ABSTRACT

PROMOTING ENVIRONMENTAL AND EDUCATIONAL BENEFITS OF A PHOTOVOLTAIC ARRAY INSTALLATION AT MIAMI UNIVERSITY

BY BRIAN KELLY

Renewable resources are widely underused in the United States. Solar electric, wind electric, and geothermal systems all are examples of renewable energy sources that promote sustainable, environmentally-sound energy use relying on local, clean energies. Prior to undertaking this study, Miami University did not have a renewable energy system on campus. A practicum was completed that began with the study of available renewable energy systems and the feasibility of the installation of one of those systems at Miami University. The funding, support, and training were all gained in order to complete the installation of a 1 kw solar electric system at Miami University’s Ecology Research Center. The installation was completed by the Fall of 2003. The solar electric system is now producing pollution-free electricity while also functioning as an educational tool that promotes renewable energy.
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EXECUTIVE SUMMARY

Beginning in May 2002, a one-year practicum was conducted to appraise the feasibility of installing a renewable energy system at Miami University to promote self-reliance, sustainability, and environmental responsibility. A photovoltaic array on the grounds of Miami University would serve as both a renewable energy source and an educational tool. To accomplish this installation, an understanding of conventional energy use, electricity, and photovoltaic systems was needed. Funding and support were also required.

Federal and state energy policies and incentive programs were considered for this project. Existing solar, wind, and geothermal renewable energy systems were compared and considered for installation at Miami University. Cost and benefit analyses for conventional and renewable energy sources were conducted. As justification for this project and for educational purposes, environmental, social, and political data were compiled and presented. The benefits of installing a small solar electric system (a 1kw photovoltaic array) at Miami University’s Ecology Research Center were explored.

The benefits of this project were three-fold. First, I gained experience in the installation of a renewable energy system. Second, the project resulted in the installation of Miami University’s first renewable energy system. Finally, since photovoltaic units have an estimated 30-year lifespan, Miami University’s unit should provide clean energy and be an educational tool for decades to come.
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Our nation has consistently depended on conventional fuels, such as oil, coal, and nuclear energy, and has underutilized viable renewable alternatives, such as wind and solar electricity\(^1\). It seems apparent that the promotion and use of renewable energies would go a long way towards bringing the U.S. into sustainability and intelligent resource management.

While the scope of this problem is almost incalculable, crossing political, environmental, social, and economic, renewable, sustainable energies have a successful track record, are domestic in nature, and should be promoted one new system at a time\(^2\). The best way to accomplish this is to identify and address the social and political processes that have inhibited the growth and pervasiveness of energy systems derived from wind, solar, and geothermal, while directly remediating the problem through the installation of one small renewable energy system. The installation of a 1kw photovoltaic array at Miami University proved the practicality of renewable energy technology. This system will generate clean energy and can promote environmental education for Miami University.

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CHAPTER 2

PROBLEM DEFINITION

It seems as though the numerous strengths of the U.S. and its gross consumption of nonrenewable resources are intertwined. With few exceptions, our nation’s infrastructure, including construction, energy supply, industry, agriculture, and transportation, is rooted in the use of fossil and nuclear fuels. From tools, computers, and vehicles to rooms, tables, and chairs, the manufactured items that fill our world have been either partially or largely created through the use of conventional fuels.

Does this mean that our nation must continue on an unsustainable path in order to maintain our economic status, level of development, and position in the world? No, this is actually impossible, due to the limited nature and polluting qualities of our current resources of choice. To accept that Americans must continue the overconsumption of fossil and nuclear fuels is fatalistic. That is the heart of my practicum. Our national infrastructure should be based on sustainable, renewable resources and systems, and one way to accomplish this is through renewable energy installations and education.

Conventional fuels include fossil fuels such as coal, crude oil, natural gas, oil shale, nuclear energy, and hydropower. A strong argument against nuclear energy as a renewable, sustainable fuel is based on our inability to remediate or safely store the radioactive waste by-products. Hydropower has its benefits and is renewable, but it introduces a host of ecological problems. It is commonly known that hydro-electric dams restrict waterflow, flood upstream areas, and often disrupt the spawning or migratory activities of certain marine species. Dams also disrupt the flow of sediments and can increase cultural eutrophication upstream of the structure. Another problem relating to hydropower is the limited number of available sites for traditional hydropower plants in the U.S.

Approximately 80% of our nation’s electricity is generated from nuclear and fossil fuels, with hydropower accounting for about 9% of energy production. Oil as a solution to our nation’s energy needs is ludicrous. The continental U.S. peaked in terms

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3 [http://solcomhouse](http://solcomhouse) 2003
of domestic oil production in 1970, and conquering oil-harboring nations everywhere does not sound like a reasonable, ethical national policy.  

Clear environmental problems exist with the continued use of fossil and nuclear fuels. All fossil fuels release pollutants that have been stored underground for millions or years, such as carbon dioxide into our atmosphere. Coal, the most abundant form of fossil fuel in the U.S. and worldwide, is clearly not exempt from this environmental blight. “Clean coal” technologies are costly and still do not filter all pollutants. Most important, coal has to be mined, and any mining operations degrade the landscape. Land reclamation still leaves behind a largely changed landscape. The costly nature of improved practices also limit their application in developing nations such as China, where coal consumption is burgeoning and much coal is burned directly by residents. There are currently about 5000 abandoned coal mines polluting 2500 miles of streams in Pennsylvania alone.  

Oil consumption is an ongoing environmental catastrophe without including countless major terrestrial and marine spills and intentional acts of sabotage as occurred following the first Persian Gulf War. Air pollution, water pollution, land degradation, oil transportation costs, refining operations, distribution, and drilling operations all contribute as environmental stressors. Factoring just a few of the external costs such as air pollution, military escorts, or various forms of land pollution into the actual costs for gas at the pump would undoubtedly make renewable sources of energy more economically competitive in the short-term.  

U.S. energy policy has historically been nebulous, shortsighted, and foolhardy. Federal renewable energy investment in research and development has decreased since 1980 while tax incentives and R&D investment is back on the rise for fossil fuels. As a current indicator of such foolish policy-making, the U.S. House of Representatives passed a bill in 2003 that permits drilling in the Arctic National Wildlife Refuge while at the same time shot down a budget request to increase fuel efficiency for autos and SUVs.

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4 [http://solcomhouse](http://solcomhouse) 2003  
5 Seth Borenstein Seth, Knight Ridder *Bush Counts on Industry’s Clean Coal Technology*. April 18, 2001  
7 Mortimer, C.M., Coal Mine Reclamation Moving too Slowly, Group Says. Tribune Review. April 9, 2002  
by a mere 5%\textsuperscript{9}. The bill, if passed by the U.S. Senate, would have granted oil and gas companies about two-thirds of the requested $17.6 billion in tax breaks. Alternative energy and energy efficiency programs would have received the other one-third.

Our nation needs to rely chiefly on renewable energy. There are ways to go about this, but concerted, continuous support barely exists to sustain a transition to sustainable, domestic fuel use. While it would be ideal for this nation to focus much of its research and development, as well political energy and human effort, on a rapid transition to alternative sources of energy, the reality is that the transition can be promoted slowly one renewable energy system at a time. Photovoltaics provide a good example of a renewable energy that will play a major role in this transition to an infrastructure based on renewable, sustainable energies.

CHAPTER 3

METHODOLOGY

In order to complete a photovoltaic installation, I needed to receive training to fully understand the process that converts sunlight into usable electricity. The training also needed to teach me how to complete a solar site analysis, solar electric system design, and most of all, an actual installation.

Miami University has a campus full of buildings, but it was important to be selective in choosing a site for the installation. It was necessary to consider the orientation of the structure, since a south-facing roof or a shade-free site is optimal. The site had to also be easily accessible while offering some means of protection from vandalism.

Another consideration was funding for all of the system costs. A photovoltaic system installed on a single residential site can cost between 30 and 60 thousand dollars, but the cost of a system can vary greatly outside that range depending on the size of the system, the equipment used, and another funding consideration: available state and federal incentives and rebates\(^\text{10}\). It was necessary to look into all possible funding sources in order to find a program that would make this project successful.

One of the most important considerations of this problem-solving process was the determination of the size and type of solar system to install or even if a renewable energy system was affordable at all. Size is a limiting factor because these systems have space requirements, and size also affects the cost of the system. The type of system is also important since there are many ways a photovoltaic system can be integrated into the electrical system of a structure.

It was necessary to gain the support of Miami University faculty, staff, and facilities management. Butler Rural Electric also had to lend its support since it is the local utility company supplying electricity to Miami University. I also sought to make this a practicum that focused on educational programming. It was important to install a

\(^{10}\) \url{http://www.dsireusa.org/index.cfm} 2003
renewable energy system on campus grounds for the sake of generating clean energy, but actually turning the system into an educational tool was equally as important.
CHAPTER 4

RESULTS AND ANALYSIS

Once I completed my first year of coursework for Miami University’s Department of Environmental Sciences Graduate Program, I registered for a two-week solar class at Solar Energy International (SEI), a nonprofit renewable energy and sustainable design educational service\(^{11}\). The class, Photovoltaic Design and Installation, offered a good mix of in-class solar electric instruction, site visits, and in-field installation.

I completed the class in May of 2002. We learned about the system components of a photovoltaic system. The in-class instruction was complemented by visits to existing photovoltaic systems. Our class also designed and installed a complete residential system. As part of the in-class curriculum, our instructors covered the photovoltaic spectrum by going over the basics of electricity as well as the individual components of a complete photovoltaic system\(^{12}\).

![Photovoltaic system installation](SEI 2002)

The program explored all of the individual components of a photovoltaic system—inverter, controllers, wiring, mounting systems, and solar panels. The inverter is required to convert the DC electricity produced by the photovoltaic panels into AC current, which is commonly used by homes and businesses. The controllers are required

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\(^{11}\) Solar Energy International 2002

to manage the flow of electricity. It is important to include controllers in the installation when batteries are being used for electricity storage. As an example, a controller can assure that a battery is not overcharged or undercharged. This will maintain the life of the battery.

The solar modules themselves require a certain degree of study. Depending on their estimated output and their physical size, they can be arranged in arrays to accumulate amps or voltage outputs. This can also group the individual modules in arrays forming a more orderly and efficient installation. The size of the total array and the distance between the array and the inverter will therefore influence the gauge of the wiring required for the system. Wiring will need to be run between each solar module, connected together in a junction box, and then run through either PVC or metal conduit. The wires are connected to a DC disconnect box and from there go to either the inverter or the battery bank, depending on the type of system.

Solar module efficiency continues to improve. Sharp Solar in the largest worldwide manufacturer of photovoltaic modules\(^\text{13}\). The silicon cell conversion efficiency of their single crystalline 185 watt module is 17.5% while the module conversion efficiency is 14.2%\(^\text{14}\). Those numbers indicate the conversion rate of light to electricity for the module.

Other advances in the industry are encouraging. Solar electric roofing shingles offer a solar application that serves as a dual use. They solar shingles function as asphalt shingles while generating electricity. Uni-solar offers such shingles using thin-film crystals\(^\text{15}\). While the overall sunlight conversion ratio is less than that of mono or poly-crystal technology, their greater applicability is very beneficial.

The types of photovoltaic systems include standalone, grid-tie, or battery back-up\(^\text{16}\). A standalone system simply is completely self-reliant. The site produces all of its own electricity on-site and does not require any electricity from a utility. This type of system works well for remote locations where a utility connection would be extraordinarily expensive or impractical. This type of a system requires a battery bank

\(^{13}\) Sharp Solar 2003  
\(^{14}\) Sharp Solar 2003  
\(^{15}\) Uni-solar 2003  
that stores the solar electricity generated during the day for use at night. The DC electricity is stored in the battery bank and will pass through the inverter and convert to AC as the electrical loads in the house demand it.

A grid-tied system produces some of its own electricity on-site through the use of a renewable energy such as solar, but remains connected to the utility grid. This system is dually beneficial because grid-tied systems draw needed electricity from the utility at times the on-site renewable energy system doesn’t produce enough to satisfy the electricity demands for the site. Secondly, during times of peak solar output, a solar system might produce more electricity than is required by the building. During these periods, most states permit the utility connected consumer to feed excess electricity back into the utility grid though net metering\textsuperscript{17}. This is valuable because the consumer receives credit for excess electricity generated during the day, and can draw electricity from the utility grid as needed on a one-to-one basis.

System sizing is one of the most important aspects of the training. Three things are normally considered during this process. One is the electrical load calculations for an individual site. The purpose of this is to estimate how large of a solar system would be required to meet a certain percentage or all of the electrical needs of a particular site. This is most often done in one of two manners. For sizing a stand-alone system, the estimate must be based on a combination of expected uses of all electric appliances in that residence. For grid-tie systems, it is most often based on calculations in kwh’s made from the previous year’s electric bill. A federal program, PVWATTS, can be used to estimate the size of the solar electric system\textsuperscript{18}.

Federal and state incentives and rebates do exist and are well documented on the internet at the Database of State Incentives for Renewable Energy\textsuperscript{19}. Federal incentives exist, especially certain tax benefits available to businesses that install clean energy systems. New Jersey’s Clean Energy Program in conjunction with its Board of Public Utilities, offer rebates for example for solar electric systems that pay for up to 70% of the

\textsuperscript{17} http://www.dsireusa.org/index.cfm 2003
\textsuperscript{18} http://rredc.nrel.gov/solar/codes_algs/PVWATTS/ 2003
\textsuperscript{19} http://www.dsireusa.org/index.cfm 2003
total costs. That rebate applies to solar electric systems up to 10 kw in size as of November 2003\textsuperscript{20}.

Renewable energy is available in many forms. A common argument opposing renewable energy and supporting oil use pertains to reliability. Apparently, many believe oil is more reliable and tangible than the sun, wind or soil. This is easy to dispute. Oil and coal, for all intents and purposes, were created by the sun. It just happened millions of years ago, and has trapped CO\textsubscript{2} and other atmospheric elements and pollutants in subsurface sinks.

Wind, solar, geothermal, and hydro all represent readily available forms of renewable energy in the U.S. Hydro can be included as a viable renewable resource despite significant environmental concerns since its application is not limited to simply damming rivers. It has been interesting to see hydro applications and interest evolve to include tidal, wave, current micro-hydro, diversion hydro, and other renewable energy forms\textsuperscript{21}.

Use of wind power is increasing rapidly worldwide and in the U.S.\textsuperscript{22} I attended the Ohio Wind Power Conference in November 2002 in Dublin Ohio along with other Institute of Environmental Sciences students. Despite the fact that Ohio on average, according to EERE, does not have great wind potential, it was very encouraging to see approximately 300 people gather out of interest for this resource. Manufacturers, installers, educators, and interested Ohioans gathered to present successful stories of wind turbine installations in Ohio and encouraged greater study into local site analyses for wind potential.

Geothermal ground loop systems are another great renewable resource. Basically, these systems are largely hidden underground or underwater and can be designed to provide space heating, space cooling, and hot water heating year-round\textsuperscript{23}. A water/antifreeze mixture is usually pumped through these lines in order to take advantage of the constant temperature that exists just a few feet below grade, usually about 55\textdegree f.

\textsuperscript{20} \url{www.njcep.com} 2003
\textsuperscript{21} \url{http://www.eere.energy.gov/RE/hydropower.html} 2003
\textsuperscript{22} Johnston, Jeff. \textit{Blowing Green}, Chemical and Engineering News. February 24, 2003, 27-30
\textsuperscript{23} \url{http://www.eere.energy.gov/RE/geothermal.html} 2003
Depending on the time of year, the temperature of the ground or water is compressed to increase or decrease the temperature indoors.

Solar, the focus of this practicum, is available in a number of forms. Passive solar design is valuable because it takes advantage of solar through the design of the structure. Proper design can allow for natural lighting and heating when needed while decreasing the impact of solar heat during the hottest periods through the use of such things as shading.

Fuels cells also provide good potential for renewable energy use, or at least for the near future greater control over emissions. Unfortunately, it is very energy intensive to separate the hydrogen atoms for use as fuel. The use of the hydrogen itself only produces by-products of water, but the inputs can be very costly financially and environmentally. Even though our brilliant president, George Bush II, directed much federal funding towards hydrogen fuel research, the hydrogen will principally derive from hydrocarbons such as coal or oil, clearly defeating the purpose of renewable energy use.24

Active solar use is more applicable for this practicum and was made the focal point of this project, not to take away from any of the other renewable energy forms. Active solar, also referred to as photovoltaics, converts solar energy into AC electricity through a process that will be described in greater detail further into this report. I chose to focus on photovoltaic systems because of their general applicability, and because it was the first form of renewable energy I wanted to study in detail.

Site Analyses

A site analysis for placement of a wind turbine was completed at Miami University’s ERC. One benefit of this site was the existence of an unused but operational 10 meter tower located near the weather station. As the graduate student in charge of operating the weather station, I had daily access to the wind speed data accumulated at

the site. An operational 10 meter tower located less than 100 feet from the unused 10 meter tower had an anemometer located on it that had been taking in wind speed data for years.

I converted the units and realized that average wind speeds at this location were not favorable for the installation of a small wind turbine at this site. Minimum wind speed requirements were not met in consideration of existing wind turbine technology currently available.

Site analyses were conducted in order to find the best site for a photovoltaic array installation. One possible site was the location of the Institute of Environmental Sciences in Boyd Hall at Miami University. The focus of the program and location of the building on Western Campus made it a possible site being of high exposure to students and faculty. Patterson Avenue runs right along the front of the building, but the roof area of Boyd Hall was cramped and flat and the orientation was not optimal for a photovoltaic unit. The roof was not easily accessible and the panels would function largely unnoticed by people, limiting its value as an educational tool. Partial shading was likely at this site, unless a ground level site was chosen.

A second potential site was the sustainable living house located off-campus. A clean energy system would clearly be appropriate and valued by the students living as self-sufficiently as possible. The site was largely shaded by a number of trees and was not a high profile location that would likely attract much attention from Miami University staff or students. It also was not located on University property.

Another possible site for placement of the solar array was located at the ERC. The Center for Building Science Research was redesigned by Scott Johnston, a professor of architecture with Miami University and my major professor for this practicum. The redesign plans were completed and the building was renovated and added onto in the 1980’s using a passive solar design. It has a relatively large, south-facing roof with a 14º pitch. There is minimal shading at this location.
Partial shading of a monocrystalline solar array will reduce the overall efficiency of the unit dramatically\textsuperscript{25}. The following table illustrates the approximate effects of shading on a 36 cell monocrystalline module.

**Table 1. The Effects of Shading on One Solar Module.**

<table>
<thead>
<tr>
<th>% of One Cell Shaded</th>
<th>% Loss of Module Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>25%</td>
<td>25%</td>
</tr>
<tr>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>75%</td>
<td>66%</td>
</tr>
<tr>
<td>100%</td>
<td>75%</td>
</tr>
<tr>
<td>with 3 cells shaded</td>
<td>93%</td>
</tr>
</tbody>
</table>

(\textit{SEI 1998})

In some situations, partial shading at least over part of the day is unavoidable with the changing angle and azimuth of the sun and location of certain obstacles such as trees, power lines, and other structures. There are partial remedies to the problem of shading. The most common addition to a photovoltaic array appears to be a bypass diode\textsuperscript{26}. The diode is wired into each module and will isolate it from the other modules of an array.

\textsuperscript{26} Solar Energy International, Design & Installation of Photovoltaics (Carbondale, CO, 1998).
should its module become shaded. The reason for this is that modules connected to each other and wired in parallel affect the overall efficiency of an array. Basically, one shaded module will reduce the efficiency of unshaded modules it is connected with by bringing each module’s output down to the level of output of the shaded module. A bypass diode will direct current from unshaded cells around that of shaded ones.

I purchased a Solar Pathfinder, which enables the user to conduct a shading analysis for a particular site. The analysis can be done any time of year during daylight hours, and almost under any conditions\textsuperscript{27}. The Solar Pathfinder is a simple, but invaluable tool to use for locating a photovoltaic unit. There are no electronics involved with this piece of equipment. The clear globe on top of the unit reflects an image of any obstructions that will shade the solar panel and indicates the time of the year it will occur. From this data, the user can estimate the percentage of available solar radiation lost to shading on a monthly and annual basis.

The south-facing roof was relatively free from any obstructions such as trees, wires or structures that could shade the solar array. The roof is situated adjacent to exterior stairs and a deck. The deck allows for easy observation of the array.

Another photovoltaic array accessory designed to improve year-round efficiency is a solar tracker\textsuperscript{28}. A solar tracker can either have a single or dual-axis to allow the solar panel or array to follow the altitude and/or azimuth of the sun. A tracker will align the solar panel(s) with the sun throughout the day. Initially, I believed a tracker would actually consume too much electricity, diminishing the value of its purpose. However, trackers operate using a gaseous refrigerant that expands and condenses as it is heated and cooled in position with the sun. Trackers often aren’t used because they increase the cost and size of the system while adding complexity and increased maintenance issues with moving parts.

The ERC is also a good site because it is the site for our weather reporting station. As the graduate assistant in charge of managing Miami University’s weather station, I’ve been collecting and reporting weather data while school has been in session since August of 2001. While there is a great deal of weather monitoring equipment at the station, the

\textsuperscript{27} Solar Pathfinder 2002
Two Eppley pyranometer solar radiation globes will be relevant to this practicum. Two Eppley globes are on-site. One has a shadow band that blocks the direct sunlight, and a second globe measures direct and diffuse sunlight.

The latter one will be useful in making comparisons between available sunlight and the actual efficiency of the photovoltaic units. The Eppley solar radiation globe takes measurements in watts/m$^2$/hr. The Shell SM55 solar panels output is rated using the same units$^{29}$. We will be able to test for the actual electricity output for the photovoltaic system since the Eppley globe will act as a good on-site data source for actual available solar radiation.

A combination of contributors would likely be needed for the installation of the photovoltaic system at Miami University. The system components, including the solar panels, the inverter, wiring, as well as other supplies, were required for this installation. An installer also was required to put the system together, and get it up and running.

In terms of grant opportunities and additional funding and material support, the Foundation of Environmental Education had much to offer. One major component, the solar modules, would be donated by Glen Kizer and the Foundation for Environmental Education. The modules had been donated to the Foundation by a utility company. The panels are used, but in good condition. The donated solar array consisted of 20 modules that were 13” x 51” each, weighing 12 lbs with a thickness of 1.3”. The Foundation donates the 1kw photovoltaic array to Ohio schools participating in the Solar Schools program. The value of the donated array is approximately $3,000 and the modules would have to be picked up from Columbus, Ohio.

The remainder of the components for the photovoltaic system would be provided by Geoff and Michelle Greenfield, owners of Third-Sun Inc. Third-Sun Inc is a renewable energy company based out of Athens County, Ohio, that designs and installs solar and wind systems. The $3,000 cost of the equipment was paid for with a grant received from Ohio’s Department of Development’s Office of Energy Efficiency (OEE). The Institute of Environmental Sciences offered to provide up to an additional $500 for supplies for a photovoltaic project through a grant received from Cinergy.

Rob Coveney, Manager of Electrical Distribution on campus, offered to volunteer some time in order to complete the final wiring requirements for a solar electric system in order to get it operational.

The other options were all dependent on responses that I received from letters and e-mails directed at solar panel and equipment manufacturers in the industry. Other than a number of ‘good luck’ responses, the only somewhat viable option resulted from a reply

from a representative from Xantrex Inc, a manufacturer for Trace inverters. I received a reply informing me that inverters intended for use in school projects could be sold at 40% off MSRP. I did not receive any such offers from the photovoltaic manufacturing companies I had contacted.
After assessing all the factors, it was determined that the 1kw photovoltaic array could be installed at the Ecology Research Center (ERC), Miami University, Oxford, Ohio. It could be installed on the roof of the ERC’s main building, the Center for Building Science Research. This location would have a good choice for a number of reasons.

One reason was that educational programs occur on a regular basis at the ERC. The building houses a lab, a classroom for environmental education, computers, and science related equipment. Educational programming and projects are geared towards Miami University students as well as high school students via outreach programs. As students visit the ERC for various reasons, they will be exposed to this solar renewable energy system since it will be visible, accessible, and located on the roof of the main building.

The ERC’s electrical needs are constant. On a regular basis, refrigerators, freezers, computers, lights, and other electrical loads are using grid-supplied electricity. The 1 kw solar array would provide a portion of that electricity demand on a daily basis.

Boyd Hall was a location that had some potential as the site of choice for the solar array. A few things were problematic, though, in terms of its being the best location. As was previously mentioned, the roof of Boyd Hall was not of ideal orientation for a solar application and was not automatically accessible by students and staff. Also, a ground mount would have required a fence be built around it to protect it from vandals.

The sustainable living house was located off-campus in a highly shaded area. The grant requirements and agreement with the Foundation for Environmental Education required that the system be installed on university grounds in order to qualify the school as a solar school of Ohio.

Regarding funding, working with Glen Kizer and the Foundation for Environmental Education appeared to be a good idea. The combination of the grant money received from the Ohio Department of Development’s Office of Energy
Efficiency, the donated panels, and my interest in installing the system on my own made the system affordable. The additional cooperation from the electrical distribution and maintenance offices of Miami University, located in Cole Services Building, helped bring the entire project together.

Wind and geothermal applications were considered, but neither seemed to be a viable option at this point. Geothermal costs were just too high, and proper site analysis could not be performed without greater expertise. Wind power also has great potential and can be affordable, but the minimum wind speed requirements could not be met based on existing technologies.
CHAPTER 7

RECOMMENDATION

The Ohio Department of Development grant provided a substantial opportunity for funding. Working with Glen Kizer from the Foundation for Environmental Education to put together a photovoltaic installation project at the Ecology Research Center also seemed like a good option. The Funding, including the additional $500 from IES, as well as the help of a large number of people now associated with this project, made this the plan of choice. The system would be a grid-tied one that would enable the ERC to pull electricity from both the solar array and the utility company.

The solar electric system would interface with a computer using an EZMeter used to measure kwh generation. The data would then be presented in an education format that highlighted the ecological benefits of the clean energy production. The kwh production would be gauged on the physical meter as well as on the computer by measuring electron flow.

The educational programming could be enhanced by setting up other solar electric displays inside the classroom at the ERC. The DC disconnect could be located near the educational displays to include part of the actual system in the display. The educational display could include diagrams of the photovoltaic system in use as well as other pertinent information about solar electricity.
It was recommended that the system be installed at ERC after obtaining the funding support from Ohio’s Department of Development’s Office of Energy Efficiency. Coordination between staff at the ERC, campus administrators, electrical distribution and other project supporters gave the solar electric project great potential.

Solar modules were picked up from storage in a Columbus warehouse. Two classmates, Tom Arbour and Naveen Sundar, and I drove a Miami University van, funded by IES, to get the modules. The bulk of the other equipment, particularly the 1800 watt Sunnyboy inverter, the EZMeter, and the solar racks were supplied by ThirdSun and paid for with the $3,000 grant and additional funding supplied to IES from Cinergy. The solar modules were installed.

The installation of each component of the photovoltaic system was completed in August of 2003. The racks, manufactured by Uni-Rac, were installed first. The feet of the racks were screwed into the roof rafters using stainless steel lag screws. The roof rafters, spaced 24” apart from each other, had to be located using a tape measure and a hammer. Studfinders do not work particularly well on asphalt roofs. Butyl rubber was placed between the bottom of the foot and the asphalt shingles to form a better seal to protect against water leaks. Roof caulk was also applied under and around the butyl rubber and feet.
The 20 solar modules were then attached to the racks, completing the second portion of the installation. The modules were rewired and connected to each other. The modules were connected in series within groups of ten to increase the voltage. The two strings of ten modules were then connected in parallel to increase the ampacity of the system.
Another important part of the installation involved bringing all the system wires into a junction box on the roof. In addition to that, the conduit leading from the junction box needed to be brought into the attic. We decided to drill a hole through the roof under the solar array.

The conduit was routed into a junction box in the attic and brought through the ceiling of the classroom of the ERC. It was connected to a DC disconnect box. The location of the DC disconnect box served two functions. One, it was located within five feet of where the wires and conduit entered the building as required by the National
Electric Code\textsuperscript{31}. It was also a good location because it was integrated into the classroom educational programming on this project.

Once the DC disconnect box was connected, the wire was run back into the attic and through conduit that led to the northern side of the building. We brought the conduit down into a utility room that already housed the electric panel. The 1800 watt Sunny Boy inverter was placed on the wall of the utility room along with a code required AC disconnect. Both were attached to plywood backing that had been painted black.

\textsuperscript{31} National Electric Code 2002
Rob Coveney, manager of electrical distribution on campus, came out to the ERC a few weeks later to make all the final wire connections. He also attached the solar electric system, on the AC side, to a breaker in the panel. This allowed the electricity from the solar array to feed the ERC once it went through the inverter.

The educational portion of the system included data collection, interpretation, and presentation. Ryan Stander connected the EZMeter on November 10, 2003, and it began measuring electron flow on a system that had actually been producing electricity for the ERC for over one month. After the meter had been connected for three weeks, the meter indicated that the 1kw system had produced over 50kwh of electricity. The kwh reading was a good indication that the photovoltaic system was performing well. It is also important to note that this first data collection was taken during the month of November. Winter months commonly are not the most productive because there are fewer daylight hours and the altitude of the sun is decreased.

The educational component to this project also included a visual display that illustrated the basic components of the photovoltaic system. The display was located in the ERC lab near where the systems DC disconnect and EZMeter were located.

As the system continues to operate, data can be accumulated and interpreted to illustrate the electricity production and ecological benefits of a small clean energy system. This will achieve the primary purpose of the practicum, which was to install a small renewable energy system on campus that actually produced clean energy while
serving as an educational model supporting the increased use of sustainable systems in the near future.
Additional References


http://userwww.sfsu.edu/~ciotola/solar/pv.pdf -


http://www.units.muohio.edu/erc/ - homepage of Miami University’s Ecology Research Center; includes links for all facilities on-site.


The Associated Press, Solar cells less pricey, more efficient, April 14, 2003.