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2004 Fall ENGR333 Final Report on Wind Generation (Section B)

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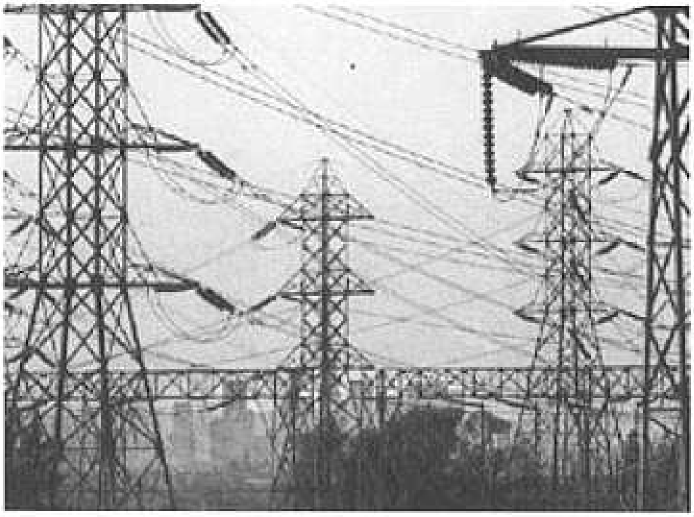
CALVIN COLLEGE ENERGY SAVINGS ANALYSIS



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DECEMBER 16, 2004

ABSTRACT

An energy savings plan for Calvin College has been developed. The plan suggests implementing a small-scale wind turbine pilot program and an energy usage awareness program (Powerful Savings). If implemented, this proposal could save around $6,400 annually with a payback period of 8 years.

Abstract

An energy savings plan for Calvin College has been developed. The plan suggests implementing a small-scale wind turbine pilot program and an energy usage awareness program (Powerful Savings). If implemented, this proposal could save around $6,400 annually with a payback period of 8 years.

INTRODUCTION

The idea of Calvin College being "off the grid" was initially very appealing. It would protect the campus from grid power failures, the electricity needed could be generated using green sources, and it gave the option of having multiple sources of power to fall back on. Also, it gives opportunity to be at the cutting-edge of technology, creating an educational benefit. However, after a detailed investigation, an energy savings plan was found to not only be more economically feasible, but also safer than any realistic plan to make Calvin College energy independent. The energy savings plan combines the use of some alternative sources and an energy usage awareness program.

ON-SITE ENERGY GENERATION OPTIONS

The technology options considered for the campus were photo-voltaic solar cells, co-generators, fuel cells, wind turbines, solar thermal, and geothermal sources. Based on thorough analyses, the strongest options were found to be co-generation, wind power, and solar power (Appendix E). However, even within these optimal sources, issues arose that affected the final decision.

Currently, Calvin College operates a **600 kW** co-generation system. After thorough analyses (See Appendix B), a surprising fact resulted. The co-generation system is not always saving Calvin College money. In fact, depending on natural gas price fluctuations, the campus may actually lose money on some days. Thus, due to the high economical risk factor, it is recommended that no other co-generation system be implemented, especially in light of the fluctuating fuel prices. A "cut-off" line has been determined also, illustrating exactly when it is economical to use a co-generation system (See Appendix B, Figure B.2).

Similar to the co-generation system, wind power generation depends on a fluctuating fuel source; wind speed. Studies seem to suggest a wind turbine could be successfully implemented for power generation in West Michigan (See Appendix C). To its advantage, a financial analysis revealed wind power as being economical. Nevertheless, a major setback of wind power is the height regulations imposed on the campus by the airport. Because of this and the uncertainty of exact wind conditions, implementing a small-scale, **250 kW** (185 ft. tall) wind turbine has been proposed. This would serve as a pilot program. The possibility of adding more small-scale wind turbines in the future would depend on the success of this test wind turbine.

Photo-voltaic solar cells are also a possible addition in the future. Presently, the up-front cost of solar cells is much too high to be economically feasible (Appendix D). In fact, the cost of solar cells is so high, that even the non-economical benefits did not make it a convincing technology to use on campus. However, it is very likely that the price of solar cells will go down as the technology develops. Campus plans for new buildings are being developed. It would be to the college's advantage to design buildings that could easily accommodate photo-voltaic solar cells when they are less costly and possibly more effective in the future. The average power generation for solar cells is approximately **1 kW/m^2**.

Powerful Savings Program

Aside from these technologies, an energy-saving program was developed (Appendix F). The total savings from this program is about **$8000** yearly.

In order to initiate a student-awareness program for Calvin College, one must effectively compare this campus' power usage to other schools—how frugal is Calvin College in terms of energy consumption compared to other colleges? Secondly, it is important to be conscious of what other schools have accomplished. These two tools shaped the awareness program for Calvin College that has been named "Powerful Savings."

A comparison number was developed to compare a school's energy consumption with its building square-footage, all floors included. Through calculations (Appendix F) it was found that Calvin College had energy consumption per unit area equal to **380 kW-h/m^2**. Compare this to Yale University, which had energy consumption per unit area of **620 kW-h/m^2**. However, Calvin College is right on par with the national average of **375 kW-h/m^2**. There is still room for improvement though, since the typical "green" building's number is approximately **250 kW-h/m^2.**

Research has shown that many other campuses nationwide are performing similar analyses. A case study of Boulder University in Colorado proves the effectiveness of such a program. With a $15,000 budget and one year of intense programming, the program changed the energy consumption trend from an increase of **5%** per year to a decrease of **1%** per year. This study encourages optimism in campus energy savings programs.

From a business perspective, a student-awareness program in which students become involved in energy savings is simply a step towards Total Quality Management (TQM). The "business," Calvin College, can benefit by increasing the quality of its "employees," the students. The techniques of TQM have proven to yield surprising and substantial overall benefits. Likewise, Powerful Savings has the potential to affect campus savings.

Conclusion

The initial proposal combines the use of a small test wind-turbine and the Powerful Savings program. Also, new buildings should be designed that can readily accommodate solar cells. It is not recommended to add any more co-generation systems, as the current one at the current fuel price is not always economical. This proposal is appealing for two reasons: It has a relatively small up-front cost, and the risk is small. As discussed in the above summary, the proposal is flexible and future implementations will be based on the future market conditions and the success of the initial system (See Figure 1, following page and in Appendix G). Finally, certain opportunities exist in which government funding, grants, and loans could be implemented (Appendix A). The current model will have a payback period of approximately **8 years**, with levelized annual savings of around **$6,400**.

Appendix Outline

A. Project Funding

B. Co-generation Analysis

C. Wind Turbine Analysis

D. PV Solar Panels Summary

E. Technology Comparison Analysis

F. Powerful Savings Program

G. Final Model

Appendix A: Project Funding

TFKA Geothermal
November 19, 2004

Off The Grid Funding

The only funding available to our project, besides grant subsidies, would be through fund raising. Henry DeVries has said of the funds that:

> "The college endowment is essentially not liquid, all of the invested funds are already earmarked to support a specific purpose. Consequently, there aren't any undesignated earnings that could be directed at [the off the grid project]. The typical pattern at Calvin to raise funds for large projects like this is through direct gifts from donors. Of course, that implies that there are one or more donors who are interested in this kind of project and have the resources to give."

Federal and State Government Funding Options

Unfortunately there are very few government funding opportunities for renewable energy projects in Michigan. The Michigan NEXTEnergy Authority has recently been developed to promote alternative energies and provide funding for the future. Currently the options for school sectors are very limited.

Typically there are only grants for developing technologies, so while there are opportunities for a grant or two for any solar, grants for wind power are unlikely because it is considered more or less fully developed.

Our team is currently waiting responses from John Trieloff of the Energy Office of Michigan who was a contact for the Bunker Center Group.

State Programs

Community Energy Project Grants

- To assist in selecting energy efficient and renewable energy options
- Max Limit of $6000
- Good chance of Calvin receiving this grant

Michigan Energy Efficiency Grants

- Grant to fund renewable energy technologies
- Awarded by Michigan's Low-Income and Energy Efficiency Fund
- Max Limit of $6 million
- Very competitive as only 1 grant awarded

Large-Scale PV Demonstration Project Grants

- Available to public and non-profit groups to help fund purchase and demonstration of new PV systems
- Max limit of $60,000
- Less likely as only 3 grants are awarded each year

Federal Programs

Alternative Energy Property and Real Tax Exemption

- Qualifying equipment can be exempt from business property taxes
- Federal government offers an accelerated 5 year (normally 20) depreciation for solar equipment
- Federal tax credit of 10% of purchased cost for solar and thermal systems

Green Tag Purchase Program

- Opportunity to see renewable energy credits
- Roughly 2 cents/kWh for PV and 0.23 cents/kWh for Wind

Appendix B: Co-Generation

Kurt Koubal
Dan Kuiper
Andy Wermel
Engr 333B

Off-Grid Project: Co-Generation

Introduction

The group was tasked with researching the possibility of using co-generation to supply the campus' electricity and heating needs in an attempt to get off the power grid. The several options considered for accomplishing this goal were: fuel cells, nuclear, internal combustion engines, and turbines.

Analysis

A rough cut analysis was performed to see which of the options merited a more in depth look. This rough cut analysis compared install cost, maintenance costs, footprints, and thermal and electrical outputs. We were able to eliminate two options almost immediately. Then we put the remaining options into a decision matrix, which the integration team used to decide how much power from each source they required. They requested 2.6 MW from a turbine and nothing from our other power options. The power source they requested was researched further in depth. The turbine provided an excessive amount of steam, which the campus could not completely use. An analysis was requested to determine the feasibility of using a micro-turbine to meet the heating needs of the new Health and Wellness Center with any electricity produced as a bonus. To do this analysis the focus was switched to see how effective the fuel usage was on a co-generation system as compared to a standard boiler system producing an equal amount of steam and purchasing electricity from the utilities (see Figure B.1 for economic model). This analysis was then extended to the internal combustion engine and to a larger scale turbine.

Conclusions

The nuclear reactor was eliminated because of obvious safety concerns, prohibitive government regulations, and high all-around costs. The fuel cell was removed from the feasible choices because of high installation and maintenance costs. This was because it is still a developing technology. It was concluded that any large cogeneration system would provide more steam than Calvin College could use even after proposed expansion. If all the steam were not used, its efficiency benefits would be wasted, making it more expensive than purchasing power directly from the grid. It was found that as long as the price of natural gas remained more than $7 per thousand cubic feet any cogeneration system will be more expensive than making steam and buying electricity at current prices of around $0.055/kW-hr. Natural gas prices have been fluctuating between $7 per thousand cubic feet and $11 per thousand cubic feet over the past three months. These prices seemed too volatile to justify the risk of the capital investment over the long term. Unless the price of power increased dramatically or the price of natural gas decreased predictably over the long term, the co-generation sources of power are not feasible (see Figures B.2, B.3, B.4).

Figure B.1

hf_{cogen} = 303.352 [BTU/ft^3] the amount of heat in the form of steam generated by 1 cubic foot of fuel in the cogenerator

hf_{boiler} = 982.3 [BTU/ft^3] the amount of heat in the form of steam generated by 1 cubic foot of fuel in the boilers

ef_{cogen} = 0.089 [kW-hr/ft^3] the number of kW-hrs produced by the cogenerator for each cubic foot of fuel

r_{fuel} = 0.05 the inflation rate of fuel

$r_{elec} = r_{fuel}$ the inflation rate of electricity

n = 30 [yr] the life of the project

i_{nom} = 0.12 the nominal rate of capital investment

$C_{fuel,today}$ = 0.008 [$/ft^3] the cost of natural gas today .0428

$C_{elec,peak}$ = 0.11 [$/kW-hr] the cost of electricity

$C_{elec,offpeak}$ = 0.03 [$/kW-hr] the cost of electricity

$\dot{Fuel}_{cogen}$ = 5778 [ft^3/hr]

OT_{peak} = 8 [hr]

$OT_{offpeak}$ = 16 [hr]

Determine the cost of each system per day.

We want to ensure that we are producing equivalent amounts of steam, so the fuel required by the cogenerator is the amount neccessarry to produce the same amount of steam as the boiler

$Fuel_{cogen,peak,i} = \dot{Fuel}_{cogen} \cdot OT_{peak}$ for $i = 1$ to 1

$Fuel_{cogen,offpeak,i} = \dot{Fuel}_{cogen} \cdot OT_{offpeak}$ for $i = 1$ to 1

$$Fuel_{boiler,peak,i} = \frac{Fuel_{cogen,peak,i}}{hf_{boiler}} \cdot hf_{cogen} \quad \text{for } i = 1 \text{ to } 1$$

$$Fuel_{boiler,offpeak,i} = \frac{Fuel_{cogen,offpeak,i}}{hf_{boiler}} \cdot hf_{cogen} \quad \text{for } i = 1 \text{ to } 1$$

$Elec_{prod,peak,i} = Fuel_{cogen,peak,i} \cdot ef_{cogen}$ for $i = 1$ to 1

$Elec_{prod,offpeak,i} = Fuel_{cogen,offpeak,i} \cdot ef_{cogen}$ for $i = 1$ to 1

$FVC_{fuel,cogen,peak,i} = C_{fuel,today} \cdot Fuel_{cogen,peak,i}$ for $i = 1$ to 1

$FVC_{fuel,cogen,offpeak,i} = C_{fuel,today} \cdot Fuel_{cogen,offpeak,i}$ for $i = 1$ to 1

$FVC_{fuel,boiler,peak,i} = C_{fuel,today} \cdot Fuel_{boiler,peak,i}$ for $i = 1$ to 1

$FVC_{fuel,boiler,offpeak,i} = C_{fuel,today} \cdot Fuel_{boiler,offpeak,i}$ for $i = 1$ to 1

$FVC_{elec,peak,i} = C_{elec,peak} \cdot Elec_{prod,peak,i}$ for $i = 1$ to 1

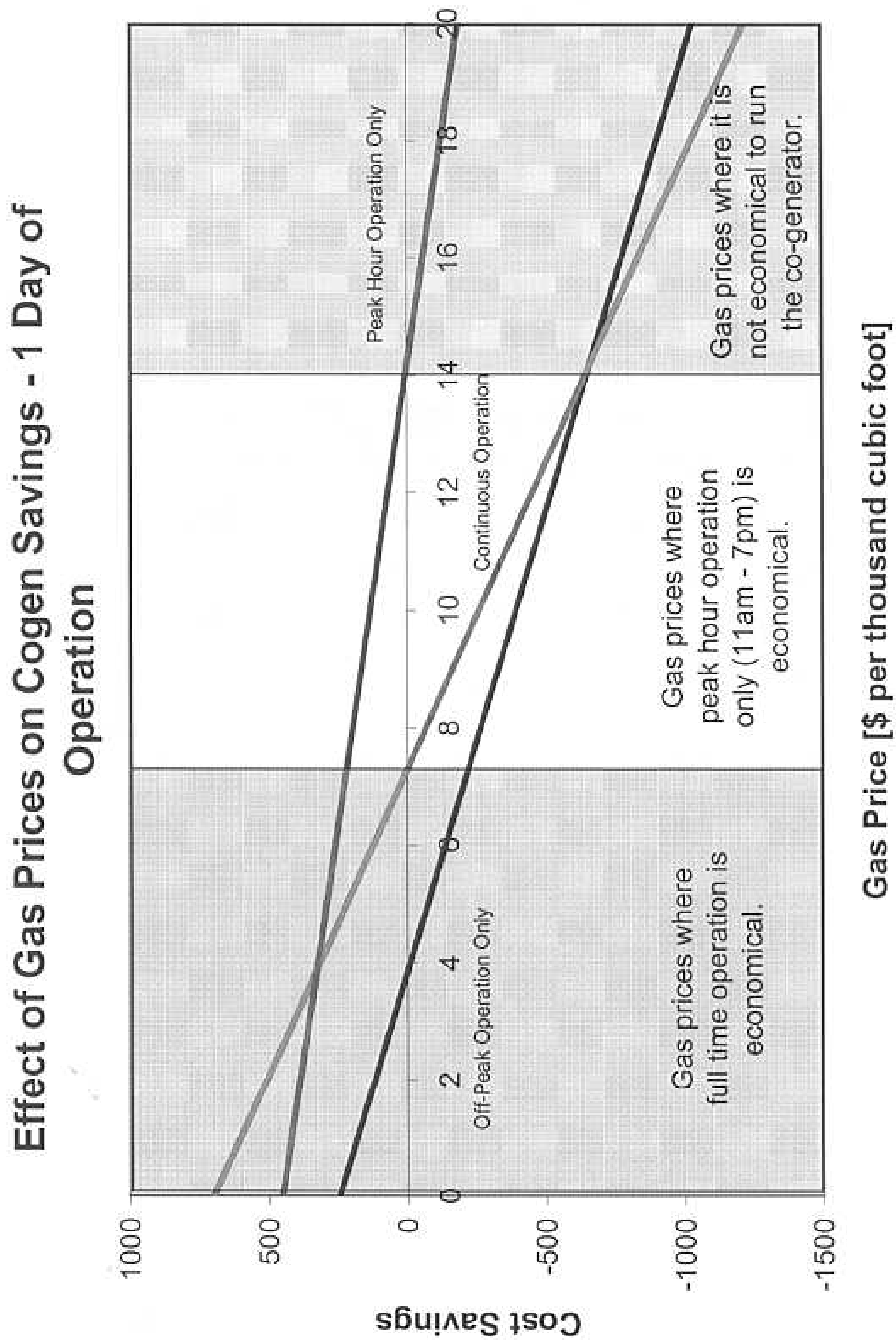
$FVC_{elec,offpeak,i} = C_{elec,offpeak} \cdot Elec_{prod,offpeak,i}$ for $i = 1$ to 1

$Savings_{peek,i} = FVC_{fuel,boiler,peak,i} + FVC_{elec,peak,i} - FVC_{fuel,cogen,peak,i}$ for $i = 1$ to 1

$Savings_{offpeek,i} = FVC_{fuel,boiler,offpeak,i} + FVC_{elec,offpeak,i} - FVC_{fuel,cogen,offpeak,i}$ for $i = 1$ to 1

$Savings_i = Savings_{peek,i} + Savings_{offpeek,i}$ for $i = 1$ to 1

Figure B.2



Effect of Gas Prices on Cogen Savings - 1 Day of Operation
Cost Savings
1000
500
0
-500
-1000
-1500
0
2
4
6
8
10
12
14
16
18
20
Off-Peak Operation Only
Continuous Operation
Peak Hour Operation Only
Gas prices where full time operation is economical.
Gas prices where peak hour operation only (11am - 7pm) is economical.
Gas prices where it is not economical to run the co-generator.
Gas Price [$ per thousand cubic foot]

Figure B.3

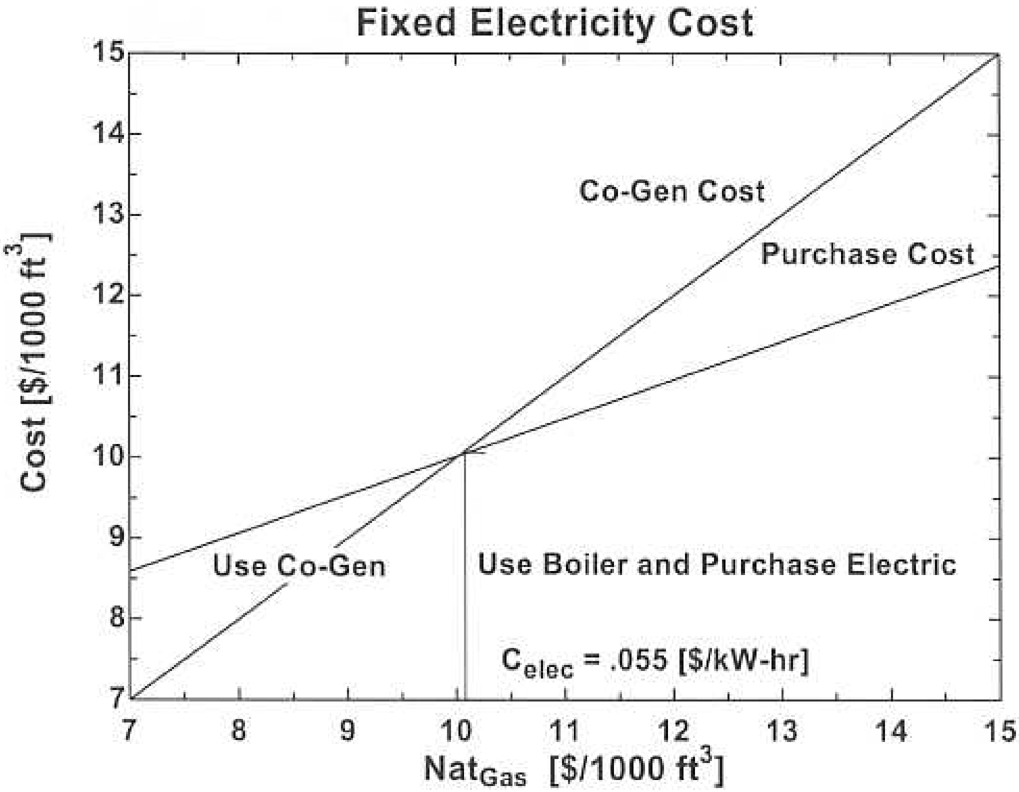
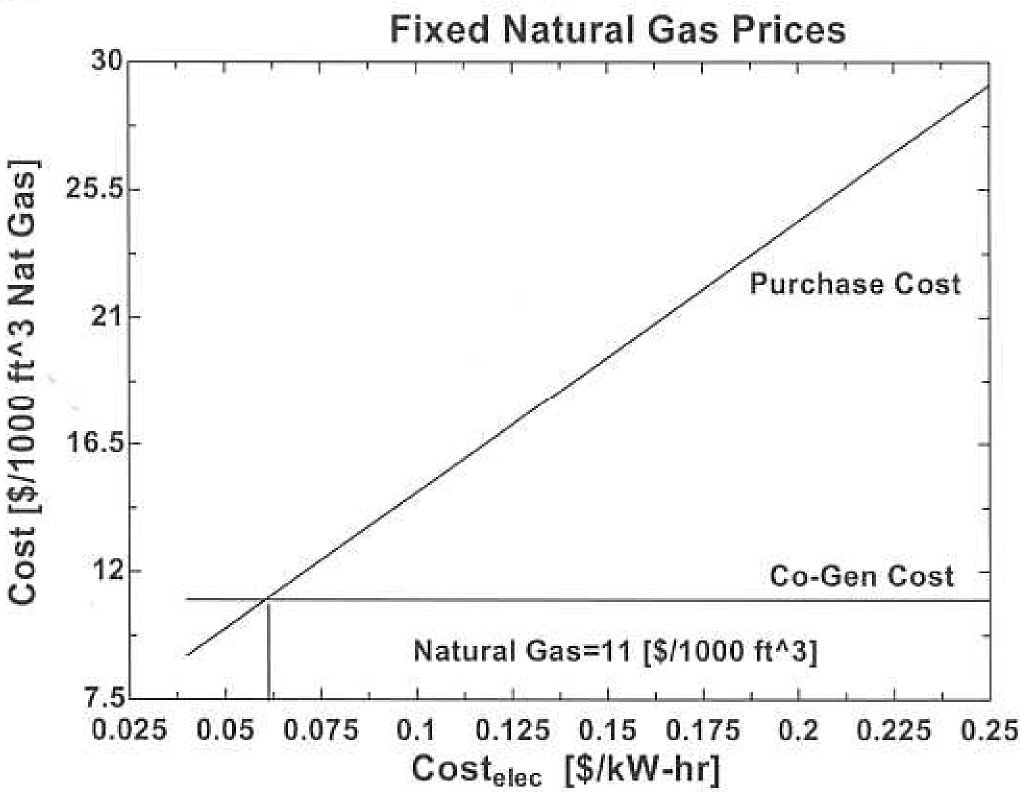


Figure B.4



Appendix C: Wind

Wind Power at Calvin

Final Recommendation

Thursday December 9, 2004

Ryan DeWall
Eddie Lucas
Dawn Svenkeson

Introduction

The goal of this project was to evaluate the feasibility of wind power on Calvin's campus and make a recommendation for implementing wind power. This goal was accomplished by wind turbine research, a cost analysis and an evaluation of realistic community approval. The final recommendation is for a Fuhrlander **250kW** wind turbine located east of the Calvin College nature preserve.

Analysis

The first step in this analysis was to analyze the feasibility of integrating wind energy into Calvin's campus. To start the feasibility study a first-cut analysis was performed. Several examples of campuses currently producing wind power were researched. These examples showed that is was possible to integrate wind power onto a college campus in some situations. In order to determine if this was a possibility at Calvin College wind speeds had to researched and analyzed. It was found that Grand Rapids had class two wind speeds with an average wind speed of **9.8** mph. These wind speeds are sufficient to turn large turbine blades.

The second-cut analysis involved a more in-depth investigation of available turbines and location restrictions. Several turbine suppliers and manufacturers were contacted. (Appendix C1) Turbine specifications and costs were obtained from these businesses. In order to assess the legality of constructing a wind turbine the Gerald R. Ford International Airport and Grand Rapids City Planning Commision were contacted. According to the airport official, a tower up **200 ft** tall could be constructed without lighting or further studies. The Grand Rapids Planning Commission provided information on the permitting procedure. (Appendix C2) The Planning Commission stated that there are no specific ordinances regarding wind turbines. From this investigation it was determined that were no unrealistic obstacles in completing the permitting and construction process. It was decided that a tower under **200 ft** would be realistic approach to gaining approval for wind power on Calvin's campus.

Once the scope of the project was determined a cost analysis of available small-scale industrial wind turbines was conducted. (Appendix C3) First a total cost analysis was performed based on equipment costs provided by vendors. The total cost included purchased equipment, installation, and maintenance costs. A graph was constructed that shows total lifetime turbine costs for turbines ranging from **50 kW** to **600 kW**.

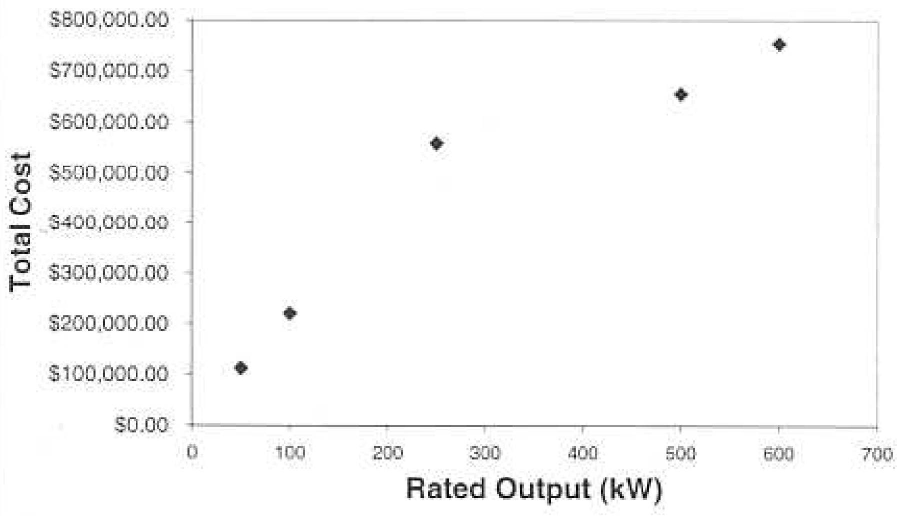


Figure C3.1 Lifetime Turbine Cost

This graphs shows how the lifetime costs of different turbines compare. The turbines under **500 kW** generally cost **$2.00** per watt whereas the larger turbines cost **$1.00** per watt. The next step of our cost analysis was to determine the payback periods of these turbines. Throughout the analysis it was assumed that **80%** of the initial turbine cost was covered by a loan and **20%** was funded by grants and fundraising. The loan used in this analysis was a **7** year loan at a **6%** interest rate. With this information a graph of payback periods for the various turbines was constructed.

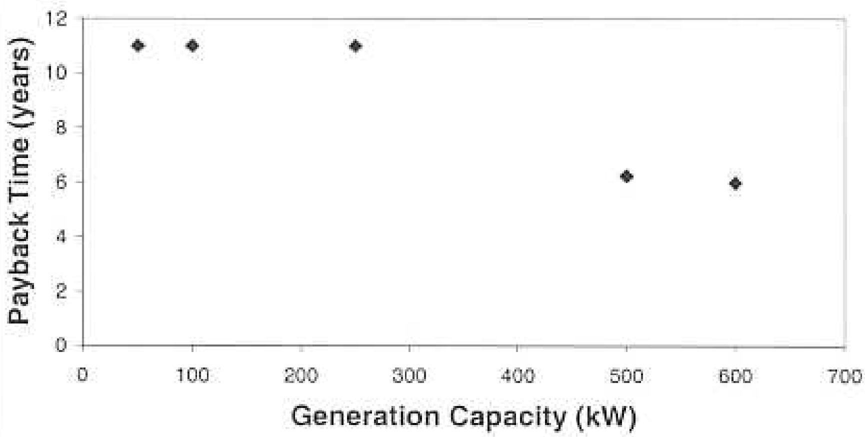


Figure C3.2 Payback Period

It was noted that the payback periods for the small three turbines were similar whereas the payback periods were substantially smaller for the larger turbines.

<u>Results</u>

Based on the analysis the wind power team recommends installation of a **250 kW** turbine. (Appendix C4) The total height of this turbine would be **185 ft** with a **94 ft** blade diameter. This size was chosen because it would be a substantial contributor to campus power needs while remaining under the **200 ft** height limit. It also could be used as a pilot program for future options at Calvin College. Although the purchased equipment cost of the **250 kW** turbine is significantly greater than the smaller turbines it has the same payback period. Overall, the **250 kW** option is the most economically viable option within the campus size limitations. The total lifetime cost of the system would be **$560,000** and the payback period would be **11 years**. This works out to a cost of **$.028/kW-hr** for electricity for a **30 year** turbine life.

<u>Conclusion</u>

This investigation determined that it would be feasible to incorporate wind power onto Calvin's campus. The permitting process would be difficult but if public concerns were addressed appropriately the project could gain community support. (Appendix C5) Based on the financial analysis, feasibility study and non-economic benefits the recommendation is for a **250 kW** Fuhrlander wind turbine. (Appendix C6) The project would contribute to the goal of Calvin College being independent from the grid as well as providing an opportunity for Calvin to be a leader in renewable energy production.

Appendix C1: Business Contacts and Resources

Businesses

Enerex L.L.C.

41775 Production Drive
Harris Twp., MI 48045
Telephone: (586) 468-1858
Fax: (586) 468-5217

Freedom Power L.L.C.

200 Veridian Drive
Muskegon, MI
Telephone: (800) 873-8020

Entegrity Wind Systems Inc. (formerly Atlantic Orient Corporation)

Charlottetown, PE C1A 7L9
Canada
Telephone: (902) 368-7171
Fax: (902) 368-7139
Email: aocadmin@aocwind.com or info@entegritywind.com
Web: www.aocwind.com or www.entegritywind.com

Other Contacts

Midwestern Regional Climate Center

c/o Illinois State Water Survey
2204 Griffith Drive
Champaign, Illinois 61820-7495
Telephone: (217) 244-8226
Fax: (217) 244-0220
Email: mcc@sws.uiuc.edu
Web: http://mrcc.sws.uiuc.edu

Dale Fitz

Grand Rapids City Planning Commission
(616) 456-3031

Henry DuPont

Lorax Energy Systems, LLC
4 Airport Road
Block Island, RI 02807 USA
Phone: (401) 466-2883
Fax: (401) 466-2909
Email: hdp@lorax-energy.com
Web: www.lorax-energy.com
Lorax Energy Systems, LLC is a North American Distributor for Fuhrlaender Wind Turbines which are available in sizes from 30kW to 1500kW.

Laura Rip

National Wind Technology Center
Laura K Rip <lrip@libretech.org>

Roy Hawkins - Airport Planning Engineer

Other Resources

American Wind Energy Association
http://www.awea.org

Danish Wind Industry Association
http://www.windpower.org

Midwest Renewable Energy Association
http://www.the-mrea.org

Appendix C2: Permitting for Wind Power

Steps to obtaining a permit for a small wind turbine

The following steps are based on the state of California. The information is taken from *Permitting of Small Wind Turbines, A Handbook.* Lacking documented policies, most states refer to California's standards in permitting wind turbines. The handbook can be viewed at http://www.bergey.com/School/Cal.Permitting.Handbook.pdf . The actions taken toward each step is recorded in bold type.

1. Contact your county planning department or permitting agency. Find out if small wind energy systems are addressed by local ordinance and, if so, get a copy of the ordinance.

   Preliminary contact was made Dale Fitz, a member of the Grand Rapids Planning Commission staff. He indicated that small wind energy systems are not addressed by local ordinance.

Learn the relevant permitting procedures. Determine what documents will be required.

   A wind turbine construction project would be permitted with approval. A public hearing before the planning commission would be required. The permitting process will require the following documents.

   - **A legal description of the proposed site**
   - **Site Plans**
   - **Wind Turbine Plans**
   - **A letter to the planning commission detailing intent and motivation**

2. Review applicable standards and restrictions.

   Minimum parcel size – California requires one acre.
   Minimum allowable tower height – varies.
   Setback – No part of the system may be within 30 ft. of the property boundary.
   Noise levels – must not exceed 60dB during normal operation as measured from the closest neighboring inhabited dwelling.
   Equipment – from a list of certified small wind turbines.
   Building code compliance – standard drawings and an engineering analysis must show compliance with the Uniform Building Code.
   Electric code compliance – Line drawings of system electrical components showing sufficient detail to determine that the installation conforms to the National Electric Code.
   Fedral Aviation Administration requirements – **Preliminary contact has been made with an engineer at Gerald R. Ford International Airport. He has indicated that a tower up to 200 feet should be permissible. He has been provided with specific site options and is currently gathering more specific feedback for the project. The FAA will honor approval of the local airport.**

3. For grid connected systems:

   Notify the utility.
   Obtain an interconnection agreement.

4. Notify neighbors.

   Required within 300 feet of proposed site.
   Recommended within a larger proximity.

5. Comply with permitting requirements.

   Fees can range from $100 to $1600

Appendix C3 Cost Anaylsis

System Parameters	
Operation Time (hours/year)	8760
Rated Generating Capacity (kW)	250
Capacity Factor	30%
Actual Capacity (kW)	75
O & M Costs Percent	1.25%
System Costs	
PEC:	($511,000.00)
Miscellaneous Costs:	($3,500.00)
OMC ($/yr):	($6,387.50)
Electric Output (kW-hr/yr):	657000
Savings ($/yr):	$52,560.00
System Loan Parameters	
Cost of System:	($514,500.00)
% of Cost Paid by Loan:	80%
Interest Rate of Loan:	6%
Payback Period (years):	7
Amount of Loan:	($411,600.00)
Economic Parameters	
nominal inflation rate	4.00%
Interest Rate:	12%
Electricity Inflation Rate:	4%
Cost Electricity ($/kW-hr):	$0.08
Time Period (years):	30
Grants	
Subsidized spending	($102,900.00)

Year	Electricity Cost	Electricity Savings	O & M	Loan
1	$0.08	$52,560.00	($6,387.50)	($73,731.97)
2	$0.08	$54,662.40	($6,643.00)	($73,731.97)
3	$0.09	$56,848.90	($6,908.72)	($73,731.97)
4	$0.09	$59,122.85	($7,185.07)	($73,731.97)
5	$0.09	$61,487.77	($7,472.47)	($73,731.97)
6	$0.10	$63,947.28	($7,771.37)	($73,731.97)
7	$0.10	$66,505.17	($8,082.23)	($73,731.97)
8	$0.11	$69,165.37	($8,405.51)	$0.00
9	$0.11	$71,931.99	($8,741.73)	$0.00
10	$0.11	$74,809.27	($9,091.40)	$0.00
11	$0.12	$77,801.64	($9,455.06)	$0.00
12	$0.12	$80,913.71	($9,833.26)	$0.00
13	$0.13	$84,150.25	($10,226.59)	$0.00
14	$0.13	$87,516.26	($10,635.66)	$0.00
15	$0.14	$91,016.91	($11,061.08)	$0.00
16	$0.14	$94,657.59	($11,503.53)	$0.00
17	$0.15	$98,443.89	($11,963.67)	$0.00
18	$0.16	$102,381.65	($12,442.21)	$0.00
19	$0.16	$106,476.92	($12,939.90)	$0.00
20	$0.17	$110,735.99	($13,457.50)	$0.00
21	$0.18	$115,165.43	($13,995.80)	$0.00
22	$0.18	$119,772.05	($14,555.63)	$0.00
23	$0.19	$124,562.93	($15,137.86)	$0.00
24	$0.20	$129,545.45	($15,743.37)	$0.00
25	$0.21	$134,727.27	($16,373.11)	$0.00
26	$0.21	$140,116.36	($17,028.03)	$0.00
27	$0.22	$145,721.01	($17,709.15)	$0.00
28	$0.23	$151,549.85	($18,417.52)	$0.00
29	$0.24	$157,611.85	($19,154.22)	$0.00
30	$0.25	$163,916.32	($19,920.39)	$0.00

Appendix C3 Cost Anaylsis

Total Annual	PV Annual	Payback Period	Year	PV O&M	PV Loan	PV Savings
($27,559.47)	($27,559.47)	($27,559.47)	1	($6,387.50)	($73,731.97)	$52,560.00
($25,712.57)	($22,957.65)	($50,517.13)	2	($5,931.25)	($65,832.12)	$48,805.71
($23,791.80)	($18,966.68)	($69,483.80)	3	($5,507.59)	($58,778.68)	$45,319.59
($21,794.19)	($15,512.67)	($84,996.48)	4	($5,114.19)	($52,480.96)	$42,082.48
($19,716.68)	($12,530.31)	($97,526.78)	5	($4,748.89)	($46,858.00)	$39,076.59
($17,556.07)	($9,961.78)	($107,488.57)	6	($4,409.68)	($41,837.50)	$36,285.40
($15,309.03)	($7,756.03)	($115,244.60)	7	($4,094.71)	($37,354.91)	$33,693.59
$60,759.86	$27,484.68	($87,759.92)	8	($3,802.23)	$0.00	$31,286.90
$63,190.25	$25,521.48	($62,238.44)	9	($3,530.64)	$0.00	$29,052.12
$65,717.86	$23,698.52	($38,539.92)	10	($3,278.45)	$0.00	$26,976.97
$68,346.58	$22,005.77	($16,534.15)	11	($3,044.28)	$0.00	$25,050.05
$71,080.44	$20,433.93	$3,899.78	12	($2,826.83)	$0.00	$23,260.76
$73,923.66	$18,974.36	$22,874.14	13	($2,624.91)	$0.00	$21,599.27
$76,880.61	$17,619.05	$40,493.19	14	($2,437.42)	$0.00	$20,056.47
$79,955.83	$16,360.55	$56,853.74	15	($2,263.32)	$0.00	$18,623.86
$83,154.06	$15,191.94	$72,045.68	16	($2,101.65)	$0.00	$17,293.59
$86,480.23	$14,106.80	$86,152.47	17	($1,951.53)	$0.00	$16,058.33
$89,939.44	$13,099.17	$99,251.64	18	($1,812.14)	$0.00	$14,911.31
$93,537.01	$12,163.51	$111,415.16	19	($1,682.70)	$0.00	$13,846.21
$97,278.49	$11,294.69	$122,709.85	20	($1,562.51)	$0.00	$12,857.20
$101,169.63	$10,487.93	$133,197.78	21	($1,450.90)	$0.00	$11,938.83
$105,216.42	$9,738.79	$142,936.57	22	($1,347.26)	$0.00	$11,086.05
$109,425.08	$9,043.16	$151,979.73	23	($1,251.03)	$0.00	$10,294.19
$113,802.08	$8,397.22	$160,376.96	24	($1,161.67)	$0.00	$9,558.89
$118,354.16	$7,797.42	$168,174.38	25	($1,078.69)	$0.00	$8,876.12
$123,088.33	$7,240.46	$175,414.84	26	($1,001.65)	$0.00	$8,242.11
$128,011.86	$6,723.29	$182,138.13	27	($930.10)	$0.00	$7,653.39
$133,132.34	$6,243.05	$188,381.18	28	($863.66)	$0.00	$7,106.72
$138,457.63	$5,797.12	$194,178.30	29	($801.97)	$0.00	$6,599.09
$143,995.93	$5,383.04	$199,561.34	30	($744.69)	$0.00	$6,127.73

TOTALS	Net	OM	Financed Equip	Savings
	$199,561.34	($79,744.04)	($376,874.15)	$656,179.53

Subsidized Equipment
($102,900.00)

Lifetime Project Cost	($559,518.19)	Including subsidized spending
Lifetime Project Cost	($456,618.19)	Excluding subsidy
Lifetime Electricity Savings	$656,179.53	
Lifetime Net Total	$199,561.34	Excluding subsidy
Payback Period	11	years
Cost of Electricity Production	$0.0284	($/kWh) Including subsidy

in present dollars

Summary

Turbine Size (kW)	Lifetime Project Cost Including Subsidy	Payback Period
50	$112,119.82	11
100	$220,975.87	11
250	$559,518.19	11
500	$656,400.07	6.25
600	$754,370.52	6

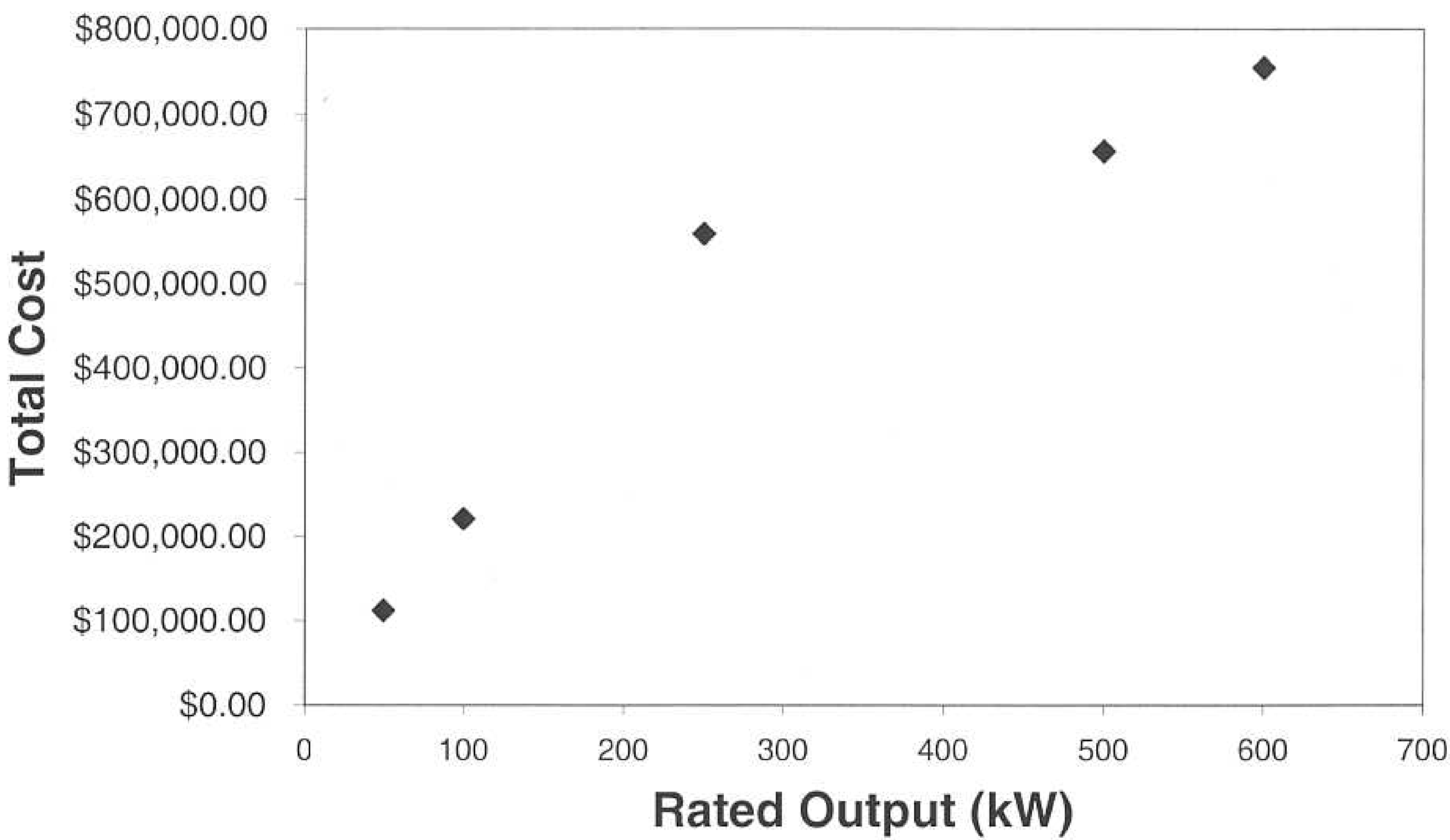


Figure C3.1 Lifetime Turbine Cost

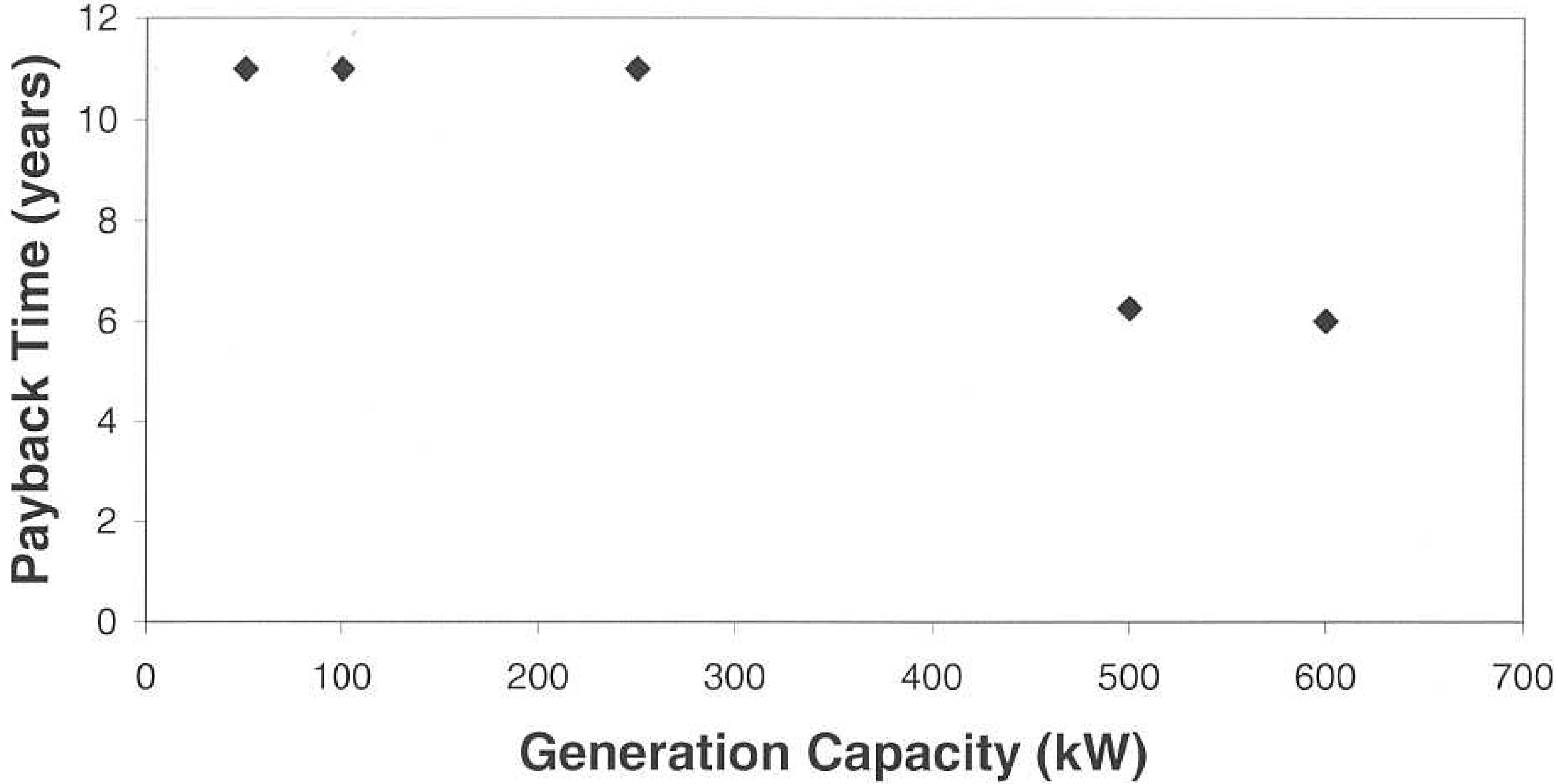


Figure C3.2 Payback Period

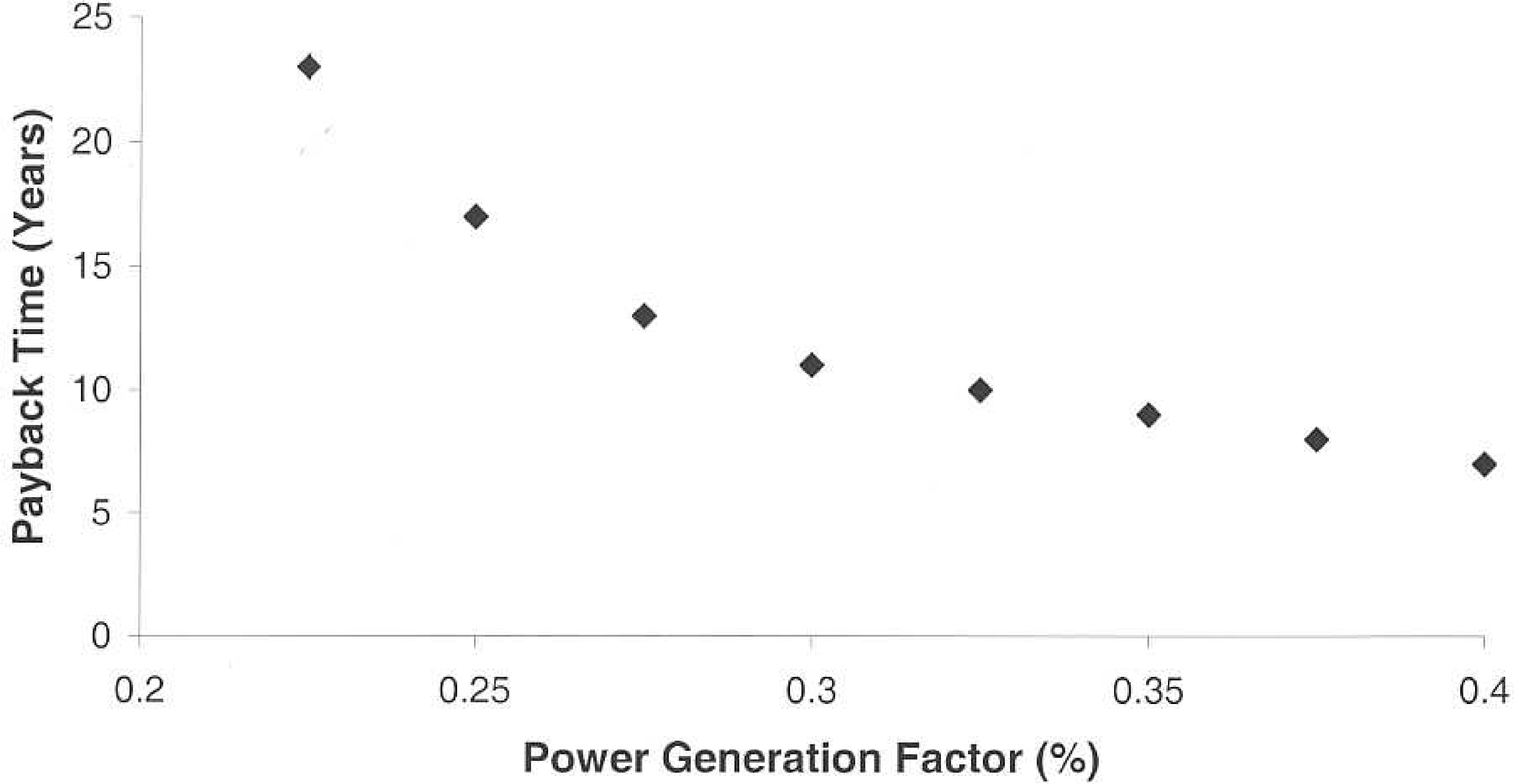


Figure C3.3 Power Generation Factor vs. Payback Time for 250 kW Turbine

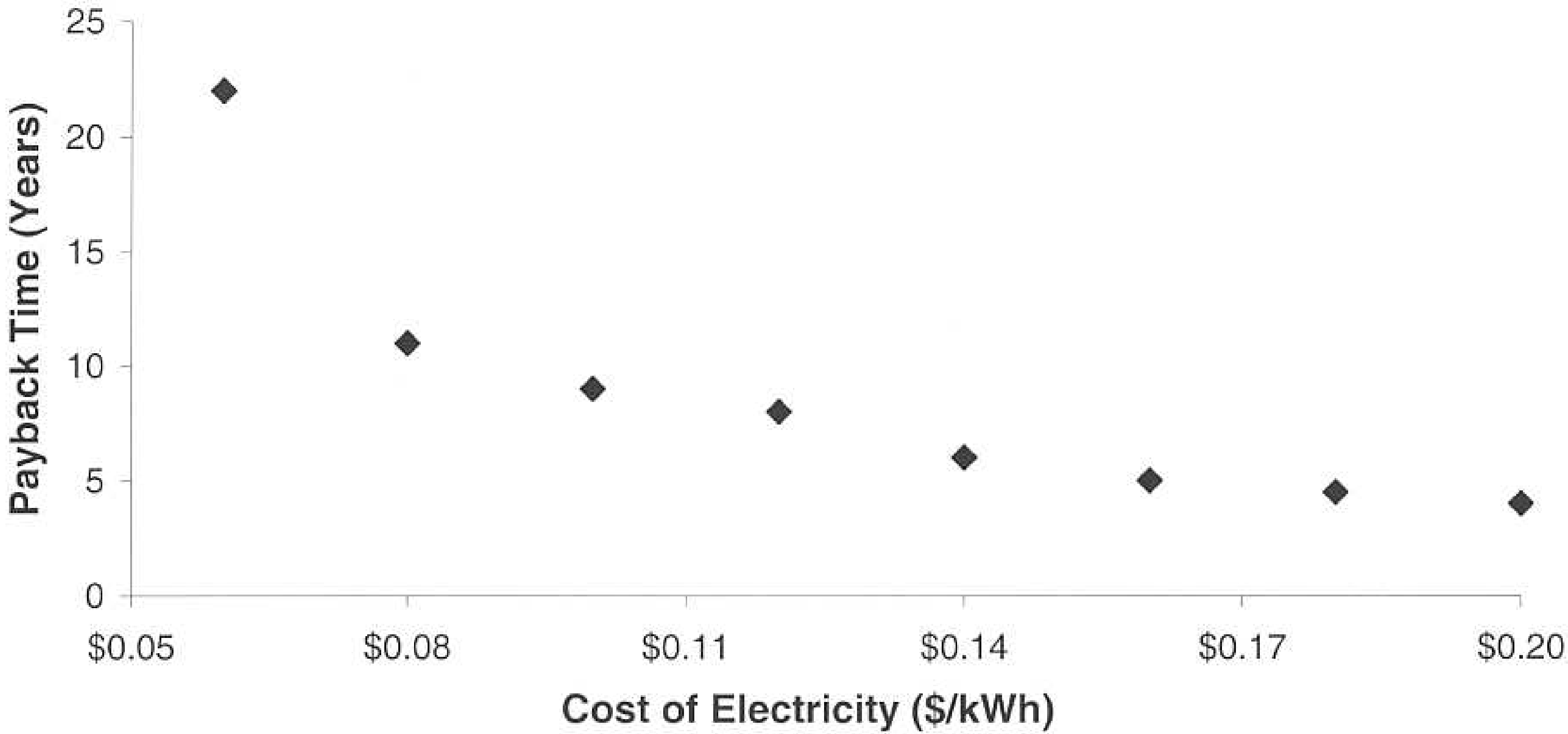


Figure C3.4 Base Cost of Electricity vs. Payback Time for 250 kW Turbine

Appendix C4 – Fuhrlander 250

A **Fuhrlander 250** was the turbine that was selected. This turbine has a tower height of **137 ft**. and the length of the blade is **48 ft.** This allows the turbine to stay in the recommended height requirement of the airport. The turbine has three blades and contains an aerodynamic brake that is used to protect them if wind speeds pass the recommended level of operation. The power that this turbine outputs is three phase at **480 Volts**. The wind turbine has a cut in speed of **5.6 MPH**, which is well below the Grand Rapids average of **9.8 MPH**. The rated output at **33 MPH** is **250 kW** and the peak output of the wind turbine is **300 kW** at **55 MPH.** The wind turbine has a sophisticated controller with communication capabilities and the noise level of the turbine is **98 dB** with a total weight of 34 tons.

Appendix C5: Possible Public Concerns

The purpose of the public hearing would be to provide the opportunity for community members to raise concerns they may have about the wind turbine. The following is a list of anticipated concerns followed by factual information that addresses these issues.

1. Acoustics

   The sound pressure level created by a small wind turbine is approximately equal to that which is found in a typical living room. Research has found that background noises of trees, cars, and animals can be almost as noisy as the wind turbine. At low wind speeds the background noises will usually mask the wind turbine noise. Turbines are generally quieter than a loud conversation. Specific noise measurement data is available for individual wind turbines. Noise complaints are rarely lodged against small wind turbines.

2. Aesthetics

   Many find wind turbines aesthetically pleasing. The relative visual impact can be considered in comparison to water towers, billboards, relay towers, and utility lines. The visible impact can be minimized by tower construction and even color.

3. Property Values

   There is no documented evidence that wind turbines, including commercial wind farms, have ever lowered the values of surrounding properties.

4. Electronic Interference

   The rotors on small-scale turbines are not large enough to interfere with TV or telecommunications signals. Also, larger modern wind turbines typically do not interfere with signals because of their composition and their size.

5. Safety

   No public injuries have been attributed to falls from the thousands of unfenced small turbine towers installed over the past 25 years. Turbine towers should be required to have access restrictions similar to structures such as radio towers, that is fencing or warning signs. The small wind industry does not recommend fencing or anti-climbing devices. The tower must comply with building and electric codes.

6. Avian Risk

   Bird collisions with small wind turbines are very rare. Statistically, a sliding glass door is a greater threat to birds than a small, unlighted wind turbine. Tower design changes and siting practices have made modern wind turbines much safer for birds than the original wind experiments.

Appendix C6 - Non-Economic Benefits

There are many other benefits of owning a wind turbine besides financial savings. Some of these advantages may include that it is a green energy. A green energy means that there is no burning of coals or other fuels. This means that the process of making the energy is cleaner and better for the environment concerns of polluting lakes, drinking water, air, and global warming. The next benefit that a wind turbine would give to Calvin College is a learning tool for students. Some possible departments that could use this turbine for teaching are biology, engineering, business, and geology. The wind turbine on campus would also be a constant reminder that every time a light is turned on or a computer is used, there has to be a device that is producing the energy. This may cause students to be aware of the energy wasting activities they have in their life. The final benefit of using a wind turbine is the act of being good stewards of the resources that God has given us. This means that we can use the wind resource on campus to help provide electricity for the campus demand. The wind turbine would also be good stewardship of the land that Calvin has compared to other energy sources that require more land area to produce the same amount of electricity. The final reason why we chose one wind turbine is to use it as a pilot program for future possibilities of wind power at Calvin College.

Appendix C7 - Work Log

The first action that we took to this project was research. We needed to find what applications are out there and which applications were feasible to Calvin College. The other research that we needed to do was to find how many types of wind turbines were available and the distributors that made them. With this research, we found that there were both small and large wind turbines. The limit to a small scale wind turbine or farm was considered to be around 750 kW. After this research, we then looked at the colleges with wind turbine energy systems and the applications they used for this power. The final section that we looked at before the first presentation was a rough estimate on the cost of a wind turbine and the advantages that were associated with a wind turbine system.

Our focus for the group then moved into locations that we could put a turbine and also the applications that were feasible to Calvin College given our annual wind speed average of 9.8 MPH. The next step that we took before our second presentation was to look at colleges that had the same conditions for wind turbines and what they were able to accomplish with their systems. The final step that we took before our second presentation was to contact local suppliers and use their knowledge for possible applications around Grand Rapids.

Before the next presentation we were given a requirement by the integration team to provide them with 1.5 MW of power from wind turbines. After finding our capacity factor and the location of our wind turbine, we recommended they needed to install 5 MW of electricity. The next choice that we needed to make was to find the location we needed to achieve this power. This would tell us how big our tower would need to be and any special considerations we would need to take into account for the wind turbine. The next step in the process would then be to consider how we could hook up to the grid and the maintenance that would be associated with the wind turbine. The final aspect that we considered was to look at a more informed guess on the cost of the wind turbine system and the economic benefits that the college would see due to the wind turbine.

After this presentation, the integration team refocused our requirement to the most financially feasible option given our height requirements and permitting process of Grand Rapids. The FAA requires towers to be restricted to 200 ft. when they are in the path of a flight zone of local airports. This restricted our search to wind turbines of less than 500 kW due to the high heights of the larger wind turbines to reach acceptable efficiencies. The other restriction that we found was to get the public approval of the wind turbine and possible problems that may be encountered for the system. These requirements would need to be addressed before our next presentation and the turbine recommendation for Calvin College campus.

The next step that was taken in the analysis was a more detailed cost model for implementation on the Calvin campus. With this cost study and the above guidelines, the proposed wind turbine was found to be a Fuhrlander 250. This turbine would meet all of the requirements and have a payback period of 12 years. The final step that must be considered for the class project would be to look at a ten step process of implementing the wind turbine. This would allow college administration to see the next steps that would be needed to implement the turbine and the steps that were already taken by our group. This concluded our study of wind turbines for the class project and the final report and presentation would be produced to inform the college on the results we found.

Appendix D: Solar Photo-Voltaic

Solar PV Technical Group

Final Tech Report


Courtesy http://www.oja-services.nl/iea-pvps/ar02/images/aus03.jpg

Introduction

Photovoltaic solar cells convert incident radiation to electricity. Over the last 30 years, increased demand and manufacturability has driven solar panels from the realm of specialized scientific apparatus to commercial availability as a power source. Photovoltaic solar cells have become a competitive and reliable source of alternative energy. As part of Calvin College's plan to become electrically self-sufficient, solar cells provide a low maintenance means of electricity generation. This feasibility study of PV solar cells in Calvin College's "Off the Grid" plan includes estimation of startup cost, maintenance cost, and present value cost analysis.

Objective

To investigate Solar Photovoltaic cell technology as an alternative to get Calvin off the grid or reduce its dependence on the grid and to analyze how a PV system could be implemented into the proposed Health and Wellness (H&W) Center at Calvin. By looking at the best and worst case scenarios of PV solar cost analysis, feasibility of solar panel use at Calvin College can be determined.

PV Solar Cells Technology

PV panels absorb sunlight during the day and are able to convert the energy from the sun into electrical energy. This DC electrical energy is supplied to the present AC power grid using power inverters.

The three primary groups of commercially available solar panels are crystalline, polycrystalline, and amorphous. Crystalline are the most efficient, and amorphous are the least (Table 1). However, amorphous PV panels are more versatile in their installation. See Appendix 2 for a comparison of amorphous and crystalline PV panels and various panel vendors.

Table 1: Panel Efficiency

Solar Panel	Description	Efficiency
Crystalline	Grown and cleaved from a single crystal	12%
Polycrystalline	Made of smaller crystals with grain boundaries in crystal lattice	9%
Amorphous	Non Crystalline structure	6%

- Advantages and Disadvantages of using Solar Energy (Table 2)

Table 2: Advantage and Disadvantage

Advantages	Disadvantages
Little environmental impact	Weather dependant power output
Low maintenance cost	High start up cost
Few system components	Large surface area requirement

Implementing PV System into H&W Center

- Types of PV panels to be used: Decision Matrix (Table 3)

Table 3: Decision Matrix

Types of Panels	Efficiency (10)	Cost (10)	Ease of (10) Implementing	Total (30)
Crystalline	6	5	4	15
Polycrystalline	4.5	6	4	14.5
Amorphous	**3**	**8**	7	**18**

- Assume the roof space is approximately **91.4m x 61m** and only **70%** of this is available for placing panels.
- Using the annual weather conditions in Grand Rapids, MI (Appendix 1).

Results

A cost model was developed to analyze the feasibility of implementing PV solar panels on Calvin's campus. This model was applied to the proposed Health and Wellness Center. With the available roof area for placing solar panels on the H&W Center, the present value of system costs and power outputs assuming a 30 year system life are given by Table 4 below:

Table 4: Cost Model Analysis of H&W PV System

Total Rated Power Output (kW)	**240**
Average Power Output (kW)	**50**
Number of panels	1867
Present Value Cost of Solar Panels ($)	860000
Present Value Cost of Power Inverters ($)	84000
Present Value Operation/Maint. Cost ($)	290000
Total Present Value Start up Cost ($)	**0.94 million**
Breakeven Cost ($)	**1.25 million**
Number of Years to Breakeven	**34 years**

The solar panel breakeven analysis provides below Figure 1 of present value system costs vs. years of system operation. It can be seen that startup costs overshadow maintenance costs.

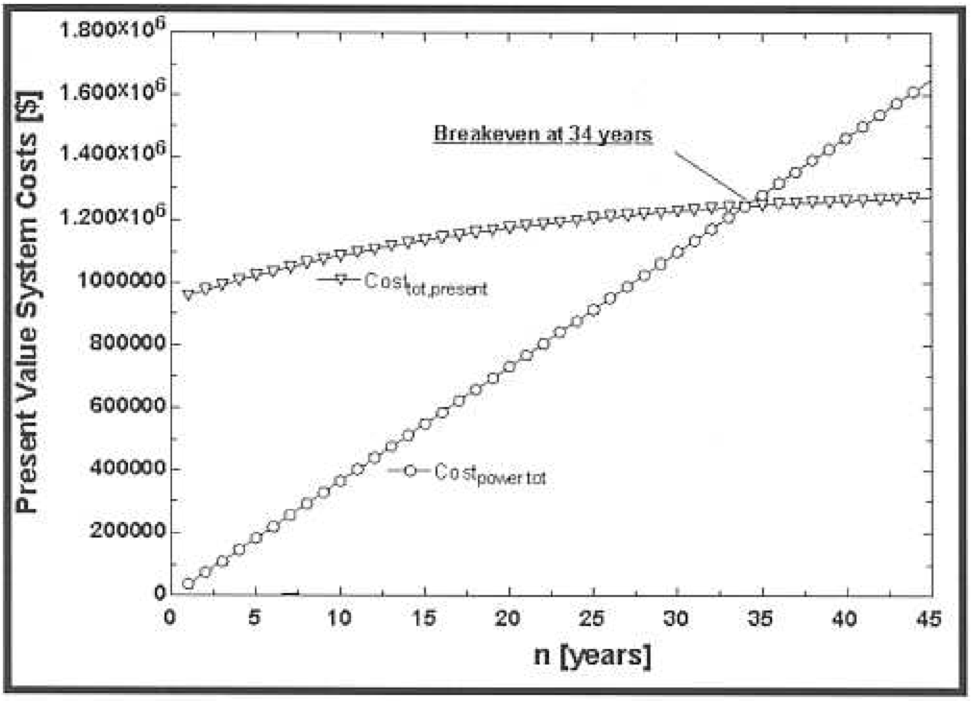


Figure 1: Breakeven Point for a 240 kW system

It would be advisable to buy solar panels if the price of solar panels reduced significantly. In the case of the new Health and Wellness Center, the 128 watt panels would have to drop by about 56% to $260 per panel (Figure 2). In the future this might be possilbe, but currently the price of the cells are simply too high.

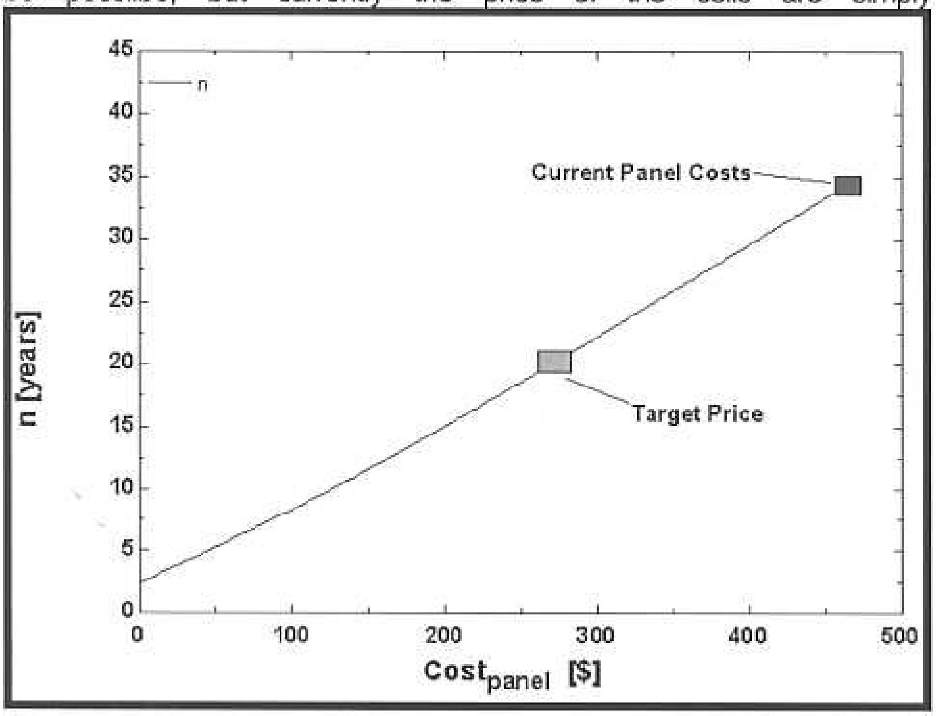


Figure 2: Years to Breakeven Based on 128 watt Panel

Conclusion

The time period for a PV system to breakeven is 34 years, assuming no replacement of PV panels during that time. While the maintenance cost associated with solar power systems is low, the owner must account for the high start up cost involved in implementing these systems. For this reason, solar power use at Calvin College requires subsidization to become profitable in the immediate future.

The power output of the solar system on the proposed Health and Wellness Center will not be able to meet the building's total power needs. It is not feasible for this building to be off grid due only to solar power. Power from the grid would be a necessary supplement to solar power for successful operation of the Health and Wellness Center.

Appendix 1: Environmental Conditions

The efficiency of solar panels is very dependent on the environment in which it operates. Conditions such as cloud cover, magnitude of incident solar radiation, and surrounding temperature affect the amount of power generated by the panel. See Appendix A for details of the environmental conditions for solar panels at Calvin.

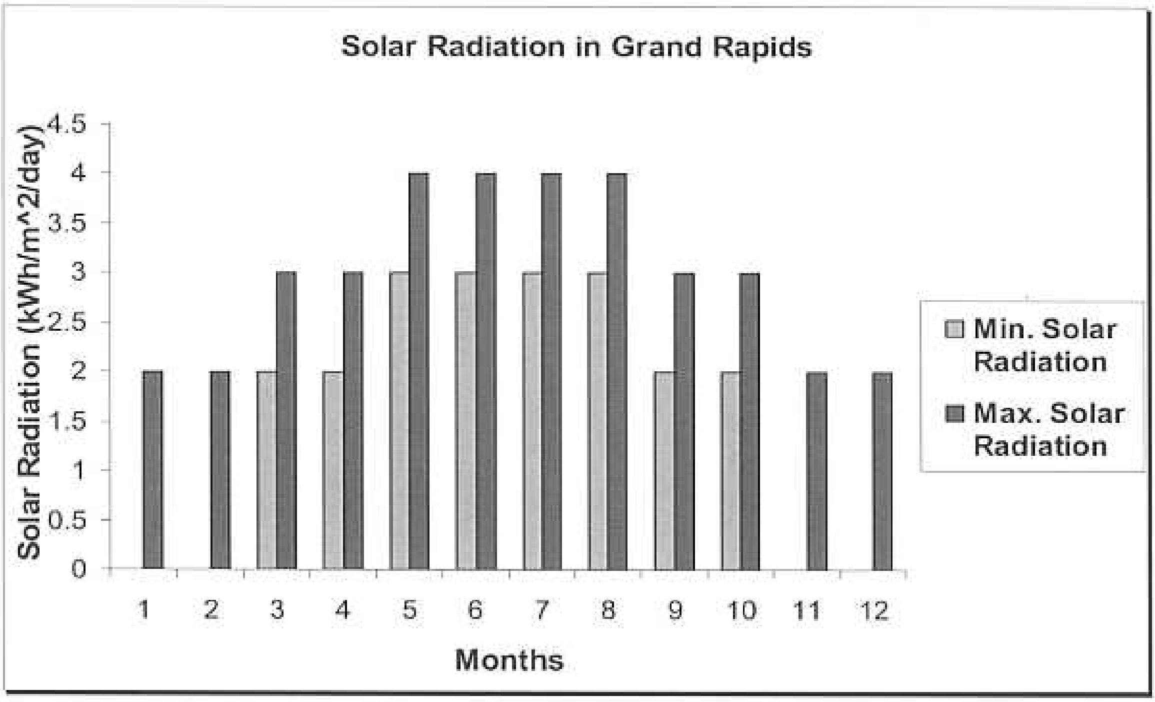


Figure 1.1: Solar Radiation in Grand Rapids

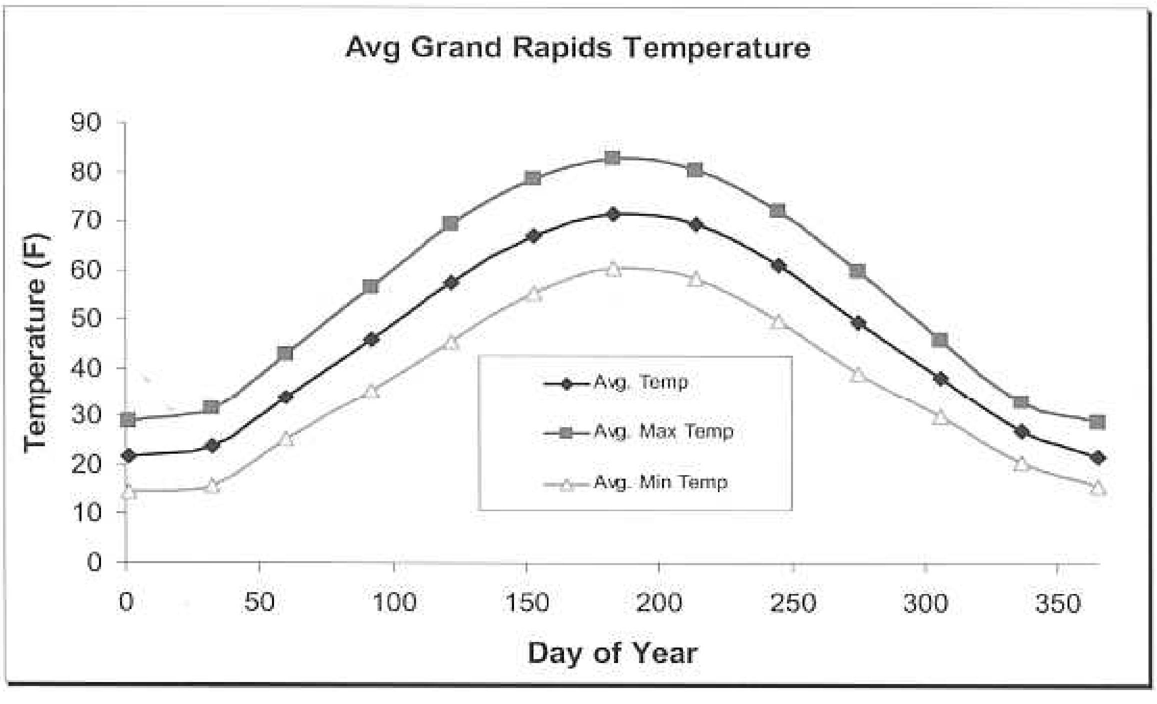


Figure 1.2: Average Temperature in Grand Rapids

Appendix 2: System Cost Analysis

Startup Costs

Photovoltaic solar panels have a high initial startup cost, but low annual maintenance costs. Initial costs include the panel price, the power conditioning equipment, and any power metering devices.

Maintenance Costs

One of the primary benefits of photovoltaic solar panels is the low annual maintenance costs. Solar panels must be correctly installed and oriented. After initial installation, maintenance includes the annual cleaning of solar panels. Maintenance costs were determined by assuming annual maintenance cost is 2% of initial startup cost.

Table B.1: Panel Vendors and Pricing

Watts	Kilowatts	Cost ($)	Length (in)	Width (in)	Area (in^2)	Area (ft^2)	Pricing ($/kW)	Efficiency (kW/ft^2)		$/KW-ft^2
SunWize										
5	0.005	$58	11.82	9.84	116.31	0.81	11600.00	0.00619		$14,361.77
10	0.01	$89	15.15	14.76	223.61	1.55	8900.00	0.00644		$5,731.30
20	0.02	$131	20.86	16.93	353.16	2.45	6550.00	0.00815		$2,670.75
40	0.04	$224	38.38	17.13	657.45	4.57	5600.00	0.00876		$1,226.56
85	0.085	$351	56.89	22.83	1298.80	9.02	4129.41	0.00942		$457.83
90	0.09	$365	56.89	22.83	1298.80	9.02	4055.56	0.00998		$449.65
100	0.1	$421	56.93	25.43	1447.73	10.05	4210.00	0.00995		$418.75
115	0.115	$493	56.93	25.43	1447.73	10.05	4286.96	0.01144		$426.41
120	0.12	$510	56.93	25.43	1447.73	10.05	4250.00	0.01194		$422.73
SHARP be sharp									Minimum	$418.75
80	0.08	$668	47.28	20.88	987.2064	6.8556	8350.00	0.01167		$1,217.98
123	0.123	$944	59.02	26.06	1538.0612	10.68098056	7674.80	0.01152		$718.55
165	0.165	$1,220	62.01	32.52	2016.5652	14.003925	7393.94	0.01178		$527.99
									Minimum	$527.99
Sanyo										
167	0.167	$710	52	35.24	1832.48	12.72555556	4251.50	0.01312		$334.09
180	0.18	$725	52	35.24	1832.48	12.72555556	4027.78	0.01414		$316.51
190	0.19	$760	52	35.24	1832.48	12.72555556	4000.00	0.01493		$314.33
bp solar									Minimum	$314.33
5	0.005	$75	9.86	10.6	104.516	0.725805556	15000.00	0.00689		$20,666.69
10	0.01	$96	16.6	10.6	175.96	1.221944444	9600.00	0.00818		$7,856.33
20	0.02	$169	16.7	19.75	329.825	2.290451389	8450.00	0.00873		$3,689.23
30	0.03	$207	23.4	19.75	462.15	3.209375	6900.00	0.00935		$2,149.95
40	0.04	$241	37	19.75	730.75	5.074652778	6025.00	0.00788		$1,187.27
50	0.05	$235	33	21.2	699.6	4.858333333	4700.00	0.01029		$967.41
60	0.06	$284	43.5	19.8	861.3	5.98125	4733.33	0.01003		$791.36
65	0.065	$291	43.7	18.8	821.56	5.705277778	4476.92	0.01139		$784.70
80	0.08	$318	47.6	21.1	1004.36	6.974722222	3975.00	0.01147		$569.92
125	0.125	$530	69.4	28.5	1977.9	13.73541667	4240.00	0.00910		$308.69
150	0.15	$630	62.7	31.1	1949.97	13.54145833	4200.00	0.01108		$310.16
160	0.16	$660	62.7	31.1	1949.97	13.54145833	4125.00	0.01162		$304.62
Shell Solar Dealer									Minimum	$304.62
5	0.005	$53	12.9	8.1	104.49	0.725625	10600.00	0.00689		$14,608.10
10	0.01	$106	15.3	12.9	197.37	1.370625	10600.00	0.00730		$7,733.70
20	0.02	$183	29.5	12.9	380.55	2.642708333	9150.00	0.00757		$3,462.36
40	0.04	$228	50.9	12.9	656.61	4.559791667	5700.00	0.00877		$1,250.06
80	0.08	$328	47.2	20.8	981.76	6.817777778	4100.00	0.01173		$601.37
130	0.13	$603	63.8	32.8	2092.64	14.53222222	4638.46	0.00895		$319.18
140	**0.14**	**$541**	**63.8**	**32.8**	**2092.64**	**14.53222222**	**3864.29**	**0.00963**		**$265.91**
150	0.15	$640	63.8	32.8	2092.64	14.53222222	4266.67	0.01032		$293.60
160	0.16	$660	63.9	32.1	2051.19	14.244375	4125.00	0.01123		$289.59
									Minimum	$265.91
									ABS MIN	$265.91

Appendix C: EES Model- System Cost Analysis

Solution

A_panel=2.09 [m^2]

A_sys=3902 [m^2]

BE=-130093 [$]

Cost_invrt_swtch=350 [$/kW]

Cost_OM_annual=18799 [$]

Cost_OM_present=288990 [$]

Cost_panel=458.8 [$]

Cost_power=0.08 [$/kW-hr]

Cost_power_1=700.8 [$/kW-yr]

Cost_power_future=0.3458 [$/kW-hr]

Cost_power_tot=1.099E+06 [$/yr]

Cost_savings=1.92 [$/kW]

Cost_start_annual=61146 [$]

Cost_start_present=939960 [$]

Cost_tot_annual=79945 [$]

Cost_tot_present=1.229E+06 [$]

Duty_cycle=0.2188

F_S_light_hours=0.25

F_S_months=0.3333

i_money=0.05

i_OM=0.02

L_panel=5.486 [m]

L_roof=60.96 [m]

n=30

Panels=1867

P_output=238.9 [kW]

P_output_actual=52.27 [kW]

P_solar=1 [kW/m^2]

Rating_panel=0.128 [kW]

Summer_light_hours=0.3333

Summer_months=0.25

Winter_light_hours=0.125

Winter_months=0.4167

w_panel=0.381 [m]

w_roof=91.44 [m]

Appendix C: EES Model- System Cost Analysis

Engineering 333B
Team 8- PV Analysis
Cost Model Development

Function for Calculating Present Value of an Annuity

Function **Present** (n, i, A)

$$Present := A \cdot \left[\frac{(1+i)^n - 1}{i \cdot (1+i)^n} \right]$$

End **Present**

Function **Future** (n, i, P)

Function for Calculating Future Value from a Present Value

$$Future := P \cdot (1+i)^n$$

End **Future**

Function **Annual** (n, i, P)

Function for Calculating the Annual Value from a Present Value

$$Annual := P \cdot \left[\frac{i \cdot (1+i)^n}{(1+i)^n - 1} \right]$$

End **Annual**

Define System Life

$n = 30$ System Life Years

Define System Parameters

$P_{output,spec} = 3000$ [kW]

Power Output Requirement

$Rating_{panel} = 0.128$ [kW] Panel Power Rating

$Cost_{panel} = 458.75$ [$] Cost Per Panel

$$Panels = \frac{P_{output}}{Rating_{panel}}$$ Number of Panels

$$Cost_{savings} = \frac{Cost_{panel}}{P_{output}}$$

Roof Dimensions

$$L_{roof} = 200 \text{ [ft]} \cdot \left| 0.3048 \cdot \frac{m}{ft} \right|$$ Roof Length

$$w_{roof} = 300 \text{ [ft]} \cdot \left| 0.3048 \cdot \frac{m}{ft} \right|$$ Roof Width

$A_{sys} = 0.7 \cdot L_{roof} \cdot w_{roof}$ Total System Area is 70% of total roof area

Estimated Daily Output

$Winter_{light,hours} = \frac{3}{24}$ Hours per day of Full Output in Winter

$Summer_{light,hours} = \frac{8}{24}$ Hours per day of Full Output in Summer

$FS_{S,light,hours} = \frac{6}{24}$ Hours per day of Full Output in Fall/Spring

$Winter_{months} = \frac{5}{12}$ Months per Year of Winter

$Summer_{months} = \frac{3}{12}$ Months per Year of Summer

$FS_{S,months} = \frac{4}{12}$ Months per Year of Fall/Spring

$Duty_{cycle} = Winter_{light,hours} \cdot Winter_{months} + Summer_{light,hours} \cdot Summer_{months} + FS_{S,light,hours} \cdot FS_{S,months}$

Weighted Total harvest hours per day at full output

Define Panel Geometry

Panel Electrical Efficiency

$L_{panel} = 18 \ [ft] \cdot \left| 0.3048 \cdot \frac{m}{ft} \right|$ Panel Lenght

$w_{panel} = 1.25 \ [ft] \cdot \left| 0.3048 \cdot \frac{m}{ft} \right|$ Panel Width

$A_{panel} = L_{panel} \cdot w_{panel}$ Single Panel Area

$A_{sys} = A_{panel} \cdot Panels$ Total System Area

Define Total Rated System Output

$P_{solar} = 1 \ [kW/m^2]$ Average Solar Output

$P_{output,actual} = P_{output} \cdot Duty_{cycle}$ Total System Power Output

Auxillary Systems (Inverters and Switches)

$Cost_{invrt,swtch} = 350 \ [\$/kW]$ Inverter and Switch Costs

Define Cost Parameters

$Cost_{start,present} = Panels \cdot Cost_{panel} + Cost_{invrt,swtch} \cdot P_{output}$ Startup Investment

Operation and Maintenance Costs

$i_{OM} = 0.02$ OM costs each year are 2% of upfront investment

$Cost_{OM,annual} = i_{OM} \cdot Cost_{start,present}$

Annual Interest Rate

$i_{money} = 0.05$ Annual Interest Rate- inflation

Specify Cost Model

Convert Annual O/M Cost into a Present Cost

$Cost_{OM,present} = \textbf{Present}\left(n, i_{money}, Cost_{OM,annual}\right)$

Convert Startup Cost into an Annual Cost

$Cost_{start,annual} = \textbf{Annual}\left(n, i_{money}, Cost_{start,present}\right)$

Calculate Total System Cost in Present Value Terms

$Cost_{tot,present} = Cost_{OM,present} + Cost_{start,present}$

Calculate Total System Cost in Annual Value Terms

$Cost_{tot,annual} = Cost_{OM,annual} + Cost_{start,annual}$

Calculate Power Production Savings

$Cost_{power} = 0.08 \quad [\$/kW\text{-}hr]$ Power Savings = cost of buying power from grid

$Cost_{power,future} = \textbf{Future}\left(n, i_{money}, Cost_{power}\right)$

$$Cost_{power,1} = \frac{Cost_{power}}{\left|0.000114155 \cdot \frac{year}{hr}\right|}$$ Power Savings per year per generating power

$Cost_{power,tot} = Cost_{power,1} \cdot P_{output,actual} \cdot n$ Power Savings over system life

Break Even

$BE = Cost_{power,tot} \cdot 1 \quad [yr] - Cost_{tot,present}$

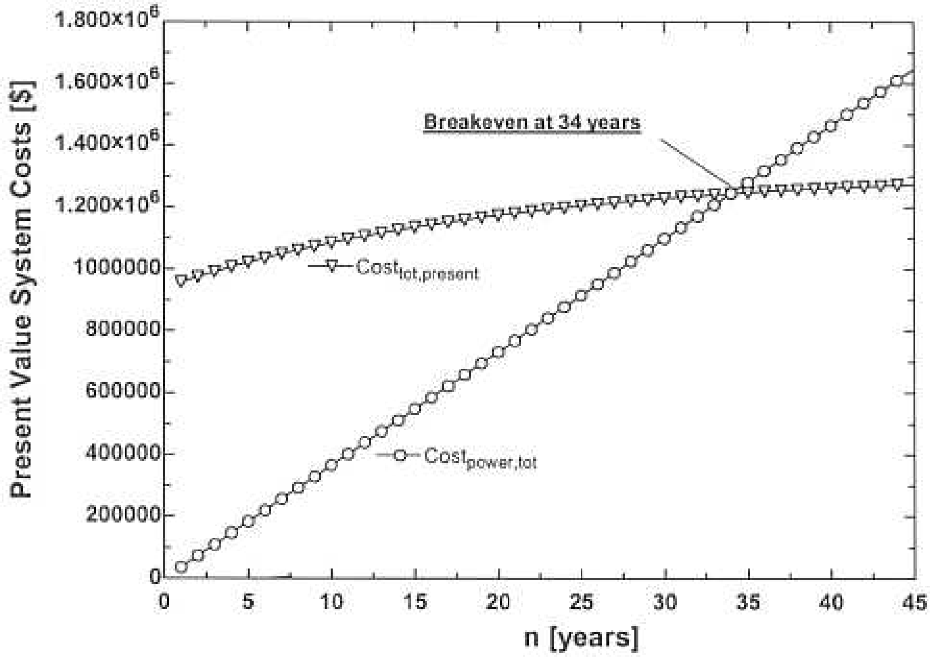


Figure C.1: Breakeven Point for 240 kW system

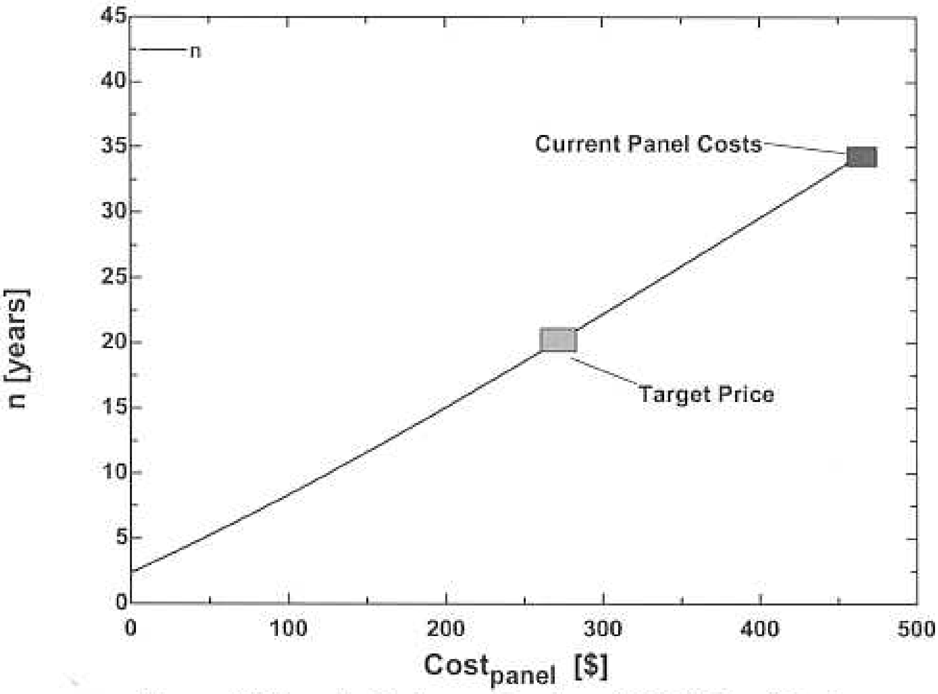


Figure C.2 Years to Breakeven Based on 128 Watt Panel Cost

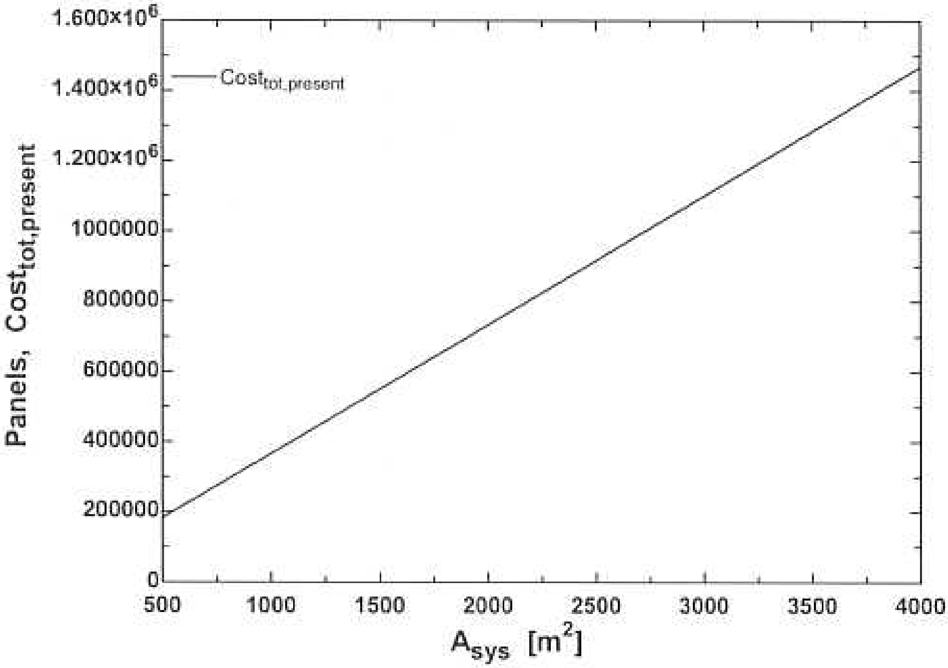


Figure C.3: Effect of System Area on Total System Cost

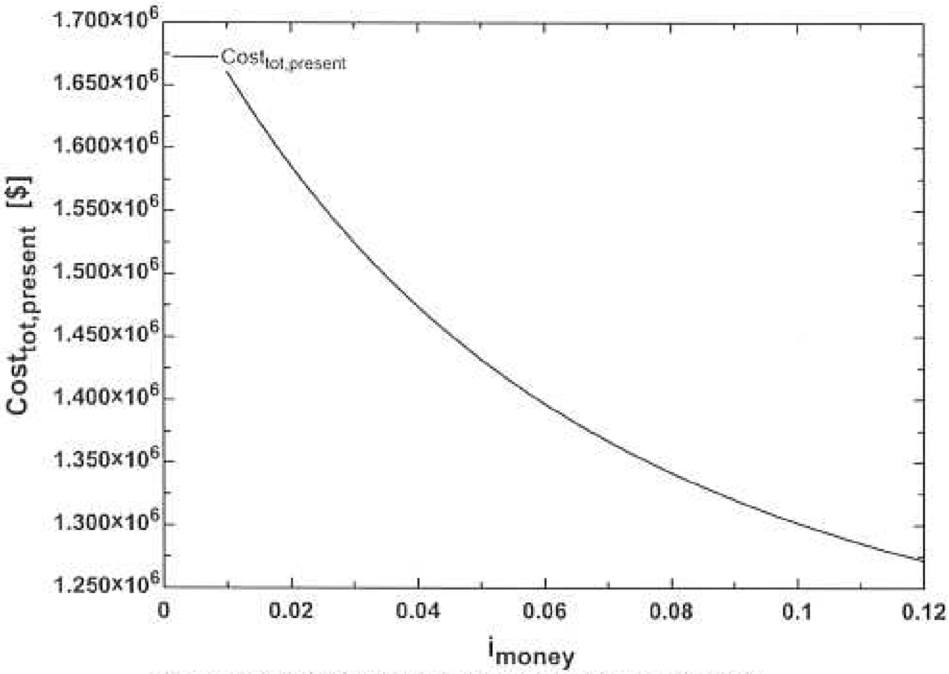


Figure C.4: Effect of Interest Rate on Total System Cost

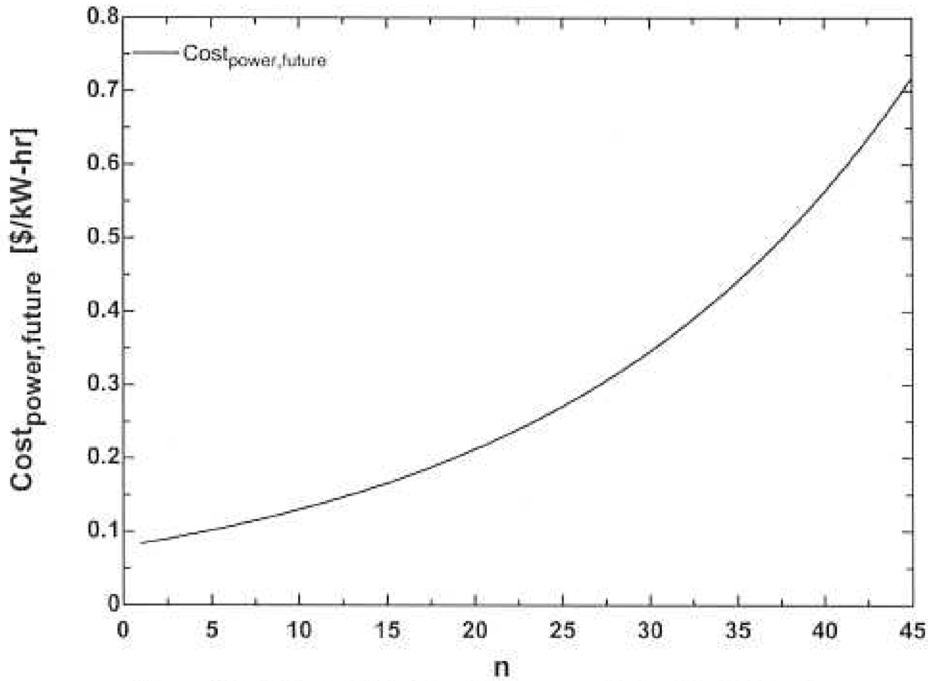


Figure C.5: Effect of Number of years on Future Electricity Costs

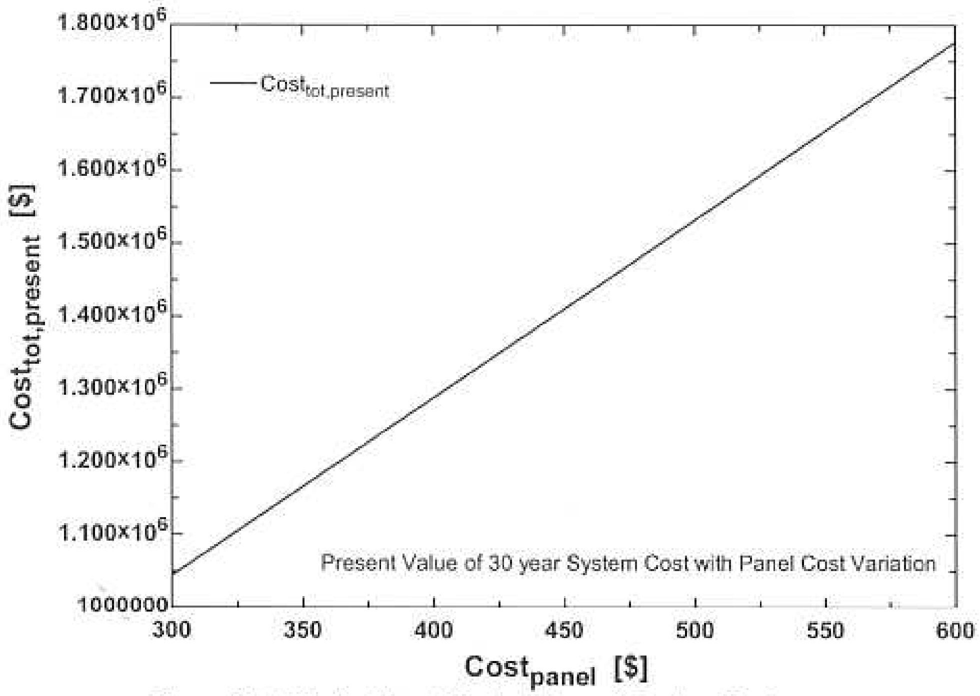


Figure C.6: Effect of Panel Cost on Overall System Cost

Appendix E: Comparison Analysis

Figure E.1

Values Underlying the Proposal

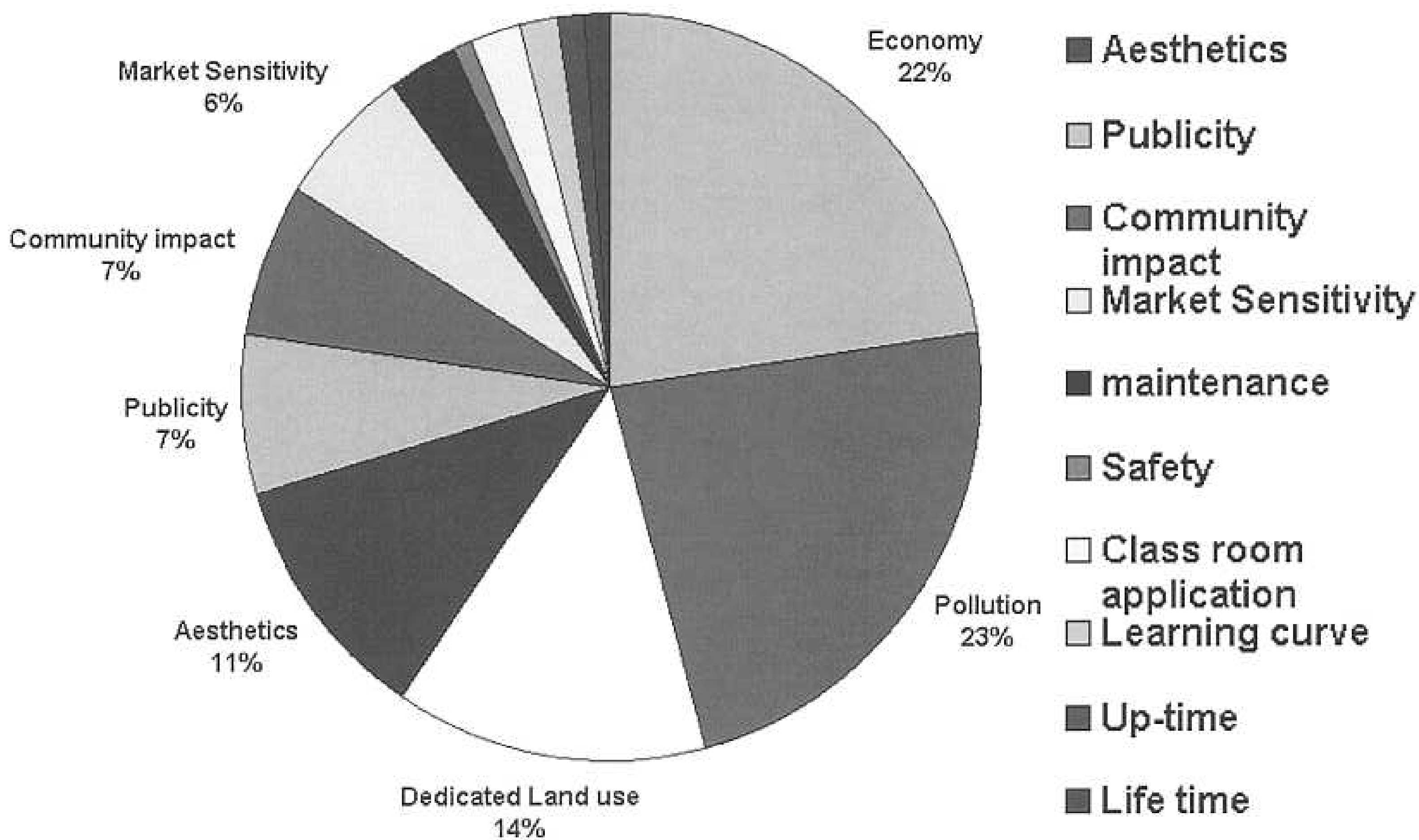
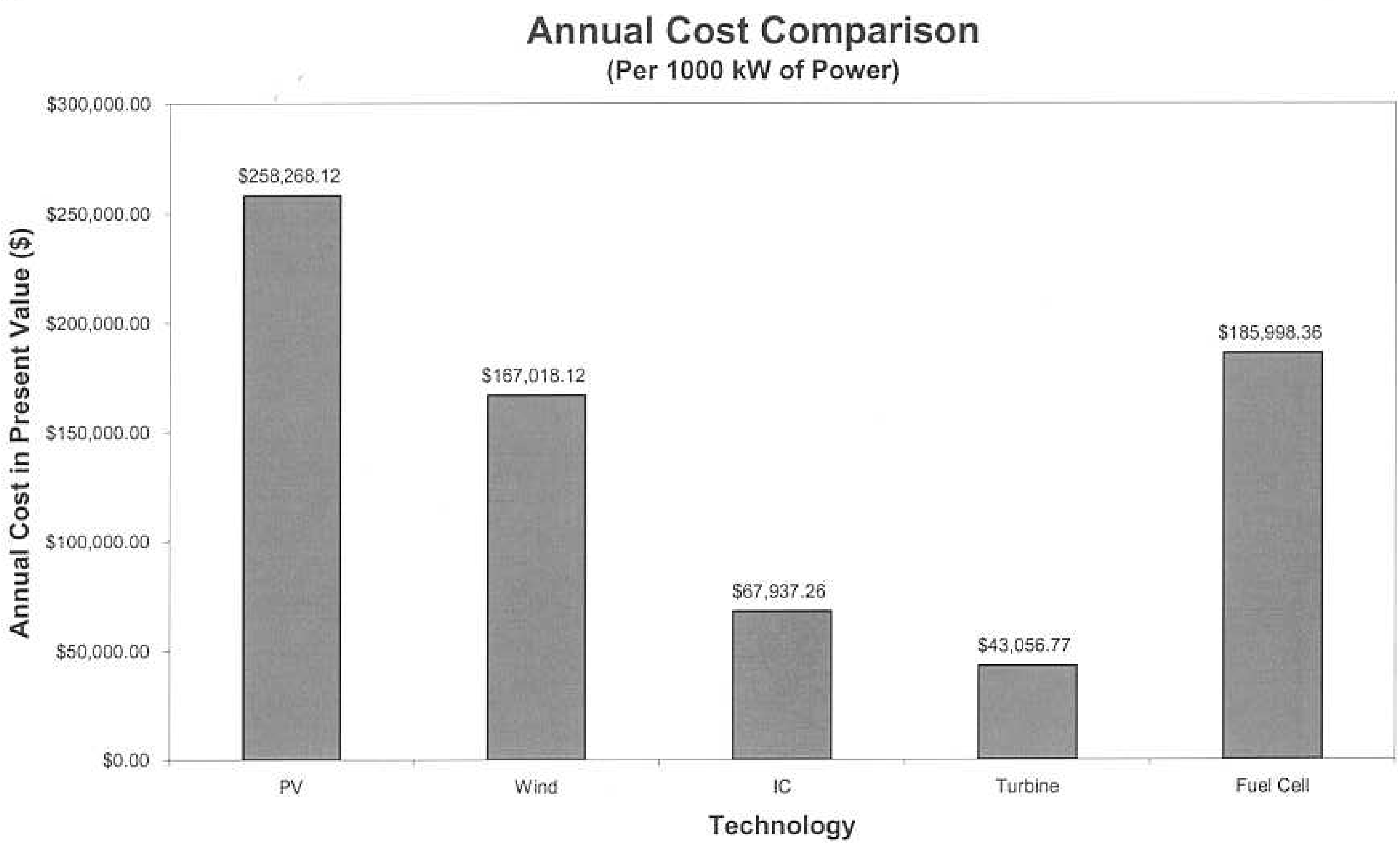


Figure E.2
DECISION MATRIX

Criterion	Description	PV	Wind	IC	Turbine	Fuel Cell
		Normalized Scores				
Economy	The cost of the project	1	5	8	9	3
Pollution		10	10	8	8	9
Dedicated Land use	The amount of space required to implement the proposal	2	8	6	7	5
Integratability		8	6	4	4	4
Aesthetics	How well will the facility integrate with the Calvin landscape – will it be an eyesore?	8	2	8.5	8.5	8.5
Publicity	How will implementing the technology effect calvin's image	9	8	5	6	8
Community impact	How will the technology impact the community.	7	6	5	5	8
Market Sensitivity	How dependant is the technology on market variability (ie gas prices)	10	10	2	2	5
maintenance	How much maintenance is required	9	8	5	6	6
Safety		8	9	7	7	8
Class room application	Is there a an educational benefit	6	9	5	7	9
Learning curve	How difficult will it be for phys. Plant personnel to learn the new technology. Will we need to hire new experts to operate/maintain it.	10	8	10	6	3
Up-time	How reliable/sustainable is the energy supply	5	7	9	9	8
Life time	How long can the facilities be expected to last.	8	8	8	8	8
	Totals	101	104	90.5	92.5	92.5

Weighting	PV	Wind	IC	Turbine	Fuel Cell
150	0.23	1.15	1.83	2.06	0.69
150	2.29	2.29	1.83	1.83	2.06
90	0.27	1.10	0.82	0.96	0.69
70	0.85	0.21	0.91	0.91	0.91
45	0.62	0.55	0.34	0.41	0.55
45	0.48	0.41	0.34	0.34	0.55
40	0.61	0.61	0.12	0.12	0.31
20	0.27	0.24	0.15	0.18	0.18
5	0.06	0.07	0.05	0.05	0.06
15	0.14	0.21	0.11	0.16	0.21
10	0.15	0.12	0.15	0.09	0.05
7.5	0.06	0.08	0.10	0.10	0.09
7.5	0.09	0.09	0.09	0.09	0.09
655	**6.13**	**7.13**	**6.87**	**7.32**	**6.43**

Figure E.3


Annual Cost Comparison
(Per 1000 kW of Power)
Annual Cost in Present Value ($)
$300,000.00
$250,000.00
$200,000.00
$150,000.00
$100,000.00
$50,000.00
$0.00
$258,268.12
$167,018.12
$67,937.26
$43,056.77
$185,998.36
PV
Wind
IC
Turbine
Fuel Cell
Technology

Appendix F:
Powerful Savings Program

Summary of Findings

Figure F.1

Focus	Participation	Yearly Savings
Academic Computer Shut-off	100%	$1,034
Dorm Awareness	50%	$5,681
Save $ Stickers	20%	$1,313
Total	57%	$8,028

Figure F.2

Dorm Awareness	Yearly Savings
Computers off (day/night)	$6,326
Room Lights off	$3,062
Bathroom Lights off	$1,975
Participation Rate	0.5
Total	$5,681

Powerful Savings Calculations

1. Replacing non-EnergyStar Monitors

$MONITORS\_TOT := 2043$

$MONITORS\_STAR := 1795$

$MONITORS\_NON := 248$

$PERCENT\_NON := \frac{MONITORS\_NON}{MONITORS\_}$ $PERCENT\_NON = 12.14\%$

According to the CIT, a replacement program for the Non-EnergyStar monitors has been setup, and the 248 Non-EnergyStar monitors are on their way out in the next few years. That being said, the replacement analysis is not applicable because it has already been analyzed, found feasible, and implemented. Thus, we will assume all computers are EnergyStar for our analysis.

2. Turning off Academic Computers at Night

How much electricity is being used by computers left on at night?

The average computer uses about 120 Watts (75 Watts for the screen and 45 Watts for the CPU) whether you're using it or not. Based on the "watts up" readings in the Engineering building, the Energy star computers were using 53 W and the monitors 54 W.

EnergyStar computers in sleepmode (at night) use 70% less electricity

(http://www.energystar.gov)

$CPU := 53W$ $SLEEPMODE_{COMP} := .3$

$ESTAR_{COMP} := CPU \cdot SLEEPMODE_{COMP}$

EnergyStar monitors in sleepmode (at night) use 90% less electricity

$MONITOR := 54W$ $SLEEPMODE_{MONITOR} := .1$

$ESTAR_{MONITOR} := MONITOR \cdot SLEEPMODE_{MONITOR}$

The average energy used by an EnergyStar computer left on at night is:

$AVE_{ENERGYNIGHT} := ESTAR_{MONITOR} + ESTAR_{COMPGYNIGHT} = 21.3\,W$

Total number of computers in academic buildings: $COMP_{TOT} := 2043$

Some computers are being shut off at night already:

$COMP_{SB} := 449$

$COMP_{EB} := 20$

$COMP_{ON} := COMP_{TOT} - COMP_{SB} - COMP_{EB}$ $COMP_{ON} = 1574$

Total energy used by all computers left on at night:

$ENERGY_{TOT} := COMP_{ON} \cdot AVE_{ENERGYNI}$ $ENERGY_{TOT} = 33.53\,KW$

$ELECT\_COST\_NIGHT := \frac{.03}{KW \cdot HR}$ What Calvin pays at night

What if all these computers were shut off for 8 hours (12-8) each night?

$SHUTOFF := 8HR$

Already Saving

$$SAVINGS_{ORIG} := (COMP_{SB} + COMP_{EB}) \cdot AVE_{ENERGYNIGHT} \cdot SHUTOFF \cdot ELECT\_COST\_NIGHT$$

$SAVINGS_{ORIG} = 2.4$ \$ (Total daily savings)

Could be saving (total of computers)

Need manual labor to shut them down

$PAY := \frac{8}{HR}$

$COST_{SHUTOFF} := PAY \cdot .5HR$ Assume it will take 1/2 hour to shut off remaining computers

$$SAVINGS_{NEW} := COMP_{ON} \cdot AVE_{ENERGYNIGHT} \cdot SHUTOFF \cdot ELECT\_COST\_NIGHT - COST_{SHUTOFF}$$

$SAVINGS_{NEW} = 4.05$ \$ (Total daily savings)

Account for Current Low-Usage Times

What happens to computers over Christmas Break, summer? Also, on weekends, some computers don't get turned on at all. Thus, the savings from these time periods are already taking place and cannot be included in our new savings analysis.

Conservatively, chose that overall yearly computer usage will be around 70%. That is, 70% of the year there are computers left on at night that we can turn off to obtain savings.

$FRACTION := .7$

$YEARLY_{COMPS} := SAVINGS_{NEW} \cdot 365 \cdot FRACTION$

Yearly savings for overall system:

$YEARLY_{COMPS} = 1033.83$ \$

Yearly Savings Per Computer:

$PERCOMP := \frac{YEARLY_{COMPS}}{COMP_{ON}}$ $PERCOMP = 0$ [\$]

3. Energy Savings in the Dorms

Dorm Data: If all students with computers turned them off at night

Survey Results: 90.8% of dorm residents have computers
Currently, only 28.9% of residents turn off computers at night (i.e. 71.1% are on)

Assumptions: All dorm residents have computers that are EnergyStar

$NUMBER_{STUDENTS} := 2150$

$NUMBER_{COMPUTERS} := .908 \cdot NUMBER_{STUDENTS}$

$STUDENTS_{COMPSON} := NUMBER_{COMPUTERS} \cdot .711$

$SAVINGS\_DORMSCOMPS\_NIGHT := ELECT\_COST\_NIGHT \cdot \left(AVE_{ENERGYNIGHT} \cdot STUDENTS_{COMPSON}\right) \cdot SHUTOFF$

Daily: $SAVINGS\_DORMSCOMPS\_NIGHT \$ 7.1$

Dorm Data: If all students with computers turned them off during the day when not in use

Survey Results: 93.8% of students leave computers on during the day.

$ELECT\_COST\_DAY := \frac{.11}{KW \cdot HR}$ $SHUTOFF\_DAY := 4HR$

$STUDENTS_{COMPSONDAY} := .938 \cdot NUMBER_{STUDENTS}$

$SAVINGS\_DORMSCOMPS\_DAY := ELECT\_COST\_DAY \cdot \left(AVE_{ENERGYNIGHT} \cdot STUDENTS_{COMPSONDAY}\right) \cdot SHUTOFF\_DAY$

Daily: $SAVINGS\_DORMSCOMPS\_DAY = 1\$8.9$

So total potential savings if students turned off computers when not in use:

$YEARLY_{DORMSCOMPS} := (SAVINGS\_DORMSCOMPS\_NIGHT + SAVINGS\_DORMSCOMPS\_DAY) \cdot 365 \cdot \frac{8}{12}$

Yearly Savings: $YEARLY_{DORMSCOMPS} = 6325.7$

Dorm Data: If all students turned off their lights when not in the room (during the day)

Survey Results: 13.3% of students leave their lights on when not in the room

$NUMBER_{ROOMLIGHTS} := \frac{NUMBER_{STUDENTS}}{2}$ Number of Dorm Rooms

$ELECTRICITY_{ROOMLIGHTS} := 200W$ Average Wattage of Lights in Dorms

$STUDENTS_{LIGHTSON} := .133 \cdot NUMBER_{ROOMLIGHTS}$ Number of rooms with lights left on

$SHUTOFF\_LIGHTS := 4HR$ Smaller than computer shutoff b/c will be in room at times when lights are being used but computer is not

$SAVINGS_{DORMSLIGHTS} := STUDENTS_{LIGHTSON} \cdot ELECT\_COST\_DAY \cdot ELECTRICITY_{ROOMLIGHTS} \cdot SHUTOFF\_LIGHTS$

Daily Savings: $SAVINGS_{DORMSLIGHTS} \$ 12.58$

$YEARLY_{DORMSLIGHTS} := SAVINGS_{DORMSLIGHTS} \cdot 365 \cdot \frac{8}{12}$

Yearly Savings: $YEARLY_{DORMSLIGHTS} = 30\$1.57$

Dorm Data: If all students turned off bathroom light when not in use

Survey Results: 14.3% of all bathroom lights get left on during the day

$NUMBER_{BATHROOMS} := \frac{NUMBER_{STUDENTS}}{4}$ Assume four suitemates share one bathroom

$ELECTRICITY_{BATHROOMS} := 120W$ Average wattage of lights in bathrooms

$BATHROOMUSAGE := 4HR$ Assume average of 4 hours spent in the bathroom

$SHUTOFF\_BATHROOMS := 12HR - BATHROOMUSAGE$ Assume most, if not all bathroom lights get turned off at night already (12 hrs. in the day minus hrs. used)

$STUDENTS_{BATHLIGHTSON} := .143 \cdot NUMBER_{BATHROOMS}$

$SAVINGS_{BATHROOMS} := STUDENTS_{BATHLIGHTSON} \cdot ELECT\_COST\_DAY \cdot ELECTRICITY_{BATHROOMS} \cdot SHUTOFF\_BATHR$

Daily: $SAVINGS_{BATHROOMS} = 8.12$ \$

$YEARLY_{BATHROOMS} := SAVINGS_{BATHROOMS} \cdot 365 \cdot \frac{8}{12}$

Yearly Savings: $YEARLY_{BATHROOMS} = 1975.06$

Monthly Rewards for dorms--At first, test hypothesis that promise of "tuition cuts" be enough. That way, we avoid putting in flow meters, paying for parties, etc.

$YEARLY_{DORMS1} := YEARLY_{DORMSCOMPS} + YEARLY_{BATHROOMS} + YEARLY_{DORMSLIGHTS}$

$PARTICIPATION_{DORMS} := .5$

$YEARLY_{DORMS} := YEARLY_{DORMS1} \cdot PARTICIPATION_{DORMS}$

Dorm Yearly Savings: $YEARLY_{DORMS} = 5681.17$

4. "Save power...Save $" stickers on switches around campus (Andy)

Assumptions: Around 90 bathrooms around campus
Average wattage in 1 bathroom is 600 W
Bathroom lights already get turned off at night

$NUMBER_{BATHROOMS.SCHOOL} := 90$

$BATHROOMUSAGE_{SCHOOL} := 4HR$

$SHUTOFF\_BATHROOMS_{SCHOOL} := 12HR - BATHROOMUSAGE_{SCHOOL}$

$ELECTRICITY_{BATHROOMS.SCHOOL} := 600W$

$SAVINGS_{BATHSCHOOL} := SHUTOFF\_BATHROOMS_{SCHOOL} \cdot ELECT\_COST\_DAY \cdot ELECTRICITY_{BATHROOMS.SCHOOL} \cdot NU$

Daily: $SAVINGS_{BATHSCHOOL} = 47.52$

$COST_{STICKERS} := 1000$

$YEARLY_{STICKERS1} := SAVINGS_{BATHSCHOOL} \cdot 365 \cdot \frac{8}{12}$

$YEARLY_{STICKERS1} = 11563.2$ $PARTICIPATION_{STICKERS} := .20$

$YEARLY_{STICKERS} := YEARLY_{STICKERS1} \cdot PARTICIPATION_{STICKERS} - COST_{STICKERS}$

$YEARLY_{STICKERS} = 1312.64$

5. Replacing Big Monitors By LCD's

Already being implemented by Calvin to replace big monitors by flat screens

Total Yearly Savings

$SAVINGS_{YEARLY} := YEARLY_{COMPS} + YEARLY_{DORMS} + YEARLY_{STICKERS}$

$SAVINGS_{YEARLY} = 8027.63$

Tuition Cut:

$STUDENTS := 4300$

$SAVINGS_{TUITION} := \frac{SAVINGS_{YEARLY}}{STUDENTS}$

$SAVINGS_{TUITION} = 1.87$ Potential amount that can be taken off each student's tuition for the year

$YEARLY_{COMPS} = 1033.83$

$YEARLY_{DORMS} = 5681.17$

$YEARLY_{STICKERS} = 1312.64$

Focus	Participation
Academic Computer Shut-off	100%
Dorm Awareness	50%
Save $ Stickers	20%
Total	57%

Appendix G: Final Model

Figure G.1

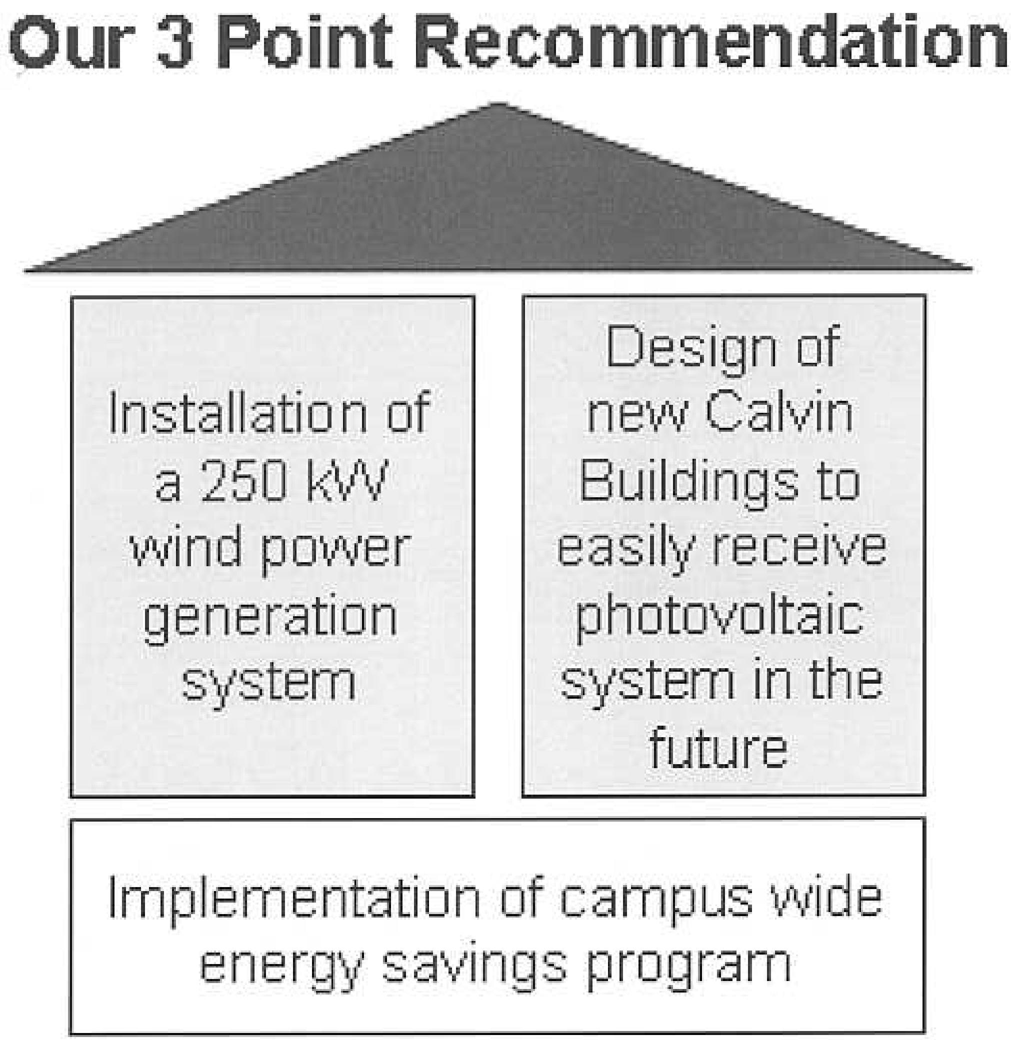

Our 3 Point Recommendation
Installation of a 250 kW wind power generation system
Design of new Calvin Buildings to easily receive photovoltaic system in the future
Implementation of campus wide energy savings program

Figure G.2: The recommended power distribution for Calvin College, at the future operating capacity of 5 MW. Depending on the success of the wind pilot program, more wind power could be added for additional savings.

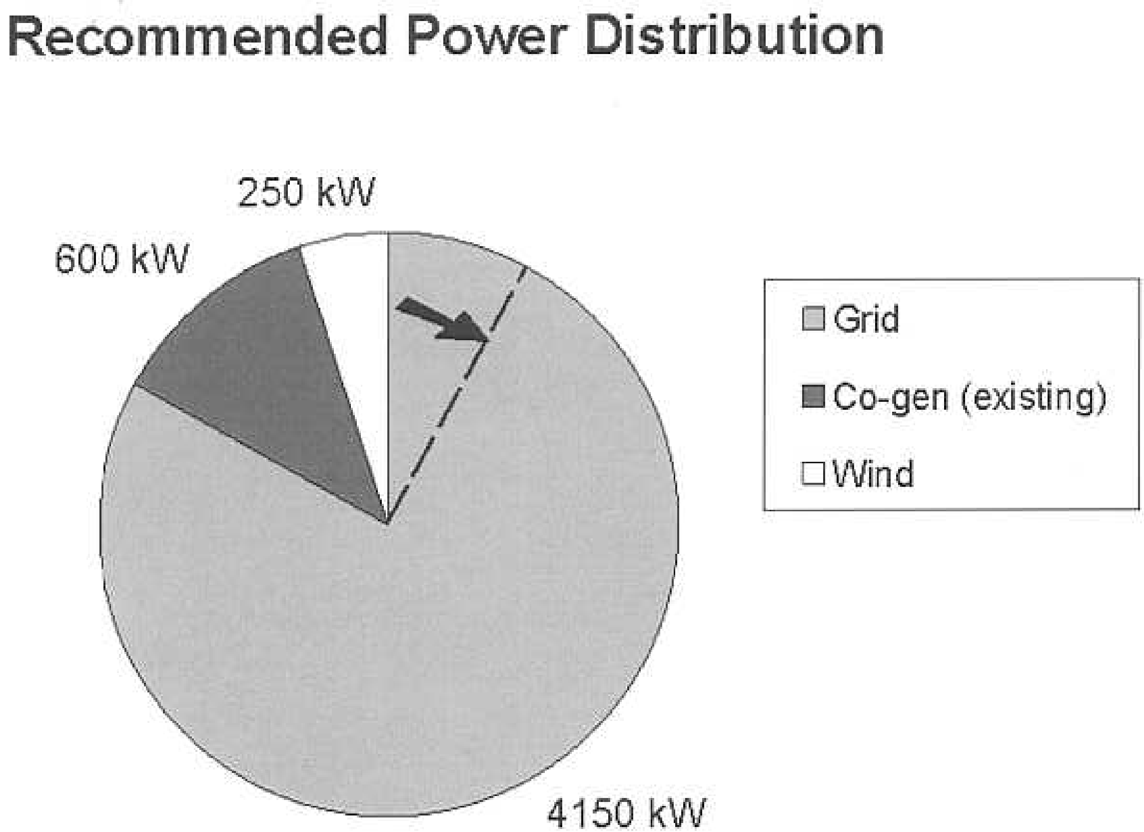


Figure G.3
TIME VALUE OF MONEY ASSUMING LOAN

	Annual Payments (Future Value)									
Year	OMC	FC	Cost Electric	Electric Savings	Loan Payments	Total Annual	PV Annual	Levelized	Payback	Year
1	($5,322.92)	$0.00	$0.08	$54,662.40	($73,230.40)	($23,890.83)	($21,331.10)	$7,740.92	($21,331.10)	1
2	($5,322.92)	$0.00	$0.09	$56,848.90	($73,230.40)	($21,704.33)	($17,302.56)	$7,740.92	($38,633.66)	2
3	($5,322.92)	$0.00	$0.09	$59,122.85	($73,230.40)	($19,430.37)	($13,830.16)	$7,740.92	($52,463.82)	3
4	($5,322.92)	$0.00	$0.09	$61,487.77	($73,230.40)	($17,065.46)	($10,845.41)	$7,740.92	($63,309.22)	4
5	($5,322.92)	$0.00	$0.10	$63,947.28	($73,230.40)	($14,605.94)	($8,287.80)	$7,740.92	($71,597.03)	5
6	($5,322.92)	$0.00	$0.10	$66,505.17	($73,230.40)	($12,048.05)	($6,103.92)	$7,740.92	($77,700.94)	6
7	($5,322.92)	$0.00	$0.11	$69,166.37	($73,230.40)	($9,387.84)	($4,246.58)	$7,740.92	($81,947.52)	7
8	($5,322.92)	$0.00	$0.11	$71,931.99	$0.00	$66,609.18	$26,902.33	$7,740.92	($55,045.19)	8
9	($5,322.92)	$0.00	$0.11	$74,809.27	$0.00	$69,486.46	$25,057.52	$7,740.92	($29,987.68)	9
10	($5,322.92)	$0.00	$0.12	$77,801.64	$0.00	$72,478.84	$23,336.25	$7,740.92	($6,651.43)	10
11	($5,322.92)	$0.00	$0.12	$80,913.71	$0.00	$75,590.91	$21,730.58	$7,740.92	$15,079.15	11
12	($5,322.92)	$0.00	$0.13	$84,150.25	$0.00	$78,827.46	$20,233.06	$7,740.92	$35,312.19	12
13	($5,322.92)	$0.00	$0.13	$87,516.26	$0.00	$82,193.48	$18,836.62	$7,740.92	$54,148.82	13
14	($5,322.92)	$0.00	$0.14	$91,016.91	$0.00	$85,694.13	$17,534.72	$7,740.92	$71,683.54	14
15	($5,322.92)	$0.00	$0.14	$94,657.59	$0.00	$89,334.81	$16,321.14	$7,740.92	$88,004.67	15
16	($5,322.92)	$0.00	$0.15	$98,443.89	$0.00	$93,121.12	$15,190.07	$7,740.92	$103,194.74	16
17	($5,322.92)	$0.00	$0.16	$102,381.65	$0.00	$97,058.89	$14,136.08	$7,740.92	$117,330.82	17
18	($5,322.92)	$0.00	$0.16	$106,476.92	$0.00	$101,154.16	$13,154.06	$7,740.92	$130,484.87	18
19	($5,322.92)	$0.00	$0.17	$110,735.99	$0.00	$105,413.24	$12,239.19	$7,740.92	$142,724.06	19
20	($5,322.92)	$0.00	$0.18	$115,165.43	$0.00	$109,842.69	$11,387.04	$7,740.92	$154,111.10	20
21	($5,322.92)	$0.00	$0.18	$119,772.05	$0.00	$114,449.31	$10,593.38	$7,740.92	$164,704.48	21
22	($5,322.92)	$0.00	$0.19	$124,562.93	$0.00	$119,240.20	$9,854.31	$7,740.92	$174,558.79	22
23	($5,322.92)	$0.00	$0.20	$129,545.45	$0.00	$124,222.73	$9,166.14	$7,740.92	$183,724.93	23
24	($5,322.92)	$0.00	$0.21	$134,727.27	$0.00	$129,404.55	$8,525.44	$7,740.92	$192,250.37	24
25	($5,322.92)	$0.00	$0.21	$140,116.36	$0.00	$134,793.65	$7,929.01	$7,740.92	$200,179.38	25
26	($5,322.92)	$0.00	$0.22	$145,721.01	$0.00	$140,398.31	$7,373.83	$7,740.92	$207,553.22	26
27	($5,322.92)	$0.00	$0.23	$151,549.85	$0.00	$146,227.16	$6,857.12	$7,740.92	$214,410.33	27
28	($5,322.92)	$0.00	$0.24	$157,611.85	$0.00	$152,289.17	$6,376.24	$7,740.92	$220,786.57	28
29	($5,322.92)	$0.00	$0.25	$163,916.32	$0.00	$158,593.65	$5,928.75	$7,740.92	$226,715.32	29
30	($5,322.92)	$0.00	$0.26	$170,472.97	$0.00	$165,150.31	$5,512.37	$7,740.92	$232,227.69	30

Figure G.4: TVM Diagram