting from Real Goods. Eight percent of this total is $2,382.98 and this value will be used as the equipment delivery cost for the remainder of the case study.

Another component of the capital cost will be the installation costs. The Treasurer of Whitman College, Peter Harvey, reports that Whitman paid $2,356 for the installation of the solar panels for the roof of the environmentally minded interest house, the Outhouse, in October of 2002. In 2005 dollars, the installation costs equal $2,603.52. Walla Walla Electric performed the installation. Mike Morton, a technician for Real Goods, said that one should expect to pay an installation fee equal to 25% of the initial capital cost. For a PV system with an equipment cost of approximately $30,000, this percentage would make the installation costs $7,500. Mike Nelson, founder of the Northwest Solar Center in Seattle, Washington, has years of experience installing solar panels and he has volunteered to help with the installation because FWWM is a non-profit organization. However, it is useful to estimate the installation cost for the typical case. Mike Nelson informed the author that the typical charge for the installation of a 3.75kW PV system would typically be $1-$2 per watt regardless of the type of solar panels chosen. If the PV system is 3,750W the cost of installation will be somewhere between $3,750 and $7,500 (M.

Nelson, personal communication, October 5, 2005), the midpoint estimate of $5,625 will be used.

Once the equipment for the PV system has been purchased, shipped, and installed, the museum will be responsible for periodic maintenance costs. Maintenance costs are very low for PV and this is why solar is such an attractive alternative. There are no moving parts so there is little to maintain and only two tasks are required. First the PV array should be hosed off twice a year, avoiding the hottest part of the day.[2] This is assumed to entail no additional cost for the museum. The second part of maintenance would be replacing any parts that become worn out over the life of the solar panels. The warranty for the solar panels is twenty-five years, which is a conservative estimate. The inverters typically need to be replaced every ten years, complete with installation and equipment costs, at ten and twenty years after the initial installation. The installation cost is assumed to be 25% of the equipment cost (M. Morton, personal communication, October 18, 2005). So the museum will pay $4906.25 (3925 x 1.25) for the new inverter in year 10 and year 20.

Now the benefits of PV will be considered. These will include a reduction in energy costs over the twenty-five year life of the modules, the reward from Washington State's legislation to promote renewable energy, and the increase in the FWWM's delivery of educational services to its visitors.

The most significant benefit of the proposed project is a reduction in FWWM's energy bills. The PV system is expected to produce 5,550 kWh of electricity annually, five percent of the museum's total electricity consumption. At the retail price of $.068/kWh the museum will save $374 every year in real terms (2005 dollars). The rate of electricity price increases is assumed to match the general rate of inflation for simplicity. It must be emphasized that these savings might be underestimated if the expected future electricity prices increase at a higher rate than inflation.

An additional benefit is the incentives introduced by recent Washington State Senate bill SB 5101 that requires utilities to pay $.15 to private producers for every kWh the PV system produces, no matter if it is consumed at the site or not, up to a yearly maximum of $2000 (Broehl, 2005). Broehl writes that this law was initially written to provide a form of subsidy for small renewable energy systems of up to 3.5kW. The meter keeps track of all of the production of the PV system and the museum would be paid $.15/kWh for that electricity. So the additional benefit is .15 times 5550kWh which equals $832.50 for the years of this subsidy. The availability of the benefit began on July 1, 2005 and will end June 30, 2014 (Broehl, 2005).

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[2] The museum has a salaried maintenance person, so assuming that he has enough knowledge to maintain the system there might not be any additional costs associated with hosing off the panels. The value of the maintenance costs is the opportunity cost of approximately two afternoons, one day, of maintenance every year. If the additional work can be absorbed with out replacing other activities, which the author is assuming it will be, the opportunity cost is zero.

Even if the legislation is reauthorized in 2014, it likely will only apply to new PV installations. So assuming that the PV system would be started in June 30, 2006, these benefits would persist for the first eight years of the project.

The museum has an additional benefit that cannot be quantified or monetized in this study, though is extremely important to the FWWM and its mission. There are two components of this benefit. First is the museum's benefit from providing increased educational services, from the new renewable energy component, to existing visitors. As mentioned in the introduction of this thesis, the museum desires to connect the past with the future by education about regional heritage. The PV system will represent the future and the two windmills, used to pump water, will represent the past in a display explaining both methods of producing energy. Second, the museum will benefit from the expected increase in visitors who are interested in learning about solar energy. For this study, this benefit is noted but not quantified or monetized.

The private costs of the project presented in this chapter are the capital costs, which include the PV array, the BOS, transportation, and installation, and the maintenance costs. The private benefits consist of the reduction in energy bills, the subsidy from the renewable energy incentive bill, and the unquantifiable education benefit. These costs and benefits, along with the discounted values, are presented in Table 6. The results of the private BCA will be given in the form of net benefits—the total private benefits minus the total private costs.

Another important parameter for the BCA is the discount rate at which future benefits and costs are converted to present values. There is a good deal of controversy about the appropriate discount rate in BCA. For this project, the author will consider three different discount rates: 3%, 5%, and 7% and undertake a simple sensitivity analysis (Norgaard, 1986) to see if the outcome of the BCA is robust to different discount rates.

There are three future costs or benefits that must be discounted so that their values can be compared in present value terms. First is the cost of replacing the inverter after ten and twenty years. The present value of this inverter replacement cost (equipment cost of \$3,975 plus installation cost, 25% of the equipment costs, of \$933.75) for some discount rate (r) will be: $[(3{,}975.00 + 993.75)/(1+r)^{10}]$ and $[(3{,}975.00+993.75)/(1+r)^{20}]$.

The second item to be discounted is the energy saving benefits. This amount must be discounted over the life of the PV system, 25 years. The three different discount rates (3%, 5% and 7%) are used. The first benefit that must be discounted is the benefits received from the legislation. The museum will receive \$.15 for every kWh it produces, so 5,550kWh multiplied by \$.15 equals \$832.50. Thus, the benefit will be \$832.50 over eight years which equals \$832.50 $\sum^{7}_{t=0} [1/(1+r)^{t}]$. The specific calculations for the three different discount rates are provided in the appendix.

The benefit from the reduction in energy bills over the life of the PV system equals \$9435. This benefit can be assumed to exist over the 25 year life of the PV system. The equation was calculated in excel. The annual power produced has been calculated to be 5550kWh per year. Assuming the cost of a kWh of power is $.068, the value of the energy bills savings will be $377.40. Therefore the benefits will be $377.40 annually over 25 years which equals $\sum^{24}_{t=0} [\$377.40 /(1+r)^{t}]$. The equations and calculations are shown in the appendix.

All of the discounted figures show that a benefit or cost in the future is worth less in present day dollars. The sensitivity analysis will be used to compare the net benefits of the PV systems. Table 6 is a complete summary of the costs and benefits of the PV system for difference discount rates. The differences in the costs of a single system are attributed to the use of different discount rates.

Table 6: Summary of Benefits and Costs

	Dollar Amount ($) r = 0	Present Value ($) with r = .03	Present Value ($) with r = .05	Present Value ($) with r = .07
COSTS:				
Capital Costs:				
Array				
Option A: Sharp 167	$23,772	$23,772	$23,772	$23,772
Option B: KC 80	$25,462	$25,462	$25,462	$25,462
BOS				
Inverter	$3,975	$3,975	$3,975	$3,975
Mounting (Sharp 167)	$2,601	$2,601	$2,601	$2,601
Mounting (Kyocera 80)	$3,786	$3,786	$3,786	$3,786
Extraneous Parts	$212.20	$212.20	$212.20	$212.20
Shipping (Sharp 167)	$2,444.82	$2,444.82	$2,444.82	$2,444.82
Shipping (Kyocera 80)	$2,674.82	$2,674.82	$2,674.82	$2,674.82
Installation	$5,625	$5,625	$5,625	$5,625
Subtotal of Capital Costs for Sharp 167:	**$38,630.02**	**$38,630.02**	**$38,630.02**	**$38,630.02**
Subtotal of Capital Costs for Kyocera 80:	**$41,735.02**	**$41,735.02**	**$41,735.02**	**$41,735.02**
Operation and Maintenance:				
Spring & Fall Cleaning	No add'l cost	No add'l cost	No add'l cost	No add'l cost
Replacement of Inverter After 10 Years	$4,968.75	$3,697.21	$3,050.39	$2,525.86
Replacement of Inverter Year 20	$4,968.75	$2,751.08	$1,872.44	$1,284.02
Subtotal of O&M Costs:	**$9,937.50**	**$6,448.29**	**$4,922.83**	**$3,809.88**
BENEFITS:				

WA State Renewable Energy Incentive Program (Years 0-7)	$6,660	$6,019.21	$5,649.66	$5,319.08
Energy Bill Savings (Years 0-24)	$9,435	$6,768.87	$5,585.01	$4,705.93
Education Services	Not monetized	Not monetized	Not monetized	Not monetized
Subtotal of Benefits:	**$16,095**	**$12,788.08**	**$11,234.67**	**$10,025.01**
Present Value of Total Costs for Sharp 167:	$48,567.52	$45,078.31	$43,552.85	$42,439.90
Present Value of Total Benefits for Sharp 167:	**$16,095**	**$12,788.08**	**$11,234.67**	**$10,025.01**
Present Value of Net Benefit for Sharp 167:	**-$32,473.52**	**-$32,290.23**	**-$32,318.18**	**-$32,414.89**
Present Value of Total Costs for Kyocera 80:	$51,672.52	$48,183.31	$46,657.85	$45,544.90
Present Value of Total Benefits for Kyocera 80:	**$16,095**	**$12,788.08**	**$11,234.67**	**$10,025.01**
Present Value of Net Benefit for Kyocera 80:	**-$35,577.52**	**-$35,395.23**	**-$35,423.18**	**-$35,519.89**

For every discount rate and module, the private costs are higher than the private benefits. As shown in table 6, the costs are larger than the benefits by more than seventy-five percent for the Sharp 167 and Kyocera 80, the two lowest cost systems. The outcome is the same no matter what discount rate is used. Thus a private BCA indicates that it is not feasible for the museum to pursue a PV system. In the next chapter, the results of the private BCA will be compared to a social BCA that includes LCA.

Chapter 4: Social Benefit Cost Analysis

This chapter offers a social feasibility analysis of the FWWM's proposed PV project based on a comparison of the social costs (SC) and social benefits (SB) and differs from the private BCA of the previous chapter in which only private benefits and private costs are considered in calculating net benefits. In addition this analysis will incorporate elements of a life cycle analysis in the calculation of the social costs of PV. Hohmeyer (1992) argues that PV technology appears more favorable when subjected to a social BCA which considers the disparities between the private and SC for conventional electricity. For the social BCA of the proposed FWWM project, the author will define the baseline from which SB and SC will be calculated. One important SB of the project is the avoided coal-related environmental costs associated with the project's production of 5,550kWh of electricity by the PV system. An important social cost of the project is the environmental cost of the PV system over its life cycle. These elements of benefits and costs are factors external to private decision makers and they will be added to the private BCA to build a social BCA. The social cost of the PV system will equal the private costs plus any environmental costs. Similarly, the social benefits of the PV system will be determined by adding the avoided environmental costs to the private benefits.

A fuller description of the baseline is required for the expansion of the private BCA to a social BCA. The museum is grid-tied and consumes its power from the local utility, Pacific Power and Light. The character of the grid makes it impossible to determine the source of a given kW of power, but for the entire system of Pacific Power and Light 67.3% of the electricity that is fed into the grid is from coal, 6.4% is from natural gas, 4.7% is from hydroelectric dams, .2% comes from wind turbines, and 21.4% is from other contracts and PP&L cannot identify the fuel sources (B. Clemens, personal communication, October 14, 2005). In terms of the national energy mix, the United States Department of Energy reports that coal supplies more than half of the nation's energy (http://www.energy.gov/engine/content .do?BT_CODE=COAL: Accessed 10-28-05). For purposes of this thesis, the author will assume that all 5,550kWh of the power comes from coal. This simplifies the analysis but it tends to overstate the benefits of the project (the avoided environmental costs of power from conventional sources) because coal is the dirtiest of the conventional fuels.

One important benefit of the proposed PV system project is the electricity cost savings already accounted for in the private BCA based on the price of electricity. However, electricity prices do not reflect the environmental damage associated with production of electricity using conventional fuels, so an additional benefit in the social BCA is the avoided environmental costs of electricity from conventional fuels. The environmental impacts of coal production and consumption in electricity generation include the environmental degradation from coal extraction and transportation and the pollution that is emitted when coal is burned in electricity generating plants. Because these impacts are external to the utilities, the price of electricity is lower than the marginal social cost. A complete examination of these avoided costs associated with electricity generation from coal would require a LCA. For purposes of this thesis, however, only the major environmental costs of coal-burning to generate electricity are included. These are the costs of emissions of carbon dioxide, sulfur dioxide, and nitrogen oxides. These three chemical compounds will be a representative sample of the environmental impacts for energy technologies. Carbon dioxide (CO_2) is a greenhouse gas and the focus of efforts to stop global warming. In terms of modern coal plants, the CO_2 is released during the operation and maintenance of the coal-fired plant (Matsuhashi, 2002). The values for emissions of CO_2 can differ because of differences in the efficiency of the equipment. If the entire effect of CO_2 emissions is to be measured, a worldwide environmental assessment would be needed because of the global nature of this pollutant. Another main pollutant is sulfur dioxide (SO_2). The amounts of SO_2 emissions from a plant depend on the grade of the coal used and the plant's emission abatement technology (Owen, 2004). The third pollutant that most literature includes in the social impact analysis of energy sources is nitrogen oxide (NO_x).

Other researchers have estimated the amounts of pollution emitted per unit of electricity produced from coal, usually reported in kWh. These researchers' estimates of avoided pollution from coal generated electricity are summarized in Table 1. These figures are the source of the estimate of the avoided pollution benefits of the FWWM's PV project. The benefits will be calculated as 5,550kWh times the grams of pollutant/kWh caused by coal. This will signify the amount (in grams) of pollutant avoided annually by relying on PV for those units of power. The author has surveyed the relevant literature and collected data on the environmental impacts of various energy technologies. Although the researchers present generalizations of pollutant quantities, the amount of pollution will vary from region to region and more specifically site to site. Table 1 shows the ranges of values, in grams per kWh, for all three of these pollutants. Then a range and an average for the quantities of pollutants are given at the bottom of the table.

Table 1: Summary of Research on Environmental Damage of Coal

Author	Emissions of CO_2 in g/kWh	Emissions of SO_2 in g/kWh	Emissions of NO_x in g/kWh
Koch (2000)	790-1,182 g/kWh (avg. 986)	0.7-32.32+ g/kWh	0.7-5.27+ g/kWh
Sorensen (2004)	880 g/kWh	1.1g/kWh	2.2g/kWh
Sandia National Laboratories (2000)	372.8 gC/kWh	3.4 g/kWh	1.8g/kWh
Owen (2004)	874.5g/kWh		
Range (g/kWh)	372.8-1,182	.7-32.32	0.7-5.27
Average (g/kWh)	778.32	7.00	2.33

When monetizing pollutant costs, the measurement can either be made in terms of the damage cost or the cost of pollution abatement. The damage cost is the health and environmental damage of one unit of pollution. The calculation of damage costs will be society's loss of wellbeing because of the harm from a specific negative environmental effect (Owen, 2004). It is an accurate economic measurement because it also signifies the willingness to pay to avoid that pollution damage. The cost of pollution abatement it is reported as the cost of abating a one unit of the pollutant.

In 1995, the Energy Information Administration compiled a summary of each state's policies towards environmental energy externalities. As discussed in Chapter 4 of this thesis, the study reported each state's status as "operational", "developing", "awareness", or "none". Of the states with operating policies on electricity generation environmental externalities, six states have made estimates of monetary amounts for specific pollutants that the utilities should use when doing sensitivity analyses. These amounts are labeled environmental or externality adders for specific pollutants, defined by Owen (2004) as, "the unit externality cost added to the standard resource cost of energy to reflect the social cost of its use." These amounts should be added to the resource costs so that utilities can make production decisions with the lowest total social costs (EIA, 2004). For the ranges and averages of CO_2, SO_2, and NO_x in Table 2 the values were converted from \$/ton to \$/gram. The dollar per gram average will be used in the social BCA of the FWWM as the dollar value for the CO_2, SO_2, and NO_x emissions for both the avoided environmental costs from the emissions from coal and the environmental costs of PV technology. The most relevant values are for attainment areas because Walla Walla is an attainment area.

Table 2: Environmental Adders

State	CO_2 (1992\$)	CO_2 (2005\$)	SO_2 (1992\$)	SO_2 (2005\$)	NO_x (1992\$)	NO_x(2005\$)
Wisconsin:	\$15/ton	\$21.25/ton			\$2,700/ton	\$3825.80
California:	\$9/ton	\$12.75/ton	\$1,720/ton	\$2,437.18	\$7,467/ton	\$10,580.47

			(Attainment areas)		(Attainment Areas)	
Massachusetts:	\$24/ton	\$34.01	\$1,700/ton	\$2408.84	\$7,200/ton	\$10,202.14
Nevada:	\$24/ton	\$34.01	\$1,716/ton	\$2431.51	\$7,480/ton	\$10,598.89
New York:	\$8.6/ton	\$12.19	\$1,367/ton	\$1936.99	\$6,524/ton	\$9,244.27
Range (2005\$/ton)		\$12.19-\$34.01		\$1,936.99-\$6,356.50		\$2,833.93-\$12,922.71
Range (2005\$/gram)		$\$1.34x10^{-5}$-$\$3.75x10^{-5}$		\$.002-\$.007		\$.003-\$.014
Average (2005\$/ton)		\$22.84/gram		\$8,142.58		\$14,562.14
Average (2005\$/gram)		$\$2.52x10^{-5}$/gram		\$.009/gram		\$.016/gram

Source: Energy Information Administration. (1995). Electricity Generation and Environmental Externalities: Case Studies. Washington, D.C.

The information from Table 1, the ranges and averages of pollution from the coal generated electricity, and Table 2, the ranges and averages of the environmental adders that various states have determined for CO_2, SO_2, and NO_x, have been used to calculate the total cost of emissions for one kWh and for one year. The averages are multiplied by the respective average dollar/gram value of the environmental adders from Table 2. The value of the additional social cost for each pollutant is then multiplied by 5,550kWh to find the yearly dollar amount of the avoided environmental cost. These results are shown in Table 3. Table 4 shows the results of taking the total annual cost and discounting it over the 25 year life of the PV system, the equation that was used for this is $\sum^{24}_{t=0} [\text{Total Annual Cost}(\$)/(1+r)^{t}]$ for the three different pollutants and discount rates.

Table 3: Averages and Costs of Emissions for Coal

	CO_2	SO_2	NO_x
Average Environmental Adder (2005\$/gram)	$\$2.52x10^{-5}$	\$.009	\$.016
Average Emissions (g/kWh)	788.32	7.00	2.33
Cost of Emissions (\$/kWh)	\$.018	\$.063	\$.037
Total Annual Cost (\$ for 5550kWh)	\$98.44	\$349.65	\$206.90

Table 4: Discounted Emissions Costs for Coal

	R = 0	R = .03	R = .05	R = .07
CO_2	\$2,461.00	\$1,765.57	\$1,456.78	\$1,227.48

SO_2	\$8,741.25	\$6,271.16	\$5,174.35	\$4,359.90
NO_x	\$5,172.50	\$3,710.86	\$3,061.84	\$2,579.91
Total	\$16,374.75	\$11,747.59	\$9,692.97	\$8,167.29

For the social BCA the private benefit from the Washington State incentive will not be included. This is because it is a subsidy and from the view of society, subsidies distort markets and prevent the correct price from prevailing. If it was possible to determine the monetary amounts for the subsidies in the market for coal, those would also be removed at this point. But since it is not possible to determine the values of subsidies in the conventional energy markets, specifically coal, and it is possible to subtract out the PV subsidies, the social benefits of PV might be underestimated.

Next the new social costs of the FWWM's PV system that are not part of its private costs will be considered. PV systems emit no pollution materials during use but environmental damages can occur in the production and disposal stages. Life cycle analysis is used to capture these environmental costs that are not accounted for in the private BCA. The end result will be the social cost of PV including the environmental cost.

A first step is to consider the raw materials needed to produce a PV module. These modules are silicon, although for simplicity the full social costs of producing these materials are assumed to be imbedded in the cost of PV modules and this accounted for the cost of the modules in the private BCA. The main component for PV modules is silicon, one of the most abundant elements in the world. Besides silicon, large amounts of iron, copper, and bauxite are used and the specific amounts, given in grams per kWh of electricity, are shown in Table 5.

Table 5: Life Cycle Raw Material Requirements

Material	PV
Iron [g/kWh]	5.35-7.30
Copper [g/kWh]	.24-.33
Bauxite [g/kWh]	2.04-2.75

Source: Voss, 2001

During the production of PV modules, CO_2, SO_2, and NO_x pollution are emitted. Most of this pollution is released during the manufacture of solar modules because the PV plant uses fossil fuels for power. Table 6 below is a summary of other researchers' quantified estimates of the pollution emitted from production of PV modules. The author has standardized the units of the pollution to grams emitted per kWh of electricity. This would be the number of kWh produced after taking into account all of the inefficiencies.

Environmental costs at the disposal stage will depend on the existence of markets for recycled solar panels and component parts. The best option is to recycle of PV modules. The industry as a whole is very forward thinking and has made great strides in inventing recycling technology (Fthenakis, 2000). Complications surrounding the recycling of solar modules result from environmental regulations—if any of the component materials are hazardous, disposal becomes more complicated and more expensive. But if there are ways to recycle solar panels the disposal of the solar modules is not an issue and the technology will not contribute hazardous waste to landfills. In terms of the costs to society, Fthenakis (2000) estimates the total cost of collecting and recycling to be within the range of \$0.08-0.11/W or \$80-110/kW and these costs should decline as the technology advances. Assuming these costs, the author has calculated the cost of disposing the proposed PV system at the end of its life, which has been assumed to be 25 years. The cost of collecting and recycling on average is \$95/kW and the proposed PV system is 3.75kW so the total cost of recycling is \$356.25. This amount must be discounted for the using the three discount rates where t=24, the equation for this is $\$356.25/(1+r)^{24}$. The results are given in Table 10.

Similar to the summary of emissions from the production of electricity from coal, Table 6 shows the emission estimates of four different researchers. These values represent the pollutants that are emitted during the manufacturing of PV.

Table 6: Summary of Research on Pollution Emissions During the Manufacture of PV.

Author	Emissions of CO_2 in g/kWh	Emissions of SO_2 in g/kWh	Emissions of NO_x in g/kWh
Koch (2000)	13-171	0.024-0.49	0.016-0.34
Sandia National Laboratories (2000)	10.6	3.4	0.007
Owen (2004)	4.5		
Sorensen (2004)	75	0.3 g of SO_2 and NO_x/kWh	
Range (g/kWh)	4.5-171	0.024-3.4	0.007-0.34
Average (g/kWh)	45.53	1.32	.185

For this thesis, the amount of pollutant discharged from the production of a unit of electricity from coal and PV are assumed to have the same damage cost. Thus, the environmental adders that will be used to determine the social environmental cost of PV are identical to those used to determine the social benefit. The average damage cost, in 2005 dollars per gram, of CO_2, SO_2, and NO_x will be used to calculate the environmental cost of PV.

Table 7: Environmental Adders

State	CO_2 (1992\$)	CO_2 (2005\$)	SO_2 (1992\$)	SO_2 (2005\$)	NO_x (1992\$)	NO_x(2005\$)
Wisconsin:	\$15/ton	\$21.25/ton			\$2,700/ton	\$3,825.80/ton
California:	\$9/ton	\$12.75/ton	\$1,720/ton	\$2,437.18/ton	\$7,467/ton	\$10,580.47/ton

			(Attainment areas)		(Attainment Areas)	
Massachusetts:	$24/ton	$34.01/ton	$1,700/ton	$2,408.84/ton	$7,200/ton	$10,202.14/ton
Nevada:	$24/ton	$34.01/ton	$1,716/ton	$2,431.51/ton	$7,480/ton	$10,598.89/ton
New York:	$8.6/ton	$12.19/ton	$1,367/ton	$1,936.99/ton	$6,524/ton	$9,244.27/ton
Range (2005$/ton)		$12.19- $34.01		$1,936.99- $6,356.50		$2,833.93- $12,922.71
Range (2005$/gram)		$\$1.34\text{x}10^{-5}$- $\$3.75\text{x}10^{-5}$		$.002-$.007		$.003-$.014
Average (2005$/ton)		$22.84		$8,142.58		$14,562.14
Average (2005$/gram)		$\$2.52\text{x}10^{-5}$		$.009		$.016

Source: Energy Information Administration. (1995). Electricity Generation and Environmental Externalities: Case Studies. Washington, D.C.

In Table 8, the dollar values for the environmental adders are multiplied by the average emissions. This is labeled the cost of emissions. This is then multiplied by 5,550kWh to find the Total Annual Cost of emissions. These annual emissions costs were then discounted over the 25 year life of the PV system, using the equation $\sum^{24}_{t=0} [\text{Total Annual Cost}(\$)/(1+r)^{t}]$ for CO_2, SO_2, and NO_x for the three different discount rates. The life cycle discounted values are shown in Table 9.

Table 8: Averages and Costs of Emissions for PV

	CO_2	SO_2	NO_x
Average Environmental Adder (2005$/gram)	$\$2.52\text{x}10^{-5}$/gram	$.009/gram	$.016/gram
Average Emissions (g/kWh)	45.52 g/kWh	1.32g/kWh	1.85g/kWh
Cost of Emissions ($/kWh)	$.001	$.012	$.030
Total Annual Cost ($ for 5,550kWh)	$5.55	$66.60	$166.50

Table 9: Discounted Emissions Costs for Coal

	R = 0	R = .03	R = .05	R = .07
CO_2	$138.75	$99.54	$82.13	$69.20
SO_2	$1,665	$1,194.51	$985.59	$830.46
NO_x	$4,162.5	$2,986.27	$2,463.97	$2,076.14
Total	$5,699.25	$4,280.32	$3,531.69	$2,975.80

The social costs that have been monetized are the cost of emissions from the making of PV modules and the social cost of recycling the modules. These social costs will be added onto the private costs because they are summed to not already be included in the price of PV modules that the museum will pay for the PV technology.

The results from the social BCA analysis are shown alongside the results from the private BCA in Table 5.

Table 10: Results from Social BCA

	Dollar Amount ($) r = 0	Present Value ($) with r = .03	Present Value ($) with r = .05	Present Value ($) with r = .07
COSTS for Sharp 167:				
PC for Sharp 167:	$48,567.52	$45,078.31	$43,552.85	$42,439.90
SC of Sharp 167:				
CO_2	$138.75	$99.54	$82.13	$69.20
SO_2	$1,665	$1,194.51	$985.59	$830.46
NO_x	$4,162.5	$2,986.27	$2,463.97	$2,076.14
Total of PV Emissions	$5,699.25	$4,280.32	$3,531.69	$2,975.80
Collecting/Recycling	$356.25	$175.25	$110.46	$70.23
Total SC for Sharp 167 (PC + SC):	**$54,623.02**	**$49,533.88**	**$47,195**	**$45,485.93**
BENEFITS for Sharp 167:				
PB for Sharp 167:	$16,095	$12,788.08	$11,234.67	$10,025.01
SB for Sharp 167:				
CO_2	$2,461.00	$1,765.57	$1,456.78	$1,227.48
SO_2	$8,741.25	$6,271.16	$5,174.35	$4,359.90
NO_x	$5,172.50	$3,710.86	$3,061.84	$2,579.91
Total of Avoided Emissions	$16,374.75	$11,747.59	$9,692.97	$8,167.29
Removal of WA State Renewable Energy Incentive Program	-$6,660	-$6,019.21	-$5,649.66	-$5,319.08
Total SB for Sharp 167 (PB + SB):	**$25,809.75**	**$18,516.46**	**$15,277.98**	**$12,873.22**
Net PB for Sharp 167:	**-$32,473.52**	**-$32,290.23**	**-$32,318.18**	**-$32,414.89**
Net SB for Sharp 167:	**-$28,813.27**	**-$31,017.42**	**-$31,917.02**	**-$32,612.71**
COSTS for Kyocera 80:				
PC for Kyocera 80:	$51,672.52	$48,183.31	$46,657.85	$45,544.90
SC of Kyocera 80:				
CO_2	$138.75	$99.54	$82.13	$69.20
SO_2	$1,665	$1,194.51	$985.59	$830.46

NO_x	$4,162.5	$2,986.27	$2,463.97	$2,076.14
Total of PV Emissions	$5,699.25	$4,280.32	$3,531.69	$2,975.80
Collecting/Recycling	$356.25	$175.25	$110.46	$70.23
Total SC for Kyocera 80 (PC + SC):	**$57,728.02**	**$52,638.88**	**$50,300**	**$48,590.93**
BENEFITS for Kyocera 80:				
PB for Kyocera 80:	$16,095	$12,788.08	$11,234.67	$10,025.01
SB for Kyocera 80:				
CO_2	$2,461.00	$1,765.57	$1,456.78	$1,227.48
SO_2	$8,741.25	$6,271.16	$5,174.35	$4,359.90
NO_x	$5,172.50	$3,710.86	$3,061.84	$2,579.91
Total of Avoided Emissions	$16,374.75	$11,747.59	$9,692.97	$8,167.29
Removal of WA State Renewable Energy Incentive Program	-$6,660	-$6,019.21	-$5,649.66	-$5,319.08
Total SB for Kyocera 80 (PB + SB):	**$25,809.75**	**$18,516.46**	**$15,277.98**	**$12,873.22**
Net PB for Kyocera 80:	**-$35,577.52**	**-$35,395.23**	**-$35,423.18**	**-$35,519.89**
Net SB for Kyocera 80 (SB – SC):	**-$31,918.27**	**-$34,122.42**	**-$35,022.02**	**-$35,717.71**

The social BCA shows that PV is more favorable than it was in the private BCA. But the measurements for the social benefits from avoided costs of using conventional fuels were not enough to outweigh the costs of the PV system. For the Sharp 167 modules, the net SB are -$31,017.42 and the net PB are -$32,290.23 using a discount rate equal to .03. The difference of $1,272.81 represents the added benefit of considering social costs that are above the private costs. For the Kyocera 80 modules, the net SB and net PB are -$34,122.42 and -$35,395.23, respectively. The difference between the net SB and net PB is also $1,272.81, which makes since because the social costs and benefits for the two modules are the same. The disparity between NSB and NPB is attributable to the environmental costs of coal generated electricity production that are considered as the social benefits of the PV system. This suggests a good rationale for PV subsidies. This is good rationale for the PV subsidies. As discussed in Chapter 5, the Washington State renewable energy incentive program acts as a subsidy for PV. This subsidy can be seen in two ways. First, it can be seen as a source of market distortion which is why is it removed in the calculation of social benefits. PV system buyers view the price of a PV system as the market price, so the subsidy, consequently, makes the prices for PV artificially low. Alternately, the PV subsidy can be seen as acting to offset a portion of the external environmental costs in the market for electricity generated from conventional fuels, primarily coal. It is difficult to know the percentage of the total subsidy for coal would theoretically be offset by this PV subsidy. In other words, the PV subsidy could be seen as "leveling the playing field."

This chapter discussed the social benefits and social costs that arise from a PV system. Table 10 summarizes the results and shows that the net social benefits, like the net private benefits, are negative signifying that even when the environmental and other social costs are taken into account the PV system is not feasible, meaning the museum is advised against investing in the PV system. The next chapter summarizes the results from this thesis, discusses the outcome, and offers extensions that could be explored in further studies.

Chapter 5: Conclusion

The private BCA summarized the private benefits and private costs that are involved with installing two different types of modules, the Sharp 167 and Kyocera 80. The net benefits were negative for both modules, at every discount rate. The social BCA looked at the environmental costs and benefits of PV, the costs being the pollution from production of PV modules and the recycling costs and the benefits being the avoided cost of PV. Although including the social costs improved the net benefits of the proposed project, except for when $r = .07$, it did not make a large difference. According to the results of this feasibility study, the FWWM should not invest in a PV system. The total costs outweigh the total benefits in both the private BCA and the social BCA for every discount rate.

It is the government's responsibility to limit subsidies and to insure that energy prices fully reflect the environmental costs. This will help insure that energy distribution decisions in the long term make sense. When society begins to get the prices right PV will become a more feasible option. Right now private decision makers rarely incorporate the externalities or environmental costs caused by their consumption into account when choosing their actions. This occurs because of a lack of information about the amount of pollution caused by different types of power generation. Sun is a very uniform source of power when compared to wind and fossil fuels. Because PV systems are dependent on solar insolation, solar power will become feasible in the sunniest parts of the earth first (Oliver, 2000). It must be emphasized that the increase in demand is already happening to some degree. At this time the increase in demand is causing a worldwide shortage driving the price of PV modules up. Over time, firms will enter the market causing supply to increase and prices to fall.

There are many extensions that would enhance this thesis. One would be to monetize the expected increase in attendance due to the installation of the solar panels. The increased revenue from the increased attendance is a monetary benefit that could be determined using the travel-cost method or contingent valuation method. Another extension would be to obtain figures on the subsidies in the markets for conventional energy and then these could be added as social benefits of switching to PV. Also, the social BCA would be enhanced if a complete LCA of coal was conducted and a more extensive LCA of PV. Fourthly, forecasting future electricity prices would be an additional area of study. If the researcher was able to predict increases in conventional energy prices over the next few years that were rising at a rate faster than inflation and the cost increases were significant, the private BCA might have produced different results.

Chapter 6: Appendix I

Table 1: Discounted Inverter Capital and Installation Costs

Cost of Inverter	Present Value
$\$3975/(1+.03)^{10} =$	\$2957.77
$\$3975/(1+.05)^{10} =$	\$2440.31
$\$3975/(1+.07)^{10} =$	\$2020.69
Cost of Installation	Present Value
$\$993.75/(1+.03)^{10} =$	\$739.44
$\$993.75/(1+.05)^{10} =$	\$610.08
$\$993.75/(1+.07)^{10} =$	\$505.17
Cost of Inverter	Present Value
$\$3975/(1+.03)^{20} =$	\$2200.86
$\$3975/(1+.05)^{20} =$	\$1498.14
$\$3975/(1+.07)^{20} =$	\$1027.22
Cost of Installation	Present Value
$\$993.75/(1+.03)^{20} =$	\$550.22
$\$993.75/(1+.05)^{20} =$	\$374.53
$\$993.75/(1+.07)^{20} =$	\$256.80

Table 2: Summary of Discounted Revenues from WA State Legislation

Year	Present Value ($) with r=.03	Present Value ($) with r=.05	Present Value ($) with r=.07
0.00	832.50	832.50	832.50
1.00	808.25	792.86	778.04
2.00	784.71	755.10	727.14
3.00	761.86	719.14	679.57
4.00	739.67	684.90	635.11
5.00	718.12	652.29	593.56
6.00	697.21	621.22	554.73
7.00	676.90	591.64	518.44
Total:	6019.21	5649.66	5319.08

Table 3: Discounted Energy Bill Savings

	0.03	0.05	0.07
0.00	377.40	377.40	377.40
1.00	366.41	359.43	352.71
2.00	355.74	342.31	329.64
3.00	345.37	326.01	308.07
4.00	335.32	310.49	287.92
5.00	325.55	295.70	269.08
6.00	316.07	281.62	251.48
7.00	306.86	268.21	235.03
8.00	297.92	255.44	219.65
9.00	289.25	243.28	205.28
10.00	280.82	231.69	191.85
11.00	272.64	220.66	179.30
12.00	264.70	210.15	167.57
13.00	256.99	200.14	156.61
14.00	249.51	190.61	146.36
15.00	242.24	181.54	136.79
16.00	235.18	172.89	127.84
17.00	228.33	164.66	119.48
18.00	221.68	156.82	111.66
19.00	215.23	149.35	104.35
20.00	208.96	142.24	97.53
21.00	202.87	135.46	91.15
22.00	196.96	129.01	85.18
23.00	191.23	122.87	79.61
24.00	185.66	117.02	74.40
	6768.87	5585.01	4705.93

Table 4: Summary of the Discounted Energy Bill Savings.

Present value when r = 0	Present value when r = 0.03	Present value when r = 0.05	Present value when r = 0.07
9435.00	6768.87	5585.01	4705.93

Table 5: Discounted Social Cost of Collecting/Recycling PV Modules

	0.03	0.05	0.07
0.00	166.50	166.50	166.50
1.00	161.65	158.57	155.61
2.00	156.94	151.02	145.43
3.00	152.37	143.83	135.91
4.00	147.93	136.98	127.02
5.00	143.62	130.46	118.71
6.00	139.44	124.24	110.95
7.00	135.38	118.33	103.69
8.00	131.44	112.69	96.90
9.00	127.61	107.33	90.56
10.00	123.89	102.22	84.64
11.00	120.28	97.35	79.10
12.00	116.78	92.71	73.93
13.00	113.38	88.30	69.09
14.00	110.08	84.09	64.57
15.00	106.87	80.09	60.35
16.00	103.76	76.28	56.40
17.00	100.74	72.64	52.71
18.00	97.80	69.18	49.26
19.00	94.95	65.89	46.04
20.00	92.19	62.75	43.03
21.00	89.50	59.76	40.21
22.00	86.90	56.92	37.58
23.00	84.36	54.21	35.12
24.00	81.91	51.63	32.82
	2986.27	2463.97	2076.14

Chapter 7: Appendix II

Photovoltaic Technology

Among renewable technologies, photovoltaic technology is consistently named as having the most potential to meet the energy needs of the future. There are multiple economic and environmental reasons why PV is a good alternative. The advantages of PV are that it has no moving parts, pollution, or noise. The disadvantages of PV are that it is expensive, requires a lot of space, and is not energy very efficient. This thesis explores the possibility of installing a grid-connected photovoltaic system for the Fort Walla Walla Museum. In a grid-connected system the solar power will first be used by the museum, but if there is any surplus power it will go directly into the grid and cause the power meter at the museum to actually run backwards. If at any point the solar panels are creating less power than the museum requires, it will receive the remaining energy from the local utility. In a sense, grid-connected systems use the grid as a huge battery. This removes the need for batteries because the utility is required by state law to allow net metering, meaning that electricity customers such as the museum can sell excess power back to the utility. Under the net metering scheme, the museum would only pay for the number of net units used. Photovoltaics, abbreviated PV, is "the direct conversion of sunlight into electricity (Zweibel, 1990, p. 1)."

A PV solar cell is a layered device that performs this conversion. Multiple cells make up one solar panel. Then several solar panels can be put together to form a module; modules can be placed next to one another to make a solar array. This is illustrated in figure 1.

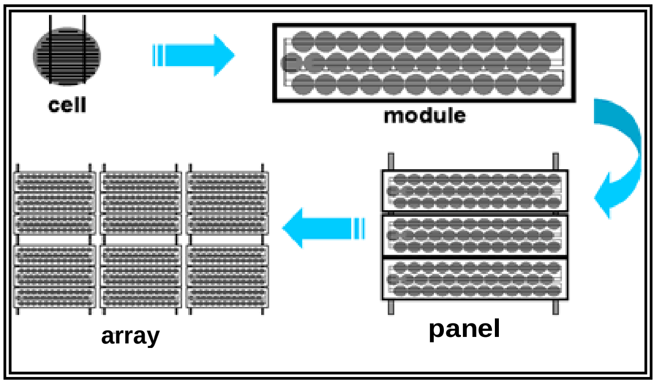

Figure 1: A Solar Array (http://www.fsec.ucf.edu/pvt/pvbasics/: Accessed 10/1/05)

There are two main varieties of PV solar panels: single crystalline and polycrystalline. Single crystalline panels are made of an unbroken crystalline structure with very few imperfections or flaws. Polycrystalline cells are made of tiny bits of single crystalline silicon. In general, polycrystalline cells are cheaper to produce than single crystalline cells. Both have efficiencies of 10-12%. This means that 10-12% of the energy that hits the panels in the form of solar radiation actually gets turned into energy. Also, the varieties of panels degrade at a rate of 0.25-0.5% per year (YMCA Boston). The rate of degradation indicates the reduction in efficiency resulting from wear and tear.

Each layer of a generic PV cell has a distinct function. The first layer is made of glass to protect the rest of the structure from the environmental factors such as hail, rain, or pollutants. The second layer is a transparent adhesive that holds the glass to the cell. The third layer is an anti-reflection coating that is designed to reduce the amount of reflected sunlight. The fourth layer is the front contact which is often made of aluminum or silver and it carries the electrical current away from the cell. The last layer is the back contact; this layer does not receive sunlight and completes the circuit because electricity flows vertically through the front contact to the back contact. The middle layers between the two contacts are the critical layers. They are called the n-type and p-type and this is where the sunlight is absorbed and electricity is generated. These layers are made of semi-conductor materials. A semi-conductor is a non-metallic substance whose electronic qualities lie between a conductor, which has no resistance to electric current, and an insulator, which resists the flow of electric current (Boyle, 2004). In a PV cell, the photons of light hit the atoms in the cell and the electrons loosen and move to one side. The side of the PV cell with the electrons becomes negatively charged and the other side becomes positively charged. There is a circuit that connects the two sides and an electric current begins to flow (Berinstein, 2001). The electricity formed in the cell is then sent to the inverter and after the power is changed into energy that is compatible with conventional wattage it can be used to power the building or if it is excess power, it can be sent to the grid.

The solar PV system requires more than just the cells explained above. Multiple mechanical components and electrical devices are needed to operate the system. The tools needed to operate a PV system compose what is called the balance of system (BOS). The most critical elements of the BOS are the grid-tied inverters, wire, batteries, a two way meter, and mounting devices. Inverters transform the DC (direct current) power produced by the solar panels into AC (alternating current) power that can be added to the power in the grid. The power must have a specific voltage and frequency that is synchronized with the grid. Wire will be needed to connect the different components of the PV system. For off-grid systems, batteries are needed to store excess power. They are expensive and need to be replaced fairly often. However, the museum will not need batteries because it will be connected to the grid, which will accept any excess power. A two way meter is needed for a net metering PV system. When the museum is using the same amount of power that the PV system is producing the meter will be at a stand still. If the museum is using more power than it is getting from the sun, the meter will spin forward indicating the amount of power being purchased from the utility. When the museum's panels are producing more than its need the meter spins backward specifying the units of power being sold to the utility. Finally, there are various mounting devices that can be used. Generally, metal devices are best and since the panels will be stationary the cost of the mounting devices needed for the FWWM are considerably lower than for panels that track/move with the sun.

The word photovoltaic comes from the greek word *photos* meaning light and then volt, a unit of electromotive force. So the word actually means the generation of electricity from light. In 1839 the French scientist Edmund Becquerel discovered the PV effect. But at this time scientists did not have the theoretical framework to explain the effect. Soon after, in 1873, Willoughby Smith found that the element selenium was light sensitive. Then in 1886 Charles Fritts invented the first practical solar cell and he wrote that “the supply of solar energy is both without limit and without cost” (Zweibel, 1990, p. 3). The first company to seriously research photovoltaics was Bell Laboratories in 1950. In 1954, Cal Fuller, Darryl Chapin and Gordon Pearson became famous with their success at creating a solar-powered transistor radio. During the energy crisis of the 1970s, people began to look at solar power seriously as an alternative energy source. The number of PV systems in rural areas used to electrify homes and provide the power needed for pumping water, telecommunications, and refrigeration increased dramatically. In recent decades the PV technology has rapidly progressed, the efficiency of PV cells has increased, and the cost has declined (Zwiebel, 1990). Today Japan and Germany lead the world in terms of research and investment in PV and the industry as a whole is growing very quickly (Sawin, 2004).

It is important to consider the cleanliness of the PV industry as its environmental advantages can make PV desirable from a social standpoint. The main component of PV cells is silicon, the sixth most common element in the world. Heavy metals, normally the most environmentally destructive materials, only compose two-percent of the panels. Another ingredient is saline gas, which is highly combustible.

A PV system has many attributes that may make it an attractive source of electricity on a private level and a social level. But to be certain that a PV system is the best choice, it is necessary to undertake an economic analysis, specifically a BCA (supplemented by LCA), of a decision to install a PV technology.

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Submission Guidelines:

Submission pieces should attempt to answer a central question. Although there are numerous ways to accomplish this, all submissions should arrive at some conclusion, even if it merely documents the need for further research. In general, empirical evidence and new applications of theory are preferred but, in some instances, a comprehensive survey of economic literature may be accepted.

For submissions, please comply with MLA standards and include all data used in the research. Please submit a Microsoft Word file of the document with size twelve font and 1.25 spacing as well as one-inch margins. We are looking for submissions ranging from five to fifty pages, although we will certainly welcome submissions of other lengths. Please email all submissions to Ben Keefer (keeferbp@whitman.edu).

For any questions about submitting material, please email Stacy Miller (millersl@whitman.edu).